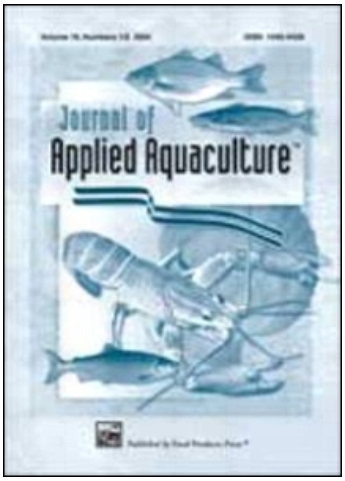

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Feed Formulation Using Linear Programming for Fry of Catfish, Milkfish, Tilapia, Asian Sea Bass, and Grouper in India

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Feed Formulation Using Linear Programming for Fry of Catfish, Milkfish, Tilapia, Asian Sea Bass, and Grouper in India

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Nutritional profiles of 25 feed ingredients available in India were selected and compiled. Their costs were ascertained from Cochin (SW), Tuticorin (SE), and Bhubaneswar (NW), where fish/shrimp farming is traditionally practiced. Least-cost feed formulations (using the linprog toolbox in Matlab software) were attempted for catfish, milkfish, tilapia, and grouper fry specifying levels of four critical limits: Ca/P ratio, digestible energy (DE), 10 amino acid levels (where data was available), and 10 ingredients, totaling 26 constraining limits to the model. Feeds formulated for catfish fry cost US$0.066 kg^{-1} at Bhubaneswar, US$0.117 kg^{-1} at Tuticorin, and US$0.153 kg^{-1} at Cochin, with poultry by-product meal and hydrolyzed feather meal as the major ingredients; limiting amino acids in these feeds were methionine and phenylalanine. Feeds formulated for milkfish fry cost US$0.110 kg^{-1} at Cochin, US$0.108 kg^{-1} at Tuticorin, and US$0.072 kg^{-1} at Bhubaneswar; the limiting amino acids in this case were histidine and threonine. The cost of feeds for tilapia fry was US$0.207 kg^{-1} at Cochin, US$0.369 kg^{-1} at Tuticorin, and US$ 0.114 kg^{-1} at Bhubaneswar; the limiting amino acid was methionine. Feed formulae for fry of Asian sea bass had an LP solution containing only five ingredients for all three places. The feed formula was the same for Cochin and Bhubaneswar market prices, and the total cost of ingredients was US$0.274 kg^{-1} and US$0.142 kg^{-1}, respectively.

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At Tuticorin market prices, the feed formula cost was US$0.397 kg^{-1}. The feed formulae for grouper fry at Bhubaneswar and Tuticorin market prices had the same three ingredients costing US$0.114 kg^{-1} and US$0.321 kg^{-1}, respectively, whereas feed formula for Cochin market price consisted of four ingredients costing US$0.280 kg^{-1}.

KEYWORDS Least-cost feeds, LP, shrimp, fish, prawn, India

INTRODUCTION

Linear programming (LP) has been used to develop least cost feeds by a number of authors: Chow, Rumsey, and Waldroup (1978); Barbieri and Cuzon (1980); Cho, Cowey, and Watanabe (1985); Engle (1987); Akiyama, Dominy, and Lawrence (1992); De Silva and Anderson (1995); Gokulakrishnan and Bandyopadhyay (1995); Khan et al. (1996); Das et al. (1996); Kouka and Engle (1996); Krishnan and Sharma (1996); Mukhopadhyay (1997) and Jeyaraman (1997). LP enables nutritionists to compare a wide range of feedstuffs to determine which will blend together to provide the desired nutrient levels at the lowest possible cost without bias toward any ingredient.

In LP, the requirements have to be measured and expressed in numerical terms. To get a linear programming solution for feed formulation, the information required is: (1) a location-specific list of ingredients available for use in the feed and their costs; (2) nutrient contents for each of the ingredients; (3) nutritional requirements of the species in terms of minimum, maximum, or exact quantities needed; and (4) any physical or non-nutritive limitation that might be imposed because of ingredient characteristics, limitation of supply, effects on feed mixture, toxic factors, and ability of feed to be pelleted. There are certain attributes such as palatability or acceptability on which it is difficult to place a numerical value. The most effective nutrient values will be those that accurately reflect the biological availability of the ingredients. Nutrient requirements determined to achieve maximum growth rates using linear programming may not be the best in terms of economic considerations. Relaxing nutrient constraints while still achieving acceptable, though lower, growth may bring down feed cost.

The objective of the present study was to formulate 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.

MATERIALS AND METHODS

Twenty-five feed ingredients available in India were compiled for feed formulation through linear programming (Table 1). Market prices of ingredients were collected from local markets at Cochin (Kerala), Tuticorin (Tamil Nadu), and Bhubaneswar (Orissa) from the Marine Products Export Development Authority (MPEDA) and also from published reports (Tacon 2000; MPEDA 2001). These are given in the Table 2. The March 2009 exchange rate of Indian rupees (INR) 50 per US$ (INR) to US$ was used in feed price calculations.

The nutritional composition of the 25 feed ingredients were collected from publications and the Internet (Nakamura 1981; New 1987; Chou 1993; Nandeesha 1993; Pantha 1993; Bautista et al. 1994; George & Gopakumar 1995; Vander & Verdegem 1996; Cruz Philip 1997; Paulraj 1997; Ahamad et al. 1998; Chiou, Lim, & Shiau 1998; Fagbenro, Smith, & Amoo, 2000; www.seaofindia.com ;www.unu.edu; and www.fao.org.)

Nutritional requirements [crude protein, arginine, histidine, isoleucine, leucine, lysine, methionine, phenylalanine, threonine, tryptophan, valine, crude fibre, nitrogen-free extract (NFE = soluble carbohydrate), lipid, digestible energy, and calcium and phosphorous ratio] for fry of species of importance to the aquaculture sector in Cochin (southwest coast of India), Tuticorin (southeast coast), and Bhubaneswar (northwest coast) were gleaned from the literature (New 1987; Bautista et al. 1994; Paulraj 1997; Chen 2001; Giri 2001; and Pandian et al. 2001) (Table 3). These species were catfish (*Clarias batrachus*), milkfish (*Chanos chanos*), tilapia (*Oreochromis mossambicus*), Asian sea bass (*Lates calcarifer*), and grouper (*Epinephelus malabaricus*). Requirements for protein, essential amino acids, and digestible energy data are kept as minimum requirements according to De Silva and Anderson (1995) and Akiyama, Dominy, and Lawrence (1992).

All nutritional requirements (except for DE kcal kg^{-1} dry weight and Ca/P ratio) are in percentage of dry weight of total feed mixture. Digestible energy (DE) of these ingredients for fish was calculated using the formulae of New (1987):

Plant origin (non legumes):

$$\text{DE (kcal/kg)} = [\text{DW\% of protein} \times 3.8 + \text{DW\% NFE} \times 3.0 + \text{DW\% of lipid} \times 8.0] \times 10$$

Plant origin (legumes):

$$\text{DE(kcal/kg)} = [\text{DW\% of protein} \times 3.8 + \text{DW\% NFE} \times 2.0 + \text{DW\% of lipid} \times 8.0] \times 10$$

TABLE 1 Nutritional Composition of Different Aquafeed Ingredients. Column 1 to 14, Values are in % of Dry Matter, DE in kcal/kg of Dry Weight

No.	Ingredients	Protein	Arg	Hist	Ile	Leu	Lys	Met	Phe	Thre	Try	Val	NFE	Fiber	Lipid	DE	Ca/P
1	Rice polish	13.50	0.57	0.19	0.39	0.78	0.58	0.22	0.42	0.38	0.11	0.80	52.00	10.00	17.80	3497	0.03
2	Rice broken	13.30	0.96	0.25	0.53	0.90	0.44	0.25	0.56	0.41	0.17	0.76	72.70	5.90	4.70	3062	0.94
3	Rice bran	14.10	0.79	0.23	0.46	0.70	0.49	0.23	0.44	0.43	0.10	0.69	40.60	21.50	12.60	2762	0.12
4	Wheat bran	15.00	1.09	0.44	0.57	1.03	0.65	0.22	0.62	0.51	0.28	0.78	65.20	13.60	2.90	2758	0.07
5	Wheat flour	16.60	1.09	0.46	0.62	1.20	0.67	0.26	0.75	0.57	0.22	0.82	73.50	3.10	4.20	3172	0.15
6	Ground oil cake meal	46.70	4.55	0.95	1.76	2.70	1.77	0.42	2.04	1.16	0.48	1.88	28.00	14.40	8.10	2983	0.30
7	Sunflower oil cake meal	42.70	4.75	1.32	2.42	4.12	2.06	1.25	2.54	2.07	0.65	2.80	29.50	16.10	4.00	2827	0.23
8	Soybean meal	52.80	3.38	1.19	2.27	3.65	2.99	0.58	2.36	1.85	0.71	2.25	46.70	6.60	1.50	3060	0.19
9	Rapeseed cake meal	40.30	2.26	1.09	1.48	2.74	2.18	0.78	1.55	1.72	0.47	1.96	36.10	14.80	1.00	2694	0.70
10	Cottonseed cake meal	46.10	4.62	1.21	1.67	2.56	1.86	0.64	2.46	1.52	0.61	2.06	31.00	15.10	0.70	2738	0.13
11	Copra meal	23.40	2.65	0.41	0.91	1.59	0.66	0.35	0.95	0.73	0.22	1.14	44.20	15.70	10.00	3015	0.36
12	Sorghum meal	10.00	0.31	0.22	0.40	1.35	0.20	0.14	0.50	0.31	0.12	0.51	84.70	1.50	2.60	3129	0.42
13	Spirulina	55.30	2.73	0.55	3.90	5.20	3.00	0.91	3.25	3.00	0.91	4.22	29.20	2.30	1.10	3065	0.15
14	*Eichhornia* meal	20.20	1.43	0.51	1.20	2.14	1.47	0.42	1.29	1.17	0.19	1.41	48.90	18.90	2.40	2427	0.97
15	Mustard oil cake	33.70	1.89	0.88	1.55	2.26	1.45	0.57	1.31	1.48	0.44	1.72	38.10	6.80	10.20	3240	0.39
16	Maize meal	9.40	0.38	0.24	0.33	1.12	0.24	0.15	0.43	0.32	0.07	0.43	85.30	1.00	3.30	3180	0.08
17	Fishmeal	55.60	3.11	1.28	2.56	4.23	4.34	1.67	2.22	2.39	0.67	3.00	8.10	3.00	12.00	3566	2.51
18	Shrimp meal	35.50	2.20	0.89	1.49	2.38	1.92	0.71	1.38	1.24	0.36	1.56	16.00	12.70	7.00	2549	7.50
19	Squid meal	76.40	5.73	1.68	3.21	5.88	6.00	2.14	2.60	3.13	0.76	3.29	2.10	4.40	5.50	3750	0.53
20	Clam meal	55.20	6.50	6.50	1.46	8.05	9.80	1.96	6.52	0.70	0.03	0.23	23.90	4.20	9.70	3839	0.74
21	Snail meal	40.81	2.20	0.75	2.89	2.29	1.11	0.76	1.63	1.52	0.48	2.22	22.90	1.58	1.77	2563	4.87
22	Blood meal	88.50	3.88	5.59	0.98	11.86	8.04	0.95	6.36	3.93	1.13	8.13	3.90	0.40	1.20	3974	1.00
23	Meat meal	54.40	3.60	1.02	1.75	3.19	3.23	0.70	1.81	1.64	0.34	2.25	28.00	7.40	4.80	3536	0.29
24	Poultry by-product meal	59.90	4.03	1.08	2.54	4.28	3.10	1.13	1.97	2.08	0.50	3.06	5.40	2.10	17.10	4076	2.08
25	Hydrolysed feather meal	91.40	7.58	1.06	4.37	7.46	2.49	0.59	3.28	4.27	0.56	6.97	0.50	0.40	3.90	4212	0.82

NFE = nitrogen-free extract; DE = digestible energy kcal kg^{-1}; Ca = calcium; P = phosphorus.

TABLE 2 Market Prices of Ingredients (US$ kg^{-1}Dry Weight) for the Three Places

No.	Ingredients	Cochin	Tuticorin	Bhubaneswar
1	Rice polish	0.160	0.300	0.300
2	Rice broken	0.240	0.200	0.130
3	Rice bran	0.062	0.100	0.060
4	Wheat bran	0.107	0.160	0.080
5	Wheat flour	0.230	0.200	0.280
6	Ground nut oil cake meal	0.240	0.260	0.210
7	Sunflower oil cake meal	0.114	0.550	0.100
8	Soybean meal	0.230	0.240	0.240
9	Rapeseed cake meal	0.140	0.350	0.160
10	Cottonseed cake meal	0.250	0.150	0.150
11	Copra meal	0.230	0.230	0.230
12	Sorghum meal	0.076	0.110	0.140
13	*Spirulina*	18.000	16.000	24.000
14	*Eichhornia* meal	0.050	0.050	0.050
15	Mustard oil cake	0.240	0.240	0.070
16	Maize meal	0.200	0.200	0.240
17	Fishmeal	0.652	1.100	0.300
18	Shrimp meal	0.514	0.900	0.600
19	Squid meal	1.134	1.100	1.134
20	Clam meal	1.185	1.500	1.185
21	Snail meal	2.250	1.000	2.250
22	Blood meal	0.365	1.000	0.365
23	Meat meal	0.170	1.200	0.191
24	Poultry by-product meal	0.246	0.150	0.070
25	Hydrolyzed feather meal	0.160	0.300	0.300

Animal origin:

$$\text{DE(kcal/kg)} = [\text{DW\% of protein} \times 4.25 + \text{DW\% NFE} \times 3.0 + \text{DW\% of lipid} \times 8.0] \times 10$$

The dry weight percentage of calcium (Ca) in each ingredient was divided by dry weight percentage of phosphorous (P) to get the Ca/P ratio.

One of the constraints placed on the program was an equality constraint corresponding to the sum of all the ingredients (SI), and the rest were less than or equal to ($\leq$) type constraints. For catfish fry and Asian sea bass, there were two equality constraints, and the remaining constraints were of less than or equal to ($\leq$) type. For all the species, the minimum limit set for all the ingredients was zero except for fishmeal, for which the minimum limit was taken as 20% in the case of Asian sea bass fry and grouper fry. Maximum limits for the ingredients were set at the SI level. As copra meal cannot be an ingredient in the case of tilapia fry, the maximum limit was set as zero to exclude copra meal.

The computer software MATLAB, a product of Math Works Inc., was used for solving each of the LP problems. It is a high performance language for technical computing and it represents the state-of-the-art in software for matrix computation.

TABLE 3 Nutritional Requirements and Ingredient Constraints (of Total Dry Feed) for Different Fishes

Sl.No.	Nutrient / Ingredient	Catfish	Milkfish	Tilapia	Asian sea bass	Grouper
1	Protein	≥35%	40%	≥35%	≥43%	≥47.8%
2	Lipid	0.1	≥7% & 10%	≥8%	10%	≤14%
3	NFE (carbohydrate)	≥49%	≥25%	≥25%	≥20%	≤20%
4	Crude fiber	≤8%	–	≤10%	–	≤6%
5	Ca/P ratio	–	–	–	≥1.88 & 2.0	–
6	Digestible energy kcal kg^{-1}	≥2700	≥2500	≥2500	≥2700	≥3400
7	Arg	≥1.51%	≥2.08%	≥1.47%	≥1.63%	–
8	Hist	≥0.53%	≥0.8%	≥0.6%	–	–
9	Ile	≥0.91%	≥1.6%	≥1.085%	–	–
10	Leu	≥1.23%	≥2.04%	≥1.19%	–	–
11	Lys	≥1.75%	≥1.6%	≥1.79%	≥1.94%	–
12	Met	≥0.81%	≥0.68%	≥0.95%	≥1.01%	≥0.97%
13	Phe	≥1.75%	≥1.28%	≥1.3%	–	–
14	Thre	≥0.7%	≥1.8%	≥1.33%	–	–
15	Try	≥0.18%	≥0.24%	≥0.35%	≥0.22%	–
16	Val	≥1.05%	≥1.44%	≥0.98%	–	–
17	Cotton seed meal	≤15%	–	–	–	–
18	Copra meal	–	–	0%	–	–
19	Fishmeal	–	–	≥18%	≥20% & 40%	≥20% & 40%

RESULTS AND DISCUSSION

Catfish Fry

All the constraints given in Table 3 for fry of catfish were used for feed formulation. At Cochin prices, the optimum LP solution selected included rice bran (16.60%), sunflower oil cake meal (21.85%), sorghum meal (4.94%), poultry by-product meal (37.96%), and hydrolyzed feather meal (10.66%). The total cost of the ingredients came to US$0.153. The optimum solution selected through LP with Tuticorin prices included sunflower oil cake meal (0.17%), cottonseed cake meal (15.00%), *Eichhornia* meal (21.48%), poultry by-product meal (54.65%), and hydrolyzed feather meal (0.70%), with US$0.117 as the total cost. At Bhubaneswar prices the optimum solution selected included sunflower oil cake meal (13.85%), *Eichhornia* meal (24.79%), poultry by-product meal (51.29%), and hydrolyzed feather meal (2.07) with US$0.066 as the total cost of the selected ingredients. Details regarding availability of different nutrients in the dry formula obtained with Cochin, Tuticorin, and Bhubaneswar prices are given in Table 4.

Feed for catfish fry formulated with Cochin prices has carbohydrate level and Ca/P ratio at 19.47% and 0.97%, respectively. Among all amino acids, methionine was found to be most limiting nutrient for both Cochin and Tuticorin formulations. The Ca/P ratio in both Tuticorin and Bhubaneswar

TABLE 4a Formulation of Catfish Fry Feed with Ingredients and Costs from Cochin

Formula	%	Nutrients in feed	Total in feed mix
Rice bran	16.60	Protein	44.65
Sunflower oil cake meal	21.85	Arg	3.52
Sorghum meal	4.94	Hist	0.86
Poultry by-product meal	37.96	Ile	2.05
Hydrolyzed feather meal	10.66	Leu	3.50
Fish oil or Soybean oil	6.00	Lys	1.98
Vitamin C + mineral premix	1.60	Met	0.81
Binder	0.40	Phe	1.75
Cost US$ kg^{-1}	0.153	Thre	1.78
		Try	0.41
		Val	2.66
		NFE	19.47
		Fiber	8.00
		Lipid	10.00
		DE	3227.01
		Ca/P	0.97

TABLE 4b Formulation of Catfish Fry Feed with Ingredients and Costs from Tuticorin

Formula	%	Nutrients in feed	Total in feed mix
Sunflower oil cake meal	0.17	Protein	44.70
Cottonseed cake meal	15.00	Arg	3.26
Eichhornia meal	21.48	Hist	0.89
Poultry by-product meal	54.65	Ile	1.93
Hydrolyzed feather meal	0.70	Leu	3.24
Fish oil or Soybean oil	6.00	Lys	2.31
Vitamin C + mineral premix	1.60	Met	0.81
Binder	0.40	Phe	1.75
Cost US$ kg^{-1}	0.117	Thre	1.65
		Try	0.41
		Val	2.34
		NFE	18.16
		Fiber	7.50
		Lipid	10.00
		DE	3193.84
		Ca/P	1.37

feed formulations are almost similar and higher than the Ca/P ratio in the Cochin feed formula. The NFE content in all the three feed formulae based on Cochin, Tuticorin, and Bhubaneswar market prices was almost equal. Among all the market prices, the LP formulated and nutritionally balanced feed of Bhubaneswar was found to be cheapest. Khan et al. (1996) showed that diet containing 42% of protein was found to be the best for tropical freshwater catfish *Mystus nemurus* when it was formulated through computerized linear programming. But in this study, all the feeds formulated for

TABLE 4c Formulation of Catfish Fry Feed with Ingredients and Costs from Bhubaneswar

Formula	%	Nutrients in feed	Total in feed mix
Sunflower oil cake meal	13.85	Protein	43.54
Eichhornia meal	24.79	Arg	3.24
Poultry by-product meal	51.29	Hist	0.89
Hydrolyzed feather meal	2.07	Ile	2.03
Fish oil or Soybean oil	6.00	Leu	3.45
Vitamin C + mineral premix	1.60	Lys	2.29
Binder	0.40	Met	0.87
Cost US$ kg^{-1}	0.066	Phe	1.75
		Thre	1.73
		Try	0.41
		Val	2.45
		NFE	18.99
		Fiber	8.00
		Lipid	10.00
		DE	3170.96
		Ca/P	1.36

catfish fry at different market prices showed slightly higher levels of protein in the diet compared to the aforementioned report.

Feed Formulation for Milk Fish Fry

Constraints given in Table 3 were used for feed formulation for fry of milkfish. With Cochin prices as the cost of the ingredients the formulation contained rice bran (37.13%), sunflower oil cake meal (36.51%), blood meal (2.32%), meat meal 0.18%), poultry by-product meal (0.68%), and hydrolyzed feather meal (18.18%) with the total cost of all the selected ingredients as US$0.110. The optimum LP solution for Tuticorin was obtained with soybean meal (2.23%), cottonseed cake meal (6.24%), *Eichhornia* meal (41.12%), poultry by-product meal (34.54%), and hydrolyzed feather meal (10.88%). Total cost of the ingredients selected through LP using Tuticorin prices was US$0.108. The ingredients selected with Bhubaneswar prices are sunflower oil cake meal (7.65%), *Eichhornia* meal (42.53%), poultry by-product meal (35.15%), and hydrolyzed feather meal (9.67%). Total cost of these ingredients is US$0.072. The details regarding the availability of different nutrients in the feed formulae for the three places are given in Table 5.

Cochin formulation showed that lysine, methionine, and threonine among the aminoacids and lipid level are balanced at the minimum required levels in the diet having fiber content and Ca/P ratio at 13.97% and 0.32%, respectively, whereas histidine, methionine, and threonine are in limited quantity in Tuticorin feed, having 9.63% and 1.22 as crude fiber and Ca/P

TABLE 5a Formulation of Milkfish Fry Feed with Ingredients and Cost from Cochin

Formula	%	Nutrients in feed	Total in feed mix
Rice bran	37.13	Protein	40.00
Sunflower oil cake meal	36.51	Arg	3.53
Blood meal	2.32	Hist	0.90
Meat meal	0.18	Ile	1.89
Poultry by-product meal	0.68	Leu	3.43
Hydrolyzed feather meal	18.18	Lys	1.60
Coconut oil	1.00	Met	0.68
Tri-calcium phosphate	2.00	Phe	1.85
Vitamin mix commercial	2.00	Thre	1.80
Cost US$ kg^{-1}	0.110	Try	0.41
		Val	2.76
		NFE	26.11
		Fiber	13.97
		Lipid	7.00
		DE	2949.69
		Ca/P	0.32

TABLE 5b Formulation of Milkfish Fry Feed with Ingredients and Cost from Tuticorin

Formula	%	Nutrients in feed	Total in feed mix
Soybean meal	2.23	Protein	42.99
Cottonseed cake meal	6.24	Arg	3.17
Eichhornia meal	41.12	Hist	0.80
Poultry by-product meal	34.54	Ile	2.00
Hydrolyzed feather meal	10.88	Leu	3.41
Coconut oil	1.00	Lys	2.13
Tri-calcium phosphate	2.00	Met	0.68
Vitamin mix commercial	2.00	Phe	1.77
Cost US$ kg^{-1}	0.108	Thre	1.80
		Try	0.37
		Val	2.57
		NFE	25.00
		Fiber	9.63
		Lipid	7.39
		DE	3103.20
		Ca/P	1.22

ratio, respectively. Histidine and threonine levels in Bhubaneswar feed are balanced but at the minimum required levels. Cochin feed was the costliest among the three feeds having US$0.110 as the total cost of selected ingredient mix. In the feed for milkfish fry, formulated by Alava and Lim (1988), with fish meal (30.0%), shrimp head meal (8.0%), soybean meal (10.0%), meat and bone meal (6.71%), corn gluten meal (10.2%), rice bran (12.1%), and wheat flour (15.9%) as major ingredients, the nutritional composition was shown as crude protein of 40.7%, crude fat of 8.4%, crude fiber of 4.2%,

TABLE 5c Formulation of Milkfish Fry Feed with Ingredients and Cost from Bhubaneswar

Formula	%	Nutrients in feed	Total in feed mix
Sunflower oil cake meal	7.65	Protein	41.75
Eichhornia meal	42.53	Arg	3.12
Poultry by-product meal	35.15	Hist	0.80
Hydrolyzed feather meal	9.67	Ile	2.01
Coconut oil	1.00	Leu	3.45
Tri-calcium phosphate	2.00	Lys	2.11
Vitamin mix commercial	2.00	Met	0.73
Cost US$ kg^{-1}	0.072	Phe	1.75
		Thre	1.80
		Try	0.36
		Val	2.56
		NFE	25.00
		Fiber	10.05
		Lipid	7.71
		DE	3088.48
		Ca/P	1.24

and NFE of 31.2%. In comparison to this feed, all the three feeds formulated for milkfish fry in the present study, through LP using market prices at Cochin, Tuticorin, and Bhubaneswar, are high in crude fiber content but have lower NFE content because the constraint set up (Table 3) did not contain limits for crude fiber.

In the practical diets for juvenile milkfish, formulated by Sumagaysay, Marquez, and Chiu-Chern (1991), with fish meal (10.0%), soybean meal (35.0%), copra meal (14.0%), wheat pollard (18.0%), and rice bran (18.0%) as major ingredients, the nutritional compositions were shown as crude protein of 27.4%, crude fat of 6.0%, crude fiber of 7.2%, and NFE of 50.6%. When compared with this feed, in all three LP formulations the amino acid balanced feeds have a higher percentage of crude protein, fat, and fiber content, and a lower percentage of NFE content in the diets.

Feed Formulation for Tilapia Fry

For tilapia fry, the optimum feed solution with Cochin prices includes rice bran (15.03%), sunflower oil cake meal (36.18%), sorghum meal (8.07%), fishmeal (18.00%), and poultry by-product meal (13.38%). The total cost of selected ingredients is US$ 0.207 kg^{-1}. Using the same constraints but with cost of the ingredients at Tuticorin, the optimum LP solution selected included sorghum meal (25.05%), fish meal (18.00%), squid meal (7.55%), and poultry by-product meal (40.07%) with the total cost of the ingredients US$0.369 kg^{-1}. With Bhubaneswar prices, the optimum solution selected

included sunflower oil cake meal (30.62%), sorghum meal (0.30%), mustard oil cake (36.71%), fish meal (18.00%), and poultry by-product meal (5.05%). Total cost of these ingredients is US$0.114 kg^{-1}. Details regarding the availability of different nutrients in these three feed formulas are given in Table 6.

Among all three feeds for Tilapia fry formulated through LP, Tuticorin feed has the lowest level of fiber content and hence was costliest (US$0.255 kg^{-1} and US$0.162 more costly than feed of Bhubaneswar and Cochin, respectively). Methionine level among all the amino acids was found to

TABLE 6a Formulation of Tilapia Fry Feed with Ingredients and Cost from Cochin

Formula	%	Nutrients in feed	Total in feed mix
Rice bran	15.03	Protein	36.40
Sunflower oil cake meal	36.18	Arg	2.96
Sorghum meal	8.07	Hist	0.90
Fishmeal	18.00	Ile	1.78
Poultry by-product meal	13.38	Leu	3.04
Cod liver oil	1.00	Lys	2.03
Vegetable oil	1.00	Met	0.95
Vitamin & mineral mix	4.33	Phe	1.69
Starch	3.00	Thre	1.55
Cost US$ kg^{-1}	0.207	Try	0.45
		Val	2.11
		NFE	25.79
		Fiber	10.00
		Lipid	8.00
		DE	2877.70
		Ca/P	0.87

TABLE 6b Formulation of Tilapia Fry Feed with Ingredients and Cost from Tuticorin

Formula	%	Nutrients in feed	Total in feed mix
Sorghum meal	25.05	Protein	42.28
Fishmeal	18.00	Arg	2.68
Squid meal	7.55	Hist	0.85
Poultry by-product meal	40.07	Ile	1.82
Cod liver oil	1.00	Leu	3.26
Vegetable oil	1.00	Lys	2.53
Vitamin & mineral mix	4.33	Met	0.95
Starch	3.00	Phe	1.51
Cost US$ kg^{-1}	0.369	Thre	1.58
		Try	0.41
		Val	2.14
		NFE	25.00
		Fiber	2.09
		Lipid	10.08
		DE	3342.07
		Ca/P	1.43

TABLE 6c Formulation of Tilapia Fry Feed with Ingredients and Cost from Bhubaneswar

Formula	%	Nutrients in feed	Total in feed mix
Sunflower oil cake meal	30.62	Protein	38.51
Sorghum meal	0.30	Arg	2.91
Mustard oil cake	36.71	Hist	1.01
Fishmeal	18.00	Ile	1.90
Poultry by-product meal	5.05	Leu	3.07
Cod liver oil	1.00	Lys	2.10
Vegetable oil	1.00	Met	0.95
Vitamin & mineral mix	4.33	Phe	1.76
Starch	3.00	Thre	1.71
Cost US$ kg^{-1}	0.114	Try	0.51
		Val	2.18
		NFE	25.00
		Fiber	8.08
		Lipid	8.00
		DE	2912.14
		Ca/P	0.77

be at the minimum required level in all types of feed. The Ca/P ratio in the diet is more for Tuticorin feed. The nutritional composition of practical diet for Nile tilapia fry—formulated by Santiago, Aldaba, and Laron (1982), with fish meal (30.17%), soybean meal (25.95%), copra meal (11.48%), rice bran (14.97%), and *Ipil-ipil* leaf meal (8.1%) as major ingredients (the minor ingredients were the same as the amount fixed for this study)—contained crude protein (38.1%), crude fat (8.7%), crude fiber (5.6%), and NFE (30.8%). The protein content of all three LP-formulated amino acid balanced feeds is obviously similar to this feed.

Feed Formulation for Fry of Asian Sea Bass

For Asian sea bass fry, the optimum solution with Cochin prices was US$0.274 kg-1. The ingredients selected under this are sunflower oil cake meal (12.92%), *Eichhornia* meal (11.99%), fish meal (20.00%), shrimp meal (6.10%), and poultry by-product meal (37.24%). The optimum solution with Bhubaneswar prices was only US$0.142 kg^{-1}. Ingredients selected under this are the same as that obtained with Cochin prices. For Tuticorin prices, the solution selected the following ingredients: cottonseed cake meal (18.87%), fishmeal (20.00%), shrimp meal (6.75%), squid meal (2.53%), and poultry by-product meal (40.09%). Total cost of this feed was US$0.397. Levels of different nutrients available in these feed formulations are given in Table 7 along with details of ingredients.

For all the three types of feed of Asian sea bass fry, methionine content and Ca/P level were found to be at the minimum required level of 1.01

TABLE 7a Formulation of Asian Sea Bass Fry Feed with Ingredients and Cost from both Cochin and Bhubaneswar

Formula	%	Nutrients in feed	Total in feed mix
Sunflower oil cake meal	12.92	Protein	43.53
Eichhornia meal	11.99	Arg	3.04
Fishmeal	20.00	Hist	0.94
Shrimp meal	6.10	Ile	2.01
Poultry by-product meal	37.24	Leu	3.37
Cod liver oil	2.88	Lys	2.58
Soybean oil	2.87	Met	1.01
Vitamin mix	4.00	Phe	1.74
Mineral mix	2.00	Thre	1.74
Cost US$ kg^{-1} (Cochin)	0.274	Try	0.45
Cost US$ kg^{-1} (Bhubaneswar)	0.142	Val	2.37
		NFE	14.28
		Fiber	6.50
		Lipid	10.00
		DE	3042.84
		Ca/P	1.88

TABLE 7b Formulation of Asian Sea Bass Fry Feed with Ingredients and Cost from Tuticorin

Formula	%	Nutrients in feed	Total in feed mix
Cottonseed cake meal	18.87	Protein	48.16
Fishmeal	20.00	Arg	3.40
Shrimp meal	6.75	Hist	1.02
Squid meal	2.53	Ile	2.03
Poultry by-product meal	40.09	Leu	3.35
Cod liver oil	2.88	Lys	2.74
Soybean oil	2.87	Met	1.01
Vitamin mix	4.00	Phe	1.86
Mineral mix	2.00	Thre	1.76
Cost US$ kg^{-1}	0.397	Try	0.49
		Val	2.40
		NFE	10.77
		Fiber	5.26
		Lipid	10.00
		DE	3130.86
		Ca/P	1.88

and 1.88, respectively. THE Cochin and Bhubaneswar formulae had 0.94% histidine, 2.01% isoleucine, 3.37% leucine, 1.74% phenylalanine, 1.74% threonine, 2.37% valine, and 6.5% crude fiber in the diet, whereas levels of these nutrients in the Tuticorin formula were 1.02%, 2.03%, 3.35%, 1.86%, 1.76%, 2.4%, and 5.26%, respectively. The Tuticorin feed was found to be the costliest among all the three.

Diet formulated for juvenile sea bass, with fishmeal (42.0%), soybean meal (9.0%), shrimp meal (*Acetes* spp.) (10.0%), squid meal (5.0%), rice meal

(14.5%), and bread flour (7.75%) as major ingredients (the minor ingredients were same as fixed in this study), was shown to contain crude protein, fat and fiber of 43.0%, 9.0% and 12.0%, respectively, with an NFE level of 25.0% in the diet (Bautista et al. 1994). The protein and lipid levels of LP formulated amino acid balanced feeds based on Cochin, and Bhubaneswar prices are similar to that of this feed in which comparatively higher levels of crude fiber and NFE were present.

Feed Formulation for Fry of Grouper

The constraints used for selecting the feed ingredients of feed formulation are given in the Table 3 for grouper fry. Using the Cochin prices, the LP solution selected sunflower oil cake meal (1.47%), fish meal (20.00%), poultry by-product meal (44.20%), and hydrolyzed feather meal (20.03%) with US$ 0.280 kg^{-1} as the total cost of selected ingredients. With Tuticorin prices, the LP solution selected fishmeal (20.00%), poultry by-product meal (59.17%), and hydrolyzed feather meal (6.53%). Total cost of the selected ingredients in this feed is US$0.321 kg^{-1}. For Bhubaneswar prices, the LP solution chose the same ingredients as that of Tuticorin market, and the total cost was US$ 0.114 kg^{-1}. For these sets of feed formulations the nutrients available in the mix are given in Table 8.

Methionine level in the feed for grouper fry, based on Cochin prices, is found to be at the minimum required level in the diet whereas the digestible energy content of all the feed formulations is balanced at the minimum required level. The feed formula based on Bhubaneswar prices was found to be the least expensive among all the three.

TABLE 8a Formulation of Grouper Fry Feed with Ingredients and Cost from Cochin

Formula	%	Nutrients in feed	Total in feed mix
Sunflower oil cake meal	1.47000	Protein	56.53
Fishmeal	20.00000	Arg	3.99
Poultry by-product meal	44.20000	Hist	0.97
Hydrolyzed feather meal	20.03000	Ile	2.55
Cod liver oil	6.00000	Leu	4.29
Lecithin	4.00000	Lys	2.77
Mineral mix	4.30000	Met	0.97
Vitamin B6	0.00029	Phe	2.01
Cost US$ kg^{-1}	0.280	Thre	2.28
		Try	0.48
		Val	3.39
		NFE	4.54
		Fiber	1.84
		Lipid	10.80
		DE	3400.01
		Ca/P	1.59

TABLE 8b Formulation of Grouper Fry Feed with Ingredients and Cost from both Tuticorin and Bhubaneswar

Formula	%	Nutrients in feed	Total in feed mix
Fishmeal	20.00000	Protein	52.53
Poultry by-product meal	59.17000	Arg	3.50
Hydrolyzed feather meal	6.53000	Hist	0.96
Cod liver oil	6.00000	Ile	2.30
Lecithin	4.00000	Leu	3.87
Mineral mix	4.30000	Lys	2.86
Vitamin B6	0.00029	Met	1.04
Cost US$ kg^{-1} (Tuticorin)	0.321	Phe	1.82
Cost US$ kg^{-1} (Bhubaneswar)	0.114	Thre	1.99
		Try	0.47
		Val	2.87
		NFE	4.85
		Fiber	1.87
		Lipid	12.77
		DE	3400.01
		Ca/P	1.79

Propensity of the LP toolbox linprog in MATLAB for fish feed formulation purposes is demonstrated. The constraints are: (1) lack of a proper database from which fish feed requirements can be drawn and (2) lack of information in the public domain regarding the technological constraints in fish feed processing and production. The above are imperative to refine the setup of constraints because, in commercial-scale feed production, the maximum and minimum limits of commonly used ingredients are defined and not revealed. Nutrient requirement data and technological constraints in using each ingredient for feed production and finally the evaluation of the feed produced on-farm will only complete the picture.

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