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MATHEMATICAL MODELLING FOR FISH FEED FORMULATION OF *MYSTUS NEMURUS* SP. CATFISH: OPTIMIZING GROWTH AND NUTRIENTS REQUIREMENTS

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Graphical abstract

Abstract

This study integrates mathematical model in the plan of producing a fish feed formulation by reducing the total cost without neglecting the nutrient requirements. This study focuses on producing the perfect combination of fish feed for *Mystus nemurus* sp. catfish in different stages of life. The mathematical model developed will consider their required nutrients in each stage, the cost of each ingredient and the amount of nutrients to be consumed (nutrient composition of fish feed ingredients). This research employs AIMMS mathematical software to assist with the computation. The results from this study obtain a much better combination of different ingredients compared to available commercial pellets in terms of nutrient composition and production cost. The combinations yield much cheaper costs yet boosts up the nutrient consumptions, which is an eye-opener for independent local fish farmers. Thorough discussion on utilizing the results with future research directions will also be included.

Keywords: Mathematical modelling, AIMMS mathematical software, *Mystus nemurus sp.* Catfish, fish feed formulation

Abstrak

Kajian ini menggunakan pemodelan matematik dalam perancangan penghasilan formulasi makanan ikan dengan pengurangan jumlah kos keseluruhan tanpa mengabaikan keperluan nutrien. Kajian ini bertumpu kepada penghasilan kombinasi makanan yang terbaik bagi *Mystus nemurus* sp. (ikan keli) dalam kitaran hidup yang berbeza. Pemodelan matematik yang dibina ini mengambil kira keperluan nutrien dalam setiap kitaran hidup, kos bagi setiap ramuan yang digunakan dan kuantiti nutrien yang diambil (komposisi nutrien di dalam setiap ramuan). Perisian matematik AIMMS digunakan bagi membantu dalam proses pengiraan ini. Hasil kajian ini mendapati suatu kombinasi dengan pelbagai ramuan makanan yang lebih baik berbanding pelet komersial di pasaran dari segi komposisi nutrien dan kos penghasilannya. Kombinasi ini memberikan kos yang jauh lebih rendah di samping meningkatkan pengambilan nutrien yang dapat membuka peluang kepada penternak ikan tempatan. Penggunaan hasil kajian ini untuk kajian akan datang juga dibincangkan secara terperinci.

Kata kunci: Pemodelan matematik, perisian matematik AIMMS, *Mystus nemurus* sp. (ikan keli), formulasi makanan ikan

1.0 INTRODUCTION

Consumption of fish in Malaysia is widespread amongst its multiracial population. According to Tan's study (as cited in Khan [1]), fish constitutes around 66% of the aggregate protein admission of the population in Malaysia, since it is the least expensive source of animal protein food and considered satisfactory by every single ethnic group in the nation. *Mystus nemurus* sp. catfish or Asian red-tailed catfish, known as "ikan baung" by Malaysians, is financially imperative nourishment that has gained fame among consumers because of its high dietary worth and great taste [2]. In the aquaculture industry, the river *Mystus nemurus* sp. catfish is an essential fresh water species with its good flesh quality and taste, high protein content, and low fat [3]. This species is popular and plentiful in Malaysia. It also constitutes a significant part of reservoir fishery [4]. Since *Mystus nemurus* sp. catfish have high demands, the quantity and flesh quality of the fish need to be maintained.

Due to its high domestic demand, it is necessary to improve the growth of *Mystus nemurus* sp. catfish. This can be done through feeding the fish with fish feed containing the maximum nutrient requirements of fish for different stages of life. However, there is still no exact feed formulation for the different life stages of *Mystus nemurus* sp. cattfish. In order to promote maximum growth of *Mystus nemurus* sp. catfish, the exact nutrient requirements and the best ingredients for feed formulation need to be determined.

Fish feed formulation is a process by which different ingredients containing several nutrients are combined to produce a highly digestible feed that provides all nutrients required by the fish at different stages of life with less environmental effects [5]. There are five life stages in *Mystus nemurus* sp. catfish which are endogenous, larval, post larval, juvenile and adult [6]. Research on fish feed formulation for the endogenous and larval stages are not recommended, since fish in these stages just hatched from their eggs and are developing their organs. In the post larval stage, the larvae just completed development of their organs and do not require much nutrition, so this stage is not recommended for fish formulation research either. The highly recommended stages to carry out fish feed formulation research are the juvenile and adult stages, since they are the grown-out and brood-stock stages respectively [6].

Sufficient nutrient is needed to maximize the growth of *Mystus nemurus* sp. catfish. The most important nutrition component in fish feed is protein [6], which is the most costly segment in aquaculture nutrition [7]. Fish meal bolsters fish development due to its protein quality; however, it is rare and costly, especially if it is of high quality, and hence, the cost of catfish production and nutrition is often very high [8].

As in most aquaculture endeavours, decreasing food expense is a steady concern because feed cost significantly impacts the production cost. The fish needs to be fed at least three to four times per day which will eventually increase the production cost. Various routines have been characterized for the plan of fish eating routine such as the square techniques, two by two matrix methods, synchronous comparison technique, trial and error method and linear programming method to plan the least cost diet [5]. Many fish farmers are still using the trial and error method. However, this method is inefficient since it takes longer time and more cost to find out the best amount of the nutrients with least cost that the fish needs in order to maximize its growth [9]. The feed formulation model seeks for the ideal blend of accessible food ingredients that will fulfil the nutritional necessities of the animal at a minimum cost.

The development of a general model to create a fish feed formulation for juvenile and adult *Mystus nemurus* sp. catfish is essential. The parameters involved in the model development were identified and the general fundamental model on the least costly production of the ingredients used in the fish feed formulation constructed for both stages was validated. The result of this technique can assist nutritionists in choosing various types of ingredients to determine the best elements that can be implemented in the formulation. This research will help fish farming increases the quality of the meat of *Mystus nemurus* sp. catfish at the lowest possible cost and will boost Malaysia's economy, especially in fisheries, through the increase of *Mystus nemurus* sp. catfish production. The data collected on the nutrient composition of the ingredients, the nutrient requirements of the fish, the ingredients' prices and the way all these data is applied to the general model of linear programming are shown in the Methodology section.

Mystus nemurus sp. catfish is a freshwater catfish distributed widely in Southeast Asian regions, such as Indochina, Thailand and Malaysia. In Malaysia, *Mystus nemurus* sp. catfish is a preferred food by all ethnicities because of its good taste and high protein level [10]. The domestic market demand for this fish has showed an increasing trend [11].

Due to increasing demand, *Mystus nemurus* sp. catfish must be propagated quickly with maximum growth and health. Fish usually require carbohydrates, protein, calcium, phosphorus, and lipids for growth and health. However, for every life stage of *Mystus nemurus* sp. catfish, different amounts of nutrients are required. Thus, information on the exact nutrient requirements of *Mystus nemurus* sp. catfish for every stage of life is crucial in order to formulate specific fish feed for specific life stages for maximum growth. Fish feed formulation is a process by which different types and compositions of ingredients that contain essential nutrients and energy are combined to give nutrition to the fish at different growth stages and to maintain physiological functions of growth, reproduction, and health [5].

Researchers have attempted to construct a fish feed formulation using different methods such as the two-by-two matrix method, trial and error method, square method, simultaneous equation method and linear programming (LP) method [5]. Among the numerous methods applied in animal feed formulation, LP is widely used and could be the best method for feed formulation because it gives the optimal solution [12].

George B. Dantzig is best known as the father of LP and the inventor of the simplex method [13]. From then onward, the LP technique has picked up ground in stockroom issue, food provider issue, staff issue, labour arranging, water quality administration and traffic light control. It has had an impressive effect on agriculture, domesticated animals and creature cultivation research in recent years and it can likewise be used in deciding fish food mixes for fish farmers to enhance the productivity of fishes [14].

An LP model was built with the aim to develop a decision support system for a production supervisor in fish-preparing firms to make decisions in the generation plants, staff planning and fish delivery [15]. The model was tested in a fish-preparing plant in Reykjavik by Gunnarsson and Jensson (as cited in [5]) and was observed to be exceptionally helpful to the production supervisors and in classifying fish. In this study, a model was built to help in determining the most beneficial classification of fish. An LP model using mathematical optimization techniques by Gunnarsson and Jensson was employed to amplify fish feed formulation and estimation of capelin, herring and shrimps, taking into account their size circulation. Thereafter, Einarsson [16] claimed that Runarsson, a professor from University of Iceland, used this information to build a linear optimization model that expanded the benefit of an Icelandic organization in the field of fish handling.

Nath and Talukdar [5] 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. This paper aims to formulate an optimized fish feed formulation at the lowest cost that satisfies the nutrient requirements of juvenile and adult *Mystus nemurus* sp. catfish using LP.

1.1 Nutrient Requirements

Fish require essential nutrients for healthy growth [17]. According to Lee [18], five basic nutrients are required by catfish: carbohydrates, protein, calcium, lipids and vitamins. These are the main energy sources for fish to grow. Each of these nutrients has its own role in supporting the growth of catfish.

Protein is important for building the muscle, blood, connecting tissues, hormones and enzymes of catfish [19]. Proteins are made up by linkages of amino acids, and these amino acids are primarily composed of oxygen, nitrogen, hydrogen, carbon, and other chemical elements [18]. Essential amino acids (EAAs) must be consumed from the diet, as animals cannot synthesize a sufficient quantity of EAAs to support maximum growth [20]. Steven and Louis [17] stated that young or juvenile catfish that are actively growing require higher levels of protein compared to mature fish. Fish will suffer protein loss in tissue if they do not receive enough protein in their diet. However, an excess of protein may cause water pollution since fish will excrete it through their kidneys and gills. Therefore, optimal amounts are needed to prevent any complications. In general, catfish requires 25-40% of protein in their diet to obtain good growth [18]. Basically, protein requirements of fish decrease with increasing size and age [21]. However, the optimal dietary protein requirement of Malaysian freshwater *Mystus nemurus* sp. catfish is unknown [7]. Soybean meal, fish meal, blood meal, feather meal and corn gluten meal are some common sources of protein in fish feed.

Carbohydrates are one of the sources of energy for fish instead of protein. Freshwater fish can use greater amounts of dietary carbohydrates than cold-water and marine fish [22]. Lipids (fats) are highly vital nutrients that can be used to substitute protein in aquaculture feeds [23]. Normally, the cost of fish feed containing carbohydrates and fats is lower than the cost of fish feed containing a high amount of proteins. Carbohydrates are not essential nutrient for catfish if other sources of energy are available. Although it is not essential, carbohydrates are still included in the diet to reduce the fish feed cost. A high concentration of carbohydrates in the fish diet results in health issues for the fish. Although expanding dietary lipids can lessen the high expenses of diets by partially sparing protein in the feed, problems arise where excessive fat deposition in the liver can diminish the health and market quality of fish. Fish meal, fish oil and soybean meal are the major sources of fat in fish feed for catfish [17, 18].

The animal body requires seven minerals: calcium, sodium, magnesium, potassium, phosphorus, chlorine and sulphur [24]. Not all of the minerals in the diet can be found in the fish body. Fish are surrounded by water that contains mineral salts in solution, and they are capable of absorbing some broken-down minerals from the water [25]. A great part of the requirements for many of the mineral components is likely met from dietary sources rather than by direct ingestion from the water especially for freshwater fish species. Like other nutrients, the exact amount of minerals required is still unknown [18].

Vitamins are needed for the health and growth of a fish. A deficiency of vitamins will cause poor growth of catfish [18]. Vitamins are characterized as complex organic compounds required for ordinary metabolism that cannot be synthesized by the animal [26]. Vitamins act as an attractant in fish feed to induce the fish to eat it [27].

Farmers usually use natural food items such as zooplankton, insects, shrimp and fish to support the growth of juvenile *Mystus nemurus* sp. catfish. However, natural food items do not fully support the growth of juvenile *Mystus nemurus* sp. catfish, as their nutrient content is incomplete. Therefore, fish feed needs to be formulated for each life stage by the combination of different ingredients to provide all the nutrients required by the fish.

Local ingredients such as fish meal, soybean meal, rice bran, snail meal, wheat middlings, and mixed vitamins are chosen to minimize the cost of ingredients, since imported ingredients are relatively higher in cost [27]. The ingredients chosen are rich in protein, which is the most important nutrient required by fish, and also consist of other nutrients such as lipids, carbohydrates, calcium and phosphorus, which are important for fish growth. However, there is still a lack of information about optimal nutrient requirements of each life stage of *Mystus nemurus* sp. catfish.

2.0 METHODOLOGY

This section explains the research work leading to an optimal solution for minimizing the cost for both the juvenile and adult stages. The model can be expressed in LP. In order to construct the model, data about the nutrient requirements of juvenile and adult *Mystus nemurus* sp. catfish, nutrient composition of fish feed ingredients, and prices of ingredients were obtained from the literature and interviews. The prices of ingredients were obtained based on standard prices from a market survey. LP is a technique for optimization of a linear objective function, subject to linear equality and linear inequality constraints [28]. The objective function will maximize or minimize some numerical value [29]. In this research, the objective function is to minimize the cost of fish feed formulation while satisfying a set of fish nutrient requirement constraints. Below is the standard form of LP model.

Objective function:
Minimize $z = c_1x_1 + c_2x_2 + \ldots + c_nx_n$
subject to:
$a_{11}x_1 + a_{12}x_2 + \ldots + a_{1n}x_n \geq b_1$
$a_{21}x_1 + a_{22}x_2 + \ldots + a_{2n}x_n \geq b_2$
.
.
.
$a_{m1}x_1 + a_{m2}x_2 + \ldots + a_{mn}x_n \geq b_m$

and

$x_1 \geq 0, x_2 \geq 0, \ldots, x_n \geq 0$

Objective function:
Overall performance measure: $c_1x_1 + c_2x_2 + \ldots + c_nx_n$
Constraints: $a_{i1}x_1 + a_{i2}x_2 + \ldots + a_{in}x_n \; (\leq or \; \geq) \; b_i \forall_i = 1, \ldots, m$ (function constraints) $x_j \geq 0, \forall_i = 1, \ldots, n$ (non-negativity constraints)

From the above general model, z is the value of performance measure, c_j is the coefficient of decision variable with $j = 1,2, \ldots, n$, x_j is the decision variable to be determined with $j = 1,2, \ldots, n$, b_j is the right hand side values of constraints with $i = 1,2, \ldots, m$ and a_{ij} is coefficient of variable x in constraints with $i = 1,2, \ldots, m$ and $j = 1,2, \ldots, n$. Constraints include the function type and non-negativity type of constraints. The group of coefficients $(c_j, a_{ij,} b_i)$ for all the values of the indices i and j are called the parameters of the model. The value of all parameters involve must be known for the model to be completely determined. We will be focusing only on the juvenile and adult stage as at these stages are the grown-out and brood-stock stage respectively. In this study, the mathematical model for fish feed formulation for growth of juvenile and adult *Mystus nemurus* sp. catfish by linear programming are shown:

Minimize Z=$\sum_{j=1}^{n} c_j x_j$
subject to $\sum_{j=1}^{n} a_{ij} x_j \leq b_i$, $\forall_i = 1, \ldots, m$
Z= the total price of the ingredients for growth
x_j = weight of ingredients j per kg (for $j = 1,2, \ldots, n$)
c_j = unit price of ingredients j per kg
b_i = nutrient requirement by the juvenile and adult *Mystus nemurus* sp. catfish (for $i = 1,2, \ldots, m$)
a_{ij} = amount of nutrient i contain in different ingredients j

Decision variables: x_j
Parameters: c_j, a_{ij}, b_i

The feed formulation model built by the LP method will search for an optimal combination of the ingredients to satisfy all the nutrient requirements of the animals at a minimum cost. The nutrient requirements of catfish, the prices of ingredients, and the nutrient composition of ingredients will be provided in the next section.

2.1 Data Collection

There is no single feed ingredient that can provide all the nutrients required for optimal growth of catfish. Hence, commercial catfish feeds contain a blend of feedstuffs and vitamin and mineral premixes that give sufficient amounts of essential nutrients and energy [30]. In this research, to get a mixture of our formulation, the fish feed ingredients used are fish meal, rice bran, soybean meal, snail meal, wheat middlings and mixed vitamins, since they are among the local fish feed ingredients that can easily be found in Malaysia [31]. The information regarding the nutrient requirements of juvenile and adult *Mystus nemurus* sp. catfish, 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 Nutrient contents for each ingredient

Ingredients	Nutrient				
	Protein %	Lipid %	Carbohydrate %	Calcium %	Phosphorus %
Fishmeal	55	1.8	-	4.5	2.5
Soybean meal	48	1.0	28.03	0.28	0.66
Rice bran	37	4.9	42.65	0.61	1.47
Snail meal	50.29	6.1	4.5	2.0	0.84
Wheat middling	38.8	3.6	55.6	0.13	1.51

Source: Robinson *et al.* [30] and Hertrampf & Piedad-Pascual [32]

Table 2 Nutrient contents of mixed vitamins (amount per tonne of feed)

Vitamin A	1000 IU
Vitamin D	500 IU
Vitamin E (%)	0.003
Vitamin K (%)	0.00044
Thiamin (%)	0.00025
Riboflavin (%)	0.0006
Pyridoxine (%)	0.0005
Pantothenic acid (%)	0.0015
Folic acid (%)	0.00022
Vitamin B-12 (%)	0.000001
Ascorbic acid (%)	0.005

Source: Jasper [33]

Table 3 Minimum nutrient requirements of juvenile and adult *Mystus nemurus* sp. catfish

Nutrient	Stages	
	Juvenile	Adult
Protein %	40	28
Lipid %	5	5
Carbohydrate %	25	25
Calcium %	0.45	0.45
Phosphorus %	0.8	0.30
Vitamin %	1	1

Source: Robinson *et al.* [30]

Table 4 Market price of ingredients (RM/kg)

Ingredients	Price (RM/kg)
Fish meal	4.00
Rice bran	0.80
Snail meal	2.13
Soybean meal	3.00
Wheat middlings	0.67
Mixed vitamin	100.00

Source: Zakaria [27], QL Fishmeal Sdn Bhd [34] and market survey

2.2 Formulation of the LP Model for Juvenile and Adult *Mystus nemurus* sp. Catfish

The LP model constructed was based on information obtained from the previous section. The quantity of mixture to be prepared was 100 kg as in Nath and Talukdar [5]. The formulation models for the juvenile and adult stages are as in models A and B respectively.

The main objective of the constructed model is to minimize the cost of fish feed production. In this model, the decision variables are the amounts of each ingredient needed in 100 kg of fish feed. The first six constraints are the nutrient restriction type of constraints, which are needed to ensure the fish feed produced reached the minimum nutrients required. Through these six constraints, it is assured that the fish consume their nutrient requirements in order to grow normally.

Let x_1, x_2, x_3, x_4, x_5 and x_6 be the respective quantities in kg of fish meal, rice bran, snail meal, soybean meal, wheat middlings and mixed vitamin required for the mixture. The minimum cost LP models for juvenile and adult *Mystus nemurus* sp. catfish are as in models A and B respectively.

Model A

Min $z = 4x_1 + 0.8x_2 + 2.13x_3 + 3x_4 + 0.67x_5 + 100x_6$ (1)

subject to

$0.55x_1 + 0.37x_2 + 0.5027x_3 + 0.48x_4 + 0.388x_5 \geq 40$ (2)

$0.018x_1 + 0.049x_2 + 0.061x_3 + 0.01x_4 + 0.036x_5 \geq 5$ (3)

$0.4265x_2 + 0.045x_3 + 0.2803x_4 + 0.556x_5 \geq 25$ (4)

$0.045x_1 + 0.0061x_2 + 0.02x_3 + 0.0028x_4 + 0.0013x_5 \geq 0.45$ (5)

$0.025x_1 + 0.0147x_2 + 0.0084x_3 + 0.0066x_4 + 0.0151x_5 \geq 0.8$ (6)

$x_5 \geq 1$ (7)

$x_1 + x_2 + x_3 + x_4 + x_5 + x_6 \geq 100$ (8)

$x_1, x_2, \dots, x_6 \geq 0$ (9)

Model B

Min $z = 4x_1 + 0.8x_2 + 2.13x_3 + 3x_4 + 0.67x_5 + 100x_6$ (10)

subject to

$0.55x_1 + 0.37x_2 + 0.5029x_3 + 0.48x_4 + 0.388x_5 \geq 28$ (11)

$0.018x_1 + 0.049x_2 + 0.061x_3 + 0.01x_4 + 0.036x_5 \geq 5$ (12)

$0.4265x_2 + 0.045x_3 + 0.2803x_4 + 0.556x_5 \geq 25$ (13)

$0.045x_1 + 0.0061x_2 + 0.02x_3 + 0.0028x_4 + 0.0013x_5 \geq 0.45$ (14)

$0.025x_1 + 0.0147x_2 + 0.0084x_3 + 0.0066x_4 + 0.0151x_5 \geq 0.30$ (15)

$x_5 \geq 1$ (16)

$x_1 + x_2 + x_3 + x_4 + x_5 + x_6 \geq 100$ (17)

$x_1, x_2, \dots, x_6 \geq 0$ (18)

As can be seen, the mathematical models are given in a similar manner, except for the different parameters used for each stage. Equations (1) and (10) are the objective function of the mathematical model that determines the minimum cost for fish feed formulation represented by Z. The decision variable x_j represents the different types of ingredients, where the coefficient c_j is the unit price of the ingredients. Equations (2) to (9) and (11) to (18) represent the minimum nutrient requirement restrictions from protein, lipids, carbohydrates, calcium, phosphorus, and vitamins that juvenile and adult *Mystus nemurus* sp. catfish should consume. Equations (8) and (17) are the total quantity restriction (total amount of fish feed to be produced).

The differences between these two models are the requirement of protein and phosphorous since the protein requirement for juvenile *Mystus nemurus* sp. catfish is 40% and adult *Mystus nemurus* sp. catfish is 28%, while the phosphorus requirement for juvenile *Mystus nemurus* sp. catfish is 0.8% and adult *Mystus nemurus* sp. catfish is 0.3%.

3.0 RESULTS AND DISCUSSION

This section shows the results of the fish feed formulation using the LP model. Optimal results were obtained using mathematical software AIMMS with CPLEX 12.6.3 as the solver in two iterations for both juvenile and adult *Mystus nemurus* sp. catfish. The tables below (Table 5 and Table 6) present details on the nutrient composition of the ingredients for juvenile and adult *Mystus nemurus* sp. catfish.

Table 5 Input for nutrient composition of ingredients in AIMMS for juvenile *Mystus nemurus* sp. catfish

	Nutrients composition of ingredients						Nutrient requirement
	fish meal	rice bran	snail meal	soybean meal	wheat middling	mixed vitamin	
protein	0.55	0.37	0.50	0.48	0.39		40.00
lipid	0.02	0.05	0.06	0.01	0.04		5.00
carbohydrate		0.43	0.04	0.28	0.56		25.00
calcium	0.04	0.01	0.02	0.00	0.00		0.45
phosphorus	0.03	0.01	0.01	0.01	0.02		0.80
vitamin						1.00	1.00
cost price per kg	4	1	2	3	1	100	

Table 6 Input for nutrient composition of ingredients in AIMMS for adult *Mystus nemurus sp.* catfish

	Nutrients composition of ingredients						Nutrient requirement
	fish meal	rice bran	snail meal	soybean meal	wheat middling	mixed vitamin	
protein	0.55	0.37	0.50	0.48	0.39	N/A	28.00
lipid	0.02	0.05	0.06	0.01	0.04	N/A	5.00
carbohydrate		0.43	0.04	0.28	0.56	N/A	25.00
calcium	0.04	0.01	0.02	0.00	0.00	N/A	0.45
phosphorus	0.03	0.01	0.01	0.01	0.02	N/A	0.30
vitamin						1.00	1.00
cost price per kg	4	1	2	3	1	100	-

From the results obtained, it was found that 64.46 kg of rice bran, 23.92 kg of snail meal, 10.62 kg of wheat middling, and 1 kg of mixed vitamins are required to formulate 100 kg of fish feed that satisfies the minimum nutrient contents requirements of juvenile *Mystus nemurus* sp. catfish at a total cost of RM 209.63. For the adult *Mystus nemurus sp.* catfish, 86.58 kg of rice bran, 12.42 kg of snail meal, and 1 kg of mixed vitamins are required for the mixture of 100 kg of fish feed that satisfies nutrient requirements at the least cost of RM 195.71. The cost for adult fish feed is slightly lower because adults required less protein and phosphorus compared to juvenile catfish.

Table 7 shows the type and amount of ingredients at the least cost of fish feed formulation for juvenile and adult *Mystus nemurus* sp. catfish. Figure 1 shows the amount of ingredients used in the fish feed formulation for juvenile and adult *Mystus nemurus* sp. catfish.

Soybean meal and fish meal are not chosen because of their high price. The quantity of nutrients needed in the selected ingredients is sufficient for the requirements of juvenile and adult *Mystus nemurus* sp. catfish at less cost. Furthermore, the selected ingredients (rice bran, snail meal, wheat middling, and mixed vitamins) have other nutrients that are needed and sufficient at less cost compared to the ingredients that were not chosen. The mathematical model constructed chooses the minimum cost of ingredients while respecting other needs. Thus, the probabilities of a high-price ingredient to be chosen are low.

Table 7 The type and amount of ingredients at the least cost of fish feed formulation for juvenile and adult *Mystus nemurus* sp. catfish

Stages	Type of Ingredients		Amount of ingredients' needed (kg)	Cost (RM)
Juvenile	Fish meal		-	-
	Rice bran	√	64.46	51.57
	Snail meal	√	23.92	50.95
	Soybean meal		-	-
	Wheat middling	√	10.62	7.11
	Mixed vitamin	√	1.00	100
	Total (in whole number)			210 (209.63)
Adult	Fish meal		-	-
	Rice bran	√	86.58	69.26
	Snail meal	√	12.42	26.45
	Soybean meal		-	-
	Wheat middling		-	-
	Mixed vitamin	√	1.00	100
	Total (in whole number)			196 (195.71)

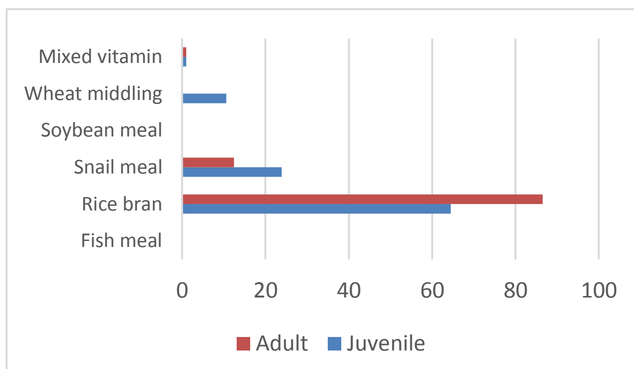

Figure 1 Amount of different ingredients used (kg) in fish feed formulation for juvenile and adult *Mystus nemurus* sp. catfish

The results obtained showed the difference between the selected ingredients for juvenile and adult *Mystus nemurus* sp. catfish. Juvenile and adult fish require almost the same ingredients for fish feed formulation. The selected ingredients for juveniles are rice bran, wheat middling and mixed vitamins, and with the addition of snail meal. Meanwhile, adult fish feed requires rice bran, wheat middling, and mixed vitamins to cover the nutrients needed by the fish in this life stage. This is because juveniles require more protein and phosphorus for growth compared to adults, and the cost of the selected ingredients is the lowest with optimal nutrient requirements.

3.1 Fish Feeding Rate

Juvenile and adult *Mystus nemurus* sp. catfish are usually fed the same feed. It is advisable to feed the adult catfish with 28% protein feed once daily where the feeding rate should be around 5% of the fish body weight [30]. Based on Isyagi et al. [19], the formula used to calculate the amount of feed required by catfish per day is shown below.

Amount of feed required by catfish (per day) = average fish size (weight) × fish rate (%)

The weight of juvenile *Mystus nemurus* sp. catfish normally ranges from 300 g to 600 g, while the weight of adult *Mystus nemurus* sp. catfish is expected to be more than 700 g. Therefore, approximately 22.5 g of feed per day is required for the juvenile stage and 35 g of feed per day for adult *Mystus nemurus* sp. catfish. The calculations are shown below.

Amount of feed required by juvenile catfish (per day) = average fish size (weight) × fish rate (%) =450 g × 5%
= 22.5 g

Amount of feed required by adult catfish (per day) = average fish size (weight) × fish rate (%)
= 700 g × 5%
= 35 g

Usually, *Mystus nemurus* sp. catfish are reared in a pond and the fish are fed according to the amount calculated by the formulation of Isyagi et al. [19], as shown below.

Amount of feed required by catfish (per day) = average fish size (weight) × fish rate (%) × total number of fish in the pond
From the above formula, fish farmers would easily know the approximate amount of fish feed needed for the fish. For example, in a pond consisting of 500 juvenile *Mystus nemurus* sp. catfish, the amount of fish feed to be fed is 11.25 kg/day. Meanwhile, a pond at the size of 360 square metres that can rear about 1000 adult fish requires roughly 35 kg/day of pellets per feeding time [35].

3.2 Comparison of Price Rates of Fish Feed

In Malaysia, the market price for 20 kg of fish feed is around RM 61.00, and fish feed manufacturers sell fish feed at a price of 130% of its production cost [27]. In the results obtained from this research, the feed cost of juvenile *Mystus nemurus* sp. catfish is RM 209.63, while the feed cost for adult *Mystus nemurus* sp. catfish is RM 195.71. Juvenile and adult catfish feed costs are approximately RM 41.93 and RM 39.14, respectively, for 20 kg of fish feed. The selling prices of juvenile and adult catfish fish feed are shown below.

Juvenile *Mystus nemurus* sp. catfish = (209.63/5) × 130%
=RM 54.50

Adult *Mystus nemurus* sp. catfish = (195.71/5) × 130%
=RM 50.88

From the calculations above, the costs of the fish feed formulated are much lower than the market price of fish feed. This result proved that the fish feed formulation produced from this research is successfully reduced to a minimum cost. Table 8 below shows the comparison between the commercial pellet market price and the juvenile and adult catfish feed formulation production cost and selling price.

Table 8 Comparison between the commercial pellet market price and the juvenile and adult catfish feed formulation production cost and selling price

***Mystus nemurus* sp. catfish stages**	**Catfish feed formulation**				**Commercial pellet**	
	Production cost (RM)		Selling price(RM)		Market price (RM)	
	20 kg	100 kg	20 kg	100 kg	20 kg	100 kg
Juvenile	41.93	209.63	54.50	272.50	61.00	305.00
Adult	39.14	195.71	50.88	254.40	61.00	305.00

3.3 Growing Juvenile *Mystus nemurus* sp. Catfish into Adults

As mentioned above, the weight of juvenile *Mystus nemurus* sp. catfish is 300 g to 600 g while the weight of adult *Mystus nemurus* sp.catfish is known to be more than 700 g. It takes four months for juveniles to grow into adult catfish. For a pond that consists of 500 juvenile *Mystus nemurus* sp. catfish, the amount of fish feed to be fed is 11.25 kg/day, as calculated in the previous section. Therefore, farmers need 1372.5 kg of fish feed for juvenile *Mystus nemurus* sp. catfish during the growth into adult catfish. The cost of fish feed at 1372.5 kg is RM 4186.13 at the commercial pellet market price. The commercial pellet does not focus on satisfying the nutrient requirements in the different stages of life. However, the price for juvenile catfish feed formulation is RM 2877.17. Through this research, fish farmers can reduce the fish feed cost by about RM 1308.96. Fish farmers not only can reduce fish feed cost but they also can reduce the harvest time and increase the production of fish, since the fish feed formulation satisfies optimal nutrient requirements for fish growth that will shorten the period for juvenile catfish to grow into adults. Table 9 shows the summary of feed cost for juvenile catfish to grow into adult *Mystus nemurus* sp. catfish.

Table 9 Feed cost for juvenile catfish to grown into adult *Mystus nemurus* sp. catfish

Criteria	Juvenile
Amount of feed required (per day)	22.5 g
Amount of feed required in 1 pond (500 fish) (per day)	11.25 kg
Amount of feed required to turn juvenile to adult (4 months ≈ 122 days) for 500 fish (1 pond)	11.25 kg * 122 days = 1372.5 kg
Price of fish feed for 4 months period (price based on production cost)	RM 209.63 / 100kg * 1372.5 kg RM2877.17

The best growth rate comes from optimal fish feed. In Malaysia, most fish farmers use the same type of feed for fish regardless of their life stages and species. Logically, one type of feed to feed all stages and species of fish can reduce the production cost of fish farmers, but the consumption of specific fish feed for every stage and species of fish may slightly increase the production cost of fish farmers. However, from another view, fish feed that gives an optimal growth rate can reduce the harvest time of fish. This means that the number of fish harvested can be increased in a shorter period and will lead to profit increment due to a high supply to the market. Hence, the increased profit is able to cover the production cost for fish farmers.

Development of the fisheries sector is extremely important to the people of Malaysia to ensure continuity of the food sources that act as a vital sector for the income of the nation. It is necessary for the government to focus more on and encourage this sector so that the products can be exported out of the state and thus increase the income of the nation. Success in this sector will not only benefit the farmers, but also create opportunities for the food fishery sector.

The positive outcome of this study leads to another opportunity in the research area to consider research gaps. It is recommended to seek additional alternative sources for fish feed formulation in order to further reduce production costs and increase the quality and health of fish thus increasing profits for fish feed manufacturers and fish farmers. Through this research, we are interested in developing a feed formulation for ornamental fish, since they are widely bred in Malaysia and contribute much to the country's economic development in terms of employment and exportation. For future work, the LP method will be used to optimize the nutrient requirements for ornamental fish feed formulation at the least cost to improve growth and colour. Since commercial pellet for maintaining the colour of fish is expensive, we are keen to formulate a low cost ornamental fish feed with alternative sources such as waste from natural sources that can aid in colour enhancement and fulfil nutrient requirements. The success of the project will highly develop the ornamental fish field, and the cost of fish feed can be reduced.

4.0 CONCLUSION

It is important for fish farmers to seek alternative feedstuffs in order to reduce the cost of rearing fish without affecting the quality of the feed and productivity of the fish. The results obtained from our mathematical model showed a reduction in fish feed formulation cost compared to commercial fish feed. This research contributes not only to fish farmers but also to fish feed manufacturers, as it allows them to gain a higher profit. Through this research, fish feed manufacturers can produce two types of fish feed at a lower production cost, and fish farmers will certainly choose these types of feed to make their fish grow faster in a shorter period of time while lowering rearing costs.

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