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POTENTIAL GROUPER FEED FORMULATION BASED ON EVOLUTIONARY ALGORITHM CONCEPT WITH A UNIQUE SELECTION OPERATOR

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Abstract

The problems of insufficient wild catch grouper fish and the high demand in the market have increased the need of farming the grouper fish. In order to farm the grouper fish, there is a need to have abundant of trash fish as their feeds since grouper fish is a carnivorous fish. But, trash fish is dramatically expensive and hard to store, hard to maintain the quality of nutrients as well as the quantity throughout the years. Therefore, turning to formulated feed mix is the alternative. However, the issue is on its cost while providing quality feed mix. That leads to the search for an approach which could provide the most suitable feed ingredients and nutrients. One potential approach is the Evolutionary Algorithm (EA) which has been used to solve the feed formulation problems in poultry, shrimp and cattle. Hence, in this study, an EA-based approach with a refinement on using the standard deviation in the strategy of tournament selection has been proposed to minimize the total cost in formulating the feed of grouper fish. Results show that the lowest cost can be accepted while satisfying the nutrient requirements of grouper fish.

Keywords: Grouper feed formulation, Tournament selection operator, Nutrient requirements, Heuristic approach, Evolutionary Algorithm.

1. Introduction

Global marine water fishery production in the year 2011 and 2012 were 82.6 million tonnes and 97.7 million tonnes respectively [1]. The 18 major countries with a production of at least one million tonnes per year, constitute at least 76 percent of the global marine catch. Malaysia is one of the major producers ranked at 15th place, with 12.5% contribution to global fish rankings in grouper fish production [2, 3]. These carnivorous groupers are the focus for this study due to the current trend of high market demand especially in many seafood restaurants [2-5] with their high price as compared to that of the other fish species [2-7] and the desired taste [2, 3, 6, 7].

Currently, grouper fish farming is becoming increasingly lucrative [1, 9] and popular due to that high market demand. More significantly, the number of farmed grouper fish harvest surpasses many folds as compared to the wild grouper fish [1] being caught from the ocean. As a result, the supply of this type of fish is sustained and remains uninterrupted to meet the market demand. However, the biggest challenge to the farmed grouper industry is the related operational costs [10-12] whereby minimizing cost is the ultimate goal in this type of agricultural business [3, 13-14].

Consequently, the main operational costs direct to the provision of the fish feed [10-12] with its complexity in ensuring sufficient ingredients [11, 15, 16] and appropriate nutrients [17-22]. In relation to that, an overview on the priorities of ingredients and nutrients in feed fish for grouper is elaborated in the study by [5]. The study revealed that there are 15 nutrients considered as the most important ones, which need to be fulfilled. The ingredients which suit to the grouper fish are such as trash fish, potato protein concentrate, oats, alfalfa meal, soybean oil, soybean seeds, wheat flour, shrimp meal, corn grain meal, cottonseed meal, spirulina, barley, to name a few, have been also identified. The studies of nutrient requirements [23], new feed ingredients [10, 24-25] and feed formulation [3-5, 26-29] attempted to find a replacement of fish meal and fish oil, which can minimize the cost of trash fish, simultaneously keeping fish health and well-being. The issue that is still being contented among researchers and practitioners is the feed mix or formulation [4, 26], such that the best suitable formulation [3-5, 26-29] is achieved. Hence, this issue has driven the initial motivation of our study in searching for the most suitable feed ingredients and nutrients as have similarly been done by [3-5, 26-29]. Eventually, this leads to another issue of identifying the most appropriate approach in doing so.

However, with regard to grouper fish feed, there is a limited number of studies [4, 30] being carried out in term of the approach. The relevant approach thus far being done for grouper fish feed formulation is experimental design such as by [10, 24-25, 31]. Shapawi et al. [24] used various vegetable oils dietary formulations for humpback grouper without compromising growth or feed utilization efficiency. Besides that, cottonseed meal is used by Agbo et al. [10] in the diet of O. niloticus without adversely affecting growth and feed utilization. In addition, the poultry by-product meal (PBM) is used by Gunben et al. [25] in the diets of juvenile tiger grouper that helps to reduce the dependency of tropical marine fish farming on fish-based feeds. Moreover, soybean meal (SBM) is used for the feed formulation as in the study of [31]. Subsequently, for the purpose of unlocking the frontier in research on formulating the fish feed, our study further explores on the new possibilities in the formulation. Therefore, the objective of this paper is to propose a modelling approach, i.e., a heuristic that is based on the Evolutionary Algorithm (EA) concept in designing the feed formulation, which is able to produce reasonable and feasible solutions successfully in the complex problem and yet in only short time.

In demonstrating the proposed approach, the grouper fish feed formulation problem is taken as a case study. Some related studies are reviewed in section 2. The detailed explanation of the EA-based architecture is given in section 3, while the results and analysis are illustrated in section 4. Finally, section 5 concludes the study with some remarks for future works.

2. A Review on Feed Formulation Strategies

A number of previous studies have been identified to work on related issues with feed formulation. One feasible approach that has been regularly used in testing and examining the formulation or mix for animal feed is the Experimental Design (ED) approach [10, 11, 19, 20, 24, 25, 31-34]. A study on fish feed formulation that used the ED approach is such as by [23], who discussed on nutrient requirements and feed ingredients similar to the works by [10, 24, 25, 31]. In addition, [23] also evaluated and formulated the feed or diet that promotes effective production, while keeping up with the fish health and well-being as carried out also by [10, 24, 25, 31]. Other studies in fish diet involved investing new ingredients used in the feed formulation are such as by [10, 11, 35, 36]. These studies tried to find a least cost diet for fish using new ingredients by replacement of fish meal or trash fish. The findings confirmed that fish meal [10, 25, 31] and fish oil [24] are able to replace the same ingredients without compromising growth [10, 24] or feed utilization efficiency [10, 24]. However, these studies used ED or similar to ED, which can be described as a trial-and-error type [37, 38] of approach. So far, for the fish feed formulation problem, there is no work reported on using a modelling or algorithmic type of approach, such as the Evolutionary Algorithm (EA) [39-45] which is categorized as an artificial intelligence approach [46].

Using EAs gives multi fold advantages. Firstly, it is simple, robust to change circumstances and flexible [39, 42]. EAs are easy to apply and very often provide satisfactory solutions as compared to other global optimization techniques [42]. Furthermore, [39, 42] suggested that EAs can be applied to problems where heuristics solutions lead to unsatisfactory results. Therefore, EAs have been widely applied for practical problem solving [39, 42]. This can be evidenced in the study by [26] who implemented the particle swarm optimization (PSO) method in cost optimization of the feed mixtures in poultries and various farm animals (cattle, sheep, rabbit).

Secondly, [41] is in similar judgment with [39, 42, 44] that the aim in choosing an EA it is able to solve combinatorial optimization problems or learning tasks in comparison with other conventional methods. In addition, [40, 44, 45, 47] emphasized that EAs have appeared as most prominent and powerful black-box optimization tool in solving combinatorial optimization problems. This can also be evidenced in the study by [13], who utilized EAs to minimize the cost in satisfying constraints. On the other hand, [14] also worked on to obtain the least-cost feed mixture based on nutrient requirements. Thus, it can be concluded that EAs are able solve combinatorial optimization problems as claimed by [14, 39, 40-42, 44, 45, 47].

Thirdly, EAs are able to tackle complex problems such as discontinuities, multimodality, disjoint feasible spaces and noisy function evaluations, as suggested by [40, 44, 45, 47]. Thus, it reinforces the potential effectiveness of EAs in search and optimization approaches. This can be evidenced in the study of [28-30], who utilized the EAs to minimize cost of diet in farmed shrimps and satisfied its nutritional requirements. Their approach is to decrease the penalty function and offer a better solution for the shrimp feed mix problem. Hence, it can be emphasized that EAs can solve complex problems as claimed by [28-30, 40, 44, 45, 47].

Unfortunately, to the best of our knowledge, this beneficial optimizing approach of EA has not been experimented in any fish feed formulation problem. However, the advantageous EA approach has been studied in a similar feed formulation for an aquaculture species, which is shrimp as carried out by [27-29, 48]. These are the most similar and nearest work to the problem of fish feed formulation that can be used as a guidance or benchmark. In the EA by [48] the combination of both Roulette Wheel Selection (RWS) and Binary Tournament Selection (BTS) in two phases of selection could produce a comparable solution with the other established selection operators [48]. The result shows that the RWS is still the best suitable selection operator to the diet formulation problem for shrimp in terms of best-so-far solution and the number of feasible solutions obtained. However, the result by [48] also shows that their proposed RTS operator is better in term of its ability to provide many good feasible solutions, when a population size of 30 is used. Thus, in this case, the EA performs better in term of providing the number of feasible solutions, and is suitable and comparable to be used in problems with real value encoding [27-29]. Their studies convinced us that EA is still the best suitable approach to the diet formulation problem in terms of the best-so-far solution and number of feasible solutions obtained.

Other real life problems involving feed formulation known to have successfully implemented EA and its variants in the strategy of obtaining the best suitable mix are such as in livestock [42], poultry [13-14], cattle [13], sheep [14], rabbit [14] and shrimp [27-29]. The main objective being the target of those studies is to find a good feasible solution with minimum cost, while dealing with various complex problems. In these handful studies, it is evidenced that there are still rooms for improvement, thus providing the opportunity and motivation to further explore and refine the applicability of existing EAs in grouper fish feed formulation problem. In addition, potential explorations for emergence of new knowledge are highly rewarding, specifically in the grouper fish feed formulation approach or technique. Our impetus is also supported by the fact that an EA is an established algorithm for performing optimization or learning tasks with the ability to evolve [39, 40, 41, 49] in the positive manner. Moreover, its capability of evolving [39-41, 44, 47] to achieve efficient solution is in generally sufficient time frame.

Subsequently, due to the reason that the EA approach with flexibility in designing [39-41] its operators is able to produce reasonable and feasible solution successfully in a complex problem, thus it is deemed suitable to be adopted in our study of grouper fish feed formulation. Furthermore, the adoption is also due to the similarity and successful outcome by [27-29] towards optimizing the solution. However, our study aimed to refine further the algorithm as presented in the following section.

3. Architecture of the Proposed EA-based Approach

An EA begins with the initialization stage, and followed by selection, crossover and lastly the mutation stage, whereby the generation is continued until the termination criterion is satisfied [41]. Each stage has its special operator. Fitness evaluation is embedded to measure the performance of each potential solution [41]. There are several variations of each stage in the EA as suggested by previous researchers, such as selection [43], crossover [45, 50] mutation [51]. However, in this study we partly adopt the basic and established operators, while proposing our unique selection operator. The basic architecture of the EA-based approach with the proposed standard deviation-based selection and other established operators are described in this section. The intention of applying this approach is to search the optimization or sub-optimization solution where conventional heuristics lead to unsatisfactory results. The fundamental of EA is adopted from [41] and adapted into this sophisticated proposed model as illustrated in Fig. 1.

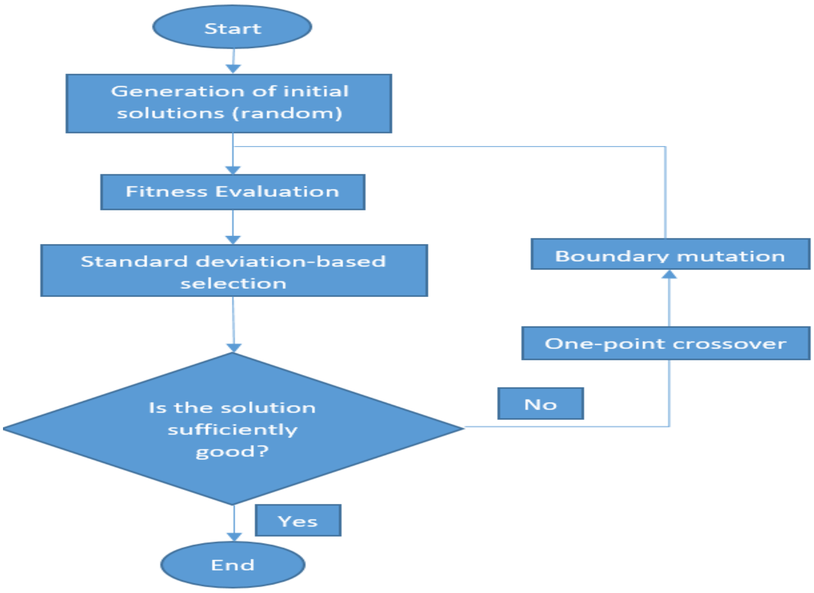

Fig. 1. Architecture of selection operator in the EA-based approach.

In this first stage, the population size needs to be determined and yet should not be kept constant, for example, it can be 20, 30 or even 100 of individuals or chromosomes. In this study, the individual represents one solution that consists of a combination of ingredient 1 until ingredient 14 with its specific weight. The representation is in the form of an array with the size of 1x14. The values of allele represent the weight of ingredients in the solution. The sizes can be in any range of variable numbers. A small population size is merely taken in most of the early experimental studies. Bhatia [51] suggested that the population size of 20-30 as a genetic parameter. On the other hand, [52] stated that the population size between 30 and 100 is generally recommended. Hence, initial solution in this proposed EA-based heuristic is generated randomly with population size of 30, which depend on the fitness evaluation of these two studies [51, 52].

A fitness function is a particular type of objective function that is used to summarise, as a single figure or value, how close a given design solution is to achieving the set aims. Thus, fitness evaluation in this study not only refer to a set of total nutrients required for the grouper fish such as crude protein, crude fat, crude fibre, moisture, ash, phosphorus, calcium, Arginine, Histidine, Threonine, Valine, Isoleucine, Leucine, Lysine, Methionine and Phenylalanine, but included total weight, ingredients constraints, nutrients constraints and total ingredients.

In this stage, roulette wheel selection [39-42], tournament selection [39-42] and ranking selection [39-42] are the usual choice of practice as the selection operator in the EA operator. Roulette Wheel (RW) selection procedure is where every individual reproductive probability is proportional to the individual's relative fitness [39-42]. On the other hand, Ranking Selection (RS) procedure is where a reproductive or survival probability to each individual that depends merely on the rank ordering of the individuals in the current population [39, 40, 41, 42]. In addition to that, Tournament Selection (TS) procedure is where *k* individuals are randomly selected from a set of population with or without replacement, where their fitness values (total nutrients) are compared. The best pair wins the tournament and is prepared to the mating pool.

Since the grouper ingredients are represented by real valued alleles in the chromosome or individual of the EA, standard deviation-based selection is introduced as the new selection operator, which is similar to the tournament selection [39, 40] (as presented in Fig. 2) is considered for exploration and exploitation to improve the overall EA process [41, 42]. As is known, the standard deviation is a relevant and most-used measure of dispersion [53]. The value of the standard deviation tells how closely the values of a data set are clustered around the mean [53]. A larger value of the standard deviation for a data set indicates that the values of that data set are spread over a relatively larger range around the mean and vice versa. [53].

Thus, in our new selection operator, two randomly selected individuals with their standard deviation values and their respective fitness are compared. One of those individuals with a larger dispersion is elected to the mating pool and due to chance the higher and lower fitness are illustrated as in Fig. 3. Some are rejected due to small dispersion.

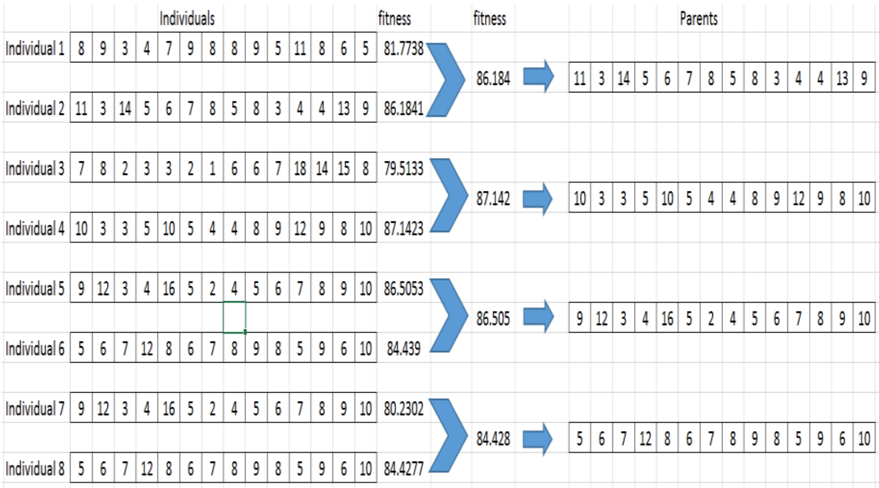

Fig. 2. Potential parents based on Tournament Selection.

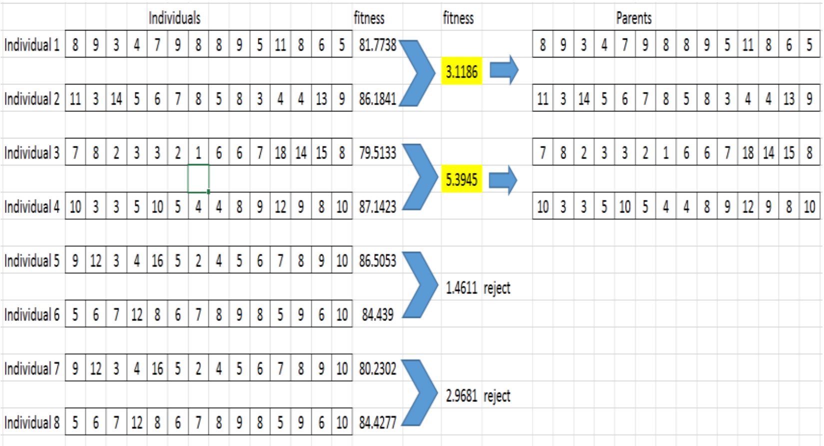

Fig. 3. Potential parents based on Standard Deviation Selection.

In this crossover stage, a one-point crossover is adopted as suggested by [27-29], which is similar to those used in feed formulation of their EA strategies. The mechanism of one-point crossover is shown in Fig. 4. A randomly selected crossover point within the chromosome is identified, which then an exchange of two different parts of the chromosomes is done to produce two new offspring.

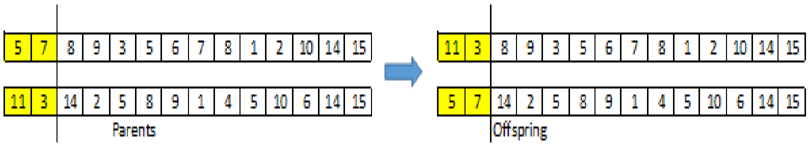

Fig. 4. One-point crossover.

In this stage, mutation in general means that one allele of a gene is randomly replaced by another [40]. Boundary Mutation [41] and power mutation [40, 42] have been suggested as good potential operators in the EA. Power mutation is the improvement of uniform mutation designed based on a random concept [40, 41] and boundary mutation is such that making use of the lower and upper bounds of constraints [40, 42]. We adopt Boundary Mutation, which is depicted as in Fig. 5. In this study, minimum and maximum boundaries are applied where the identified minimum value is exchanged with the maximum value and vice versa.

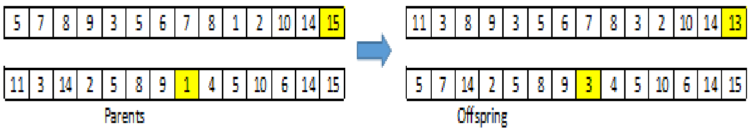

Fig. 5. Boundary mutation in the EA-based heuristic.

Evolution in nature will never stop. However, we need to define some stopping termination criteria for the optimization or learning problems we face. There are three types of stopping criteria often used by EA practitioners; that are to (i) stop with fitness value achieved, (ii) stop with fitness change, and (ii) stop with time allocation as stated in [43].

4. Results and Analysis

In this study, we managed to obtain data from two sources. The first data set is from 30 manufacturers of grouper fish feed meal, while the second data set is from experts, researchers, practitioners and past literature. These are discussed and summarized in [5].

Subsequently, in this section, the analyses on the fitness of each individual in 30 samples are carried out. Fitness is calculated based on the total nutrients selected for each item of crude protein, crude fat, crude fibre, moisture, ash, phosphorus, calcium, Arginine, Histidine, Threonine, Valine, Isoleucine, Leucine, Lysine, Methionine and Phenylalanine. Descriptive statistics are also given involving coefficient of variance (CV), mean, standard deviation, range of sample, maximum and minimum sample as illustrated in Table 1. These analyses are obtained through the use of Statistical Package for the Social Sciences (SPSS) 13.0 for Windows Version [54]. The CV in Table 1 is computed for each sample, which is based on the fitness values. All of them are less than 1.0. It is acknowledged that the smaller the CV value of the fitness, the residuals to the predicted value are good. Thus, it is a sign of a good variable. Hence, it is proven that these are good suggestive nutrients.

Table 1. Coefficient of variance for grouper fish feed formulation samples.

	N	Range	Min	Max	Mean	S. D.	CV
sample_1	4	26.45	75.91	102.36	90.0091	11.02775	0.123
sample_2	4	21.54	76.24	97.78	84.8472	10.15861	0.120
sample_3	4	21.23	79.74	100.97	85.9473	10.10405	0.118
sample_4	4	22.37	65.06	87.43	79.3245	9.88108	0.125
sample_5	4	27.84	66.37	94.22	82.5067	11.66298	0.141
sample_6	4	6.94	78.83	85.76	82.1699	2.88935	0.035
sample_7	4	11.87	76.89	88.76	83.0637	6.17829	0.074
sample_8	4	15.10	71.65	86.76	78.4752	6.31505	0.080
sample_9	4	50.62	57.34	107.97	80.6236	21.83849	0.271
sample_10	4	28.43	56.44	84.87	67.4003	12.56811	0.186
sample_11	4	41.34	58.00	99.35	82.3994	17.48226	0.212
sample_12	4	19.41	85.34	104.75	94.2501	7.97915	0.085
sample_13	4	17.37	75.50	92.88	84.3357	7.77613	0.092
sample_14	4	54.29	50.37	104.66	80.1681	23.21413	0.290
sample_15	4	14.85	76.87	91.73	84.7972	6.10869	0.072
sample_16	4	22.40	70.74	93.14	81.0445	9.82669	0.121
sample_17	4	33.34	64.12	97.46	83.8802	14.65743	0.175
sample_18	4	16.77	79.73	96.50	85.8926	7.96734	0.09
sample_19	4	40.14	54.12	94.26	75.5231	16.62319	0.220
sample_20	4	9.17	82.98	92.15	87.3222	3.76524	0.043
sample_21	4	9.50	73.61	83.11	77.3040	4.24204	0.055
sample_22	4	19.11	73.70	92.81	83.0826	9.67505	0.116
sample_23	4	21.90	74.46	96.37	85.2734	9.97750	0.117
sample_24	4	17.46	62.52	79.98	73.2072	7.49372	0.102
sample_25	4	16.42	75.70	92.12	83.0228	8.46153	0.102
sample_26	4	19.29	72.73	92.02	84.0806	8.12802	0.097
sample_27	4	29.40	74.21	103.61	91.8645	12.84601	0.140
sample_28	4	13.73	78.39	92.12	87.6602	6.25738	0.071
sample_29	4	1.62	83.60	85.22	84.6279	.73387	0.009
sample_30	4	.72	83.35	84.07	83.7923	.32019	0.004
Valid N	4						

A feasible solution means that the individual generated can satisfy the nutrients constraints. Based on Fig. 6, the first three lowest mean of fitness are 67.4003 (sample no. 10), followed by 73.2072 (sample no. 24) and the third lowest fitness is 75.5231 (sample no. 19). While for the first three highest mean of fitness are 94.2501 (sample no. 12), followed by 91.8645 (sample no. 27) and the third highest fitness is 90.0091 (sample no. 1). The difference for the highest mean of fitness and the lowest mean of fitness is 26.8498 (i.e., 94.2501-67.4003).

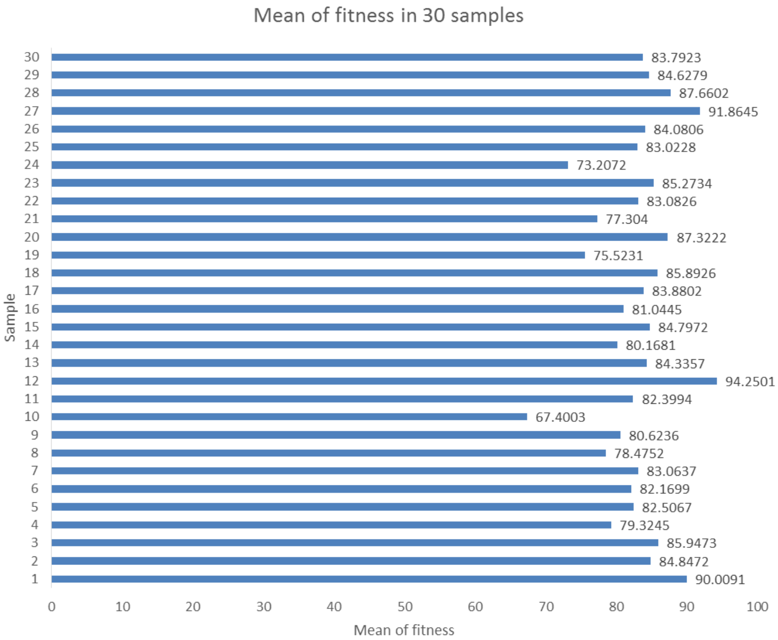

Fig. 6. Mean of fitness in 30 samples.

The mean of the minimum fitness (i.e., total nutrients) is 71.817 and the mean of the maximum fitness (total nutrients) is 93.5063. The maximum and minimum fitness based on 30 samples are depicted as in Fig. 7. However, merely 38 fitness fulfil the priority of nutrients in feeding the grouper fish as discussed in the study of [3] and the costs also counted in as shown in the Table 2. The lowest costs are RM442 and RM465 with the fitness 79.7377 and 86.7031 respectively. Even though the lowest cost is not the highest fitness, it is still the second higher fitness.

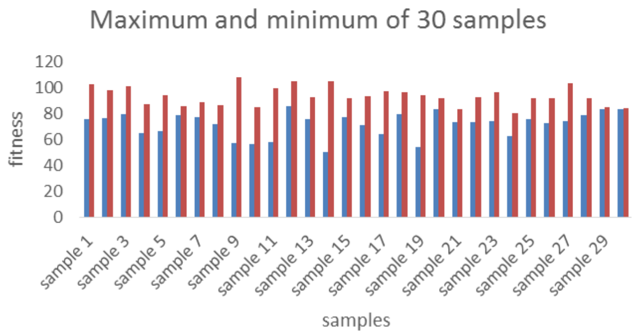

Fig. 7. Maximum and minimum fitness of 30 samples.

Table 2. Costs of fitness that fulfilled nutrients requirement.

		Fitness ID	Fitness Value	Total Costs of Feed/ 100kg
1	**sample1**	fitness4	88.4465	587
2	**sample2**	fitness4	88.107	845
3	**sample3**	fitness1	79.7377	(1)442
4	**sample4**	fitness1	87.4255	757
5	**sample4**	fitness2	80.8719	912
6	**sample4**	fitness4	83.9433	744
7	**sample5**	fitness2	84.0552	777
8	**sample5**	fitness3	94.2164	708
9	**sample6**	fitness1	85.7642	853
10	**sample6**	fitness2	82.7225	875
11	**sample6**	fitness3	81.3659	657
12	**sample7**	fitness1	88.7601	796
13	**sample8**	fitness2	86.7555	774
14	**sample9**	fitness4	86.7452	616
15	**sample10**	fitness3	84.8702	644
16	**sample11**	fitness1	84.2797	907
17	**sample11**	fitness4	87.9666	543
18	**sample15**	fitness1	91.7257	1082
19	**sample15**	fitness3	84.7095	665
20	**sample15**	fitness4	85.879	584
21	**sample16**	fitness3	84.3633	584
22	**sample17**	fitness3	81.9315	809
23	**sample18**	fitness2	87.5482	613
24	**sample18**	fitness3	79.7886	626
25	**sample20**	fitness2	86.7031	(2)465
26	**sample20**	fitness3	87.4613	765
27	**sample20**	fitness4	82.9789	767
28	**sample21**	fitness2	83.1122	718
29	**sample26**	fitness4	86.2976	772
30	**sample28**	fitness4	78.3912	638
31	**sample29**	fitness1	83.6006	779
32	**sample29**	fitness2	85.0807	689
33	**sample29**	fitness3	85.2236	713
34	**sample29**	fit.ness4	84.6065	707
...	**…**	…	…	…
38	**sample30**	fitness4	83.7835	694

Thus, the proposed standard deviation-based selection method and tournament selection method convinced that can be used and applicable not merely in Grouper feed formulation, but also some other real life problems as in the study of [55, 56].

5. Conclusions and Future Work

A mechanism to implement the EA-based approach in formulating the Grouper feed mix is presented in this paper. A proposed micro strategy based on standard deviation from sub-module of Tournament Selection in an Evolutionary Algorithm can be used and applicable to the Grouper fish feed formulation. Results show that the cost of RM 442 was obtained with fitness 79.7377. Thus, it reflects that this new algorithm is capable in its function of exploiting and exploring into potential alternatives and thus, improving the methodology in formulating the problem of fish feed. Furthermore, the cost gained is also the cheapest with the high fitness. As a conclusion, this research effort helps to unlock frontiers for more extensive research with respect to in-depth development on Grouper fish feed formulation.

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