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Research Article

An Improved Evolutionary Algorithm in Formulating a Diet for Grouper

Cai-Juan Soong[1,*], Rosshairy Abd Rahman[2] and Razamin Ramli[2]

[1]INTI International University, Malaysia
caijuan.soong@ewinti.edu.my
[2]Universiti Utara Malaysia, Kedah, Malaysia
shairy@uum.edu.my; razamin@uum.edu.my
*Correspondence: caijuan.soong@ewinti.edu.my

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Abstract: This paper reveals the high demand of fish products in many countries, which subsequently highlighted the high demand of grouper fish species for human consumption. This high demand leads to the insufficient supply of wild ocean grouper fish in the market, thus justifying the need for farmed or cultured grouper fish. Basically, in grouper fish farming, large amounts of trash fish are needed as the feed for grouper fish, which is the carnivorous type of fish. However, since the cost of trash fish is too high, searching for alternative ingredients for the feed through modelling of feed formulation is an option for reducing or minimizing the farming cost. This led to the search for methods in giving the best combination of feedstuff ingredients with appropriate nutrients in formulating the feed. One prospective method is the Evolutionary Algorithm (EA) that has been applied in solving similar problems of diet formulation for several types of animals including livestock, poultry and shrimp. Hence, in this paper, an improved EA method known as the SR-SD-EA is proposed highlighting three important EA operators, which are initialization, selection and mutation. A semi random initialization operator is introduced to filter some important constraints thus increase the chances of obtaining feasible formulations or solutions. Subsequently, the novel selection operator embeds the concept of standard deviation in the SR-SD-EA as part of the function in minimizing the total cost of the formulated grouper fish feed. Eventually, the enhanced boundary-based mutation is also introduced in the algorithm to ensure the crucial constraint of the ingredients' total weight must be met. The overall structure of the SR-SD-EA is presented as a framework, where the three methodological contributions are embedded. The preliminary findings of SR-SD-EA show that the obtained cost computed based on the Best-So-Far feed formulation as the solution is comparable, while all the crucial constraints are fulfilled.

Keywords: ***Binary-Standard Deviation Tournament Selection; Boundary-based Mutation; Evolutionary Algorithm; Feed formulation; Grouper fish***

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1. Introduction

Fish and fish products are enormously important for many people in various countries around the world since they are made as staple foods. This can be the evidence that fish for human food consumption continued to show a remarkable growth from 110 million tons in 2006[1], 128 million tons in 2012[2], 151 million

[1] Food and Agriculture Organization, "Climate change implications for fisheries and aquaculture", The State of World Fisheries and Aquaculture. pp. 212-218, 2009.
[2] Food and Agriculture Organization (FAO), "The State of World Fisheries and Aquaculture", FAO, United Nations, Rome, Italy, Report, pp.1-153, 2012.

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tons in 2016[3] and unto 156 million tons in 2018[4]. Similarly, fish consumption for individuals has also continued with impressive increment from an average of 9 kg in 1961, 16.7 kg in 2006, 18.4 kg in 2012, 20.2 kg in 2015, 20.3 kg in 2016 and 20.3 kg in 2017[3], while 20.5 kg in 2018[4]. Subsequently, Table 1 indicates that many countries with high captures are in the Asian region, where Malaysia is one of the major countries with large captures of fisheries at the 11th rank in 2016[5].

Table 1. Top Countries for Marine Captures of Fisheries[5]

2016 Ranking	Country	2015 (in Tons)	2016 (in Tons)
1	China	15314000	15246234
2	Indonesia	6216777	6109783
3	United States of Amerika	5019399	4897322
4	Russian Federation	4172073	4466503
5	Peru	4786551	3774887
6	India	3497284	3599693
7	Japan	3423099	3167610
8	Viet Nam	2607214	2678406
9	Norway	2293462	2033560
10	Philippines	1948101	1865213
11	Malaysia	1486050	1574443
12	Chile	1786249	1499531
13	Morocco	1349937	1431518
14	Republic of Korea	1640669	1377343
15	Thailand	1317217	1343283
16	Mexico	1315851	1311089
17	Myanmar	1107020	1185610
18	Iceland	1318916	1067015
19	Spain	967240	905638
20	Canada	823155	831614
21	Taiwan	989311	750021
22	Argentina	795415	736337
23	Ecuador	643176	715357
24	United Kingdom	65451506	701749
25	Denmark	868892	670207
Total 25 major countries		**66391560**	**63939966**
World total		**81247842**	**79276848**

The fisheries industry contributed significantly to the economies of many countries, which include various activities such as fish processing, trade and marketing and ancillary services. Thus, it is a strong indication that the fisheries industry plays a very important role of industries and is vital in multiplying employment which supports the economy of Malaysia. In addition, there are more than 2000 fish farmers in Malaysia who are in the marine finfish culture, that is the sub-sector of the fisheries industry, in which its main goal is to enhance the fishery resources and replenish natural captures whose populations have been decreasing through over-exploitation or environmental degradation.

On the other hand, the wild catch of natural fisheries stocks in the ocean has been declining, while the finfish culture industry has grown faster in the world food production sector and this drift is seen to endure. Among many finfish species being cultured with the entire brackish-water fishes and cultured marine production exceeded 600,000 tons, the grouper fish comprised 75,000 tons. It implied that the grouper fish contributed 12.5% of the global fish cultured. Moreover, the amount of cultured or yield in grouper fish farming is in numerous and varied in comparison to the amount of wild-caught. Therefore, grouper fish culture is a potential commercialized food production sector, which can provide significant impacts to entrepreneurs, as well as to the nation's economy.

Furthermore, there are increasingly rewarding and profitable grouper fish farming as reported in [1]. Additionally, a survey was carried out by [2] among quite a number of seafood restaurants to rationalize

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[3] Food and Agriculture Organization, "The State of World Fisheries and Aquaculture - Meeting the Sustainable Development Goals", FAO, United Nations, Rome, Italy, Report, 2018.

[4] Food and Agriculture Organization (FAO), "The State of World Fisheries and Aquaculture - Sustainability in Action", FAO, United Nations, Rome, Italy, Report, 2020.

the potential local market demand. The survey found that there was a trend of continuous human consumption and consistent market demand of Grouper fish as presented in Figure 1 in their weekly serving. Meanwhile, it has also been surveyed that the prices for various species of grouper fish are quite high and competitive in several live or wet fish markets as compared to other types of fish. Moreover, the unique and desirable taste are also the extra advantage of this Grouper fish.

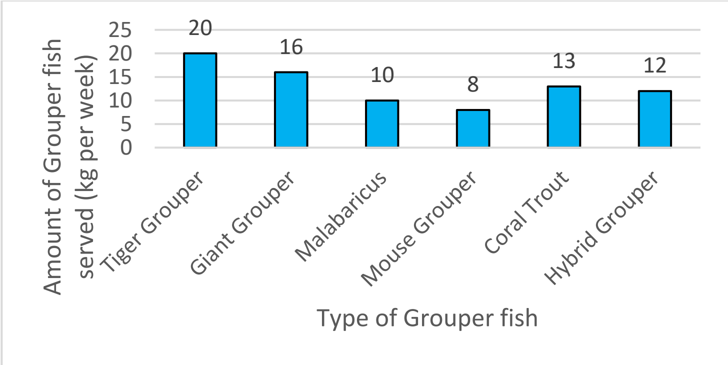

Figure 1. Amount of Grouper Fish Served [2]

Although there are good demands in its consumption and commercialized food production, there still exists a challenge in the related industry. It is the industrial challenge of farmed grouper fish that is related to its operational costs of the aquaculture business in which the quest is always to minimize the cost [3]. In the conventional grouper farming, the trash fish is used heavily as its feed. This practice may cause the uneven nutritional quality in the farmed grouper due to lack of diversity in the ingredients choice. Moreover, the trash fish may not be available all year round. Hence, the fish feed for the farmed grouper should be prepared and formulated according to the required nutritional needs as recommended in various related studies to avoid sole dependence on the trash fish. Therefore, this study on feed formulation for the farmed grouper fish was embarked to investigate on the most suitable feed formulation strategy and thus, enhance the knowledge in this appropriate field.

It has been suggested that studies relevant to the modelling of feed formulation in animals, in general is still limited [4], while similar studies on aquaculture including the grouper fish is even more limited [5]. Hence, it is crucial to develop the grouper fish feed formulation, which takes into consideration the important ingredients and nutrients priorities. Subsequently, the problem of grouper fish feed formulation has been reported as an NP-hard due to its complexity nature. As an alternative formulation approach, the metaheuristic method, specifically the Evolutionary Algorithm (EA) has shown promising results in handling the feed formulation problems [3]. Therefore, it has sparked the interest that the EA is a potential solution avenue to tackle and improve this similar problem of formulating the diet for grouper fish, where various ingredients and nutrient constraints need to be met, thus filling in the gap in this research landscape. Hence, our paper contributes in the designing of the feed formulation framework for the grouper fish based on the potential EA approach, where there are still ample possibilities of new horizon in the aspect of this metaheuristic method that can be explored.

In demonstrating the proposed EA framework, which is aimed to exhibit the improved operators employed in this study, the formulated diet for the grouper fish problem is engaged to be the pivotal circumstance. In doing so, a related background of studies is presented and discussed in the next section. An improved EA framework is exemplified in section 3, whereas some preliminary outcomes are proved in section 4. To end section 5 accomplishes the research with some annotations for forthcoming research.

2. Some Related Studies

A single ingredient is difficult and impractical to design the feed in providing the nutrients prerequisite for animals, as a specific ingredient might remain at least solitary nutrients besides lacking other nutrients. Hence, it is all the time beneficial to have a mixture of many different ingredients to make up a feed formulation. As is known, feedstuff formulation is a complex manner of measuring the amount of feedstuff ingredients in order to satisfy nutritional requirements. Consequently, there has been quite a rigorous effort in quantifying nutrients of available feedstuff ingredients in lieu of selection utilizing several techniques in empirical formulations. These several formulation techniques are mainly using the algebraic, optimization and heuristic approaches.

In the algebraic approaches, two methods or techniques have been demonstrated in feed formulation design, which are the Pearson Square and simultaneous algebraic equation methods. However, the drawback of Pearson Square method is that it is not suitable to be applied in a complex feed mix problem [10] which involves many ingredients and nutrients requirements. Meanwhile, the drawback of simultaneous algebraic equation, that is it is also impractical to solve complex problems that require multiple ingredients and nutrients at a time.

On the other hand, Linear and Nonlinear Programming techniques, which are classified as the optimization approaches have also been studied previously to solve the feed formulation problem. The relationship between nutrients and the respective animal products can sometimes be constructed as linear relationships, but when it deals with the complexity of many different nutrients then the non-linear relationships are the better option in representing the problem. Therefore, the Nonlinear Programming technique can be used to explain the feed mix or formulation problems in a better manner. However, the disadvantages of the Nonlinear Programming technique are hard in searching global minimum value and certainly needs derivative computation of a particular function that may confined accessible or difficult to compute. Thus, the Nonlinear Programming technique is considered hard and inadequate to handle such complex problems and can be very time-consuming [6-8] indeed.

Another approach that was commonly employed in previous studies involving various feed formulation problems is the heuristics, which by practice adopt the concept of trial-and-error technique [9]. However, the limitation of this trial-and-error technique is more computation times required when there are large amounts of ingredients as well as nutrients required to be addressed [10-11]. Furthermore, the feed formulation problem is an NP hard problem [11-14], which consists of various linear and nonlinear constraints. Thus, this complicated problem and hard to elucidate by just merely applying heuristic techniques. Consequently, the growing of population-based algorithms in heuristic approaches in particular the EA is deemed more effective and able to provide potentially practical solutions to the feed formulation.

Due to the successful studies in utilizing the EA, such as in [3-4] and having certain similarities to the case of formulating grouper fish feedstuff problem, thus advisable to adopt the EA technique. Furthermore, the requirements and constraints involved in this feed formulation problem are a mixed of linear and nonlinear in nature. These conditions have made the problem complex and hard to solve, in which various metaheuristics could be to the rescue. The EA as a metaheuristic, can be utilized in solving complex combinatorial problems such as the grouper fish feed formulation as quickly and effectively.

EA commences with an initialization operator, then accompanied by the selection, crossover and mutation operators for one complete generation or run of the algorithm. Subsequently, continuing to the next generation with other operators, that are regeneration or reproduction and termination strategy [14]. Initialization is normally based on random or semi random methods, while selection is commonly based on tournament, roulette wheel, or ranking methods. The common crossover used is the one-point crossover or two-point crossover, whilst the mutation being experimented is related to power and power boundary. A mutation operator is normally designed based on type of encoding such as bits and real number. An allele in a chromosome characterizes the type of representation in either by bits or real valued.

The EA have shown good solutions in solving real valued representation problems of the feed formulation [7, 15]. The first effort using the EA was carried out by [3] which studied on a general feed formulation of livestock. The EA effort was followed by [4] that focused on poultry and cattle feed formulation. They used semi-random initialization, tournament selection and enhanced one-point crossover and lastly, the mutation was based on a probability value generated randomly. Subsequently, the effort in enriching the knowledge on EA with regard to feed formulation has been continued by [9] that focused specifically on shrimp feed. New initialization operator was constructed in those studies and known as the power heuristics. Other operators implemented are the roulette wheel selection, enhanced crossover known as average crossover and finally, the power mutation. These studies have sparked the interest to explore further and then refine the prevailing EA in formulating the feedstuff problem but focusing on the grouper fish feed. Hence, the following section is dedicated to the methodology in carrying out the study.

3. Material and Method

There are two kinds of information engaged in this research, namely primary information and secondary information. The primary information is actually about the knowledge and experience of four grouper fish experts who have been involved in grouper fish research for more than 10 years. This data is regarding the requirements of ingredients and nutrients along with their priorities as well as the range of weight of ingredients measured in per 100 kg. Some of this data is qualitative in nature. This important primary data is used as an input to construct all requirements related to the diet or feed formulation, specifically for the grouper fish culture. These requirements also include relevant information on its nutritional needs and industrial practice. Nutrients that are required in feed formulation are such as phosphorus, crude fiber, calcium, crude protein, nine essential amino acids (EAA), crude ash and crude fat. On the other hand, ingredients that are required in feed formulation are such as soybean meal, wheat flour, dried yeast, squid meal and cod liver oil. Eventually, the requirements are constructed whereby the normal descriptions are transformed into logical mathematical structures or constraints for the purpose of experimentations on the modeling of the proposed EA. All requirements act as the control mechanism in ensuring that the feed formulations generated as solutions are acceptable and suitable to be consumed by the grouper fish.

On the other hand, there are two types of secondary data involved. The first secondary data is the specifications of grouper fish feed from 30 manufacturers around the world, such as Vietnam, China, Indonesia, United States of America, Japan, Taiwan, including Malaysia available through their corporate websites. Another secondary data was obtained from reports of the [16-19]. This is the crucial real data regarding nutrients and ingredients for grouper fish feed. Based on this data, appropriate constraints necessary for the modeling of the EA, where relevant variables involving nutrients and ingredients requirements are constructed accordingly.

3.1. Constraints of Grouper Feed Formulation Problem

The constraints constructed were based on the data gathered and are described in this section. These important constraints must be fulfilled when the proposed EA is activated.

(i) The total weight of plant-based ingredients must be in the range of 0 to 60 kg.
(ii) The total weight of animal-based ingredients must be in the range of 40 to 100 kg.
(iii) Both weights must equal to 100 kg, that is the total required weight of all ingredients considered is 100 kg.
(iv) The range of required percentage for kth nutrient in all ingredients is in accordance with the maximum and minimum values.

3.2. Proposed Improved EA Framework

The aim of developing the EA is to find an achievable and suitable formulation solution for the grouper fish feedstuff that fulfils the nutritious requirements with a minimum cost of ingredients used subject to certain important constraints. The solution representation of grouper feed formulation is in 2-dimensional matrix that is 1 x G, where column g consists of individual ingredients with a possible combination of calcium, crude protein, phosphorus, crude ash, crude fat, crude fiber and nine essential amino acid (EAA). This representation is known as the chromosome, where in each of its allele the information on ingredients and nutrients are recorded in the form of real values. In this study, $G = 14$ since the chromosome consists of combination of 14 different selected ingredients along with its individual nutritional values.

In this proposed EA, the objective function used which is also considered as the fitness function is to minimize the cost of the combined ingredients resulted in the feed formulation as a solution. The role of objective function is to assess each chromosome generated throughout the activation of each operator of the EA, while inspecting each constraint. This objective function is computed based on the combination of ingredient's cost values as displayed in Table 2 together with nutrients requirements as exhibited in Table 3.

Table 2. Ingredients, Type, Range and the Respective Costs

Ingredients	Type	Min Weight (kg)	Max Weight (kg)	Price (RM/kg)
Algae Meal (Spirulina)	Plant	0	40	0.21
Cottonseed meal	Plant	0	40	0.89
Potato Protein concentrate	Plant	0	40	51.91
Rice bran	Plant	0	40	0.80
Soybean meal	Plant	0	40	1.90
Wheat Flour	Plant	0	40	0.01
Dried Yeast	Plant	0	40	2.50
Soy Bean Oil	Plant	0	40	4.28
Poultry by-product meal	Animal	10	100	0.20
Fish Meal (anchovy)	Animal	10	100	3.51
Fish Meal (white)	Animal	10	100	3.01
Dried Shrimp meal	Animal	10	100	2.27
Squid Meal	Animal	10	100	3.30
Cod Liver Oil	Animal	10	100	35

Table 3. Minimum and Maximum Nutrients Required Percentages

Nutrients	Minimum (%)	Maximum (%)
Crude protein	40	45
Crude fat	8	10
Crude fibre	0.5	8
Crude ash	0.4	18
Phosphorus	0.1	1.8
Calcium	2	4
Arginine	2.06	4.21
Histidine	0.66	1.26
Isoleucine	1.37	2.57
Leucine	2.23	4.23
Lysine	1.96	4.04
Methionine	0.89	1.81
Phenylalanine	1.2	2.46
Threonine	1.29	2.59
Valine	1.46	2.86

Hence, the objective function value is taken as the minimization value of the summation of the weight for each ingredient multiply with its respective cost per kg, as formulated Equation (1). The value obtained is the lowest cost able to achieve in each combination of appropriate ingredients that carried along the information on its respective nutritional values. Indeed, this lowest cost is the measure towards achieving optimality and is also in line with the industrial practice in which cost is the main concern.

$$f(h_o) = \min \left(\sum_{g=1}^{g=J} p_g w_g \,\delta_v\right) \tag{1}$$

Where,

h_o is the cumulative cost value for each chromosome or feed solution assessed,

p_g is the cost of each ingredient g per kilogram,

w_g is the weight of the gth ingredient in kilogram,

$$\delta_v = \begin{cases} 1 \text{ If total weight of all ingredients, } v \text{ equal to 100 kg for each chromosome,} \\ 0 \text{ Otherwise.} \end{cases}$$

$o = 1, 2, 3, 4, \dots, O$ where O is the total number of chromosomes generated in a population,

$g = 1, 2, 3, 4, \dots, G$ where G is the total number of ingredients considered,

$e = 1, 2, 3, 4, \dots, E$ where E is the total number of nutrients considered,

$v = 1, 2, \dots, V$ where V is the total weight of all ingredients g in kilogram.

Subsequently, the proposed EA framework or model is presented in which the initialization, parent selection and mutation operators are rearranged in such a way that the resulting EA is improved and known as the SR-SD-EA as in Figure 2. These operators are elaborated in the following sub-sections.

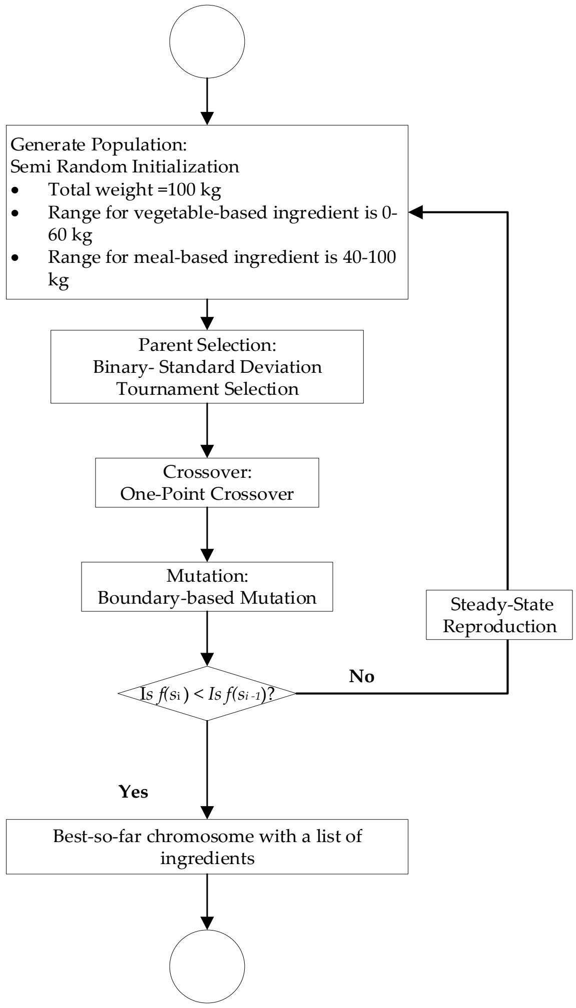

Figure 2. The Proposed SR-SD-EA Framework for the Grouper Feed Formulation

3.2.1. Improved EA Operators

In general, the main operators of EA are the initialization of population, parent selection, crossover, mutation, and regeneration, which can be referred to [7, 13]. Therefore, the three operators that portray several EA gaps being examined in this study are the special attention in this improved SR-SD-EA. Meanwhile, the other operators used in complementing the whole proposed EA are one-point crossover as presented in elitism in regeneration and stopping criterion with a predefined number of generations.

3.2.2. Semi Random Initialization

The initialization of population in the EA employed a semi-random (SR) initialization method or strategy instead of the total random initialization commonly used. The impetus for this SR strategy is due to the drawback of total or pure random initialization when incomplete search in the potential solution space occurs all the times. Therefore, requirements on total weight, range of total animal-based ingredients and range of total plant-based ingredients have to be preassigned so that feasible chromosomes are obtained in prior similar to the strategy by [7]. Furthermore, the SR initialization would reduce the search time in initiating a chromosome based on the crucial constraints fulfillment. In utilizing the SR initialization, the expectation is that the chromosome would be a good potential solution, which can be used to start or initiate the subsequent processes of the EA with less computational time and enhance the solution quality.

3.2.3. Binary-Standard Deviation Tournament Selection

The next operator that has been enhanced in its method or strategy is the Binary-Standard Deviation (SD) tournament selection, which was inspired by the original Binary Tournament (BT) selection operator explained by [20]. This SD Tournament selection is similar to the BT selection operator, whereby the concept of standard deviation of a sample is adapted in the BT selection. The objective function or fitness value computed for each chromosome is considered as the data used to compute the respective standard deviation. These standard deviation values are then compared, where the chromosome with the greater value is selected as Parent 1. The operation is repeated to obtain Parent 2. The rational for selecting chromosome with bigger standard deviation is that there would be a high chance of exploration to take place, which would lead to lower fitness. The SD Tournament selection mechanism is as shown in Figure 3. The two obtained chromosomes as Parent 1 and Parent 2 can be ready for the next operator, which is the crossover.

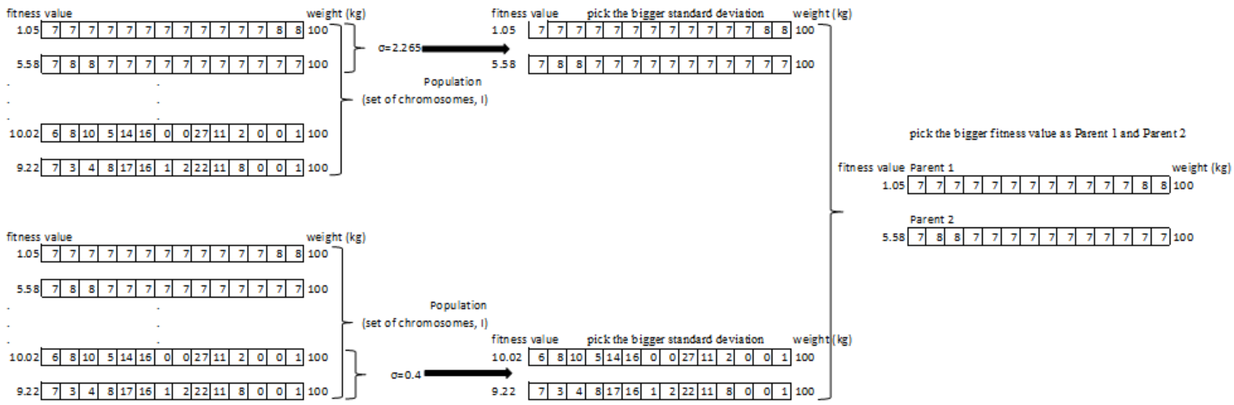

Figure 3. An Example of Binary-Standard Deviation Tournament Selection Mechanism

3.2.4. Boundary-Based Mutation Operator

Finally, the third operator enhanced in this proposed EA is the mutation, known as the Boundary-based Mutation (BM) operator. This BM operator is introduced to modify the chromosome when its total weight is not equal to 100 kg. However, if the total weight of the chromosome is equal to 100 kg, then no mutation is applied. This boundary refers to the crucial limit of total weight in each chromosome. The BM operator computes the difference to the total weight needed. The difference is then adjusted accordingly. The BM rate, *m* applies. If the total weight is less than 100kg, the divided amounts of weight difference are added to the selected alleles with lower individual weight of ingredients to make it equal to total weight needed. On the other hand, if the total weight is greater than 100 kg, then the divided amounts of weight difference are subtracted to make the total weight equal to 100 kg. The BM mechanism is as presented in Figure 4.

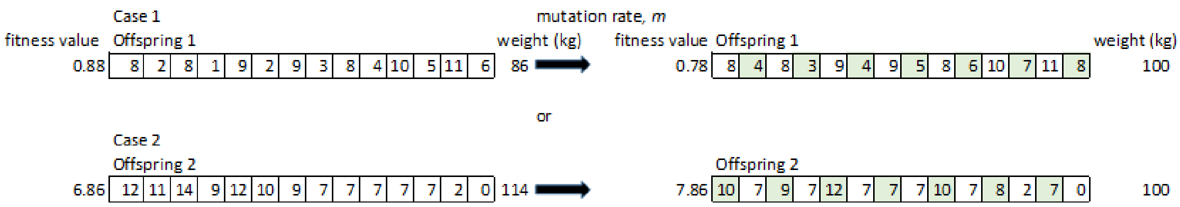

Figure 4. An Example of the Boundary-based Mutation Mechanism

4. Findings and Discussions

In this study, quite a number of testing and evaluation procedures need to be carried out. Reasonable generations of the proposed SR-BT-EA framework for the grouper feed formulation have been successfully delivered. Therefore, findings discussed in this section are still considered at the preliminary level. It is with certainty that the algorithmic structures in the proposed SR-SD-EA are working as expected. Hence, a good enough or feasible solution, which is the feed formulation can be shown in the form of chromosome. This feasible formulation achieved until the stopping criterion is met with the minimum cost is specified as the Best-So-Far solution as given in Figure 5 as a sample.

As mentioned earlier that the solution representation is in 2-dimensional matrix of 1 x *G*, where each column *g* represents each of the 14 ingredients with possible combination of phosphorus, crude fiber, calcium, crude protein, nine essential amino acids (EAA), crude ash and crude fat. Referring to Figure 5 as an example, the value $g_1 = 6$ in column 1 represents 6 kg of ingredient 1 (i.e., Algae Meal (Spirulina)) is chosen in the combination or formulation of the grouper feed mixed. Similarly, those values of ingredients' weight shown in each allele of the chromosome represent the respective ingredients following the order in the list as in Table 2. In addition, the information on the respective nutrients is embedded in the allele of each ingredient.

g_1	g_2	g_3	g_4	g_5	g_6	g_7	g_8	g_9	g_{10}	g_{11}	g_{12}	g_{13}	g_{14}
6	**1**	**0**	**2**	**1**	**27**	**1**	**1**	**47**	**4**	**6**	**2**	**2**	**0**

Figure 5. A Sample of Chromosome with Best-So-Far Solution for the Grouper Feed Formulation

After a number of generations (i.e., runs) on the proposed SR-SD-EA, data on the Best-So-Far values were recorded and plotted as presented in Figure 6. Based on Figure 6, the initial minimum cost obtained when the SR-SD-EA started its generation was RM264.04 for the formulated feed that weights 100 kg. Between generation 60 and generation 200, there seems to be a fluctuating pattern reflecting the search exploration with dynamic changes in the values of the minimum costs recorded. Eventually, only at generation 200 the SR-SD-EA obtained a minimum cost value of RM65.34. The subsequent generations showed that this attained minimum cost value did not changed until generation 300 is reached, which is the imposed stopping criterion. Hence, this minimum cost of RM65.34 ($15.64) for the weight of 100 kg feed formulation is considered the best thus far able to achieve with the appropriate combination of ingredients, while taking into consideration all the crucial constraints. The benchmark used in evaluating the Best-So-Far solution refers to the lowest cost attained for a chromosome at the end of each generation of the EA. As a result, the SR-SD-EA framework in this preliminary study is able to produce the grouper fish feed of RM65.34 that is considered very low if compared to the grouper fish feed available in the market, that is about RM472 ($112.81) for 20kg or RM2360 ($564.08) for 100 kg[5]. The high market price has evidently shown that the SR-SD-EA process has portrayed the improvement with the feed price can be used as the yardstick. The commercial process is commonly experimental in nature with the underlying concept of heuristic or trial and error. Therefore, the SR-SD-EA solution, which is in the form of grouper feed formulation generated from the EA-based approach has successfully provide a reasonable and feasible solution for the complex problem in a short time due to advanced computing technologies. Thus, these preliminary findings reflect a more promising performance could be accomplished in various different settings of experiment.

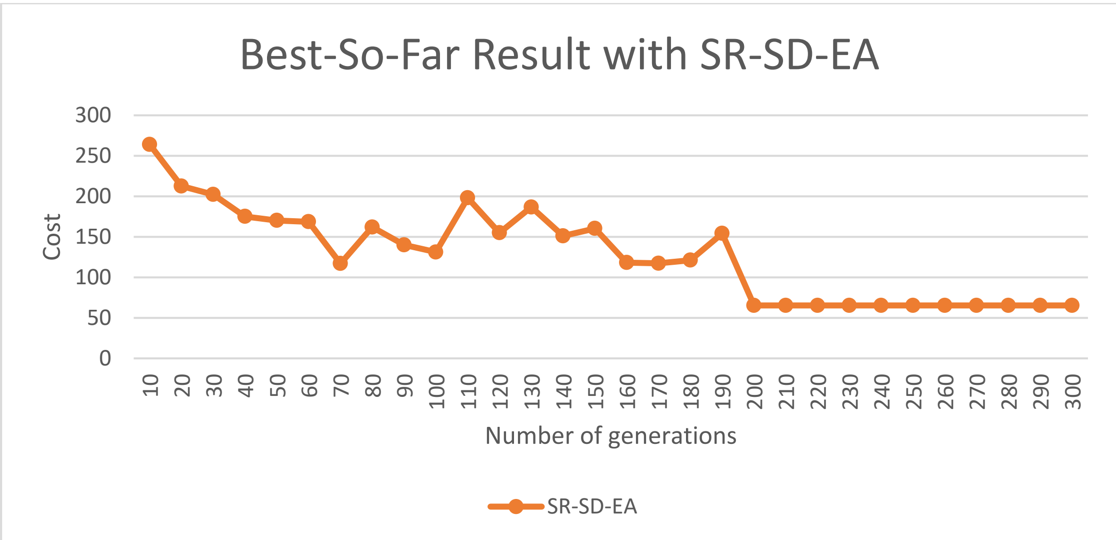

Figure 6. A Graphical Presentation of the Performance of SR-SD-EA throughout the 300 Generations

[5] Guangdong Yuechun Marine Biological Research and Development Co. Ltd., "Ruby Marine Fish Compound Feed Grouper Feed Bait Breeding Food Fish Diets", 2022

5. Conclusion

The process and accomplishment of the proposed improved SR-SD-EA framework have been described and attempted in the case of grouper fish feed formulation problem. The proposed micro-strategies involving three operators, namely the SR initialization, SD tournament and BM have been successfully established in the improved SR-SD-EA. The effort has suggested that this variant of EA has shown the function of exploring and exploiting potential alternative solutions, hence refining the methodology for complex formulated feed for grouper fish. In addition, stability of the algorithmic functions is of high value. Potentially, further works on other operators and methodology of the EA can be explored thus opening a wider research space for the development and impact of the grouper fish feed formulation. As future work, other related constraints and detailed evaluation procedures involving penalty values with regards to nutritional needs of the grouper fish shall be investigated. In addition, the improvement of other operators and methodology could also be explored.

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References

[1] Ahmad Daud Om, "*Pembiakan dan penternakan kerapu harimau*", 1st ed. Kuala Lumpur, Malaysia: Dewan Bahasa dan Pustaka, 2012.
[2] Soong Cai-Juan, Razamin Ramli and Rosshairy Abd Rahman, "Fish consumption and track to a fish feed formulation", *AIP Conference Proceedings*. Vol. 1691, No. 1, AIP Publishing LLC, 2015.
[3] Furuya, Tatsumi, Takaaki Satake, and Yoshlyuki Minami, "Evolutionary programming for mix design", *Computers and Electronics in Agriculture*, Vol. 18, No. 1, pp. 129-135, 1997.
[4] M. Akif Şahman, Mehmet Cunkas, Seref Inal, Fatma Inal, Behic Coskun *et al.*, "Cost optimization of feed mixes by genetic algorithms", *Advances in Engineering Software,* Vol. 40, No. 10, pp. 965-974, October 2009, Published by Elsevier B. V., Online ISSN: 1873-5339, Print ISSN: 0965-9978, DOI: 10.1016/j.advengsoft.2009.04.003, Available: https://www.sciencedirect.com/science/article/abs/pii/S0965997809000866.
[5] Soong Cai-Juan, Razamin Ramli and Rosshairy Abd Rahman,"Investigating nutrient requirements of grouper fish for feed formulation", *Journal of Telecommunication, Electronic and Computer Engineering (JTEC),* Vol. 8, No. 8, pp. 19-25, 2016.
[6] Sihananto, Andreas Nugroho, M. Shochibul Burhan and Wayan Firdaus Mahmudy,"Chicken feed optimization using evolution strategies and firefly algorithm", *International Journal of Electrical and Computer Engineering,* Vol. 9, No. 1, pp. 585-592,2019.
[7] Rosshairy Abd Rahman, Razamin Ramli, Zainoddin Jamari and Ku Ruhana Ku-Mahamud, "Evolutionary algorithm with roulette-tournament selection for solving aquaculture diet formulation", *Mathematical Problems in Engineering,* Vol. 2016, No. 1, pp. 1-10, 2016, Published by Hindawi Publishing Corporation, DOI: 10.1155/2016/3672758, Available: https://www.hindawi.com/journals/mpe/2016/3672758/.
[8] Guo, Peng and Longhao Zhang, "Automatic feed formulation method based on Differential Evolution algorithm for precision feeding of dairy cows", IOP Conference Series: Materials Science and Engineering, Vol. 768, No. 1, pp.1-7, 2020.
[9] Michael Florian, Jan Karel Lenstra and Alexander H. G. Rinnooy Kan, "Deterministic production planning: algorithms and complexity", *Management Science*, Vol. 26, No. 7, pp. 669-679, 1980, DOI: 10.1155/2016/3672758, Available: https://www.hindawi.com/journals/mpe/2016/3672758/.
[10] Olalere Olusegum Abayomi, Alao Kehinde Temitope, Oyedele Oyelayo and Adebimpe A Oluseye, "A productivity outlook for a multi-criteria animal feed formulation problem: a case study of Nigerian feed mill industry", *International Journal of Advancements in Computing Technology*, Print ISSN: 0976-4860, Vol. 6, No. 1, pp. 1-9, 2015, DOI: 10.4172/0976-4860.1000145.
[11] Rosshairy Abd Rahman, Graham Kendall, Razamin Ramli, Zainoddin Jamari and Ku Ruhana Ku-Mahamud, "Shrimp feed formulation via evolutionary algorithm with power heuristics for handling constraints", *Complexity,* Vol. 2017, No. 1, pp. 1-12, 2017, Published by Hindawi, DOI: 10.1155/2017/7053710, Available: https://www.hindawi.com/journals/complexity/2017/7053710/.
[12] Soong Cai-Juan, Rosshairy Abd Rahman and Razamin Ramli, "Prioritizing the Nutrients of Grouper Fish for Feed Formulation Using Inversely Proportional to the Variance and Weighted Sum of Z-Scores", *International Journal of*

Innovative Technology and Exploring Engineering (IJITEE), Vol. 8, No. 4S, pp. 351-356, 2019, Available: https://www.ijitee.org/wp-content/uploads/papers/v8i4s/DS2888028419.pdf.
[13] Soong Cai-Juan, Razamin Ramli and Rosshairy Abd Rahman, "Potential grouper feed formulation based on evolutionary algorithm concept with a unique selection operator", *Journal of Engineering Science and Technology*, Vol. 13, No. 2, pp. 332-346, 2018.
[14] Supachai Pathumnakul, Mongkon Ittiphalin, Kullapapruk Piewthongngam and Somkiet Rujikietkumjorn, "Should feed mills go beyond traditional least cost formulation?" *Computers and Electronics in Agriculture*, Print ISSN: 0168-1699, Vol. 75, No. 2011, pp. 243-249, 2011, Published by Elsevier, DOI: 10.1016/j.compag.2010.11.009, Available: https://www.sciencedirect.com/science/article/abs/pii/S0168169910002334.
[15] Shiva Zargar Ershadi, Mohammad Davoud Heidari, Baishali Dutta, Goretty Dias and Nathan Pelletier, "Comparative life cycle assessment of technologies and strategies to improve nitrogen use efficiency in egg supply chains", *Resources, Conservation and Recycling*, Vol. 166, No. 105275, pp. 1-12, 2021, Published by Elsevier, DOI: 10.1016/j.resconrec.2020.105275, Available: https://www.sciencedirect.com/science/article/pii/S0921344920305905.
[16] Deepak E. Velayudhan and Martin Nyachoti, "Characterization of dietary energy in swine feed and feed ingredients: a review of recent research results", *Asian-Australasian Journal of Animal Sciences*, Vol. 28, No. 1, pp. 1-13, 2015, Published by Asia-Australasian Journal of Animal Sciences, DOI: 10.5713/ajas.14.0001R, Available: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC4283177.
[17] Yi-Feng Hung, Ching-Ping Chen, Chia-Chung Shih and Ming-Hsiau Hung, "Using tabu search with ranking candidate list to solve production planning problems with setups", *Computers & Industrial Engineering*, Vol. 45, No. 4, pp. 615-634, December 2003, Published by Elsevier B. V., DOI: 10.1016/j.cie.2003.09.006, Available: https://www.sciencedirect.com/science/article/abs/pii/S0360835203000949.
[18] G. Joan Holt, "*Larval Fish Nutrition*", 1st ed. New Jersey, USA: John Wiley & Sons, Print ISBN: 9780813817927, Online ISBN: 9780470959862, 2011.
[19] Syed Ahamad Ali, "*Nutritional Feeding of Fish and Shrimps in India*", 1st ed. Tamil Nadu, India: MJP Publisher, 2019.
[20] Crina Grosan and Ajith Abraham,"Hybrid Evolutionary Algorithm: Methodologies, Architectures, and Reviews", *Studies in Computational International (SCI)*, Vol. 75, No. 1, pp. 1-17, 2007, Available: https://link.springer.com/chapter/10.1007/978-3-540-73297-6_1.

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