Optimization of Broiler Chicken Feed Mix Using Evolution Strategies

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Abstract**—Mixing chicken feed using some feed ingredients is a difficult task. The process must ensure that the feed mixing fulfill the nutrient requirement and the constraint. Some approaches, such as the Pearson's Square have been introduced to solve this problem. However, these approaches fail to fulfill the nutrient requirements and desirable price. This study proposed the use of Evolution Strategies to address the negative solutions and fulfill the optimum feed composition requirements. This method resulted in a broiler chicken feed mix that meets the nutritional requirements with the minimum cost with best composition, which resulted in the fitness value of 0.15023 and price Rp. 3,185/chicken/2 weeks.**

Index Terms**—Evolution Strategies; Mixing Feed; Nutrient Requirement; Pearson's Square**

I. INTRODUCTION

Broiler chicken is widely consumed by humans as an inexpensive, high-quality protein source [1]. In raising livestock such as broiler chicken, one aspect that must be considered is the aspect of feeding the livestock. The food must have sufficient nutrition to keep the livestock grow well. Even so, the fulfillment of nutritional needs of livestock requires considerable daily cost, which is about 70% of operating costs. Therefore, farmers have to figure out how to meet the nutritional needs of livestock at the minimum cost [2], [3]. Animal feed usually are a mixture of feed materials from agricultural and industrial waste. Further, necessary additional components such as vitamins and mineral extracts may be added. The main nutrient contents that must be considered are the protein, fat, and fiber [3]. The composition of the feed itself must be adapted to the type of livestock and the age of the animals, whether is it on starter phase or it is about to enter a period of finisher.

Broiler chicken is one of livestock animals that are usually reared for their meat. In Indonesia, it became popular on 1980s. The farmers like this breed of chicken because they can harvest them in 5 or 6 weeks only after the egg hatches [4]. Although broiler chicken is a superior breed and can be harvested on short amount of time, farmers must pay attention on the feeding process. Like other livestock, broiler chicken needs various nutrients such as protein, carbohydrate, fat, vitamin, mineral and water to live and grow [2].

Most farm businesses in Indonesia are still practicing the traditional way of breeding chicken, an approach which has not been changed since the 1980s. The practice of this approach leads the broiler chicken farmer to face a problem on feeding. Feeding needs quite a lot of money and sometimes it becomes very difficult to measure the optimum feed composition for the chickens. Sometimes the farmers have to pay quite a sum of money to buy the factory-made, feed, although the feed may not contain enough nutrients needed for the chickens. Further, there are occasions where essential ingredients do not exist on certain season; hence, a system that can recommend a new mixing formula based on availability of alternative ingredients is needed [5].

II. RELATED WORKS

A. *Broiler Chicken Nutrient Requirements*

In general, livestock feed requirements of broiler chickens can be divided into two age groups: the starter (0-3 weeks old) and finisher (> 3 weeks - harvest). The details of needs of the broiler chickens as set by *Badan Standar Nasional* (Indonesia's National Standard Department) for the starter age and finisher age are shown in Table 1 and 2 [6], [7].

Table 1
Broiler Chicken Nutrients Requirement (Starter)

No.	Parameter	Measure	Constraint
1	Water	%	Max 14,0
2	Raw Protein	%	Min 19,0
3	Raw Fat	%	Max 7,4
4	Crude Fiber	%	Max 6,0
5	Ash / Minerals	%	Max 8,0
6	Calcium	%	0,90 – 1,20
7	Total Phosphor	%	0,60 – 1,00
8	Phosphor	%	Min 0,40
9	Aflatoxin	µg/kg	Max 50,0
10	Metabolism Energy	kcal/kg	Min 2900
11	Amino Acid		
	Lysine	%	Min 1,10
	Methionine	%	Min 0,40
	Methionine + Cystine	%	Min 0,60

Table 2
Broiler Chicken Nutrients Requirement (Finisher)

No.	Parameter	Measure	Constraint
1	Water	%	Max 14,0
2	Crude Protein	%	Min 18,0
3	Crude Fat	%	Max 8,0
4	Crude Fiber	%	Max 6,0
5	Ash / Minerals	%	Max 8,0
6	Calcium	%	0,90 – 1,20
7	Total Phosphor	%	0,60 – 1,00
8	Phosphor	%	Min 0,40
9	Aflatoxin	µg/kg	Max 50,00
10	Metabolism Energy	kcal/kg	Min 2900
11	Amino Acid		
	Lysine	%	Min 0,90
	Methionine	%	Min 0,30
	Methionine + Cystine	%	Min 0,50

Based on [8], a starter chicken needs 0.5 kilograms of feed, while a finisher chicken needs 1.5 kilograms.

B. Pearson's Square

Two common methods used to make feed mixture are the *trial-and-error* and the *Pearson's Square*. The preparation of the feed mixture using *Pearson's Square* [9], [10] are described below.

Suppose there is a feed ingredient A has a crude protein content of 13% and feedstuffs B has a 20% crude protein, these two ingredients will be mixed to create a ration with 15% crude protein. The steps that must be carried out are as follows:

Determine the mean value of both the feed material and put two compositions of feed on the left side of the square.

A → 13		
	15	
B → 20		

Next, determine the difference between the value of the feed material to the value of the middle, then cross it.

A → 13		|15-20| = 5
	15	
B → 20		|15-13| = 2

Add up the difference between the two feed ingredients, namely: 5 + 2 = 7.

Determine the percentage of feed material difference value to a second amount of the difference.

A → 13		5/7 *100% = 71,43%
	15	
B → 20		2/7 *100% = 28,57%

To make a desirable livestock feed rations, we had to mix the feed A 71.43% and 28.57% of feed B.

Person Square's Method is widely used because it is easy to understand, although its solution is often not optimal. Therefore, this method is not suitable for complex feed mixing [11].

C. Evolution Strategies

Composition problems are oftenly solved by a group of algorithm named Evolutionary Algorithms. These algorithms have been successfuly used to solve many composition problem on many disciplines such as Engineering, Biomedical, Economy, Operation Research, Social Science, Physics and many more. Some examples of its usage are for drugs composition, livestock feed composition and Cutting Stock Problem. [11],[12],[13].

Among the many Evolutionary Algorithm's branch, there is an algorithm named *Evolution Strategies*, an algorithm that was being invented by Ingo Rechenberg from Technical University Berlin at almost the same time with the Genetic Algorithm's invention. At first the two are standalone before they are recognized as a group of algorithms that resembles each other in 1990 [15].

Evolution Strategies algorithm aims to find the optimum solution and can be applied as a solution to solve complex problems with many parameters and restrictions [16], [17]. There have been research focusing on this algorithm to solve combinatorial problem such as work by Ahire et al.[18] which used Evolution Strategies to solve Workforce-constrained Preventive Maintenance Scheduling that is usually exist on heavy equipment overhaul facilities such as aircraft service centers or railroad yards. On the other hand, [19] and [20] have implemented this algorithm to solve the problem of the composition of animal feed for beef cattle and they managed to get fairly good result. Evolution Strategies Algorithm uses two main parameters (μ and λ), where μ is the number of candidate solutions in the generation of parent, while λ is the number of candidate solutions produced from the parent generation. Further, it should be better that λ value, which is greater than or equal to μ ($\lambda \geq \mu$) [15]. Based on [22], the process of Evolution Strategies Algorithm to produce chicken feed mix is outlined in Figure 1.

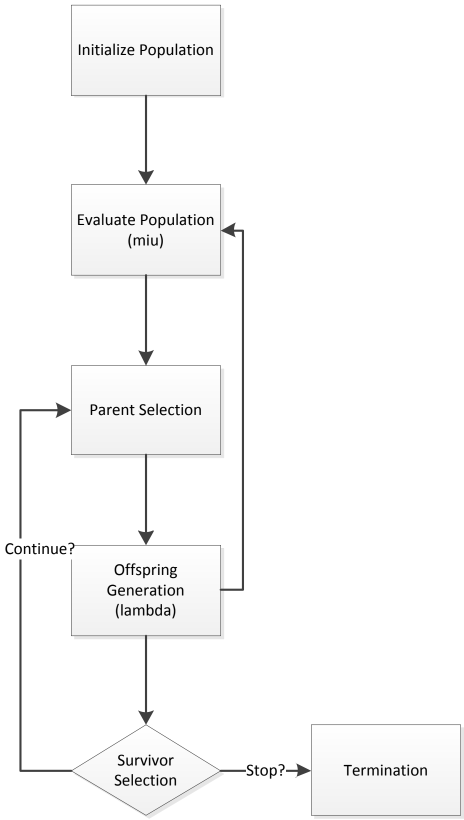

Figure 1: Evolution Strategies Workflow

After the termination phase, the process will select the best solution that fulfill or nearly fulfilled the nutrient requirements of the test.

III. METHODOLOGY

A. Fitness

To measure how good the solution is, we must use a fitness measure as seen on Equation (1) [16], [20].

$$Fitness = \frac{1000}{(total\ price + penalty * 100)} \quad (1)$$

where total price = total ingredients price

Meanwhile penalty = total penalty where the formula of this can be seen on Equation (2).

$$penalty \begin{cases} |nutrient_i - minimumConstraint| & If\ nutrient_i \geq minimumConstraint \\ |minimumConstraint - nutrient_i| & If\ nutrient_i < minimumConstraint \end{cases} \quad (2)$$

B. Evolution Strategies (ES)

The ES that we use here is (μ,λ) type; hence, it only applies mutation and does not conclude recombination process. The pseudocode of ES can be seen in Table 3 [23].

Table 3
Pseudocode of Evolution Strategies

```
t=0;
initialize (P(t=0));
evaluate (P(t=0));
while isNotTerminated() do
    Pp(t) = selectBest(μ, P(t));
    Pc(t) = reproduce (λ, Pp);
    mutate (Pc(t));
  if gen[i] Of MutatedPc(T)<0
     then gen[i]= random[0,1];
    evaluate(Pc(t));
    P(t+1) = Pc(t);
    t = t+1;
end
```

1) Chromosome Representation

The example of choromosome representation for Evolution Strategies can be seen in Table 4.

Table 4
A Chromosome Representation

	i_1	i_2	i_3	i_4	σ_1	σ_2	σ_3	σ_4	Price/ chicken
P1	7.776	0	2.217	3.0391	0.34	0.45	0.1	0.3	8000
P2	1.891	9.43	0	1.441	0.1	0.5	0.3	0.2	9600
P3	4.345	4.11	0.781	1.458	0.3	0.6	0.2	0.1	8800

Each gene i (i_1, i_2, i_3, and i_4) represents the types of ingredients such as bran, corn, peanut meal, and bone meal, while gene σ represents the mutation factor. Gen-value i of 0 indicates the material is not used, while genes that have the indicated value of the materials will be used in the composition. Meanwhile, σ (sigma) value that consists of 4 genes like i, represents the mutation factor of each i gene. The value of σ is initialized randomly at the range [0,1] and the mutation follows the rules, as presented in Equation (3).

$$x' = x + \sigma * N(0,1) \quad (3)$$

where N = a random number initialized with Equation (4).

$$N(0,1) = \sqrt{-2.\ln r_1} \sin 2\pi r_2 \quad (4)$$

where r_1, r_2 = random real number in the range [0,1]

The sigma (σ) was raised 10% if at least 20% of the mutations have a better fitness value than its parent. Conversely, if there is nothing better than the parent, then the value of σ will be reduced 10%

The last chromosome (after σ) represents feed price consumed by the chickens for 2 weeks.

2) Repair Mechanism

As can be seen on Table 3, there is a repair mechanism that can repair a gen value below zero and inject the gen with newer random decimal value ranged from 0 to 1. This must be done because it is impossible to have a composition with minus ingredients.

Suppose there is a case after mutation phase, as can be seen on Table 5, where a gene (i_2) has a negative value.

Table 5
A Chromosome With Negative Gene

	i_1	i_2	i_3	i_4	σ_1	σ_2	σ_3	σ4	Price/ chicken
P1	5.44	-3.13	2.21	3.061	0.34	0.45	0.1	0.3	5400

By following the mechanism in Table 3, we will repair gene (i_2) that resulted in a new chromosome as shown in Table 6.

Table 6
A Chromosome After Repaired

	i_1	i_2	i_3	i_4	σ_1	σ_2	σ_3	σ4	Price/ chicken
P1	5.44	1.05	2.21	3.061	0.34	0.45	0.1	0.3	5400

3) Feed Ingredients

For the test, we used 4 ingredients : barn, corn, peanut meal, and bone meal, in which the details of its price and nutritents can be found in Table 7. The test was conducted by applying the constraint from Table 1 and 2 for starter and finisher chicken.

Table 7
Testing Feed Ingredients

	Barn	Corn	Peanut Meal	Bone Meal
Price	1600	3000	3500	2500
Energy	2860	3370	2200	818
Water	12	11	8	3.5
Protein	10.2	8.6	42	12
Fat	7	3.9	1.9	3
Fiber	3	2	17	0
Calcium	0.39	0.09	0.21	26
Phosphor	0.16	0.37	0.25	13.5
Total Minerals	1.953	0.725	22.48	13.5
Cysteine	0.37	0.18	0.8	0
Lysine	0.71	0.2	1.8	0
Methionine	0.27	0.18	0.5	1.27

IV. RESULTS

1) Population Size Result

The test was conducted to search for the best population size. Each test was conducted 10 times and the average fitness or fitness rate, the best fitness and the worst fitness are shown in Table 8.

Firstly, we tested the ES based on the size of population and with a default offspring size (λ) = μ(population size) and generation size = 100. We started the test from 100 population, then 500, 1000, 1500, 2000, and lastly 2500. The result of the test can be seen in Table 8.

Table 8
Population Size Test

Population(μ)	Fitness Rate	Best Fitness	Worst Fitness
100	0,0025	0.0038	0.0024
500	0.04055	0.08625	0.03446
1000	0.10147	0.11418	0.08624
1500	0.11968	0.13791	0.10172
2000	0.12971	0.13527	0.11025
2500	0.12971	0.13409	0.11155

Figure 2: Population Size Chart

Based on chart as shown in Figure 2, the ES started to convergence when the population size is 1000 and achieved the best result when the population size (μ) = 2000 with the average fitness value is 0.12971. Adddtitionally, the worst result was achieved when the population size (μ) = 100 with the average fitness value is 0.0025. This proves that higher population size may have better chance to produce better result.

2) Offspring Size Result

The test was conducted to search the best offspring size. Each test was done 10 times and the average fitness or fitness rate, the best fitness and the worst fitness are shown in Table 9.

Based on our discovery on Figure 2, the population size for the test is 2000 and the default generation size = 100. We started the test from μ offsprings, then 5μ, 10μ, 15μ, 20μ, and lastly 25μ. The result of the test can be seen in Table 9.

Table 9
Offspring Size Test

Offspring (λ)	Fitness Rate	Best Fitness	Worst Fitness
μ	0,12971	0.13334	0.10667
5μ	0.134	0.13938	0.11151
10μ	0.1401	0.14711	0.11769
15μ	0.1431	0.14438	0.11550
20μ	0.14401	0.15002	0.12002
25μ	0.14401	0.15023	0.12018

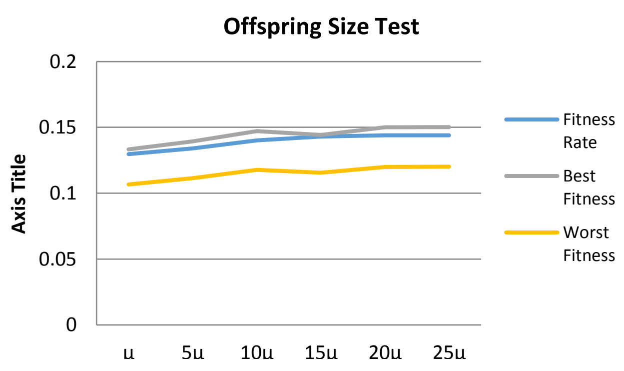

Figure 3: Offspring Size Chart

Based on Figure 2, the ES started to convergence when the offspring size (λ) is 10μ and achieved the best result λ= 20μ with average fitness value is 0.14401 and achieved the worst result when the offspring size (λ) = μ with the average fitness value is 0.12971. This proves that higher offspring size may have better chance to produce better result.

3) Generation Size Result

The test was conducted to search the best generation size a using our discovery in Table 8 and 9. We used the population size = 2000 and offspring size = 20μ. 100 generations, 300 generations, 500, 700, 900, 1000, and lastly 1100. Each test was repeated 10 times and the result of the test can be seen in Table 10.

Table 10
Generation Size Test

Generation	Fitness Rate	Best Fitness	Worst Fitness
100	0.14401	0.14753	0.11802
300	0.14329	0.14679	0.11743
500	0.14399	0.14623	0.11698
700	0.14783	0.149	0.1192
900	0.15	0.15023	0.12018
1000	0.15023	0.15023	0.12018
1100	0.15023	0.15023	0.12006

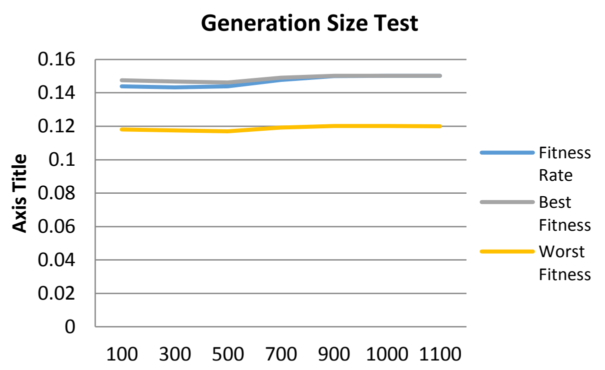

Figure 4: Generation Size Chart

In Table 10 and Figure 4, we can see that the test achieved the best result when the generation size = 1000. Therefore, it can be concluded that the ES for broiler chicken feed mix has the best parameter as follows : population size(μ)=2000, offspring size(λ) = 20 and generation size = 1000.

4) Comparison with Pearson's Square and Factory-Made Feed

By using best parameters, namely the population size(μ)=2000, offspring size(λ) = 20 and generation size = 1000, we compared the ES with Pearson's Square. As seen in Table 11, the ES outperforms Perason's Square with the fitness value 0.15023 and 0.00675 respectively. Even the Pearson's Square resulted in lower price (Rp. 2,556.872/chicken/2 weeks) compared to ES (Rp. 3,185/chicken/2 weeks). However, the fitness value of the Pearson's Square solution is far lower than ES. Therefore, the ES has better nutrient fulfillment than the Pearson's Square.

Based on the result, we can conclude that it is better to use ES solution for mixing broiler chicken feed.

Table 11
Test Result For Starter and Grower

Phase	Fitness	Price (IDR/chicken/2 weeks)
Method : Evolution Strategies		
Starter	0.15023	3,185
Finisher	0.15023	3,185
Method : Pearson's Square		
Starter	0.00675	2,556.872
Finisher	0.00675	2,556.872

V. CONCLUSION

This study has proved that the Evolution Strategies could solve the feed mix for broiler chicken feed with acceptable result and reasonable price. Additionally, this strategy may be implemented as a helper tool for farmers who breed broiler chicken, especially in Indonesia. The best result was achieved with the population size(μ)=2000, offspring size (λ) = 20 and generation size = 1000. The ES' highest fitness rate is 0.15023 and the feed price per one chicken is Rp. 3,185 per 2 weeks for both starter and finisher phase. To achieve higher fitness rate and lower price, the hybridization of ES with local search algorithm may be implemented.

APPENDIX

Table 12
Test Ingredients

Trial	Ingredients	Total Combination
1	1, 3, 4	3
2	2,3,6,9	4
3	7, 6, 16	3
4	1, 4, 5,6	4
5	13, 6, 4, 5	4
6	13, 6, 4, 5	4
7	13, 6, 14, 15	4
8	1, 3, 4	3
9	1, 3, 4	3
10	9,16, 3, 4	4

Table 13
Ingredient List for Broiler Chicken Feed

Index	Ingredient	ME	Water	Protein	Fat	Fiber	Ca	P	Total Minerals	Cys	Lys	Met	Price/kg
1	Rice Barn	2860	12	10,2	7	3	0,39	0,16	1,953	0,37	0,71	0,27	2860
2	Corn	3370	11	8,6	3,9	2	0,09	0,37	0,725	0,18	0,2	0,18	3370
3	Peanut Meal	2200	8	42	1,9	17	0,21	0,25	22,48	0,8	1,8	0,5	2200
4	Bone Meal	818	3,5	12	3	0	26	13,5	13,5	0	0	1,27	818
5	Pollard	1300	9	16.5	4	10	0.14	0.32	0	0.1	0.3	0.17	2200
6	Green Peas	2220	11.3	21.3	0.9	4.5	0.17	0.08	0	0	0	1.75	3500
7	Crude Corn Bran	2950	3.1	7.54	15.62	0.58	0.51	0.15	0	0.2	0.5	0.17	2000
8	Refined Corn Bran	2950	3.1	7.54	15.62	0.58	0.51	0.15	0	0.2	0.5	0.17	2000
9	Dried Cassava	2850	6.42	10.82	6.9	4.3	0.58	0.15	0	0.2	0.5	0.17	2000
10	Buckwheat	3250	9.7	10	2.8	2	0.41	2.13	0	0.15	0.2	0.13	2500
13	Corn Germ Meal (CGM)*	4553.91	1.37	19.75	11.35	21.5	0	0	0	0	0	0	5000
14	Blood Flour	2750	85	1.1	0.15	0.32	0.09	2.3	0.09	6.9	1.1	3.7	5000
15	Soybean Meal	2240	14	43.7	0.9	6	0.29	0.65	35	0.67	2.9	0.65	5500
16	Coconut Meal	2200	9	18.5	2.5	15	0.2	0.57	0	0.3	0.64	0.29	2500

ME = metabolism energy, Ca = Calcium, P = phosphorus, Cys = Cystine, Lys = Lysine, Met= methionine, Price = in Indonesian Rupiahs (IDR)

REFERENCES

[1] J. U-chupaj *et al.*, "Differences in textural properties of cooked caponized and broiler chicken breast meat," *Poult. Sci.*, pp. 1–10, 2017.

[2] P. P. Ketaren, "Kebutuhan Gizi Ternak Unggas Di Indonesia," *WARTAZOA*, vol. 20, no. 4, 2010.

[3] G. Xiccato, "Fat Digestion," Oxfordshire, UK: CABI, 2010, pp. 56–65.

[4] M. Rasyaf, *Manajemen Peternakan Ayam Broiler*. Jakarta: Penebar Swadaya, 2007.

[5] N. A. Hasan, I. El-Khodary, and M. Y. Dahab, "Developing a Generic Decision Support System for Poultry Feeding," *Int. J. Adv. Eng. Sci.*, vol. 5, no. 3, Jul. 2015.

[6] Badan Standar Nasional, "SNI 01-3930-2006," p. 9, 2006.

[7] Badan Standar Nasional, "SNI 01-3931-2006," 2006.

[8] Biyinzika, "Broiler Management Guide," 2015. [Online]. Available: http://www.biyinzika.co.ug/. [Accessed: 08-Apr-2017].

[9] J. Wagner and T. L. Stanton, "Formulating Rations With the Pearson Square," no. 1, pp. 1–2, 2012.

[10] S. H. Ward, "Simple Ration Formulation : Pearson ' s Square," 2010.

[11] R. A. Rahman, C. Ang, and R. Ramli, "Investigating Feed Mix Problem Approaches : An Overview and Potential Solution," *World Acad. Sci. Eng. Technol.*, vol. 46, no. 10, pp. 424–432, 2010.

[12] E.-W. Lameijer, T. Bäck, J. N. Kok, and A. P. IJzerman, "Evolutionary Algorithms in Drug Design," *J. Nat. Comput.*, 2005.

[13] R. Chiong and Ooi Koon Beng, "A Comparison between Genetic Algorithms and Evolutionary Programming based on Cutting Stock Problem," *Eng. Lett.*, no. 14, 2007.

[14] R. A. Rahman, R. Ramli, Z. Jamari, and K. R. Ku-Mahamud, "Evolutionary Algorithm Approach For Solving Animal Diet Formulation," *Proc. 5th Int. Conf. Comput. Informatics, ICOCI 2015*, no. 32, Aug. 2015.

[15] T. Bäck, G. Rudolph, and H.-P. Schwefel, "Evolutionary programming and evolution strategies: Similarities and differences," *Proc. Second Annu. Conf. Evol. Program.*, pp. 1–10, 1997.

[16] W. F. Mahmudy, Dasar-Dasar *Algoritma Evolusi*. Program Teknologi Informasi dan Ilmu Komputer (PTTIK) Universitas Brawijaya, 2015.

[17] E. Mezura-Montes, C. A. Coello Coello, and A. Hernandez-Aguirre, "Using Evolution Strategies To Solve Constrained Optimization Problems," *Evol. Algorithms Intell. Tools Eng. Optim.*, no. 4, 2004.

[18] S. Ahire, G. Greenwood, A. Gupta, and M. Terwilliger, "Workforce-constrained Preventive Maintenance Scheduling Using Evolution Strategies," *Decis. Sci.*, vol. 31, no. 4, pp. 833–859, 2000.

[19] H. Milah and W. F. Mahmudy, "Implementasi Algoritma Evolution Strategies Untuk Optimasi Komposisi Pakan Ternak Sapi Potong," *DORO Repos. J. Mhs. PTIIK Univ. Brawijaya*, vol. 5, no. 11, 2015.

[20] V. N. Wijayaningrum and W. F. Mahmudy, "Fodder Composition Optimization using Modified Genetic Algorithm," *Int. J. Intell. Eng. Syst.*, vol. 9, no. 3, 2016.

[21] J. Brownlee, *Clever Algorithms: Nature-Inspired Programming Recipes*, 2nd ed. 2011.

[22] T. Bäck, C. Foussette, and P. Krause, *Contemporary Evolution Strategies*. Springer Science & Business Media, 2013.