P-ISSN 2586-9000
E-ISSN 2586-9027
Homepage : https://tci-thaijo.org/index.php/SciTechAsia
Science & Technology Asia
Vol. 27 No.4 October - December 2022
Page: [236-247]
Original research article

Single Alternative Ingredient Assignment and its Cost Effect to Reformulation of Layer Chicken Feed in Thailand: The Multi-Criteria Approach with Case Study of Banana Peel Application

Prachya Boonprasurt[1,*], Phattalin Wiriyarungrueangkun[2]

[1]*Department of Mathematics and Statistics, Faculty of Science and Technology, Thammasat University, Pathum Thani 12120, Thailand*
[2]*Department of Research and Development, Innotope Co., Ltd., Bangkok 10510, Thailand*

Received 21 March 2020; Received in revised form 22 July 2022
Accepted 26 July 2022; Available online 31 December 2022

ABSTRACT

Many nutrients are required to feed layer chickens in the early stages before laying, and feed formulations are assured of the nutrient-required standards. However, some ingredients might be partially or totally replaced by other ingredients with the implication of environmental problems or agriculture extension policies. The multi-criteria approach is presented for the feasible ingredient replacement concurrently with the cost increment restriction. Regardless of cost concerns, the replacement boundary model is firstly proposed as the sub model for a feed reformulation to locate the maximum quantity of alternative ingredients being applied into a feedstuff under a specific replacement rate. Next, the cost-effectiveness model is presented as the main model for the formula revision (derived from the sub model) to gain the minimum cost increment under an acceptable range while nutrient requirements and replacement conditions are still maintained. In the case study, banana peel is selected as the alternative ingredient, and corn is the specific ingredient which must be mainly reduced. The results from the test problems show that banana peel can be significantly applied in the feed formula. In addition, to retain a desirable feedstuff cost, policy pricing for the alternative ingredient can be recommended from consideration of any surplus cost (if any).

Keywords: Multi-criteria model; Linear programming; Layer chicken feed formula; Nutritive value; Nutrient composition

***Corresponding author:** prachya@tu.ac.th

1. Introduction

Layer poultry farming means raising egg laying poultry birds for the purpose of commercial egg production. Layer chickens needs to be raised from when they are one day old. They start laying eggs commercially from 18-19 weeks of age and lay eggs continuously until they are 72-78 weeks of age. They can produce about 1 kg of eggs by consuming about 2.25 kg of food during their egg laying period. However, standards of nutrient requirements for each stage of feeding are also provided such as protein, fat, amino acids, and vitamins.

The layer poultry industry is an important business in Thailand for both domestic consumption and export. Furthermore, the data from Thai Feed Mill Association (TFMA) shows that egg consumption has increased about 3.85% from the last two years [1]. To comply with the standard, the Department of Livestock Development, Ministry of Agriculture and Cooperatives in Thailand recommend the nutrient requirements and local ingredient formulas. The main ingredients used are rice bran, cassava root, yellow corn, grist, etc.

Conforming to the poultry farming demand, the feedstuff industry needs more raw material and cropland for supply. It is noted that Thailand is a tropical country and agriculture is one of the main economic systems, so at least 30% of the total land area is currently used for agricultural activities of which about 10% accounts for cropland besides the paddy area. When focusing on a specific ingredient in poultry feed formulas, corn is one of the main ingredients used in the layer chicken feed since it is a nutritive ingredient, relatively inexpensive, and a drought-resistance plant.

However, until now its cultivation has been causing serious environmental problems such as deforestation, shifting cultivation, pesticide residues in soil, or field fire. Traditionally, before starting a new crop, farmers burned the land to eliminate the dry corn after harvesting even though it is illegal. This has been a serious pollution issue in the country.

According to these problems, the research objective is to develop the multi-criteria mathematical models for the feed formulation in which an alternative ingredient is mixed to reduce corn while the total cost increment of feedstuffs is concurrently concerned. In the case study, cultivated banana (Musa Sapientum Linn) peel is considered as the alternative ingredient proposed in this research because its fruit is a local plant which is fast growing and multiplying, it requires less maintenance, and it is environmentally friendly. The peel is rich in nutrients which makes it suitable for use in the feed formula.

Banana peels are currently considered as agriculture waste, and to use it as feed drying and mold free processes are required. Basically, with these operation costs, it has a higher price than corn and some ingredients in a feed formula. Later on, the results of this research are expected to support the agricommerce planning and waste management in economic and environmental policies.

2. Layer Chicken Feed

2.1 Nutrient requirements

There are many layer chicken species in Thailand such as Rhode Island Red, Barred Plymouth Rock, DLD layer, Native crossed, etc. In general, the commonly used ingredients are recommended for layer chicken feed at the growing period before laying related to the different stages of feeding, and different nutritive values of the feedstuffs are required. It is noted that the commercial standard manual such as Hy-Line International [2] categorizes layer chicken farming (at the growing period) by five stages namely, 0-3 weeks, 4-6 weeks, 7-12 weeks, 13-15 weeks, and 16-17 weeks. However, the Department of Livestock Development (Thailand) refers to only four stages namely, 0-6 weeks, 6-12 weeks, 12-18 weeks, and 18 weeks to 1st laying [3].

Since layer chickens have to be fed adequate nutrient quantities, nutrient requirements that will satisfy the necessary and sufficient conditions in a feedstuff related to an agricultural topography is recommended. In Africa, the nutrients composition is recommended for main poultry feed ingredients used in Sudan [4]. The National Research Council (USA) recommends the nutrient requirements of immature leghorn-type chickens [5, 6]. Based on the department of livestock development in Thailand [3] (page 5), the average values of nutrients recommended for the layer chicken feed are shown in Table 1 below.

Table 1. Dietary nutrient requirements for layer chicken feeds.

Nutrient	Nutrient requirement				
	0-6 (week)	6-12 (week)	12-18 (week)	18-1st laying	laying hen
Energy (kcal/kg)	2800	2800	2850	2850	2900
Protein (%)	17	15	14	16	15
Essential amino acid (%)					
Lysine	0.80	0.56	0.42	0.49	0.69
Methionine + Cystine	0.59	0.49	0.39	0.44	0.58
Tryptophan	0.16	0.13	0.10	0.11	0.60
Threonine	0.64	0.53	0.35	0.44	0.47
Isoleucine	0.57	0.47	0.37	0.42	0.65
Arginine	0.94	0.78	0.62	0.72	0.70
Leucine	1.00	0.80	0.65	0.75	0.82
Phenylalanine + tyrosine	0.94	0.78	0.63	0.70	0.83
Histidine	0.25	0.21	0.16	0.18	0.17
Valine	0.59	0.49	0.38	0.43	0.70
Glycine+Serine	0.66	0.54	0.44	0.50	-
Calcium	0.90	0.80	0.80	1.80	3.25
Phosphorus	0.40	0.35	0.30	0.35	0.25
Sodium	0.35	0.35	0.35	0.35	0.35

Some other sources provide more detail about the variation of nutritive values. Poultry Hub, the association related to the poultry cooperative research center (or Poultry CRC) in Australia, proposes the recommendation for the minimum nutrition requirements for each stage of layer chicken diets [7]. However, poultry feed availability and nutrition in developing countries are also recommended. The minimum nutrient requirements are proposed by Ravindran [8] and also found in the Hy-Line international standard manual [2].

To select a set of different ingredients, the nutritive values of the ingredients are integrated and needed to balance in a feed formula. The nutrition data is also provided from some sources [9-11], mainly referred to the department of livestock development (Thailand).

In general, ingredients and additives for layer chicken are roughly grouped as protein and amino acids, linoleic acid, macro-minerals, trace minerals, fat-soluble vitamins, and water-soluble vitamins. Local raw materials used for brown layer chicken diet formulations are studied by the animal nutrition division [12], and the Department of Livestock Development recommends formulas for each stage [13]. Table 2 shows the nutritive values of standard ingredients for brown layer chicken feeds.

According to the combination of nutrient requirements, ingredient properties, and feeding stages, utilizing the local ingredients or optimizing the feedstuff cost has drawn some studies regarding diet formulation. In an attempt to economize the ration of formulation, current concepts of feed formulation for livestock using mathematical modeling have been used with varying success. Linear programming (LP) is discussed in the study as the effective use for the least-cost ration for many years [14].

Least-cost formulation using linear programming is employed to investigate, analyze and indicate how best the available local ingredients can be combined effectively and efficiently in Jordan [15]. For the Nigerian poultry industry, the feed formulation problem is developed and parameterized using data from a typical commercial farm. The post-optimality analysis results are obtained and compared, and the reduction in the feed formula cost is given [16]. The optimal nutrients diet

formulation of broiler poultry rations in Nigeria is also proposed to select a set of nutrients that will satisfy a set of daily nutritional requirements at the minimum cost, and a sensitivity analysis also gives useful insight into the impact of changes in cost of feed inputs [17].

In addition, the use of a spreadsheet to solve linear and non-linear feed formulation problems is proposed [18]. It is noted that typical linear programming models used by the feed industry include no features to account for variability in ingredients composition. A design requirement of feed formulation software for poultry industries has also been developed in Nigerian based on local ingredients and the USDA nutrient database. Factors which may tie down the nutrients contained in a feedstuff must be built in as the users are not going to be experts [19].

Table 2. Nutritive values of ingredients.

no	Ingredient	Dry matter (%)	Energy (kcal/ kg)	Nutritive values (%/kg)									
				Protein	Fat	Fiber	Ash	Lysine	Methionine	Methionine + Cystine	Tryptophan	Threonine	Isoleucine
1	Grist	87.6	3,500	8.00	0.90	1.00	0.70	0.27	0.27	0.32	0.10	0.36	0.45
2	Corn (yellow)	86.5	3,370	8.00	4.00	2.50	1.30	0.25	0.19	0.39	0.09	0.32	0.34
3	Rice bran meal	89.9	2,710	12.00	12.00	11.00	10.90	0.55	0.25	0.50	0.10	0.4	0.45
4	Cassava (as feed)	89.6	3,500	2.50	0.75	3.70	3.70	0.09	0.03	0.06	0.02	0.07	0.07
5	Soybean meal (44% CP)	88.5	2,280	44.00	1.00	7.00	6.00	2.73	0.59	1.26	0.59	1.72	2.17
6	Fish meal (55% CP)	91.6	2,948	55.00	8.00	1.00	26.00	4.15	1.44	2.00	0.60	2.24	2.37
7	Fish meal (60% CP)	91.7	2,950	60.00	10.00	75.16	19.00	4.57	1.57	2.14	0.62	2.44	2.59
8	Shell	99.4	-	0.80	0.10		95.50	-	-	-	-	-	-
9	Leucaena leaf meal	92.2	900	20.20	3.50	18.00	8.80	1.10	0.28	0.63	0.20	0.80	1.73

Note: CP is the crude protein

Table 2. (cont.) Nutritive values of ingredients.

no	Arginine	Leucine	Phenylalanine + tyrosine	Histidine	Valine	Glycine	Calcium	Phosphorus	Sodium	Choline	Potassium	Chlorine	Linoleic Acid
1	0.36	0.71	1.15	0.18	0.53	0.71	0.03	0.04	0.07	-	0.67	0.08	-
2	0.4	1.17	0.81	0.25	0.46	0.33	0.01	0.10	0.02	0.03	0.44	0.04	2.20
3	0.95	0.81	0.92	0.32	0.69	0.61	0.06	0.47	0.04	0.07	1.27	0.07	6.60
4	0.12	0.12	0.12	0.03	0.09	0.08	0.12	0.05	0.01	-	0.74	-	3.50
5	3.18	3.39	3.82	1.11	2.24	1.83	0.25	0.20	0.04	0.20	2.07	0.05	0.40
6	3.22	3.84	4.00	1.15	2.70	4.00	7.70	3.80	1.82	0.40		1.68	-
7	3.52	4.19	4.16	1.26	2.95	4.33	3.80	3.00	-	-	0.98	-	-
8	-	-	-	-	-	-	35.63	0.03	0.21	-	-	0.01	-
9	0.95	1.50	1.80	0.40	1.10	0.53	0.54	0.30	0.00	-	0.51	0.10	0.27

2.2 Nutrients of banana peel

Banana is an edible tropical fruit which is an annual crop with rapid growth that multiplies by germination. It has a creamy pulp, sweet taste, and soft skin. All parts of banana can be used for cooking or as local medicines. In Thailand, an adult banana tree may yield about 200 fruits, and its weight may be up to 200 kg. While there are many types of bananas, a cultivated banana (Musa sapieutum L.) is used in this research due to a good yield rate and rich nutrients for the local general crops. It is noted that its peel is considered as the alternative ingredient in this research.

An overview of bananas and their by-product utilization is inspected in India [20]. In Thailand, the Bureau of Animal Nutrition Development shows some chemical compositions of banana [21], and the banana and plantain products for animal feeding information are also provided [22].

However, when considering the banana peel, it is the waste from agriproduct processing (but sold at some costs). Yet by drying and grinding, it can be used as a raw material in animal feed since it is rich in nutrients. Some references of nutritive values in banana peel for animal feeding can be found, such as the study on the nutritive value and digestibility of banana peel (Musa sapientum L.) as ruminant feed [23]. The study of using banana peel (Musa sapieutum L.) in growing pigs [24] also provides details of nutritive values. According to the article, Tables 3 and 4 show the amino acids and nutrients composition of banana peel as follows.

Table 3. Amino acid composition of banana peels (Musa sapieutum L.).

Amino acid	Type of banana peels		
	green	almost ripe	ripe
Aspartic acid (%)	0.30	0.41	0.33
Threonine (%)	0.14	0.19	0.15
Serine (%)	0.16	0.21	0.17
Glutamic acid (%)	0.38	0.54	0.45
Proline (%)	0.13	0.17	0.17
Glycine (%)	0.20	0.27	0.23
Alanine (%)	0.25	0.29	0.26
Cystine (%)	0.06	0.08	0.06
Valine (%)	0.19	0.26	0.22
Methionine (%)	0.05	0.06	0.06
lsoleucine (%)	0.12	0.16	0.13
Leucine (%)	0.23	0.30	0.24
Phenylalanine (%)	0.06	0.08	0.06
Lysine (%)	0.12	0.14	0.10
Arginine (%)	0.08	0.10	0.08

Table 4. Nutrient composition of banana peels (Musa sapieutum L.).

Nutrient composition	Type of banana peels		
	green	almost ripe	ripe
Dry matter (%)	91.62	92.38	95.66
Crude protein (%)	5.19	6.61	4.77
Ether extract (%)	10.66	14.20	14.56
Crude fiber (%)	11.58	11.10	11.95
Ash (%)	16.30	14.27	14.58
Calcium (%)	0.37	0.38	0.36
Phosphorus (%)	0.28	0.29	0.23
Gross Energy (Kcal/kg)	4383	4692	4592
Tannin (%)	6.84	4.97	4.69

3. Problem Formulation

Basically, an alternative ingredient is required to replace a specific ingredient but expected to maintain a nutritional requirement.

Mathematical models are proposed in this section to focus on the studies of ingredients replacement and total cost increment. A multi-criteria model called the cost-effectiveness model is presented as the main model. The expectation of any cost increment can be concurrently investigated under a specific replacement rate in that the maximum quantity of alternative ingredient is obtained.

However, regardless of the cost increment factor, the quantity of maximum replacement can firstly be verified. The sub model called replacement boundary model is presented to examine ingredient-reformulated effects. Thus, the assumptions are stated as follows:

1. Price of an alternative ingredient is more expensive than a specific ingredient to be replaced.
2. Cost of feedstuffs considers only the raw material cost
3. Weight ratio of ingredients in a feed formula may be modified by an alternative ingredient.

In feed formulas, the parameters and decision variables are listed as follows:

Parameter

W total weight of a feedstuff (kg),
M number of nutrients,
N number of ingredients (including specific and alternative ingredients),
B_j^U maximum requirement ratio of nutrient j in a feedstuff (%),
B_j^L minimum requirement ratio of nutrient j in a feedstuff (%),
b_{ij} ratio of nutrient j in ingredient i (%),
r_p replacement rate with respect to a specific ingredient (%),
r_c cost increment rate in a feedstuff (%),
T_0 original cost of a feedstuff without alternative ingredients (THB),
c_i cost of ingredient i (THB),
Q_s^0 original quantities of a specific ingredient in a feed formula without alternative ingredients (kg).

Decision Variable

x_i quantities of ingredient i (kg),
x_r quantities of an alternative ingredient (kg),
x_s quantities of a specific ingredient (kg).

3.1 Replacement boundary model (sub model)

Regardless of cost, the maximum quantity of alternative ingredient can be found under a restriction of a specific replacement rate (r_p) since a specific ingredient and other ingredients can be replaced but still maintain nutrient requirements in a feed formula.

Basically, a replacement rate implies an upper bound of specific ingredient quantities that can be replaced by an alternative ingredient. Linear programming is set as follows.

$$\text{Max} \quad x_r \tag{3.1}$$

subject to

$$\sum_{i=1}^{N} b_{ij}x_i - B_j^U W \le 0 \quad : j = 1,...,M, \tag{3.2}$$

$$\sum_{i=1}^{N} b_{ij}x_i - B_j^L W \ge 0 \quad : j = 1,...,M, \tag{3.3}$$

$$\sum_{i=1}^{N} x_i - W = 0, \tag{3.4}$$

$$\left(1 - \frac{r_p}{100}\right) Q_s^0 - x_s \le 0, \tag{3.5}$$

$$x_i \ge 0 \qquad : i = 1,...,N. \tag{3.6}$$

The objective function (3.1) is to find the maximum quantity of alternative ingredient which can be applied in a feedstuff under a specific replacement rate.

The nutrient requirements are implied in (3.2) and (3.3), and the total weight of a feedstuff is still maintained and presented in (3.4). Next, (3.5) quantities of a specific ingredient which are removed under a specific replacement rate must not be greater than the upper bound of its quantities. Absolutely, the nonnegative values of all ingredient quantities are assigned in (3.6).

As a result, under any assignments of specific replacement rates and nutrient requirements, remaining quantities of a specific ingredient and the maximum quantity of alternative ingredient applied to a feedstuff can be shown. It is also noted that at a 100% replacement rate, the total replacement quantities of an alternative ingredient is obtained.

3.2 Cost-Effectiveness Model (main model)

When cost increment is additionally concerned, the quantities of ingredients used in the sub model are revised to reduce the total cost. Goal programming is presented as

the main model for two objectives as follows:

Additional parameter

x_r^{max} maximum quantities of a specific ingredient with respect to a specific replacement rate derived from the sub model (*kg*).

Goal 1 (primary): The 1st priority focuses on reducing the use of a specific ingredient under a specific replacement rate. In other words, the objective is to find the maximum quantities of an alternative ingredient having been discussed in the sub model (3.1)

Goal 2 (secondary): According to the results from Goal 1, the 2nd priority is intended to maximize quantities of an alternative ingredient applied concurrently with minimizing a cost increment under the cost assumptions and an increment rate expectation. Then the objective is written as

$$\text{Min} \sum_{i=1}^{N} c_i x_i \tag{3.7}$$

The constraints are also listed as follows

$$\sum_{i=1}^{N} b_{ij} x_i - B_j^U W \le 0 \quad : j = 1,...,M, \tag{3.8}$$

$$\sum_{i=1}^{N} b_{ij} x_i - B_j^L W \ge 0 \quad : j = 1,...,M, \tag{3.9}$$

$$\sum_{i=1}^{N} x_i - W = 0, \tag{3.10}$$

$$\left(1 - \frac{r_p}{100}\right) Q_s^0 - x_s \le 0, \tag{3.11}$$

$$100\left(\frac{\sum_{i=1}^{N} c_i x_i}{T_0} - 1\right) - r_c \le 0, \tag{3.12}$$

$$x_r - x_r^{max} \le 0, \tag{3.13}$$

$$x_i \ge 0 \ : i = 1,...,N. \tag{3.14}$$

The constraints (3.8-3.11) are identical to (3.2-3.5) in the sub model. Next, the expectation for cost increment in a feedstuff is to retain a ceiling of an acceptable rate presented in (3.12). Furthermore, the constraint (3.13) is to verify quantities of an alternative ingredient recalculated for cost which is never greater than its maximum quantity (x_r^{max}) derived from the sub model. Finally, the nonnegative values of all ingredient quantities are also assigned in (3.14).

According to the main model, when quantities of an alternative ingredient are obtained, a surplus value (if any) can be indicated. It is noted that the surplus value is a different value between the result and the expected price.

In general, quantities of an alternative ingredient applied in a feedstuff from the sub model could be different from the main model. Due to the limitation of cost increment rate, an alternative ingredient is also located to replace other ingredients having higher cost (if any) meanwhile to reduce quantities of a specific ingredient under a specific replacement rate and nutrient requirements.

4. Numerical Results and Discussion

For test problems in this section, cultivated banana peel is determined as the alternative ingredient to reduce corn (the specific ingredient) in a layer chicken feedstuff. The ingredient formulas recommended for layer chicken farming are referred to the Department of Livestock Development, Ministry of Agriculture and Cooperatives (Thailand).

To exam the models, the layer chicken feed formula at stage 1 (formula 2) is selected since it generally needs more nutrients than the other stages (Table 1) and corn is used as the specific ingredient in formula 2 [3]. However, quantities of the ingredients used in the feed formula are affected by the variation of ingredient prices at a time and must be revised. Table 5 shows

the reference prices of ingredients (based on June 2022 prices) and the revised quantities in the formula of a feedstuff.

Table 5. Feed ingredient prices (June 2022) and quantities of ingredients in formula 2 at stage 1 (0-6 weeks) in 100 kg. of feedstuff.

Ingredient	Reference price (THB/kg)	Revised quantity (kg)
Grist [1]	13.00	-
Corn (yellow) [1]	13.50	30.80
Rice bran meal [1]	12.10	48.46
Cassava (as feed) [1]	9.00	-
Soybean meal (44% CP) [1]	22.95	13.83
Fish meal [1]	45.20	4.90
Shell [2]	3.00	0.71
Leucaena leaf meal [3]	8.00	-
Salt meal [2]	5.00	0.35
Premix [4]	220.00	0.25
Dicalcium phosphate [5]	18.00	0.70
DL-methionine [2]	130.00	-
Banana peel (as feed) [6]	25.00	-
Total cost	-	1,612.49

[1] http://www.cpffeed.com/price-update/
[2] www.mitrkasetphand.com/14463557/วัตถุดิบอาหารสัตว์
[3] https://www.jfkfeed.com/products_detail/view/1682921
[4] https://millspetcenter.com/product/%E0%B8%A3%E0%B8%B2%E0%B8%84%E0%B8%B2-premix-vita-red-%E0%B8%82%E0%B8%99%E0%B8%B2%E0%B8%94-1-%E0%B8%81%E0%B8%B4%E0%B9%82%E0%B8%A5%E0%B8%81%E0%B8%A3%E0%B8%B1%E0%B8%A1-%E0%B8%AA%E0%B8%B2%E0%B8%A3/
[5] https://www.jfkfeed.com/products_detail/view/1682891
[6] https://www.thairath.co.th/news/society/964233

It is noted that banana peel (as feed) means the dried mold-free ripe peel. In addition, the minimum nutrient requirements in the layer chicken feed formulas are suggested since receiving more quantities of some nutrients will affect animal growth. The suggestion is also found in [2]. By using banana peel in place of corn, its nutrient composition is already provided in the table 3 and 4, and it is considered as the agricultural recycled material in this study.

First of all, finding a replacement boundary and quantities of banana peel applied in a feedstuff under a specific replacement target, the sub model is examined. The results including cost increment of a feedstuff when comparing to the original cost (without banana peel) are shown in Table 6.

Table 6. The test results of the replacement boundary and the total quantities of banana peel from the sub model applied in 100 kg of feedstuff .

(Corn) Reduction (%) (target, result)	(Corn) Removed quantity (kg)	(Banana peel) Total quantity applied (kg)	Cost increment of feedstuff (%)
(5, 5)	1.54	27.44	32.57
(10, 10)	3.08	27.72	33.88
(25, 25)	7.70	31.75	37.14
(35, 35)	10.78	33.40	39.17
(50, 50)	15.40	36.40	42.22
(65, 65)	20.02	39.28	45.27
(75, 75)	23.10	41.24	47.30
* (100, 100)	30.80	46.13	70.48

* maximum replacement

The results from table 6 show that the ingredients in the feed formula can be reformulated by mixing banana peel into the feedstuff while the nutrient requirements are still maintained. The results also show that corn can be reduced under the specific replacement targets but the feedstuff costs increase from the original.

For example, at 25% of replacement rate, 31.75 kilograms of banana peel are applied into the feedstuff. However, this quantity is divided into the replacement part for corn and the other for some ingredients in the feedstuff. As a result, 7.70 kilograms of banana peel are applied to reduce corn while the remaining quantities, 24.05 kilograms, are also applied to replace other ingredients. In addition, the cost increment is up to 37.14 % from the original.

It is noted that at the maximum replacement rate (100%), 46.13 kilograms of banana peel can be applied (or 46.13% of the total weight) while the cost increment is up to 70.48%.

According to the results in table 6, the main model is examined to revise the cost increment but the results of quantities of

corn reduced under the replacement rates are still maintained. However, it is noted that the cost increment constraint (12) in the main model is temporarily relaxed for investigating the actual surplus values from the original cost. The difference of replacement quantities and cost increments between the sub model and main model are shown in table 7.

Table 7. The test results of the cost increment revised from the main model.

(Corn) Replacement rate (%)	(Banana peel) Total quantity applied (%)		Cost increment of feedstuff (%)	
	sub model	main model	sub model	main model
5	27.44	1.54	32.57	0.92
10	27.72	3.08	33.88	1.80
25	31.75	7.70	37.14	4.45
35	33.40	10.78	39.17	6.21
50	36.40	15.40	42.22	9.11
65	39.28	20.02	45.27	13.07
75	41.24	23.10	47.30	15.71
*100	46.13	30.80	70.48	22.31

* maximum replacement

After the revisions, the costs are reduced to the minimum increment. For example, if the maximum cost increment is accepted at 4.45%, the request for reducing corn must be at most 25% of its original quantities (25% of the replacement rate), and the quantity ratio of banana peel applied into the feedstuff is just 3.08% of the total weight. However, at the maximum request (100% of the replacement rate) for corn replacement, 30.80% of banana peel is applied to the feedstuff and the cost increment is up 22.31% from its original cost.

In addition, if 25% of replacement rate is selected as the examination in detail, the comparisons between the feedstuff quantities of the original (without banana peel) and the revision are shown in table 8.

Table 8. The revised quantities of the ingredients at 25% of replacement rate in 100 kg of feedstuff.

Ingredient	Quantity in the feedstuff (kg)		
	original	sub model	main model
Corn (yellow)	30.80	23.10	23.10
Rice bran meal	48.46	0.00	43.28
Soybean meal (44% CP)	13.83	7.21	16.05
Fish meal (55% CP)	4.90	18.20	4.57
Shell	0.71	18.99	4.00
Salt meal	0.35	0.10	0.35
Banana peel	-	31.45	7.70
Cost increment from the original		37.14 %	4.45 %

It can be seen that quantities of some ingredients are revised to gain the minimum cost, but all of the requirement conditions for corn and banana peel are still maintained. Furthermore, table 9 also shows the rate of change of ingredient quantities reformulated from the main model.

Table 9. The ingredients reformulation at 25% of replacement rate in 100 kg.

Ingredient	Rate of quantity change (%) *
Corn (yellow)	(-) 25.00
Rice bran meal	(-) 10.71
Soybean meal (44% CP)	16.09
Fish meal (55% CP)	(-) 6.77
Shell	463.78
Salt meal	0.00
Banana peel	-

* increment rates is based on the original

According to the results in table 7, the values from the last column (the main model) represent the upper bound of cost increments in the feedstuff corresponding to their replacement rates.

Since the cost increment is mainly caused by banana peel, the competitive discount can be proposed in table 10 if the original cost of a feedstuff is still retained. As a result, the discount rate for banana peel is recommended to be about 37.18% to 46.73% based on the reference price (25 THB/kg).

Table 10. Cost increment (from the main model) and competitive discount values of banana peel

(Corn) Replacement rate (%)	(Banana peel) Total quantity applied [1] (%)	Cost increment of feedstuff [2] (%)	(Banana peel) Recommended discount (%)
5	1.54	0.92	38.54
10	3.08	1.80	37.74
25	7.70	4.45	37.72
35	10.78	6.21	37.18
50	15.40	9.11	38.15
65	20.02	13.07	42.11
75	23.10	15.71	43.87
*100	30.80	22.31	46.73

[1] ratio from a total weight of a feedstuff
[2] difference from the original cost (without banana peel)

For instance, at 25% of the replacement rate the discount is recommended at 37.72%, so the competitive price should be 15.68 THB/kg instead. However, at the maximum replacement rate (100%), the discount is recommended at 46.73% and the technical price is proposed at 13.32 THB/kg.

Table 11. Test results of revised quantities of banana peel derived from the main model

Requirement (A, B) (%, %)	(Banana peel) quantity applied (%) (without cost increment constraint)	(with cost increment constraint)	Output (C, result) (%, %)
(5, 2)	1.54	3.31	(0.92, 2)
(5, 3)	1.54	4.95	(0.92, 3)
(10, 3)	3.08	5.04	(1.80, 3)
(10, 5)	3.08	8.31	(1.80, 5)
(25, 3)	7.70	7.70	(4.45, 3) *
(25, 5)	7.70	8.60	(4.45, 5)
(25, 7)	7.70	11.88	(4.45, 7)
(35, 5)	10.78	10.78	(6.21, 5) *
(35, 8)	10.78	13.60	(6.21, 8)
(50, 7)	15.40	15.40	(9.11, 7) *
(50, 12)	15.40	18.26	(9.11, 12)
(65, 15)	20.02	21.93	(13.07, 15)
(75, 15)	23.10	23.10	(15.71, 15) *
(100, 15)	30.80	30.80	(22.31, 15) *

[A] replacement rate
[B] acceptable boundary of cost increment rate
[C] absolute cost increment rate from the original
[*] the expected target is not feasible

It is noted that the results in table 10 are derived from relaxing the cost increment constraint in the main model. However, when the constraint is reconsidered under a specific replacement rate, the quantities of ingredients in the feed formula are recalculated.

The results of the revision of banana peel from the test samples in table 11 show that under the specific requirements the cost increment rates are either under or over the acceptable boundaries. For example, at 5% of replacement rate (corn reduction) corresponding with 2% of acceptable cost increment rate (feedstuff), more quantities of banana peel can be applied while all requirements are still maintained.

However, at 25% of replacement rate corresponding with 3% of acceptable cost increment rate, the minimum feasible cost increment is at 4.45% which is beyond the expectation. In other words, the price of banana peel should be recommended at 21.97 THB/kg (referred at 25 THB/kg) or 12.12% discount from the referred price.

5. Conclusion

In this research, banana peel (as feed) is proposed as the alternative ingredient to reduce corn defined as the specific ingredient in the layer chicken feed formula. Due to some agricultural environmental issues, there are a lot of problems with corn farming in Thailand which is contrary to banana farming. However, banana peel is considered as an agriculture waste but rich of nutrients (as feed).

Mathematical models are presented under the concern of the specific requirements to study the feasible quantities of banana peel that can be applied to reduce some quantities of ingredients in a feedstuff concurrently with the consideration of the cost increment effect.

The results from the test samples show that the higher the replacement rate is, the more banana peel is relatively applied into a feedstuff, while the nutrient requirements are still maintained, but the incremental cost of feedstuffs must be paid. Consequently, if corn is totally removed from a feedstuff (100% of replacement rate), 30.80 % of banana peel is applied into the feedstuff for the least cost, and the total cost

increment is at 42.7% based on the original cost (without banana peel).

However, if cost increment is allowed and limited to a certain value with respect to a specific replacement rate, either surplus or shortfall from this value is considered. In other words, concerning surplus values, the strategic pricing of banana peel can be proposed from the discount on the reference price of banana peel.

Furthermore, to control the cost increment concurrently with the environmental maintenance, the strategy of commercial agriculture extension and the policy of local economy can be promoted including waste management that can be implemented to reduce the operation cost of the banana peel processing (as feed) and transportation.

In the future work, the decision making in the economics will be involved and developed for the trade-off value model between environment sustainability and economic growth.

Acknowledgements

This research study is academically supported by Department of Mathematics and Statistics, Faculty of Science and Technology, Thammasat University, Thailand

References

[1] Situation of agricultural economics trend in 2019. Thai Feed Mill Association (TFMA). Journal of feedstuff business 2019; 36(188): 1-96.

[2] Brown chicken layer; production efficiency standard manual; Hy- Line International [internet]. [cited 2022 June 2]. Available from: https://www.hyline.com/UserDocs/products/BRN_COM_TAI.pdf.

[3] Chomchai N. Layer chicken feeding and feed formulas. Department of Livestock Development, Ministry of Agriculture and Cooperatives, THAILAND; 1999 (p.5).

[4] Babiker M S, Kijora C, Abbas S A, Danier J. Nutrient composition of main poultry feed ingredients used in Sudan. International Journal of Poultry Science 2009; 8 (4): 355-8.

[5] Nutrient Requirements of Poultry, National Research Council. 9th revised ed. Washington, D.C.: National Academy Press; 1994, (p.20).

[6] National Academy Press Washington DC (1994) Nutrient Requirements of Poultry Ninth Revised Edition, (Subcommittee on Poultry Nutrition Committee on Animal Nutrition Board on Agriculture National Research Council (NRC).

[7] Nutrient requirements of egg laying chickens; Poultry Hub [internet]. [cited 2022 June 15]. Available from: http:// www. poultryhub. org/ nutrition/ nutrient-requirements/ nutrient- requirements- of-egg-laying-chickens/

[8] Ravindran V. Poultry feed availability and nutrition in developing countries. Poultry Development Review 2013: 1-4.

[9] Collection and Improvement in Nutritive Values DataBase of feed stuffs, Bureau of Animal Nutrition Development, Department of Livestock Development, Ministry of Agriculture and Cooperatives, THAILAND, 2016.

[10] Collection and database establishment on nutritive value of forage crops, Department of Livestock Development, Ministry of Agriculture and Cooperatives, Thailand, 2010.

[11] Raw materials for animal feeds. Department of Livestock Development [internet]. [cited 2022 June 25]. Available from: http://nutrition.dld.go.th/Nutrition_Knowlage/index_nutrition.htm.

[12] Poathong S. Local raw material use for pig and poultry feed. Animal nutrition division, Department of Livestock,

Ministry of Agriculture and Cooperatives; 2014.

[13] Layer chicken feed formulas; Department of Livestock Development [internet]. [cited 2022 June 30]. Available from: https://nutrition.dld.go.th/nutrition/index.php/ 2015- 08- 06- 09- 04- 25/ 2229-2021-12-09-08-07-45

[14] Ghosh S, Ghosh J, Pal D T, Gupta R. Current concepts of feed formulation for livestock using mathematical modeling. Animal Nutrition and Feed Technology 2014; 14: 205-23.

[15] Al-Deseit B. Least- cost broiler ration formulation using linear programming technique. Journal of Animal and Veterinary Advances 2009; 8(7): 1274-8.

[16] Oladokun V O, Johnson A. Feed formulation problem in Nigerian poultry farms: a mathematical programming approach. American Journal of Scientific and Industrial Research 2012; 3(1): 14-20.

[17] Olugbenga O S, Abayomi O O, Oluseye A A , Taiwo T A. Optimized nutrients diet formulation of broiler poultry rations in Nigeria using linear programming. Journal of Nutrition & Food Sciences 2015; S14: 1-6.

[18] Pesti G M. , Seila A F. The use of an electronic spreadsheet to solve linear and non- linear stochastic feed formulation problems. The Journal of Applied Poultry Research 1999; 8(1): 110-21.

[19] Afolayan M O, Afolayan M. Nigeria oriented poultry feed formulation software requirements. Journal of Applied Sciences Research 2008; 4(11): 1596-1602.

[20] Mohapatra D., Mishra S., Sutra N. Banana and its by- product utilization: an overview. Journal of Scientific & Industrial Research 2010; 69:323-9.

[21] Banana utilization for animal feeding. Department of Livestock Development Knowledge Management, [internet]. [cited 2022 May 12]. Available from: http://nutrition. dld. go. th/ Nutrition_Knowlage/ ARTICLE/ArtileF.htm

[22] Babatunde G M. Availability of banana and plantain products for animal feeding, [internet]. [cited 2022 June 25]. Available from: http: / / www. fao. org/ 3 / T0 5 5 4 E /T0554E17.htm

[23] Saensed S. Study on the nutritive value and digestibility of banana peels (Musa sapientum L.) [Ph.D. thesis]. Chengmai: Meijo University; 2012.

[24] Tartrakoon T., Chalearmsan N., Vearasilp T. , Meulen, U. The nutritive value of banana peel (Musa sapientum L.) in growing pig. In proceedings of the Deutscher Tropentag 1999, Berlin (Humboldt University of Berlin and ATSAF, Berlin).