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RESEARCH ARTICLE

Optimal Lamb Feed Formulation using Mathematical Programming Model

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ABSTRACT

Feed formulation is important in ensuring the quality of livestock production and sustaining the self-sufficient of the livestock industry in the country. Currently, local farmers have been feeding their lambs with goat pellets and this has caused an imbalance between nutrient feeding in lambs. In this study, a modified linear programming (LP) model is proposed to optimize a specific lamb feed formulation that satisfies the nutrient requirement at a minimum cost. The dietary nutritional requirements for lambs were derived from the standard criteria of the 1985 National Research Council. The modified LP model considers the nutrients needs of lambs according to their weight, the amount of nutrients to be consumed and the cost of each feedstuff. This study focuses on obtaining the optimal amount of feedstuff in the lamb feed that is determined based on the solution of a modified model. The analysis of the resulting price of goat pellets available in the local market was performed. The result shows that the new feed formulation for lamb recorded a price reduction of 53.65% compared to the commercial goat pellet yet fulfils the nutrient requirements for lamb.

Keywords: lamb feed formulation, linear programming, nutrient requirement, optimization

1. INTRODUCTION

As a result of the increasing domestic demand for sheep production, the business of feed supply for sheep is also developing fast. The demand for supply is important to support the maintenance, production, performance, and reproduction of sheep. Feed formulation is the process of determining the amount of ingredients that need to be composed to form a mixture feed that satisfies the nutrients requirements of the targeted species at a reasonable cost (Lall and Dumas, 2015). Among the aspects that need to be considered when formulating animal feeds are the ingredient used and its nutrient content, nutritional requirements, digestibility and palatability of feedstuff, diet acceptability, nutrients toxicity and cost of ingredients (Coloso, 2015). Feed formulation is important in sheep farming to ensure the quality of sheep production and to support the growth of the sheep industry. Since domestic demand for sheep is high and expected to increase, it is important to make sure the sheep quality and growth are also enhanced and maintained. Besides, the formulated feed must support the optimal production and cost-effectiveness to ease the burden of poor farmers.

As far as it is concerned, there is no specialized feed pellet for sheep in the local market. Many of the local farmers have been using goat pellets to feed their sheep by considering that both are similar types. Even though goats and sheep are small ruminants, however, their nutrient requirement is different. Goats require a high level of copper; however, a large amount of copper can be fatal for sheep (Greene and Huston, 2009). Copper is still required as a mineral supplement in sheep diets but in an allowable amount depending on the type of breed and age of the animal.

Sheep should be fed with sufficient nutrients according to their production phases to fulfil the nutrient requirement. However, many sheep farmers are less concerned with the importance of balance feeding. This may be due to some limitations such as time constraints and high operating cost. Imbalance feeding will lead to nutrients imbalance, which means some nutrients are in excess while others are deficient. This will negatively affect sheep's health, growth, as well as milk production (Garg, 2012). Locally produced livestock products are more expensive than imported products due to the high cost of animal feed. Malaysia is highly dependent on expensive imported animal feeds such as soybean meal and maize. Animal feed contributed almost 70 per cent of the total production costs in the ruminant industry (McGrath et al., 2018). If the animal feed price continues to rise, the production cost will also increase. As a result, local farmers have no choice but to increase the prices for local products as well as to raise the profit margin. Consumers who cannot afford to pay for the price would choose to buy import products which have always been a lot cheaper than local products. This will lead to a low in domestic demand and the local smallholders may not be able to sustain in the livestock business. This situation will affect the development and production of sheep and thus, it will not support all government plans to increase local livestock production. Therefore, the objectives of the research are to modify a linear programming model for the optimization of cost in lamb feed formulation, to determine the optimal amount of feed ingredients in the lamb feed based on the solution of the modified model and to analyse the price between the proposed feed for lamb and commercial goat pellets available in the local market.

Among the significance of this research is the production of a least-cost feed that satisfies the nutrient requirement for lambs. The dependence on the imported feedstuff in the feed formulation for lambs can be reduced by maximizing the usage of local ingredients and by-products. The composition of formulation feed obtained from this study can be used as guidelines by livestock food producers in formulating least-cost feed for lambs. The novelty of the research is the inclusion of a specific ratio of forage-to-concentrate, which is intended to satisfy the required percentage of ingredients. As far as it is concerned, this type of ingredient has not been considered in any sheep feed formulation model in the past studies. In addition, this study calculates the feed formulation for different weights of lamb in a single model. Previous studies determined the formulation of different weight animals in separate models.

Lamb and sheep refers to the same animal, in which the former refers to the young offspring of the latter. This animal has different stages of development, and the nutritional needs vary greatly according to the life stages. Many literatures focused on sheep farming rather than lamb farming because lamb only takes a period of a few months and then it would be called sheep. Sheep farming practices can be classified into three management systems which are extensive, semi-intensive, and intensive systems. Extensive farming is free range farming where sheep are free to graze in open pastures and grazing land with no provided supplementary feed, while in semi-intensive farming, sheep are released for a 4-to-8-hour grazing time, with supplementary feed and forage given to the animals (Nantoume, 2021). An intensive system is when the animals are constantly housed indoors and stalled to concentrate feed, forage, or other agricultural by-products with no access to grazing (Nantoume, 2021; Sachse, 2000).

Sheep are herbivores that mainly consume plant-based feeds. Just like humans, sheep also have their basic dietary requirements. For an optimum growth of sheep, essential nutrients such as water, proteins, carbohydrates, fats, minerals, and vitamins are strongly required. They may also need supplements to make up for the insufficient nutrients in their feed. Each of these nutrients has a vital part in supporting the growth of sheep. Sheep gain energy from

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carbohydrates and fats. Inadequate energy can cause a decrease in sheep's growth rate, weight loss, fertility decline, reduced milk production, and low quality and quantity of wool (Nantoume, 2021). Hay, pasture, silage, and grain are the main sources of energy for sheep (Sachse, 2000). There are many ways to quantify energy in feeds such as total digestible nutrients (TDN), metabolism energy (ME), and net energy (NE) (Weiss and Tebbe, 2019).

Protein is important to restore old tissues and build new tissues for sheep (Spencer, 2021). Protein also is highly needed to build muscle for young, growing lambs and to produce milk protein for lactating ewes (Selmi et al., 2020). Protein supplements such as oilseed meals (soybean meal, cottonseed meal) can be added into sheep's diet to make up the insufficient crude protein in existing forages so that nutrient requirement is satisfied (Florou-Paneri et al., 2014). In contrast to energy and protein, sheep only require a small amount of minerals in their feed (Spencer, 2021). Minerals can be categorised into two types which are macro-mineral and micro-mineral. Calcium, phosphorus, sodium, potassium, chloride, sulfur, and magnesium are part of the macro-mineral required for sheep, whereas manganese, iron, copper, cobalt, zinc, iodine, selenium and molybdenum are essential micro-mineral for sheep (Soetan et al., 2010). Micro-minerals or also known as trace minerals are required in a very small amount. Salt, calcium, and phosphorus are the most important mineral components in sheep diets. Insufficient salt intake will cause sheep to consume less feed and water, reduce milk production, and slow growth (Nantoume, 2021). Calcium and phosphorus deficiency in sheep will lead to poor growth and development of bone (Shen et al., 2019).

Basically, the lamb is a young sheep under 1-year old. Due to this reason, this study assumes that the types of nutrients required by both lamb and sheep are equal but with different amounts. In terms of nutrients, this animal requires vitamins A, D, and E in their diet. It synthesizes vitamins B and K in its rumen and vitamin C in its tissues. Vitamins A and E can be obtained from green forage while vitamin D is received from sunlight (Nolan, 2021). At different life stages of development, the nutritional requirements are different. This study looks at the types of nutrients that largely required in the life stages of lambs.

2. MATERIALS AND METHODS

2.1 Data Acquisition

Various types of mathematical models have been widely used in formulating feeds for animals. The purpose of modelling a feed formulation is to identify the set and quantity of feed ingredients to achieve specific objective functions while satisfying the nutritional requirement for an animal. This study uses a linear programming (LP) model because it is a substantial revolutionary approach to solve realistic circumstances of great complexity. In sheep farming, the feeding guide and the nutritional composition of the feed ingredients was acquired from a ration formulation tool built by the Malaysian Department of Veterinary Services (MDVS, 2021). Based on the model presented by Namoco (2016), the feed formulation problem is transformed into a LP model. Namoco's model formulation was used to find the optimal least-cost feed for swine while this study is finding the optimal least-cost feed for lambs. The basic nutrients used are crude protein, crude fibre, crude fat, calcium, phosphorus, and moisture, while in this study nutrients such as dry matter, crude protein, metabolism energy, as well as calcium and phosphorus are considered. Namoco has mixed commercial feed and local ingredients in the feed formulation while this study only includes raw ingredients.

Several changes and modifications have been made in the LP model in terms of decision variables and constraints. In contrast to Namoco's, the amount of feed ingredients is calculated according to the dietary requirements for lambs with 30, 40, and 50 kg. This study also categorized the ingredients as dry matter basis and as-fed basis. There is also an additional constraint in this study where the total feeds need to satisfy the ratio requirement of forage and concentrate ingredients. Table 1 shows the list of selected feed ingredients and nutrient contents.

Table 1. Nutrient content (DM Basis) for each ingredient

Feed Ingredient	DM (% from as-fed)	ME (MJ/kg)	CP (%)	Ca (%)	P (%)
Napier grass	20	6.50	9.00	0.40	0.20
Rice straw	98.9	7.51	6.7	0.10	0.10
OPF (dry)	86	5.65	4.70	0.40	0.90
Rice bran	89	7.78	14.10	0.08	1.70
Soya waste	17.4	11.16	25.1	0.21	0.10
Soybean hull	90	8.60	19.70	0.49	0.28
Brewer's grain	95	10.78	23.1	0.30	0.60
Molasses	75	10.87	5.80	1.00	0.10
Limestone	98	-	-	34.00	0.02
Salt	93	-	-	-	-

Note: OPF-oil palm frond, DM-dry matter, ME-metabolism energy, CP-crude protein, Ca-calcium, P-phosphorus
Source: Jamli et al. (2019) and Malaysian Department of Veterinary Services (2021)

The costs of the feed ingredients applied in the model were taken from various sources. Table 2 displays the ingredient types and sources as well as its approximate costs per kilogram. The recommended inclusion rate for each ingredient was taken from multiple sources.

Table 2. Type, source, and approximate cost (kg) for feed ingredients

Feed Ingredient	Type	Source	By-products	Cost (RM/kg)
Napier grass	Forage	Local	No	0.30
Rice straw	Forage	Local	Yes	0.40
OPF	Forage	Local	Yes	0.35
Rice bran	Concentrate	Local	Yes	0.45
Soya waste	Concentrate	Local	Yes	0.30
Soybean hulls	Concentrate	Local	Yes	0.95
Brewer's grain	Concentrate	Local	Yes	0.73
Molasses	Concentrate	Local	Yes	1.20
Limestone	Concentrate	Local	No	0.35
Salt	Concentrate	Import	No	0.35

Source: Zainuddin & Zahari (1992), Lim et al. (2011), Michael et al. (2018), Jamli et al. (2019), Rasyid et al. (2020)

Table 3 shows the minimum and maximum inclusion rates for each ingredient. The model solution in this study must not be below the minimum rate or exceed the maximum rate.

Table 3. Minimum and maximum inclusion rate (DM Basis) for feed ingredients

Feed Ingredient	Minimum Inclusion (%)	Maximum Inclusion (%)
Napier grass	0	100
Rice straw	0	10
OPF	0	30
Rice bran	0	22.5
Soya waste	0	40
Soybean hull	0	15
Brewer's grain	0	45
Molasses	5	15
Limestone	0	1.5
Salt	1	1

Source: Haddad & Ata (2009), Wong & Zahari (2011), Dickson & Jolly (2011), Rahman et al. (2015), Kishore et al. (2015), Alfa et al (2016), Agriculture and Horticulture Development Board (2018)), Hassen & Ali (2019), Vargas et al. (2020)

Table 4 shows the recommended nutrient intake for lambs. The data for nutrient requirements of lamb was obtained from National Research Council (1985). The unit of ME has been converted to MJ/kg based on Geor et al. (2013) which stated that 1 Mcal is equivalent to 4.184 MJ.

Table 4. Minimum daily nutrient requirements of lamb

BW (kg)	DMI (kg)	ME (Mcal/kg)	ME (MJ/kg)	CP (g)	Ca (g)	P (g)
30	1.3	2.5	10.46	191	6.6	3.2
40	1.6	2.7	11.30	185	6.6	3.3
50	1.6	2.8	11.72	160	5.6	3.0

Note: BW – Bodyweight, DMI – Dry matter intake, ME – Metabolism energy, CP – Crude protein, Ca– calcium, P - phosphorus
Source: National Research Council (1985)

Table 5 displays the maximum nutrient requirements for calcium and phosphorus. The amount of these nutrients in the model solution should not exceed the upper bound of the percentage. These values of calcium and phosphorus are taken from the data of lambs of 4 to 7 months old.

Table 5. Maximum nutrient requirements for lamb (Total Diet Dry Matter)

Nutrient	Maximum Requirement (%)
Calcium	0.82
Phosphorus	0.38

Source: National Research Council (1985)

2.2 The Modified Mathematical Model

The LP model is constructed based on the data obtained. The notation of the indices, parameters, and decision variables of the LP model are defined as:

n = Total number of feed ingredients in the model.
m = Total number of nutrient components in the model.
k = Index for the body weight of lamb, where k = 30, 40, 50
u = Index for the type of feed ingredients in the model, where $u = 1,2,3,\ldots,n$
u_f = Index for forage type of ingredients u
u_c = Index for concentrate type of ingredients u
v = Index for the type of nutrient in feed ingredients, where $v = 1,2,3,\ldots,m$
x_{uk} = As-fed quantity of ingredient u in the ration for lamb with BW k
y_{uk} = DM quantity of ingredient u in the ration for lamb with BW k
h_u = The cost (per kilo) of each ingredient u
a_{uv} = The amount of nutrient v in feed ingredient u
b_{vk} = Minimum requirements of nutrient v for lamb with BW k
c_{vk} = Maximum requirement of nutrient v for lamb with BW k
d_u = Maximum inclusion rate of each ingredient u
T_k = The amount of DM intake per day required by lamb with BW k
e_u = Minimum inclusion rate of each ingredient u
P_{conc} = Percentage of concentrate ingredients in feeds
P_{for} = Percentage of forage ingredients in feeds
P_{dm} = Percentage of DM in ingredient u
x_{uk} As-fed quantity of ingredient u in the ration for lamb with BW k
y_{uk} DM quantity of ingredient u in the ration for lamb with BW k

The modified model is aimed to minimize the cost of total mixed rations for lamb. The form of the model is presented as:

$$\text{Minimize } Z = \sum_{u=1}^{n} h_u x_{uk} + \sum_{u=1}^{n} h_u y_{uk} \tag{1}$$

subject to

$$b_{vk} \leq \sum_{u=1}^{n} a_{uv} yuk \leq c_{vk} \tag{2}$$

$$d_u \sum_{u=1}^{n} y_{uk} \leq y_{uk} \leq e_u \sum_{u=1}^{n} y_{uk} \tag{3}$$

$$\sum_{u=1}^{n} y_{uk} \geq T_k \tag{4}$$

$$\sum_{u=1}^{n} y_{u_f k} = P_{for} \sum_{u=1}^{n} y_{uk} \tag{5a}$$

$$\sum_{u=1}^{n} y_{u_c k} = P_{conc} \sum_{u=1}^{n} y_{uk} \tag{5b}$$

$$y_{uk} = P_{dm} x_{uk} \tag{6}$$

$$y_{uk} \geq 0, x_{uk} \geq 0 \tag{7}$$

The objective function (1) is to minimize the cost of total mixed rations for lamb. Constraint (2) represents the nutrient requirement limit of nutrients v that lambs should consume on a DM basis per day. Constraint (3) forces the amount of feed ingredient u to satisfy the maximum and minimum inclusion rate in feed on a DM basis per day. Constraint (4) requires the total amount of DM in produced feeds to satisfy the amount of DM intake that a lamb needs to consume per day. The new Constraint (5a) and Constraint (5b) are to ensure that the total mixture of forage and concentration ingredients satisfies the required ratio in the produced feed. The forage to concentrate (F:C) ratio of 50:50 and 40:60 was run in this study. The feed proportion of 50:50 is a practical option to maintain the growth of lambs, especially when the cost of the concentrate is high (Claffey et al., 2018). The feed proportion of 40:60 helps to improve the performance of lambs and DM digestibility without affecting the dry matter intake and ingestive behaviour of lambs (Parente et al., 2016). Constraint (6) is the conversion of weight from a dry matter to an as-fed basis. Each ingredient must be divided by its corresponding dry matter percentage to determine the as-fed amount of needed ingredients. Constraint (7) is a non-negativity constraint to ensure the optimal value of feed ingredients in the lamb ration is not in the negative range.

3. RESULTS AND DISCUSSION

This study considered ten types of ingredients in formulating the total mixed ration (TMR) for lambs. They are Napier grass, rice straw, OPF, rice bran, soya waste, soybean hulls, brewer's grain, molasses, limestone, and salt. They are denoted by the notations $x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9$ and x_{10}. Table 6 shows the optimal ingredient amount and its costs per kg for forage-to-concentrate ratio (F:C) of 50:50 and 40:60, the total feed (as-fed) and the ration cost for 30 kg and 40-50 kg lambs. The latter weights are presented together as the results for both weights are appeared to be identical.

Table 6. Optimal ration amount for F:C ratio of 50:50 and 40:60, ingredient cost, total feed (as-fed) and the ration cost for 30 kg and 40-50 kg lambs

		30 kg		**40 - 50kg**	
Ingredients	**Cost (RM/kg)**	**A (50:50)**	**B (40:60)**	**C (50:50)**	**D (40:60)**
Napier grass	0.30	2.4166	1.6089	2.325	1.9802
Rice straw	0.40	0.1334	0.1314	0.1618	0.1618
OPF	0.35	0.0516	0.0793	0.2035	0.0976
Rice bran	0.45	0	0	0	0
Soya waste	0.30	0	0	0	0
Soybean hulls	0.95	0	0.2167	0.2667	0.2667
Brewer's grain	0.73	0.6049	0.5154	0.4665	0.6344
Molasses	1.20	0.088	0.0867	0.1067	0.1067
Limestone	0.35	0.0059	0.0177	0.0213	0.0218
Salt	0.35	0.0142	0.014	0.0172	0.0172
Total as-fed feed (kg)		3.315	2.67	3.569	3.286
Total cost (RM)		1.35	1.26	1.57	1.55

Based on the result, for 30 kg lamb, ration B is revealed to be cheaper compared to ration A with RM 1.26, while for 40-50 kg lamb, ration D is revealed to have a lower ration cost than ration C at RM 1.55. From the result, by increasing the percentage of concentrate ingredients in the ration, the lower amount of as-fed feed is required by lamb per day, which resulted in a lower total cost of the ration. All three rations, B, C and D are composed of the same mixture of ingredients which consist of Napier grass, rice straw, OPF, soybean hulls, brewer's grain, molasses, limestone and salt. The only difference in the ingredient mixture of the ration A compared to other rations is that there is no inclusion of soybean hulls in the feed. From all listed ingredients, rice bran and soya waste appeared to be the least preferred ingredients for inclusion in the feed ration. Rice bran is not chosen probably due to its low content in metabolism energy and crude protein. Soya waste is also not chosen due to its dry matter content which shows the least value with only 17.4% on as-fed basis compared to the other nine ingredients, despite having the higher metabolism energy and crude protein.

Dried brewer's grain appeared to be in every ration as the protein and energy sources for the feeds. Even though the cost for brewer's grain is more than two times higher than soya waste, its higher dry matter content, which is 95% on an as-fed basis, helps the feed to become more concentrated. Therefore, less amount of feed is required to complete an optimal ration for lambs. This can be noticed by comparing the ration with the least and greater amount of brewer's grain. Ration D with 0.6344 kg amount of brewer's grain recorded only 3.286 kg in total as-fed feed, while ration C with 0.4665 kg amount of brewer's grain recorded 3.569 kg in total as- fed feed. To determine which ration produces the lowest cost for 1 kg of as-fed feed, the total cost is divided by the total as-fed amount. The average total cost for Rations A, B, C, and D per kg are RM0.41, RM0.47, RM0.44 and RM0.47, respectively. Therefore, the proposed feed formulation with F:C ratio at 50:50 has resulted in lower cost compared to 40:60 diet.

Table 7 shows the nutrient content of the formulated rations, minimum and maximum required nutrients amount for lambs of body weight of 30 kg and 40-50 kg. All formulated feed rations satisfied the minimum and maximum nutrients content requirement of lambs. Rations D contain the highest amount of metabolism energy and crude protein compared to other rations. This is true as the heavier the lambs, the more energy they required.

Currently, there is no available pellet of lamb in the local market. Therefore, the result from this study is compared to a locally produced goat pellet in terms of selling price. The commercial goat pellet is selected because it has been widely used by the local farmers to feed lamb. For this comparison, the proposed feed formulation of the ration with A least cost of RM0.41 per kg is selected as the feed composition has achieved the least-cost ration. As the normal packaging of goat pellets in the market contains 40 kg of feed, therefore, the proposed feed cost in this study is calculated as RM16.40. According to Aizam et al. (2018), a selling price can be calculated by multiplying the cost of feed production by 130%. Therefore, the selling price for the proposed feed is approximately RM21.32. By performing a price comparison between the proposed feed formulation and the price for the commercial goat pellet in the local market of RM46.00, then the saving amount is recorded as 53.65%.

Table 7. Nutrients content in formulated rations, minimum and maximum required nutrient amount for lambs of body weight 30 kg and 40-50 kg

30 kg				
	A (50:50)	**B (40:60)**	**Minimum requirement**	**Maximum requirement**
ME (MJ/kg)	11.2952	11.1154	10.46	-
CP (g)	191	196.2	191	-
Ca (g)	6.6	10.66	6.6	10.66
P (g)	5.01	4.94	3.2	4.94
Total DM (kg)	1.3193	1.3	1.3	-

40-50kg						
	C (50:50)	**D (40:60)**	**Minimum requirement**		**Maximum requirement**	
			40 kg	**50 kg**	**40 kg**	**50 kg**
ME (MJ/kg)	12.9234	13.6805	11.3	11.72	-	-
CP (g)	215.08	241.44	185	160	-	-
Ca (g)	13.12	13.12	6.6	5.6	13.12	13.12
P (g)	6.08	6.08	3.3	3.0	6.08	6.08
Total DM (kg)	1.6	1.6	1.6	1.6	-	-

4. CONCLUSION

This study has presented a modified linear programming model to find the least cost feed ration for lambs that satisfies all nutrient requirements and restrictions needed. When the analysis of the resulting price of goat pellets available in the local market was performed, it is found that the new feed formulation for lamb can reduce the price for 53.65%, lower than the price of the commercial goat pellet. Even with a lower price, the new feed has yet fulfilled the nutrient requirements for lamb. Further research may consider other local-based plants for their feed formulation study. For example, jackfruit leaves are known to be a good source of energy and protein for small ruminants. Other local plants which do not affect animal performance and growth can also be used as an alternative source of feed in small ruminant diets. It is also recommended for the mathematical model is to be solved using a metaheuristics approach to get a better result with shorter computing time.

Declaration of Interest
The authors declare that there is no conflict of interest.

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