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Review Article

Broiler Chicken Feeds Cost Optimization using Linear Programming Technique under Egyptian Conditions

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Abstract

Most of the feed ingredients which are used in poultry feed are also used for human nutrition. So these major feed ingredients and cumulatively poultry feed are facing market competition with increased cost. This study proposed linear programming (LP) technique to minimize the feed cost for small scale poultry farms. It employs locally available feed ingredients to formulate the broiler starter and finisher feed mix. This research proposed linear programming (LP) technique to minimize the feed cost for small scale poultry entrepreneurs. It employs locally available feed ingredients to formulate broiler starter, grower and finisher feed mix. Costs of nine feed ingredients were obtained in the market at Assiut Governorate and in different areas of Egypt. The ten feed ingredients were selected to formulate the optimal feed mix to minimize the total cost of feed mix subject to the essential nutrient constraints. This study proposed linear programming (LP) technique to minimize the feed cost for small scale poultry farms. It employs locally available feed ingredients to formulate the broiler starter grower and finisher feed mix. The LiPS software were used to formulate and solve the Linear Programming model and optimal feed mix for broiler starter, grower and finisher were obtained. The result of this study shows that the proposed optimal formulation of the linear programming model gives about 8.33%, 10% and 13.53% reduction in feed formulation costs compared to the existing formulation in case of broiler starter, grower and finisher respectively on the farm.

Keywords: Linear Programming; Optimization Model; Broilers; Feeds and LiPs Software

Introduction

Broilers grow very fast since their feed conversion capacity is fast. They convert feed into food products quickly and efficiently within a short period of time, approximately 1.5–2 months duration. Their high rate of productivity results in relatively high nutrient needs. Poultry feeding is one of the important branches of poultry industry, since feed cost accounts for 70-80 percent of the total farm expenses [1]. Various methods have been employed by industrialists and agriculturists for the formulation of the best poultry feed mix with the aim of minimizing costs or maximizing profits as well as working within the dietary requirements of these birds as proposed by researchers and experts in veterinary and/or animal nutrition fields. Methods employed include the trial and error method, Pearson square method, simultaneous equation method, two-by-two matrix method, linear programming method, etc. All these methods have similar guiding principles and employed within the dietary requirements to achieve the best feed mix. This study was on the use of a computer-based technique to investigate, analyses and indicate how best the available local ingredients can be combined effectively and efficiently to formulate least-cost ration for poultry. Specifically, a linear programming technique was employed to determine the most efficient way of combining these locally available ingredients. Mathematical models were constructed by taking into consideration nutrient requirements of the poultry, nutrient composition of the available ingredient and any restriction factor of the available ingredients for the formulation.

Poultry is one of farming activity which contribute not only to the gross domestic product but also to indigenous income [2]. Moreover he pointed out that, apart from having about 72 million chickens in 2018, one of the major problems is lack of reliable supply of poultry feeds. In farming, poultry is one of the activities with Egyptian boundless and also on large scale is important to human being apart from improving household finance; it is also one of the major areas that provide not only food but also nutrients. Poultry meat is one of the crucial sources of high-quality proteins, minerals and vitamins to balance the human diet [3]. According to [4] report, chicken is usually the cheapest of all domestic livestock meats. Poultry meat and eggs are highly nutritious, cheapest and efficient feed utilized products [5-7].

For entrepreneurs to get efficient profits, the farmer needs a lot of important facts about poultry farming. These facts include cost minimization and profit maximization. There many studies done to optimize the feed mix and increase the income outside like [8-10]. but to the best of our knowledge, currently there is little or no any study which has been done in Egypt specifically in creating a linear programming modelnotimize the poultry feed mix and come up with a software application. Studies by [2] focused on poultry sector in general and one study done by [11]. focused on Evaluation of Production Performance of the broiler chicken industry, all researchers did not show the specific model which could be useful for the optimization of feed mix. Therefore, this was the drive to do the study specifically in Tanzania. Marketing of Poultry Products According [12] marketing of poultry products was defined as a movement of products that is eggs or broilers from one place to another for the purpose of medium exchange (selling). Commercial poultry farmers for layers or broilers were disorganized and there was no proper marketing.

Feed formulation is the process of quantifying the amount of feed ingredients that need to be combined to form a single uniform mixture (diet) for poultry, which supplies all of their nutrient requirements.' Since feed accounts for 65-70 percent of total production cost, a simple mistake in feed formulation can be extremely expensive for a poultry producer. So, feed formulation requires thorough understanding of the following: • Dietary nutrient requirements of the class of poultry (layers, broilers, etc.). Feed ingredients in terms of nutrient composition. Cost of feed ingredients. Availability of feed ingredients. Feed formulation, often referred as least cost formulation, is the process of matching the nutrient requirements of a class of animals with the nutrient contents of the available ingredients (raw materials) in an economic manner. Typical formulations indicate the amounts of each ingredient that should be included in the diet, and then provide the concentration of nutrients (composition) in the diet. The nutrient composition of the diet will indicate the adequacy of the diet for the particular class of poultry for which it is prepared. With this knowledge, mathematical formulas are used to derive the amounts of each ingredient that need to be included in the diet. When using only a few ingredients, the formulas are simple. However, when there are numerous ingredients available in different amounts and at different costs, more complex formulas are required [8].

Materials and Methods

Various methods have been employed by industrialists and agriculturists for the formulation of the best poultry feed mix with the aim of minimizing costs or maximizing profits as well as working within the dietary requirements of these birds as proposed by researchers and experts in veterinary and/or animal nutrition fields. Methods employed include the trial and error method, Pearson square method, simultaneous equation method, two-by-two matrix method, linear programming method, etc. All these methods have similar guiding principles and employed within the dietary requirements to achieve the best feed mix.

The mathematical model formulated will be used by producers to mix their feeds using the locally available feeds which will have a minimum cost. Moreover, the model formulated can be used in different scenario when the nutritional requirement and the costs are known then it will be easily used by the locally available feedstuffs to supply those nutrients. The study, first find the nutritious requirements for poultry at different stages, which was obtained [13]. Second, after knowing the nutritional requirement for each stage then we surveyed the costs of locally available feeds ingredients by using a uniform scale of cost per kilogram of each feed and lastly know the nutritional contribution of each feed, which is the energy, minerals, proteins, vitamins, fiber and so on Using the nutritional requirements, the feeds cost and nutritional contribution was used to formulate a linear programming model which was later be solved by LiPS software or by Simplex method which is one of the powerfully method for validity [14]. The linear programming method or simplex is a standard technique in linear programming for solving an optimization problem, typically one involving a function and several constraints expressed as inequalities.

Standard form of Linear Programming

A linear program in standard forms looks likes

$f(x_1, x_2, \ldots\ldots n_x) = c_1x_1 + c_2x_2 + \ldots\ldots c_n\, x_n$

Subject to:

$a_{11}x_1 + a_{12}x_2 + \ldots\ldots\ldots n_{1n}x_n <= b_1$

$: a_{21}x_1 + a_{22}x_2 + \ldots\ldots\ldots n_{2n}x_n \leq b_2.$

$A_{m1}x_1 + a_{m2}x_2 + \ldots\ldots\ldots n_{mn}x_n \leq b_m$

$X_1, x_2 \ldots\ldots x_n \geq 0$

The following are characteristics of standard form linear programming according to [15]

- They were about maximizing, not minimizing.
- They had positivity constraint for each variable.
- The other constraints were all of the form "linear combination of variables ≤ constant".

Linear programming is a branch of Mathematics that deals with modeling a decision problem and subsequently solving it by Mathematical techniques. It has also made a considerable impact on agricultural, livestock and animal husbandry research in recent years and it is also helpful for poultry farmers in determining the broiler or poults feed compounds to improve the productivity of poultry. Poultry feed formulation is a process where several ingredients are combined to provide necessary nutrition to fishes at different stages. The weight of marketable poultry depends on how we feed the fish during culture and this problem turns out to be an optimization problem, which depends on factors like minimum time and least costs. Adequate nutrition's in animal production system is very much essential in economically producing high quality and healthy products. Feeds must be nutritious for maintenance, reproduction and growth. The growth of poultry depends on the proper propositions of nutrients in its diets. Proper nutritious diet to poultry determines the optimal growth, health and its life span. Though natural poultry food is available, supplementary feeds are required to get more yields. Moreover, some of these by-products provide a source of protein that can be accessible, inexpensive and available from the local food industry. The energy level of diet which is less expensive than protein supplements is adjusted to the desired level by addition of high energy supplements. Every feedstuff for animal feed formulation will be determined for a specific reason and a purpose; i.e., it is rich in a limiting amino acid, it is a good energy source, and so on. Additionally, each feedstuff in a specific diet formulation should be the least costly ingredient available for its particular function. Poultry feed formulation is both a science and an art, requires good knowledge of poultry feed, some patience and innovation. Typical formulation indicates the amount of each ingredient that should be included in the poultry feed, and then provide the concentration of composition in the feed.

With this knowledge, mathematical model is constructed and formulated. They are used to derive the amounts of each ingredient to be included in the fish feed formulation [16]. studied the feed diets are made primarily from a mixture of several feedstuffs such as soybean meal, rice bran, vitamin, minerals, fish oil, di-calcium phosphate, cassava leaf meal and salt [17]. studied about a mathematical model, which has to satisfy a set of constraints on nutritional levels, special ingredients to be included, availability restrictions and budget constraint ingredients is prevalent in the industry, and availability of feed ingredients and its prevalent market prices. Linear programming technique is a powerful approach for identifying a low-cost healthy diet which is an optimization technique. This paper also illustrates how this technique can be used to minimize the cost for preparing broiler feed and maximize profit of broiler production.

Nutritionally complete supplementary feeds are required in foods which are the minor source of nutrients. Producing sufficient ingredients in feeds to fishes, there is a problem in determining digestible nutrient values. The primary importance for poultry farmers is to find affordable and high quality poultry feeds through the use of locally available ingredients. The most easily available sources of energy are the carbohydrates contained in common grains products and plant generally. Necessary quantities of fat may be added to increase dietary energy concentrations and palatability. Fish when reared in high densities require proper nutrients [18]. studied application of the linear programming technique to find the minimum-cost feed mixture meeting for several specifications in fish feed formulation. The main job is to quantify the nutritional and other specifications, and to ascertain the availability and price of feed ingredients.

Model formulation for nutrition diet is a combination of different ingredients needed for a proper and balanced diet to the poultry. The model has to satisfy a set on nutritional levels, availability restrictions, special ingredients to be included, demand constraint and energy constraints. [19] studied a linear programming problem with "n" decision variables and "m" constraints that can be mathematically modeled as follows: 2.1 Notations.

Let i = Feed nutrient components with I = 1,2,…,m
J = Feed ingredients with j = 1,2,…,n
X j = Quantity of feed ingredient j in the feed mixture
C j = Unit cost of feed ingredient j
N = Total quantity (kg) of feed to be produced
Z = Total cost of feed ingredients used to formulate fish feed.
a I j = Amount of nutrient *i* available in feed ingredient j
.b_j = Dietary requirement of nutrient i for a fish category. 2.2

Formulation of LP model

The formulation can be done mathematically as a linear programming problem. The objective of the specified model is, minimize

$Z = \sum^n = 1\ c_j x_j$
J
$Z = \sum^n = 1\ x_j = N$ (Demand Requirement)
J
$Z = \sum^n = 1\ a_{ij}\ x_j \geq b_j$ (Minimum Requirement)
j
$Z = \sum^n = 1\ a_{ij}\ x_j \leq b_j$ (Maximum Requirement)
j
$z = \sum^n = 1 a_{ij}\ x_j \leq b_j$ (Restricted Requirement)
j

Model formulation

Data collected for this study for nine feedstuffs from June to September 2022 were based on raw materials (feedstuffs) specification, constrained imposed on the selected raw material and the dietary nutrient requirements in each stage of life of broiler flocks. The main source of these data was from the farmers, Costs of feed stuffs used in the diet formulation were obtained from the prevailing market prices of feed stuffs in Egypt (Assiut governorate and different areas) municipality through survey on March 28, 2021. The analysis of feedstuffs ingredients and minimum and maximum levels of various feed stuffs used in diet obtained from standard tables and sources. Feed stuffs used in ration formulation for local poultry farms include maize (X1), soya bean meal (X2), wheat bran (X3), sunflower oil (X4), limestone (X5), bone meal (X6), dicalcium phosphate (X7), lysine (X8) and methionine (X9). The nutrient diet model formulation is a combination of different feed ingredients needed for balance diet of the broiler. The model has to satisfy a set of constraints on nutritional levels, availability restrictions, special ingredients to be included, demand constraint, energy and budget constraints. The generic mathematical model which is applicable to each type of ration using the available ingredients is constructed as follows

Let
i = feed nutrient components with i = 1, 2 … 9
j = feed ingredients with j = 1, 2…n
Xj = quantity of feed ingredient j in the feed mix (decision variable)
N = total quantity (Kg) of feed to be produced
Z = Total cost of feed ingredients used in the feed formulation
Cj = unit cost of feed ingredient j
aij = amount (in fraction of Xj) of nutrient i available in feed ingredient j
bi = dietary requirement (fraction of N) of nutrient i for a bird category

Objective function

The objective of this linear programming model is to minimize total feed costs.

Min $Z = \sum^n = 1\ c_j\ x_j$
j
Subject to

Demand requirements

The demand requirement is an indication of the total amount of feed mix required based on the
requirement of broilers at different stages according to their ages, in our study it is 1kg.
$\sum^n = 1$ xj ≥ N
j

Minimum requirement
$a_{ij} \sum^n = 1$ xj ≥ b_i (Min)
j
Non negativity constraints: Xi
≥ 0

The broiler feeds formulation problems

The generic feed formulation model can be adapted to suit any ration and its application demonstrated by broilers feed ration, with nutrient requirement as indicated in table 1.2. The model has been parameterized by the nutrients yields and costs of locally available feed ingredients summarized in table 1,2.

Model construction

Linear Programming model for Broilers Starter Ratio is

- Min: 10.6*X1 + 15*X2 + 6*X3 + 35*X4 + 0.5*X5 + 4*X6 + 28*X7 + 70*X8 + 85*X9.
- Constraint 1: 8.5*X1 + 44*X2 + 15.3*X3 > = 23.

Nutrients	Requirements		
	Broiler Strater (0-3 wks)	Broiler Grower (3-6wks)	Broiler Finisher (6-more)
Crude protein, %	23	20	18
ME (Kcal/kg)	3200	3200	3200
Fiber, %	5	6-8	6-8
Lysine, %	1.1	1.0	0.55
Methionine, %	0.5	0.38	0.32
Calcium, %	1	0.9	0.8
P, avail, %	0.45	0.35	0.30

Table 1: Nutrient Requirements with regard to Production Aims (NRC, 1994).

Ingredient	Symbole	Cost (IE/kg)	Protein %	ME (kcal/kg)	Fiber %	Fat %	Lysine %	Meth %	Ca %	avai P %
Yellow corn	X1	10.6	8.5	3470	2.2	3.8	0.25	0.18	0.02	0.08
Soybean meal,44%	X2	15	44	2230	7	0.8	2.69	0.62	0.29	0.27
Wheat bran	X3	6	15.3	1725	11	3	0.61	0.23	0.14	0.2
Sunflower Oil	X4	35		8800						
Limestone	X5	0.5							38	
Bone Meal	X6	4							24	12
Dical. P	X7	28							28	19
Lysine	X8	70		4600			100			
Methionine	X9	85		4500				100		

Table 2: Average Cost Implications from different areas in Egypt and Nutrients Levels of Feed Ingredients according to NRC (1994).

- Constraint 2: 3470*X1 + 2230*X2 + 1725*X3 + 8800*X4 + 4600*X8 + 4500*X9 > = 3200.
- Constraint 3: 2.2*X1 + 7*X2 + 11*X3 > = 5.
- Constraint 4: 3.8*X1 + 0.8*X2 + 3*X3 > = 1.
- Constraint 5: 0.02*X1 + 0.29*X2 + 0.14*X3 + 38*X5 + 24*X6 + 28*X7 > = 1.
- Constraint 6: 0.08*X1 + 0.27*X2 + 0.2*X3 + 12*X6 + 19*X7 > = 0.45.
- Constraint 7: 0.25*X1 + 2.69*X2 + 0.61*X3 + 100*X8 > = 1.1.
- Constraint 8: 0.18*X1 + 0.62*X2 + 0.23*X3 + 100*X9 > = 0.5.
- Constraint 9: X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8 + X9 = 1.

(Minimum Cost = 14.3743 Egyptian bound/kg).

Linear Programming model for Broilers Grower Ratio is

- Min: 10.6*X1 + 15*X2 + 6*X3 + 35*X4 + 0.5*X5 + 4*X6 + 28*X7 + 70*X8 + 85*X9.
- Constraint 1: 8.5*X1 + 44*X2 + 15.3*X3 > = 20.
- Constraint 2: 3470*X1 + 2230*X2 + 1725*X3 + 8800*X4 + 4600*X8 + 4500*X9 > = 3200.
- Constraint 3: 2.2*X1 + 7*X2 + 11*X3 > = 6.5.
- Constraint 4: 3.8*X1 + 0.8*X2 + 3*X3 > = 1.
- Constraint 5: 0.02*X1 + 0.29*X2 + 0.14*X3 + 38*X5 + 24*X6 + 28*X7 > = 0.9.

- Constraint 6: 0.08*X1 + 0.27*X2 + 0.2*X3 + 12*X6 + 19*X7 > = 0.35.
- Constraint 7: 0.25*X1 + 2.69*X2 + 0.61*X3 + 100*X8 > = 1.
- Constraint 8: 0.18*X1 + 0.62*X2 + 0.23*X3 + 100*X9 > = 0.38.
- Constraint 9: X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8 + X9 = 1.

(Minimum Cost = 13.8742 Egyptian bound/kg)

Linear Programming model for Broilers Finisher Ratio is

- Min: 10.6*X1 + 15*X2 + 6*X3 + 35*X4 + 0.5*X5 + 4*X6 + 28*X7 + 70*X8 + 85*X9.
- Constraint 1: 8.5*X1 + 44*X2 + 15.3*X3 > = 18.
- Constraint 2: 3470*X1 + 2230*X2 + 1725*X3 + 8800*X4 + 4600*X8 + 4500*X9 > = 3200.
- Constraint 3: 2.2*X1 + 7*X2 + 11*X3 > = 6.5.
- Constraint 4: 3.8*X1 + 0.8*X2 + 3*X3 > = 1.
- Constraint 5: 0.02*X1 + 0.29*X2 + 0.14*X3 + 38*X5 + 24*X6 + 28*X7 > = 0.8.
- Constraint 6: 0.08*X1 + 0.27*X2 + 0.2*X3 + 12*X6 + 19*X7 > = 0.3.
- Constraint 7: 0.25*X1 + 2.69*X2 + 0.61*X3 + 100*X8 > = 0.55.
- Constraint 8: 0.18*X1 + 0.62*X2 + 0.23*X3 + 100*X9 > = 0.32.
- Constraint 9: X1 + X2 + X3 + X4 + X5 + X6 + X7 + X8 + X9 = 1.

(Minimum Cost = 13.2716 Egyptian bound/kg)

Results and Discussions

The data presented in tables 3, 4, 5 and 6 in this study are the results and analysis of the formulated linear programming model for the optimization of feed cost for broiler chickens. The models for broiler starter diet, broiler grower diet and broiler finisher diet were solved using linear programming method by LiPS software.

Result of Broiler Starter Diet

The proposed diet formulation result produced by linear programming model has shown that for approximately 1kg of starter feed mix the diet consist of 0.316074 kg of maize, 0.418111 kg of soybean meal, 0.12526 kg of wheat bran, 0.01077 kg of sunflower oil, 0.007404 kg of limestone, 0.023898 bone meal and 0.001551 kg of methionine. This feed mix costs approximately 14.3743 Egyptian bound per 1Kg. The use of LP as a tool for providing a programme for least cost ration formulation is one of the recent advances made in livestock nutrition research. The advantage of using least cost ration has been reported [20]. This author found computerized strater and finisher diets were cheaper and performed better than commercial diets.

Symbols	Ingredient	Level/kg diet
X1	Corn, yellow	0.316074
X2	Soybean meal	0.418111
X3	Wheat bran	0.12526
X4	Sunflower oil	0.107703
X5	Limestone	0.007404
X6	Bone meal	0.023898
X7	Dicalcium P.	0
X8	Lysine	0
X9	Methionine	0.001551

Table 3: Quantity of broiler starter feed ingredients (Kg) proposed by LiPS software in feed formulation during the period from 0-3 wks of age.

Result of broiler grower diet

The proposed diet formulation result produced by linear programming model has shown that for approximately 1kg of grower feed mix the diet consist of 0.14749 kg of maize, 0.296429 kg of soybean meal, 0.372774 kg of wheat bran, 0.156859 kg of sunflower oil, 0.010307 kg of limestone, 0.015301 kg of bone meal and 0.000839 kg of methionine. This feed mix costs approximately 13.8742 Egyptian bound per 1Kg.

The growth in the broiler segment is expected to remain strong due to consumer preference for poultry, increasing income levels, and changing food habits. More than 80 percent of poultry output is produced by organized commercial poultry farms. Major poultry companies have vertically integrated operations which comprise approximately 60-70 percent of the total chicken production. Major companies/integrators, own hatcheries, feed mills, and primary processing facilities and often provide credit, extension services, and veterinary medicine to the contractual farmers. Integrators contract with multiple smaller farmers who rear the chicks to slaughter weight [21] reported that approximately 80 percent of rural households in developing countries engage in smallholder poultry production (village systems). The live birds are then purchased either by the integrators for slaughter and further processing or by a whole saler who distributes them via live markets. According to the Food and Agriculture Organization [4] report, chicken is usually the cheapest of all domestic livestock meats.

Symbole	Ingredient	Level/kg diet
X1	Corn, yellow	0.14749
X2	Soybean meal	0.296429
X3	Wheat bran	0.372774
X4	Sunflower oil	0.156859
X5	Limestone	0.010307
X6	Bone meal	0.015301
X7	Dicalcium P.	0
X8	Lysine	0
X9	Methionine	0.000839

Table 4: Quantity of broiler grower feed ingredients (kg) proposed by LiPS software in feed formulation during the period from 3-6 wks of age.

Result of broiler finisher diet

The proposed diet formulation result produced by linear programming model has shown that for approximately 1kg of finisher feed mix the diet consist of 0.190342 kg of maize, 0.231255 kg of soybean meal, 0.405679 kg of wheat bran, 0.150206 kg of sunflower oil, 0.010262 kg of limestone, 0.011767 kg of bone meal and 0.000491 kg of methionine. This feed mix costs approximately 13.2716 Egyptian bound per 1Kg [22] advocated that application of LP technique to solve feed formulation problem in small poultry units is uneconomical due to involvement of large initial expenditure. However [23], contradicted this idea and suggested that efficient use of computers and LP is the most effective means of attaining minimum feed cost. also supported the claim of [23] and suggested the use of LP technique to solve feed formulation problems. Use of LP technique in feed formulation problem concept was further strengthened by Olentine who opined that ration formulation has now become finely tuned through the use of large computer matrices. The computer programs perform highly defined value-based ingredients analysis and delicate ingredient combinations. Thus it is not the same old ration formulation, wherein only protein and energy values were balanced first and later on some adjustments were made for few minerals and vitamins [24] carried out a similar study on the economic use of the locally available feedstuffs to formulate least cost rations for broilers using linear programming (LP) technique to determine how available ingredients can be combined efficiently and effectively toward achieving a least cost formulation [25]. Analyzed feed formulation problems in poultries using a mathematical programming approach to formulate a viably cheaper feed mix for layer poultry. The optimal solution of the linear programming model gave 9 percent reduction in feed formulation costs compared to the existing method on the commercial farm utilized as a case study. Post optimality analysis also gave useful insight into the impact of changes in costs of feed inputs. They were able to achieve a formulation that not only satisfied all requirements and constraints but also proffered a comparatively cheaper price than the existing formulation [1] carried out optimization of broiler feed rations at least cost with a case study of Nigerian poultries. A linear programming model was also applied for this study.

Symbole	Ingredient	Level/kg diet
X1	Corn, yellow	0.190342
X2	Soybean meal	0.231255
X3	Wheat bran	0.405679
X4	Sunflower oil	0.150206
X5	Limestone	0.010262
X6	Bone meal	0.011767
X7	Dicalcium P.	0
X8	Lysine	0
X9	Methionine	0.000491

Table 5: Quantity of broiler finisher feed ingredients (kg) proposed by LiPS software in feed formulation during the period from 6-7 wks of age.

Comparison between Existing Diet Formulation and Proposed Diet Formulation.

For Broiler Starter Diet. (0-3 wks of age)

Comparison of proposed broiler starter local feed formulation with the existing feed produced in the industry show that the cost of proposed feed mix for broiler starter is 14.3743 (approximately 14.4 Egyptian bound) for 1kg of feed mix**.** The cost of the ration is around 14400 Egyptian bound for one Ton against the existing feed which produced in industry cost of 15600 Egyptian bound). This cost save about 1200 Egyptian bound/Ton and represent about 8.33%. Based on the information received from a broiler farmer, it was recorded that on the average of the first three wks of age (0-3 wks) feed consumption of 1000 broiler chickens is 800Kg starter feed. So the total cost of feed for the first three weeks will be 14.4 × 800 kgs = 11520 Egyptian bound Whereas the existing marketing feed mix which costs 15.4 Egyptian bound for one kilo, the total cost for the feed consumed during the first three weeks of age is 15.4 X 800 kgs = 12320 Egyptian bound. The saved cost of starter diet for 1000 birds = 12320-11520 = 900 Egyptian bound which represent 6.9%.

For Broiler Grower Diet (3-6 wks of age)

Comparison of proposed broiler starter local feed formulation with the existing feed produced in the industry show that the cost of proposed feed mix for broiler grower is 13.8742 (approximately 13.9 Egyptian bound) for 1kg of feed mix**.** The cost of the ration is around 13900 Egyptian bound for one Ton against the existing feed which produced in industry cost of 15300 Egyptian bound). This cost save about 1400 Egyptian bound/Ton and represent about 10%. Based on the information received from a broiler farmer, it was recorded that on the average of the second three wks of age (3-6 wks) feed consumption of 1000 broiler chickens is 2800 Kg grower feed. So the total cost of feed for the second three weeks will be 13.9 × 2800 kgs = 38920 Egyptian bound Whereas the existing marketing feed mix which costs 15.3 Egyptian bound for one kilo, the total cost for the feed consumed during the second three weeks of age is 15.3 X 2800 kgs = 42840 Egyptian bound. The saved cost of grower diet for 1000 birds = 42840-38920 = 3930 Egyptian bound which represent 10%.

For Broiler Finisher Diet (6-7 wks of age)

Comparison of proposed broiler finisher local feed formulation with the existing feed produced in the industry show that the cost of proposed feed mix for broiler grower is 13.2716 (approximately 13.3 Egyptian bound) for 1kg of feed mix**.** The cost of the ration is around 13300 Egyptian bound for one Ton against the existing feed which produced in industry cost of 15100 Egyptian bound). This cost save about 1800 Egyptian bound/Ton and represent about 13.53%. Based on the information received from a broiler farmer, it was recorded that on the average of the last wks of age (6-7 wks) feed consumption of 1000 broiler chickens is 1000 Kg finisher feed. So the total cost of feed for the last week will be 13.3 × 1000 kgs = 13300 Egyptian bound Whereas the existing marketing feed mix which costs 15.1 Egyptian bound for one kilo, the total cost for the feed consumed during the last week of age is 15.1 X 1000 kgs = 15100 Egyptian bound. The saved cost of finisher diet for 1000 birds = 15100 - 13300 = 1800 Egyptian bound which represent 13.53%.

The saved cost of the consumed diets for 1000 broiler chickens from 0-7 wks of age is 70260 -63740 = 6520 Egyptian bound which represent about 10.23%.

Discussions

From the qualitative data, it is apparent that the linear programming model is prevalent in operations research. It was first used by [26] to optimize feed ration and determine the cheapest feeding and livestock rations. Usually, LP solved problems have one goal that aims to maximize or minimize a specific goal, usually costs, revenues, or net income. The simplex algorithm has been used to solve many real-world problems. It's the classical approach to solving linear programming optimization problems for finding a maximal or minimal value of function within a set of constraints. Several researchers found that LP with a Simplex method helps to get an optimum land allocation plan [27,28,39]. They found that it improved farm productivity and increased the profit when the total allocated area was increased.

Mixed-Integer Linear Programming model also another approach was used in the feed mix, crop rotation plan, and planning and scheduling the irrigation water [30,31], This method can give a consistent optimum result, and the farm managers were satisfied with this model. On the other hand, Integer linear programming models can determine the optimum land area for growing different crops. In some cases, in the agriculture sector, the problems are defined with multi goals. So LP has a shortcoming in optimizing solutions with multi goals problem [32].

The paper has comprehensively covered the main objectives of this research related to LP and how it can be particularly useful in optimizing problems in feed formulation of poultry. LP is often applicable whenever the main goal is attaining efficiency. Due to the lack of survey paper on LP's applications in poultry and agriculture's topics, this paper investigated the applications of the LP model in the feed formulation of poultry. Based on previous studies, there are three main reasons for using the LP model to solve most farms' problems. One of them is to increase the profitability of small farmers' poultry production, help them fulfill production requirements for productivity, and encourage them to use environmental resources. Most studies proved the usefulness of using LP in solving real-world problems and provided reliable results. LP models can optimize the farm's net incomes and productivity under the available resources such as cultivated acreage, labor, fertilizers, seeds, water supply, energy, etc. One of the techniques used to analyze linear programming problems is a Simplex algorithm to locate a maximal or minimal value within a variety of restrictions. However, LP has a shortcoming in optimizing solutions with multi goals problem.

Feed consumed (cumulated) of starter diet (g/bird) from 0-3 wks of age.	800
Feed consumed (cumulated) of grower diet (g/bird) from 3-6 wks of age.	2800
Feed consumed (cumulated) of finisher diet (g/bird) from 6-7 wks of age.	1000
Feed consumed (cumulated) of starter diet (kg/ 1000 bird) from 0-3 wks of age.	800
Feed consumed (cumulated) of grower diet (kg/ 1000 bird) from 0-3 wks of age.	2800
Feed consumed (cumulated) of finisher diet (kg/bird) from 6-7 wks of age.	1000
Total feed consumed (kg/ 1000 bird) from 0-7 wks of age	4600
Minimum cost of proposed value of starter diet (Egyptian bound/kg)	14.4
Minimum cost of proposed value of grower diet (Egyptian bound/kg)	13.9
Minimum cost of proposed value of finisher diet (Egyptian bound/kg)	13.3
Total proposed cost of starter diet for 1000 bird = 800 (kg)* 14.4 (Egyptian bound)	11520
Total proposed cost of grower diet for 1000 bird = 2800 (kg)* 13.9 (Egyptian bound)	38920
Total proposed cost of finisher diet for 1000 bird = 1000 (kg)* 13.3 (Egyptian bound)	13300
Total of proposed cost of consumed diets from 0-7 wks of age	*63740*
Minimum cost of existing value of starter diet (Egyptian bound/kg)	15.4
Minimum cost of existing value of starter diet (Egyptian bound/kg)	15.3
Minimum cost of existing value of starter diet (Egyptian bound/kg)	15.1
Total proposed marketing cost of starter diet for 1000 bird = 800 (kg)* 15.4 (Egyptian bound)	12320
Total proposed marketing cost of grower diet for 1000 bird = 2800 (kg)* 15.3 (Egyptian bound)	42840
Total proposed marketing cost of finisher diet for 1000 bird = 1000 (kg)* 15.1 (Egyptian bound)	15100
Total of existing cost of consumed diets from 0-7 wks of age	*70260*
The saved cost of starter diet for 1000 bird = 12320-11520 = 800 Egyptian bound	800
The saved cost of starter diet for 1000 bird represent 800/11520*100 = 6.9%	6.9%
The saved cost of grower diet for 1000 bird = 42840-38920 = 3920 Egyptian bound	3930
The saved cost of grower diet for 1000 bird represent 3920/38920 *100 = 10%	10%
The saved cost of finisher diet for 1000 bird = 15100-13300 = 1800 Egyptian bound	1800
The saved cost of finisher diet for 1000 bird represent 1800/13300*100 = 13.53%	13.53%
The saved cost of the consumed diets from 0-7 wks of age = 70260-63740 = 6520 Egyptian bound	6520
The saved cost of the consumed diets from 0-7 wks of age represent 6520/ 63740* 100 = 10.23 % Egyptian bound	10.23%

Table 6: The saved cost for the consumed diets from 0-7 wks of age of starter, grower and finisher diets.

Conclusions

This study employed a linear programming technique for reasons of accuracy and easy of doing calculation in comparison to other manual techniques of feed formulation employed by local farms. The mathematical model results presented in this work show clearly that the linear programming method by LiPS software (LP) is the best tool which gives best outcome subject to the necessary constraints. This study has collected and provided information on various nutrients required for proper growth of broilers at different stages and the sources of these nutrients. The LP methodology used could be helpful for the academicians and entrepreneurs in developing a proper feed mix with lowest cost. The proposed broiler starter, grower and finisher diets are not having enough of some essential nutrients this could be due to sourcing of nutrient composition of feed ingredients data from various animal nutrition text books and publication that in some cases they have wide variations on feed composition information. So, these proposed diets cannot be practiced by farmers without the improvement in the nutrients requirement. From the conclusion we realized that using scientific methods to produce feed helps the poultry farmers to increase their profits. Hence we recommend the poultry entrepreneurs to adapt this model in their feed production.

Protocol and Approvals

This animal study was approved by the Animal Care and Use Committee (of the Committee on Ethics of Animal Experimentation) pursuant to Board Section No. 121 dated 2/14/2022 and pursuant to College Board Resolution No.772 Dated 3/22/2022. All experimental procedures involving quail were performed. According to the regulations for this, and the management of affairs related to experimental animals has been approved by the regulations governing this in Egypt.

Disclosures

The authors whose names are listed immediately below certify that they have NO affiliations with or involvement in any organization or entity with any financial interest such as honoraria; educational grants; participation in speakers' bureaus; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements), or nonfinancial interest (such as personal or professional relationships affiliations, knowledge, or beliefs) in the subject matter or materials discussed in this manuscript.

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