

Process Optimization Methodologies

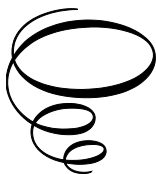
Process Optimization Methodologies:

*Current Advances in Machine
Learning and Corrosion
Technology*

Edited by

Augustine O. Ayeni, Oluranti Agboola
and Ayodeji Ayoola

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Process Optimization Methodologies: Current Advances in Machine Learning and Corrosion Technology

Edited by Augustine O. Ayeni, Oluranti Agboola and Ayodeji Ayoola

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CHAPTER 1

COMPUTATION OF OSTRICHES (STRUTHIO CAMELUS) FEED MIX USING LINEAR, GOAL AND STOCHASTIC PROGRAMMING MODELS: COMPARATIVE ANALYSES

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Abstract

This article focuses on calculating the ideal meal mix for ostriches at various growth ages. Linear, stochastic, and weighted goal programming techniques were employed to create the models. Linear Programming was used to create models for obtaining the lowest cost ratio, whereas Weighted Goal Programming was used to create models for minimizing the total of deviations from the goal values. Stochastic Programming was utilized to account for nutrient variability in order to generate the lowest cost rations

that could cover all nutritional requirements at a given probability level. The results show the market prices (MP) and objectives or cost prices of different programming models with respect to the ostriches ages. It is observed that the mix obtained from linear programming costs ₦148,231.90 while rations obtained from goal programming cost ₦260,873.47. The results were obtained at the different probability levels using stochastic programming ranged from ₦109,614.80 to ₦127,102.80. The feed mix obtained through the linear, goal and stochastic optimization techniques satisfied the minimum nutrient requirements for ostriches between 7-12 weeks as prescribed by the Nigerian Industrial Standard. The solutions to these models demonstrated that Stochastic Programming outperforms Linear and Weighted Goal Programming.

Keywords: Ostriches, Feed Formulation, Linear Programming, Goal Programming, Stochastic Programming

Introduction

Ostriches are important members of livestock production for their healthy low cholesterol meat and leather skin (Cooper and Horbanczuk, 2002). Although commercial ostrich farming has not gained widespread acceptance in the country, farmers in Northern Nigeria are beginning to raise these birds in their farms (Abraham, 2022). Successful production of ostriches from when the eggs are freshly laid until they grow to the breeder stage depends on the quality of the diets administered to the birds. To ensure optimal quality of ostrich products including their red meat, skin and oil, the nutritional composition of their diets must satisfy the minimum nutrient requirements at each of their growth stages (Miao et al., 2003).

Animal feeds are usually composed such that they offer the best combination of ingredients to meet the nutritional needs of livestock (Saxena and Kumar, 2016). Feeding costs represent the greatest percentage of the total costs of running an ostrich farm (Aganga et al., 2003). To ensure sustainable production, it has thus been a subject of interest to formulate livestock diets that match their energy and nutrient requirements while keeping the ration costs at a possible low. Mathematical programming techniques have been adopted over the years to solve problems of this nature. Several models have been used to maximize the optimal use of available feedstuff to supply adequate quantities of essential nutrients which could not have been achieved by manual conventional methods (Saxena and Kumar, 2016).

Olorunfemi et al. (2006) applied linear programming to create a least-cost ration for broilers aged 0-5 weeks. The developed model, which utilized locally available duckweed, was solved using the simplex method. Obtained results showed that use of a meal mix containing 29.50% duckweed reduced the feed cost by 20.82% and can therefore improve the profitability in broiler production. Temitope (2007) utilized linear programming for generating least-cost feed ration for turkey between 0 and 8 weeks of age. Dietary fillers were used to make up for the weight constraints of the feeds. The produced formulation showed that utilization of filler-based diets may reduce cost of feeding by as much as 24.95%.

Oladokun and Johnson (2012) applied linear programming to formulate optimized feed for Nigerian poultry using available local ingredients. The resulting formulation was 9% cheaper than commercially available feeds. This indicates the higher profitability and productivity that applying linear programming approach to feed formulation can afford the Nigerian poultry industry. Olugbenga et al. (2015) developed a linear model to formulate an optimized diet for broiler poultry in Nigeria. The most common feed ingredients used in ration formulation for local farms and broiler feed factories were utilized in the formulation. The linear programming model was solved using Excel Solver and the resulting optimal formulation yielded about 7.48% and 9.96% reduction in feed costs compared to the existing formulation for broiler starters and finishers respectively.

Zhang and Zhang and Roush (2002) applied a multiple-objective goal programming model to formulate broiler feeds while minimizing nutrient variance and the total cost of the ration. The model was constructed for a broiler grower between 3 to 6 weeks of age and solved with Excel solver. Results proved that the model was more flexible than feed formulation using a traditional linear program, as it was able to handle several conflicting objectives simultaneously as compared to the linear programming approach which could only optimize a single objective.

Babić and Perić (2011) employed goal programming to develop and solve a multi-criteria programming model to determine an optimal blend of ingredients for livestock feed. The goals of meal quality in terms of additional requirements made by decision makers were introduced into the model. Gerdessen and de Vries (2015) provided a methodological insight into achievement functions of diet models based on goal programming. These diets are usually valuable in formulating diets that are palatable and satisfy nutrition and cost constraints. They further described the extended goal programming achievement function which allows the decision maker

to minimize the sum of unwanted deviations (MinSum), minimize the largest unwanted deviation (MinMax), or a compromise between both. The MinSum achievement functions gave results that were sensitive to weight changes and that concentrated all unwanted deviations on a limited number of nutritional constraints. The MinMax achievement functions, on the other hand, distributed the unwanted deviations as evenly as possible.

Iwuji and Agwu (2017) presented a weighted goal programming DASH diet model to minimize the daily cost of the DASH eating plan as well as the deviations of the nutritional compositions of the formulated diet from the DASH diet's tolerable upper and lower intake levels. Compared to previously formulated DASH diet with linear programming, the diet plans obtained through goal programming minimized deviations from the diet's tolerable intake levels.

Udo et al. (2011) developed a stochastic programming model to accommodate the variability of feedstuff nutrients in least-cost as regards formulation of feed for African catfish. The aim was to lessen the risk of not targeting the requirements of nutrients through under-formulation or over-formulation - that leads to higher cost. The feed-mix control was formulated using the linear programming approach while the test feeds were formulated using stochastic programming at probability levels from 50 to 85%. The results establish stochastic programming as a better approach than linear programming especially in capturing variation in nutritive content.

Saxena and Khanna (2015) developed models for ruminant ration formulation for dairy cows of weight between 200kg and 680kg. The aim of the study focused on production of a least-cost ration with better shelf life. Firstly, linear programming models were developed for obtaining least cost ration with minimized water content. Then stochastic programming models were developed to incorporate nutrient variability.

Pena et al. (2009) worked on a stochastic model with multiple objectives for animal diet formulation which does not need the decision maker to provide information a priori. Unlike in other models where the nutrients probability levels are fixed in advance, their model follows an interactive decision process that allows the decision maker to have a better understanding of the system under analysis. Their model met required probability levels more accurately than commercially used formulation models. This resulted in lower cost rations and nutrient waste.

In this study, mathematical models for feed optimization were created in three stages. In the first stage, linear programming was employed to create models with the lowest cost ratio. In the second step, goal programming was utilized to minimize the total of the goals' deviations from their target values. Finally, stochastic programming was employed in the third stage to account for nutrient variability and offer the lowest cost diets that met each nutritional requirement at defined probability levels.

Materials and Methods

The feed stuff used in this research are the commonly obtained ingredients used by local farmers. 10 feed ingredients and 6 nutrients are used for optimization of feed ration. The sort of feedstuff used to prepare the feed mix for the ostriches at their different growth stages (0-6 weeks, 7-12 weeks, 12 weeks & above, Breeder), their price per kilogram, and the percentage of nutrients per ingredient unit are summarized in the Table 1. The nutritional compositions of the ingredients were derived from a local feed formulation guide (Moreson Nigeria Limited, 1998).

The constraints in the models have been developed to ensure that the produced feed mix satisfied the nutrient requirements of ostriches at different stages of life according to the Nigerian Industrial Standard (SON, 2003), as shown in Table 2. The models were solved for a total demand of at least 1000kg of all the foodstuff. The amount of salt and vitamin premix in the ration were fixed at 3kg (0.003%) each.

Table 1. Price and Nutritional Composition of Feedstuff Used

Feedstuff	Variable	Cost per kg (N)	Fats (%)	Crude Protein (%)	Energy (Kcal/Kg)	Crude Fiber (%)	Phosphorus (%)	Calcium (%)
Maize (Yellow)	X1	110	4	10	3434	2	0.09	0.01
Wheat Middlings	X2	58	3.5	17	1870	8.5	0.3	0.1
Rice Bran	X3	36	12.5	12	2860	12.5	0.46	0.04
Soyabean Meal	X4	180	2	45	2700	6.5	0.6	0.2
Groundnut Cake	X5	125	6	45	2640	5	0.2	0.2
Fish Meal (72% type)	X6	1000	8.5	70	2860	0	3	6.1
Oyster Shell	X7	25	0	0	0	0	0	36
Bone Meal	X8	70	0	0	0	0	1.5	37
Salt	X9	65	0	0	0	0	0	0
Premix	X10	750	0	0	0	0	0	0

Source: Moreson, 1998

Table 2. Nutrient Requirements for Ostriches

	0-6 weeks	7-12 weeks	Above 12 weeks	Breeder
Energy (Kcal/Kg)	2800	2800	2800	2800
Crude Protein (%)	24	20	16	15
Fats (%)	5	5	5	5
Crude Fiber (%)	5	5	5	5
Calcium (%)	1.2	1	0.9	2.8
Phosphorus (%)	0.65	24	2800	5

Source: SON, 2003

The Linear Programming Model

To minimize the cost per kg of the feed mix at the four growth stages of the ostriches, a model was build using the linear programming technique, involving equations 1 to 6, as follows:

$$\text{Minimize } Z = \sum_{j=1}^n C_j X_j \quad (1)$$

Subject to the constraints;

$$\sum_{j=1}^n X_j = X_t \text{ (Demand requirement)} \quad (2)$$

$$a_{ij} \sum_{j=1}^n X_j \geq B_i \text{ (Minimum requirement)} \quad (3)$$

$$a_{ij} \sum_{j=1}^n X_j \leq B_i \text{ (Maximum requirement)} \quad (4)$$

$$a_{ij} \sum_{j=1}^n X_j = B_i \text{ (Exact requirement)} \quad (5)$$

$$X_j > 0 \text{ (Non-negativity constraint)} \quad (6)$$

where,

i = nutrient components in feed ($i = 1, 2 \dots m$)

j = ingredients in feed ($j = 1, 2 \dots n$)

X_j = quantity of ingredients in feed (j = decision variable)

X_t = quantity of feed (kg) to be produced (based on demand)

Z = cost of ingredients used in the feed formulation

C_j = cost of j based on unit

a_{ij} = amount of i available in j

B_i = dietary requirement of nutrient i at different stages of growth

The Goal Programming (GP) Model

The model, involving equations 7 to 10, was developed to solve the diet formulation problem using goal programming technique:

$$\text{Minimize } Z = \sum_{i=1}^m (w_i^+ d_i^+ + w_i^- d_i^-) \quad (7)$$

Subject to the constraints

$$\sum_{j=1}^n X_j = X_t \text{ (Demand requirement)} \quad (8)$$

$$\sum_{j=1}^n a_{ij} X_j + d_i^- - d_i^+ = B_i \text{ (Goal constraint)} \quad (9)$$

$$\sum_{j=1}^n a_{ij} X_j = B_i \text{ (Exact requirement)} \quad (10)$$

where,

i = nutrient components in feed ($i = 1, 2, \dots, m$)

j = ingredients in feed ($j = 1, 2 \dots n$)

X_j = quantity of ingredients in feed (j = decision variable)

X_t = quantity of feed (kg) to be produced (based on demand)

Z = objective function

a_{ij} = amount of i available in j

B_i = dietary requirement of nutrient i at different stages of growth

w_i^+ = non-negative constant representing the relative weight to be assigned to the respective negative deviational variables

w_i^- = non-negative constant representing the relative weight to be assigned to the respective positive deviational variables

d_i^+ = positive deviational variable (overachievement) in goal i

d_i^- = negative deviational variable (underachievement) in goal i

The Stochastic Programming Model

The stochastic model, involving equations 11 to 15, was developed to accommodate variability in the nutritional components of the ingredients. The objective function remains the same as the corresponding Linear Programming models.

$$\text{Minimize } Z = \sum_{j=1}^n C_j X_j \quad (11)$$

Subject to the constraints

$$\sum_{j=1}^n X_j = X_t \text{ (Demand requirement)} \quad (12)$$

$$\sum_{j=1}^n \left(a_{ij} - z \left(\sqrt{\sum_{j=1}^n \sigma_{ij}^2} \right) \right) X_j \geq B_i \text{ (Probabilistic requirement) (13)}$$

$$\sum_{j=1}^n a_{ij} X_j \geq B_i \text{ (Linear requirement) (14)}$$

$$X_j > 0 \text{ (Non-negativity constraint) (15)}$$

where,

i = nutrient components in feed ($i = 1, 2, \dots, m$)

j = ingredients in feed ($j = 1, 2 \dots n$)

X_j = quantity of ingredients in feed (j = decision variable)

X_t = quantity of feed (kg) to be produced (based on demand)

Z = cost of ingredients used in the feed formulation

C_j = cost of j based on unit

a_{ij} = amount of i available in j

B_i = dietary requirement of nutrient i at different stages of growth

σ_{ij}^2 = the variance of feed nutrient i in feed ingredient j

Presentation of Results

The analysis was carried out using LINGO, a comprehensive tool for solving Linear, Nonlinear, Stochastic, and Integer optimization models. The solution reports of the linear programming models, showing the optimum value of feed mix that satisfy the nutritional requirements at minimum costs, are shown in Tables 6 - 7. Table 6 shows the results of the linear programming formulation. It presents the values and reduced costs of decision variables in each feed mix for ostriches at their different growth stages. The reduced costs are the minimum decreases of the unit price of each ingredient for which the optimal solution would be altered. The slack or surplus of each applied constraint, as well as their corresponding dual prices, are shown in Table 7.

Tables 8 – 11 combine the optimum values of feed ingredients and total cost of rations for ostriches at their different growth stages obtained using goal programming (GP) and stochastic programming (SP). The goal programming attached the same importance to the different nutrient goals by setting all values of $w_i^- = w_i^+ = 1$. The resulting feed mix formulated using the stochastic programming technique at probability levels from 60% to 95% are also shown.

Table 6. Solution Report for Linear Programming Model

Variable	0-6 weeks		7-12 weeks		12 weeks		Breeder	
	Value	Reduced Cost	Value	Reduced Cost	Value	Reduced Cost	Value	Reduced Cost
X1, Maize (Yellow)	94.04761	0	128.401	0	92.39432	0	352.6439	0
X2, Wheat Middlings	0	323.2355	0	225.9802	0	160.2286	0	160.2286
X3, Rice Bran	553.1377	0	579.1844	0	741.3061	0	424.8169	0
X4, Soyabean Meal	260.1677	0	205.7436	0	0	37.26171	0	37.26171
X5, Groundnut Cake	0	53.31321	55.71814	0	137.3419	0	141.6835	0
X6, Fish Meal (72%)	67.34751	0	0	315.6596	0	605.4223	0	605.4223
X7, Oyster Shell	0	314.0481	0	129.1055	7.480843	0	18.51596	0
X8, Bone Meal	19.29948	0	24.95287	0	15.47689	0	56.33972	0
X9, Salt	3	0	3	0	3	0	3	0
X10, Premix	3	0	3	0	3	0	3	0

Table 7. Slack, Surplus and Dual Prices of Linear Programming Solution

Row	0-6 weeks			7-12 weeks			12 weeks			Breeder		
	Slack or Surplus	Dual Price	Slack or Surplus	Dual Price	Slack or Surplus	Dual Price	Slack or Surplus	Dual Price	Slack or Surplus	Dual Price	Slack or Surplus	Dual Price
Objective		148231.9	-1	83165.06	-1	57733.53	-1	78646.36	-1	78646.36	-1	
Fat		33.83201	0	34.99205	0	54.59954	0	25.70888	0	25.70888	0	
Crude Protein		0	-472.9142	0	-487.9285	0	-383.8192	0	-383.8192	0	-383.8192	
Energy		0	-0.2926282	0	-0.2146435	0	-0.1564653	0	-0.1564653	0	-0.1564653	
Crude Fibre		37.93407	0	41.12531	0	51.37824	0	17.23916	0	17.23916	0	
Phosphorus		0	-22688.88	0	-10530.35	0	-2087.594	0	-2087.594	0	-2087.594	
Calcium		0	-1871.488	0	-1615.033	0	-1368.609	0	-1368.609	0	-1368.609	
Salt		0	-1027.784	0	-750.5174	0	-532.6993	0	-532.6993	0	-532.6993	
Premix		0	-1712.784	0	-1435.517	0	-1217.699	0	-1217.699	0	-1217.699	
Demand		0	962.7838	0	685.5174	0	467.6993	0	467.6993	0	467.6993	

Table 8. Goal Programming and Stochastic Programming Solution for Ostriches aged 0-6 weeks

Variable	GP	SP				
		60%	70%	80%	90%	95%
X1, Maize (Yellow)	439.3065	24.87155	40.74717	45.38427	58.57438	103.1713
X2, Wheat Middlings	0	0	0	0	0	0
X3, Rice Bran	307.8496	877.9834	860.0271	854.7822	839.8634	789.4215
X4, Soyabean Meal	0	0	0	0	0	0
X5, Groundnut Cake	54.65339	0	0	0	0	0
X6, Fish Meal (72%)	192.1905	71.44774	73.9211	74.64354	76.69851	83.64653
X7, Oyster Shell	0	0	0	0	0	0
X8, Bone Meal	0	19.69732	19.30467	19.18998	18.86375	17.76075
X9, Salt	3	3	3	3	3	3
X10, Premix	3	3	3	3	3	3
OBJ	260873.4744	109614.8	113160.6	114196.3	117142.2	127102.8

Table 9. Goal Programming and Stochastic Programming Solution for Ostriches aged 7-12 weeks

Variable	GP	SP						
		60%	70%	80%	90%	95%		
X1, Maize (Yellow)	515.4675	59.79867	70.57626	83.29136	91.21137	139.6827	0	
X2, Wheat Middlings	0	0	0	0	0	0	0	
X3, Rice Bran	317.5252	907.9483	897.2351	884.596	876.7233	822.1176	0	
X4, Soyabean Meal	0	0	0	0	0	0	0	
X5, Groundnut Cake	0	0	0	0	0	0	0	
X6, Fish Meal (72%)	161.0073	0	0	0	0	7.303269	0	
X7, Oyster Shell	0	8.278438	5.575321	2.386264	0.399853	0	0	
X8, Bone Meal	0	17.9746	20.61333	23.72643	25.66552	24.89645	3	
X9, Salt	3	3	3	3	3	3	3	
X10, Premix	3	3	3	3	3	3	3	
OBJ	231584.6322	43174.17	44091.17	45173.01	45846.87	56452.35		

Table 10. Goal Programming and Stochastic Programming Solution for Ostriches aged 12 weeks and above

Variable	GP	SP						
		60%	70%	80%	90%	95%		
X1, Maize (Yellow)	534.9973	48.42481	59.21145	72.88221	81.74387	136.4905		
X2, Wheat Middlings	0	0	0	0	0	0		
X3, Rice Bran	314.4004	921.6127	910.817	897.1349	888.2658	833.5529		
X4, Soyabean Meal	0	0	0	0	0	0		
X5, Groundnut Cake	0	0	0	0	0	0		
X6, Fish Meal (72%)	144.6023	0	0	0	0	0		
X7, Oyster Shell	0	23.96253	23.97153	23.98294	23.99033	21.10228		
X8, Bone Meal	0	0	0	0	0	2.854352		
X9, Salt	3	3	3	3	3	3		
X10, Premix	3	3	3	3	3	3		
OBJ	217215.4174	41548.85	42346.96	43358.47	44014.15	48194.22		

Table 11. Goal Programming and Stochastic Programming Solution for Breeder Ostriches

Variable	GP	SP				
		60%	70%	80%	90%	95%
X1, Maize (Yellow)	163.9325	319.7379	320.6342	327.4859	328.5895	351.6042
X2, Wheat Middlings	0	0	0	0	0	0
X3, Rice Bran	373.7708	597.9076	597.0166	590.2059	589.1089	566.2317
X4, Soyabean Meal	0	0	0	0	0	0
X5, Groundnut Cake	0	0	0	0	0	0
X6, Fish Meal (72%)	456.2967	0	0	0	0	0
X7, Oyster Shell	0	52.23044	52.00563	50.28718	50.01038	44.2381
X8, Bone Meal	0	24.12406	24.34352	26.02104	26.29125	31.92603
X9, Salt	3	3	3	3	3	3
X10, Premix	3	3	3	3	3	3
OBJ	490230.0238	62135.29	62211.55	62794.51	62888.41	64846.57

The market price analyses of the results from the Linear, Goal and Stochastic Programming models with respect to ostriches ages are summarized in Figure 1.

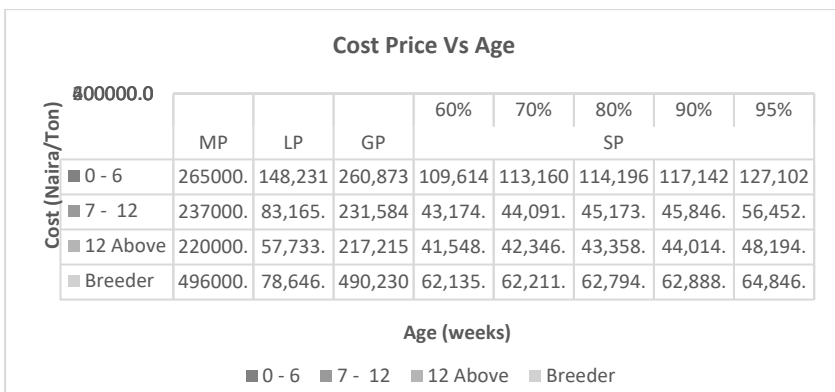


Figure 1: Market and Cost Prices of different programming models with respect to the ostriches ages.

Discussion

The feed mix obtained through the linear, goal and stochastic optimization techniques satisfied the minimum nutrient requirements for ostriches between 0-6 weeks as prescribed by the Nigerian Industrial Standard. Figure 1 shows the Market Prices (MP) and objective or cost prices of different programming models with respect to the ostriches ages. It is observed from Figure 1 that the mix obtained from linear programming costs ₦148,231.90 while rations obtained from goal programming cost ₦260,873.47. The results obtained at the different probability levels using stochastic programming ranged from ₦109,614.80 to ₦127,102.80. The feed mix obtained through the linear, goal and stochastic optimization techniques satisfied the minimum nutrient requirements for ostriches between 7-12 weeks as prescribed by the Nigerian Industrial Standard.

The mix obtained from linear programming costs ₦83,165.06 while rations obtained from goal programming cost ₦231,584.63. The results obtained at the different probability levels using stochastic programming ranged from ₦43,174.17 to ₦56,452.35. The feed mix obtained through the linear, goal and stochastic optimization techniques satisfied the minimum nutrient requirements for ostriches aged 12 weeks and above as prescribed by the

Nigerian Industrial Standard. The mix obtained from linear programming costs ₦57,733.53 while rations obtained from goal programming cost ₦217,215.42. The results obtained at the different probability levels using stochastic programming ranged from ₦41,548.85 to ₦48,194.22. The feed mix obtained through the linear, goal and stochastic optimization techniques satisfied the minimum nutrient requirements for breeder ostriches as prescribed by the Nigerian Industrial Standard.

The mix obtained from linear programming costs ₦78,646.36 while rations obtained from goal programming cost ₦490,230.02. The results obtained at the different probability levels using stochastic programming ranged from ₦62,135.29 to ₦64,846.57. Overall, the feed mixes formulated by linear programming technique resulted in higher cost than those formulated using stochastic programming at the different probability levels. Rations produced using the goal programming technique with equal weight for each nutrient goal was the most expensive. Generally, it was observed that the result of the market prices is higher than any of the cost prices of the programming model used in this study.

Conclusion

In this study, mathematical models have been developed for formulation of feed rations for local ostriches in Nigeria with the objective of cost minimization. While the linear programming technique gave the least-cost ration that satisfies the nutrient requirements, goal programming technique was useful to minimize the deviations from the nutrient goals. The use of stochastic programming guaranteed meeting the nutrient requirements at certain probabilities while accommodating nutrient variability in the feed ingredients. Results obtained from the mathematical models gave feed rations that all satisfy the standard nutrient requirements for ostriches in Nigeria. Besides, the feed mix obtained from the stochastic programming model was the cheapest, followed by linear programming model and the goal programming model, in that order. So, stochastic programming is the best mathematical technique to formulate feed diets as it yields an optimal mix that accommodates the expected variability in available feed ingredients while minimizing the total cost of the produced feed mix and reducing nutrient waste.

Conflict of Interest

The authors declare no conflict of interest.

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CHAPTER 2

OPTIMIZATION OF NUTRIENTS IN FEED FORMULATIONS FOR THE GROWTH STAGES OF DUCKS IN NIGERIA USING PROGRAMMING TECHNIQUES

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Abstract

Finding the best feed mixture for ducks at each stage of growth is the aim of this paper. The models are built using approaches from linear, goal, and stochastic programming. The least-cost ratio was achieved by using linear programming. To account for innocuous departures from the nutritional goals' target values, goal programming was employed. Nutrient variability was incorporated into the feed mix using stochastic programming. The results show the market prices (MP) and objectives/cost prices of different

programming models with respect to the duck ages. It is observed that the mix obtained from linear programming costs ₦123,505.50 while rations obtained from goal programming cost ₦220,592.00. The results obtained at the different probability levels using stochastic programming ranged from ₦120,917.20 to ₦124,779.50. The feed mix obtained through the linear, goal and stochastic optimization techniques satisfied the minimum nutrient requirements for ducks between 4-10 weeks as prescribed by the Nigerian Industrial Standard. After comparing the findings, it was discovered that, in terms of cost minimization, stochastic programming produced more effective outcomes than both linear and goal programming.

Keywords: Ducks, Growth Stages, Feed Formulation, Optimization, Programming Models

Introduction

Nutrition is the single most important factor affecting the growth and healthy performance of animals. It is expected that animal diets should supply the adequate energy and essential nutrients for body growth, metabolism, weight gain, reproduction, meat, milk and other animal yields. Animal feed rations are therefore compounded to produce the cheapest, most palatable, and easily digestible mix of ingredients that satisfy the minimum animal requirements in terms of energy and necessary nutrients at the lowest possible cost. In the end, animal diets are designed to be both nutritionally balanced and economically efficient. Ducks are among the poultry species found across local farms in Nigeria. The major breeds are the Muscovy duck (*Cairaina moschata*) and common duck (*Anas platyrhynchos*); the Muscovy ducks, also known as local ducks, are predominant in population (Oguntunji and Ayorinde, 2015).

Despite being an excellent and affordable source of animal protein, ducks are often neglected among poultry operators. This trend can be traced to the low demand of duck meat and the cultural myths and taboos associated with the species in many parts of the country (Alfred and Agbede, 2012; Oteku et al., 2006). Duck farming requires establishing a feeding protocol in supplying the energy and nutritional requirements of the ducks at their different ages and production levels.

Several mathematical techniques have been used to formulate diets over the past decades. Models are derived to obtain a well-balanced ration that satisfies animal nutritional needs using the most efficient combination of possible feed ingredients. Al-Deseit (2009) used local feed ingredients to

formulate least-cost rations for broilers using the technique of Linear Programming. His study investigated and explored how best to combine available feedstuffs to obtain the least-cost ration. Mathematical models were derived to accommodate the nutritional requirements of broilers and available feedstuff. The results gave a stable mix of ingredients that satisfied the nutrient demands at least cost.

Nabasiye et al. (2011) formulated a least-cost diet using linear programming. Microsoft Excel was used to solve the model, and the solution report was analyzed and interpreted. Olugbenga et al. (2015) developed a linear model to formulate an optimized diet for broiler poultry in Nigeria. The most common feed ingredients used in ration formulation for local farms and broiler feed factories were utilized in the formulation. The linear programming model was solved using Excel Solver and the resulting optimal formulation yielded about 7.48% and 9.96% reduction in feed costs compared to the existing formulation for broiler starters and finishers respectively.

In other studies, different optimization techniques were combined to produce efficient feed mixes for animals. Prišenk et al. (2013a) presented a new mathematical model to formulate optimal feed for sport horses. The model is built on two sub-models, the first of which is linear programming while the second is weighted goal programming. Their new model was tested on two different scenarios and results showed that rations prepared with the weighted goal programming were more balanced in satisfying all nutrient requirements of the animal and were about 10% cheaper than rations compounded with linear programming. Prišenk et al. (2013b) developed a nonparametric mathematical model that combined linear programming and multi-objective weighted goal programming to produce a balanced but economical diet for sport horses. The method incorporates the animal nutritional requirements as targets in the optimization. Their model was tested for optimization of winter and summer feed rations, and results showed that weighted goal programming proved to be more precise and helpful in practice than linear programming, where only one objective can be taken into account.

Žgajnar et al. (2008) presented a user-friendly tool combining linear programming and weighted goal programming to obtain an optimal beef-fattening diet. Linear programming is first applied to obtain a least-cost ration then the result is made a target cost goal in the weighted goal programming, with penalty functions. Results confirmed this approach as useful in formulating least-cost rations without compromising nutritional