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Linear Programming Approach to Least-cost Ration Formulation for Poults

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Abstract: This study was on the use of a computer-based technique to investigate, analyse and indicate how best the available local ingredients can be combined effectively and efficiently to formulate least-cost ration for poults. 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 poults, nutrient composition of the available ingredient and any restriction factor of the available ingredients for the formulation. The result of this study shows that utilization of diet containing fillers at 7.94% is cost effective and may reduce cost of feeding by as much as 24.95% and this will enable poultry producers to supply poults and its by-products at lower prices.

Key words: Linear programming, simplex algorithm, least-cost ration, poults, fillers.

INTRODUCTION

Linear programming is a computational method of selecting, allocating and evaluating limited resources with linear, algebraic constraints to obtain an optimal solution for a linear, algebraic objective function. They are used in administrative and economic planning to maximize the linear functions of a large number of variables, subject to certain constraints. Patrick and Schaible (1980) stated that linear programming is technically a mathematical procedure for obtaining a value-weighting solution to a set of simultaneous equations.

Linear programming was first put into significant use during World War II when it was used to determine the most effective way of deploying troops, ammunitions, machineries which were all scarce resources. There are hundreds of applications of linear programming to subjects ranging from agriculture to smelting. Taha (1987) even reported that linear programming has been applied to marriage problem and the optimum solutions show that monogamy is the best type of marriage. Olorunfemi *et al.* (2001) reviewed extensively the use of linear programming in least-cost ration formulation for aquaculture. Olorunfemi *et al.* (2006) also applied linear programming into duckweed utilization in least-cost feed formulation for broiler starter.

The recent outbreak of bird flu (*Avian influenza*) in Nigeria (Anonymous, 2006a-c) has led to drop in the patronage of poultry and its allied by-products. This zoonotic disease has led to the destruction of millions of poultry birds in the country thereby leading to loss of income to poultry farmers and also leading to severe shortage in the supply of poultry meat and its allied products that are already inadequate before now.

Poults in this study refer to turkey between 0 and 8 weeks of age after Aduku (1993a). Turkeys are large meat type birds that reach about 15 kg at 20 weeks of age after consuming about 50 kg of feed. They are usually marketed in Nigeria during festivals. Because of the high feed consumption, emphasis is greatly placed on quality of feed fed and feed efficiency.

MATERIALS AND METHODS

Data collection: Data collection for this study was based on raw material (feedstuffs) specification, constraints imposed on the selected raw materials and the dietary nutrient requirements for poults.

Costs of raw materials used in the diet formulation were obtained from the prevailing market prices of feedstuffs in Nigeria through survey. Proximate constituents, limiting amino acids, calcium and phosphorus contents, minimum and maximum dietary inclusion levels of various feedstuffs used in diet formulation were obtained from standard tables and sources (Aletor, 1986; Aduku, 1993a; Tacon, 1993; NRC, 1994). Estimation of metabolizable energy of feedstuffs for the diets were calculated by converting the gross energy using the following equation as described by Miller and Payne (1959).

$$ME\ g^{-1} = (GE\ g^{-1} \times 0.95) - (N\% \times 0.075)$$

Where:

ME = Metabolizable energy
GE = Gross Energy
N% = Dietary Nitrogen Percent

Table 1: Cost implications of raw materials and nutrient levels of feed ingredients

Ingredients	Cost (N kg^{-1})	Crude protein (%)	Fat (%)	Crude fibre (%)	Calcium (%)	Non-phytate phosphorus (%)	Lysine (%)	Methi-onine (%)	energy ME- (kcal kg^{-1})
Maize	44.50	10.0	4.0	2.0	0.01	0.09	0.25	0.18	3432
Groundnut cake	39.00	48.0	6.0	5.0	0.20	0.20	1.60	0.48	2640
Soybeans meal	66.00	42.0	3.5	6.5	0.20	0.20	2.8	0.59	2420
Rice bran	6.50	11.8	12.5	12.5	0.04	0.46	0.50	0.24	2860
Brewers grain	12.00	18.0	6.0	20.0	0.20	0.16	0.90	0.40	1980
Blood meal	27.00	80.0	1.0	1.0	0.28	0.09	6.90	1.00	3080
Fish meal	145.00	65.0	4.5	1.0	6.10	03.00	4.50	1.80	2860
Bone meal	23.00	-	-	-	37.00	15.00	-	-	-
Oyster shell	10.50	-	-	-	35.00	0.10	-	-	-
Dl-methionine	700.00	60.0	-	-	-	-	-	100.00	-
Lysine	650.00	60.0	-	-	-	-	100.00	-	-
Feed fillers	5.00	-							
Vitamin/Mineral Premix	450.00								
Salt	20.00								
Fillers	5.00								

1US$ = N130.00

Table 2: Constraints imposed on the selection of feedstuffs by computerized linear programming for Poult's mash

Feedstuffs	Constraints (%) Minimum	Maximum
Maize	-	-
Soybean meal	-	-
Fish meal	-	-
Groundnut cake	-	-
Duck weed meal	-	-
Blood meal	-	5
Rice bran	-	-
Brewer's dried grain-	-	
Dl-methionine	-	-
Lysine	-	-
Bone meal	-	-
Oyster shell	-	-
Salt	0.25	0.35
Vitamin/Mineral Premix	0.25	0.30

Table 1 and 2 summarized the raw material specifications and restrictions imposed on selected raw materials used in the computerized linear programming for formulating a least-cost diet for poults.

The data provided for poults aged between 0 and 4 weeks in NRC (1994) will be adopted since they corresponds with stage of development of poults in the tropics between 0 and 8 weeks. NRC (1994) recommended energy level of 2800 kcal kg^{-1} but the metabolizable energy level of 2750 kcal kg^{-1} (Aduku, 1993a)) will be the inclusion level in this study. A protein level of 28% recommended by NRC (1994) and supported by Aduku (1993a) will be adopted in this study. Aduku (1993a) also recommended a lysine level of 1.5%. However NRC (1977) recommended lysine level of 1.68%. In this study, a lysine level of 1.6% will be adopted in agreement with NRC (1994). A methionine level of 0.55% will also be adopted in agreement with NRC (1994).

The level of inclusion of calcium in this work will be 1.2% in agreement with Aduku (1993a) and NRC (1994).

Table 3: Least-cost formulation restrictions on nutrients for Poult's mash

Nutrients	Restriction (%) Minimum	Maximum
Protein (%)	28	-
Fat (%)	-	5.43
Metabolizable Energy (kcal g^{-1})	2750	
Fibre (%)	-	2.73
Methionine	0.55	-
Lysine	1.60	-
Calcium	1.00	1.20
Phosphorus	0.6	-

The nonphytate phosphorus of 0.6% recommended by NRC (1994) will be adopted in this study. The fibre level of 2.73% and fat level of 5.43% (Patrick and Schaible, 1980) will be adopted in this study.

Restriction data on the nutrient requirements of poults were obtained from literature (Fetuga, 1989; Oluyemi, 1989; Aduku, 1993b; NRC,1994). These values were presented in Table 3.

Data analysis: The method of data analysis employed in this study was Linear Programming (LP) model. The model was designed to reflect various feedstuff combinations used in the diet formulation, current market prices, nutrient composition and range of inclusion to obtain a least-cost ration.

Linear programming is a computational method of selecting allocating and evaluating limited resources with linear, algebraic constraints to obtain an optimal solution for a linear, algebraic objective function.

Assumptions of linear programming: Before a valid result can be obtained from linear programming technique, the following assumptions must be holding:

Linearity: There must be a linear relationship between the output and the total quantity of each resource consumed. If the objective function is not linear, the technique will not be applicable. The variable cost and resource requirements per unit do not alter over the relevant range of output.

Additivity: This means that the sum of resources used by different activities must be equal to the total quantity of the resources used by each activity for all the resources i.e. the total units of a constrained resource used is the sum of all the resource units needed to produce a given quantity of output.

Divisibility: Perfect divisibility of outputs and resources must exist. Output can be in fractions and resources also can be in fraction. It should be noted that this condition however doesn't hold for integer programming.

Non-negativity: Decision variables cannot be added to the final objective function in a negative way. That is each of the decision variables must either be positive or zero.

Simple objective: The objective in a linear programming model can either be maximization or minimization of one activity.

Finiteness: The constraints and the variables must be finite so that it can be programmed. Hence a finite number of activities and constraints must be employed.

Certainty: All values and quantities must be known with certainty. That is, the input/output coefficients are known and thus give the model the property of being deterministic.

Proportionality: This implies that the contribution of each variable to the final objective function is directly proportional to each variable. If we want to double the output then all decision variables must be doubled.

External factors: All external factors not taking into consideration in the model but can affect the final output must be unchanging e.g in the formulation of feeds, cost of milling and bagging the ingredients. (Harper and Lim, 1982; Taha, 1987; Wagner, 1989).

Simplex algorithm: Harper and Lim (1982) stated that simplex technique is used where:
(a) there are two or more products and
(b) there are two or more constraints operating so that it is not immediately apparent what product mix will minimize cost.

Supposing we are to minimize cost of a linear function subject to linear constraints as stated below:

$$\begin{aligned} &\text{minimize } Z = C_1X_1 + C_2X_2 + ... + C_nX_n \\ &\text{subject to } A_{i1}X_1 + A_{i2}X_2 + ... + A_{in}X_n \leq, =, \geq B_i \\ &\qquad I = 1,2..., m \\ &\qquad X_1, X_2, ..., X_n \geq 0 \end{aligned}$$

where A_{ij}, B_i and C_j are given constants and X_j are the decision variable. From the above format (Kuester and Mize, 1973), we are seeking the values of the X_j which will optimize (maximize or minimize) the objective function, Z.

The numbers of unknowns is usually greater than number of equations (n > m). Taha (1987) stated that by setting (n - m) variables to 0 the unique solutions are called basic solution and that if a basic solution satisfies the non negativity restrictions, it is called feasible basic solution. He also stated that variables set equal to zero are called non basic variables while the remaining ones are called basic variables. Each basic solution is usually associated with an iteration.

Beightler *et al.* (1979) stated that simplex method moves from one basic feasible solution to another vertex to vertex and usually never returns to a previous solution point, because it improves the value of objective function at each iteration. Simplex algorithm will find the optimal solution to any linear programming model in a finite number of steps but this algorithm does not usually investigate every extreme point of the convex set. Taha (1987) stated that the maximum number of iterations cannot exceed

$$C^n_m = n!/[m!(n-m)!]$$

Model construction: Mathematical models were constructed for each type of ration using limited ingredients. The objective of the model was to minimize cost of producing a particular diet after satisfying a set of constraints. These constraints were mainly those from nutrient requirements of each bird and ingredient constraints. The variables in this model were the ingredients while the cost of each ingredient and the nutrient value of each ingredient was the parameter. LP models were constructed for the two types of ration using a limited ingredients with one containing fillers. The mash without fillers acted as control.

Fillers are ingredients added to feed to make up for the weight constraints since sometimes every other constraint might have been met without meeting the weight constraint of the feeds. Oluyemi (1989) classified fillers as fibres and insoluble grits. Olorunfemi (1991) added dietary grits between 1.8 mm to 2.0 mm to broiler finishers' feed up to 7.0% without any adverse effect and the result was not significantly different from the diets without any grits. Hooge and Rowland (1978) fed broiler chicks up to 16% sand and had no effect on body weight or feed conversion of the birds. Fillers can also be non-nutritive cellulose (Aletor, Personal communication). Various dietary fillers were used by Sellers *et al.* (1980) such as sand, rice hulls, kaolin, sodium bentonite and attapulgite clay. Fillers are generally expected not to contribute any significant value to the nutritive composition of the feed.

The objective of each model was to minimize cost of producing a particular diet after satisfying a set of constraints. These constraints were mainly those from nutrient requirements of the bird and also ingredients constraints. The variables in this model were the ingredients while the cost of each ingredients and the nutrient value of each ingredient was the parameter. The specified LP model for the attainment of this objective is given by equation (1) i.e., the objective function, through Eq. 9.

$$\text{Minimize } Z = \sum C_{ij} X_i \quad (1)$$

subject to:

$$Cp_i = \sum b_{ij} X_i \quad \text{- Crude protein} \quad (2)$$
$$Ee_i = \sum d_{ij} X_i \quad \text{- Fat} \quad (3)$$
$$Ef_i = \sum e_{ij} X_j \quad \text{- Crude fibre} \quad (4)$$
$$Ca_i = \sum h_{ij} X_i \quad \text{- Calcium} \quad (5)$$
$$Ph_i = \sum k_{ij} X_i \quad \text{- Phosphorous} \quad (6)$$
$$Mt_i = \sum f_{ij} X_j \quad \text{- Methionine} \quad (7)$$
$$Ly_i = \sum g_{ij} X_j \quad \text{- Lysine} \quad (8)$$
$$Me_i = \sum a_{ij} X_j \quad \text{- Estimated metabolizable energy} \quad (9)$$

Where, Z = Sum of the total cost of the various feedstuffs used in the diet formulation program such as blood meal, soybean, maize etc.

C = Per unit cost of the different feedstuffs a_{ij}, b_{ij},……., k_{ij} = the coefficients (technical) of the component of the particular nutrient found in the given feedstuffs as obtained from proximate analysis.

The variables in these models were the ingredients while the cost of each ingredient and the nutrient value of each ingredient was the parameter.

We define the variables as follows:

x_1	=	Yellow Maize
x_2	=	Groundnut cake
x_3	=	Soyabeans meal
x_4	=	Rice bran
x_5	=	Brewers' Grain
x_6	=	Blood meal
x_7	=	Fish Meal
x_8	=	Bone meal
x_9	=	Oyster shell
x_{10}	=	Dl-methionine
x_{11}	=	Lysine
x_{12}	=	Vitamin/mineral premix
x_{13}	=	Salt
x_{14}	=	Fillers

The following constraints for both mashes of Poults were the same and they were as given below:

Total weight	=	1000.00 kg
Crude protein	>=	280.00 kg
Fat	<=	54.30 kg
Fibre	<=	27.30 kg
Calcium	<=	12.00 kg
Calcium	>=	10.00 kg
Phosphorus	>=	6.00 kg
Dl-Methionine	>=	5.50 kg
Lysine	>=	16.00 kg
Energy	>=	2750 ME Kcal kg^{-1}
Vitamin/mineral premix	>=	2.50 kg
Vitamin/mineral premix	<=	3.00 kg
Salt	>=	2.50 kg
Salt	<=	3.50 kg
Blood meal	<=	50.00 kg

However the objective function for the formulations differed.

Model construction for poults' mash without fillers: The constraints above can be transformed into standard form as follows:

$$\text{Min}(-Z) = -45x_1 - 39x_2 - 66x_3 - 6.5x_4 - 12x_5 - 27x_6 - 145x_7 - 23x_8 - 10.5x_9 - 700x_{10} - 650x_{11} - 450x_{12} - 20x_{13}$$

Subject to :

1) $x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 + x_9 + x_{10} + x_{11} + x_{12} + x_{13} = 1000$

2) $0.1x_1 + 0.48x_2 + 0.42x_3 + 0.118x_4 + 0.18x_5 + 0.8x_6 + 0.65x_7 + 0.6x_{10} + 0.6x_{11} - s_1 = 280$

3) $0.04x_1 + 0.06x_2 + 0.035x_3 + 0.125x_4 + 0.06x_5 + 0.01x_6 + 0.045x_7 + s_2 = 54.3$

4) $0.02x_1 + 0.05x_2 + 0.065x_3 + 0.125x_4 + 0.2x_5 + 0.01x_6 + 0.01x_7 + s_5 = 27.3$

5) $0.0001x_1 + 0.002x_2 + 0.002x_3 + 0.0004x_4 + 0.002x_5 + 0.0028x_6 + 0.0061x_7 + 0.37x_8 + 0.35x_9 + s_6 = 12$

6) $0.0001x_1 + 0.002x_2 + .002x_3 + .0004x_4 + .002x_5 + .0028x_6 + 0.0061x_7 + 0.37x_8 + .35x_9 - s_7 = 10$

7) $0.0009x_1 + 0.002x_2 + 0.002x_3 + 0.0046x_4 + 0.0016x_5 + 0.0009x_6 + 0.03x_7 + 0.15x_8 + 0.1x9 - s_8 = 6.0$

8) $0.0018x_1 + 0.0048x_2 + 0.0059x_3 + 0.0024x_4 + 0.004x_5 + 0.01x_6 + 0.018x_7 + x_{10} - s_9 = 5.5$

9) $0.0025x_1 + 0.016x_2 + 0.028x_3 + 0.005x_4 + 0.009x_5 + 0.069x_6 + 0.045x_7 + x_{11} - s_{10} = 16$

10) $3.432x_1 + 2.64x_2 + 2.42x_3 + 2.86x_4 + 1.98x_5 + 3.08x_6 + 2.86x_7 - s_{11} = 2750$
11) $3.432x_1 + 2.64x_2 + 2.42x_3 + 2.86x_4 + 1.98x_5 + 3.08x_6 + 2.86x_7 + s_{12} = 2950$
12) $x_{12} - s_{13} = 2.5$
13) $x_{12} + s_{14} = 3.5$
14) $x_{13} - s_{15} = 2.5$
15) $x_{13} + s_{16} = 3.0$
16) $x_7 + s_{17} = 50$

$x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}, x_{11}, x_{12}, x_{13}, s_1, s_2, s_3, s_4, s_5, s_6, s_7, s_8, s_9, s_{10}, s_{11}, s_{12}, s_{13}, s_{14}, s_{15}, s_{16}, s_{17} >= 0$

Model construction for poults' mash with fillers

$$\text{Min } (-Z) = -45x_1 - 39x_2 - 66x_3 - 6.5x_4 - 12x_5 - 27x_6 - 145x_7 - 23x_8 - 10.5x_9 - 700x_{10} - 650x_{11} - 450x_{12} - 20x_{13} - 5x_{14}$$

Subject to:

1) $x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 + x_9 + x_{10} + x_{11} + x_{12} + x_{13} = 1000$
2) $0.1x_1 + 0.48x_2 + 0.42x_3 + 0.118x_4 + 0.18x_5 + 0.8x_6 + 0.65x_7 + 0.6x_{10} + 0.6x_{11} - s_1 = 280$
3) $0.04x_1 + 0.06x_2 + 0.035x_3 + 0.125x_4 + 0.06x_5 + 0.01x_6 + 0.045x_7 + s_2 = 54.3$
4) $0.02x_1 + 0.05x_2 + 0.065x_3 + 0.125x_4 + 0.2x_5 + 0.01x_6 + 0.01x_7 + s_5 = 27.3$
5) $0.0001x_1 + 0.002x_2 + 0.002x_3 + 0.0004x_4 + 0.002x_5 + 0.0028x_6 + 0.0061x_7 + 0.37x_8 + 0.35x_9 + s_6 = 12$
6) $0.0001x_1 + 0.002x_2 + 0.002x_3 + 0.0004x_4 + 0.002x_5 + 0.0028x_6 + 0.0061x_7 + 0.37x_8 + 0.35x_9 - s_7 = 10$
7) $0.0009x_1 + 0.002x_2 + 0.002x_3 + 0.0046x_4 + 0.0016x_5 + 0.0009x_6 + 0.03x_7 + 0.15x_8 + 0.1x9 - s_8 = 6.0$
8) $0.0018x_1 + 0.0048x_2 + 0.0059x_3 + 0.0024x_4 + 0.004x_5 + 0.01x_6 + 0.018x_7 + x_{10} - s_9 = 5.5$
9) $.0025x_1 + 0.016x_2 + 0.028x_3 + 0.005x_4 + 0.009x_5 + 0.069x_6 + 0.045x_7 + x_{11} - s_{10} = 16$
10) $3.432x_1 + 2.64x_2 + 2.42x_3 + 2.86x_4 + 1.98x_5 + 3.08x_6 + 2.86x_7 - s_{11} = 2750$
11) $3.432x_1 + 2.64x_2 + 2.42x_3 + 2.86x_4 + 1.98x_5 + 3.08x_6 + 2.86x_7 + s_{12} = 2950$
12) $x_{12} - s_{13} = 2.5$
13) $x_{12} + s_{14} = 3.5$
14) $x_{13} - s_{15} = 2.5$
15) $x_{13} + s_{16} = 3.0$
16) $x_7 + s_{17} = 50$

$x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, x_9, x_{10}, x_{11}, x_{12}, x_{13}, x_{14}, s_1, s_2, s_3, s_4, s_5, s_6, s_7, s_8, s_9, s_{10}, s_{11}, s_{12}, s_{13}, s_{14}, s_{15}, s_{16}, s_{17} >= 0$

where

$x_1, x_2, \ldots, x_{13}, x_{14}$ = Various ingredients
$s_1, s_2, \ldots, s_{16}, s_{17}$ = Slack variables

Table 4: Optimal nutrient analysis of least-cost ration produced by computerized linear programming for Poults

	Dietary levels	
Energy/nutrients	Control	Filler based[1]
Protein (%)	29.89	28.00
Metabolizable Energy (kcal kg^{-1})	2950.00	2750.00
Fat (%)	4.30	4.17
Fibre (%)	2.73	2.73
Methionine	0.55	0.55
Lysine	3.68	1.60
Calcium	2.73	2.73
Phosphorus	0.60	0.60

[1]Filler substituted diet

RESULTS AND DISCUSSION

The optimum solution for the filler based ration was found at iteration 16 while the optimum solution for the control diet was found at iteration 17.

The results of optimal nutrient analysis produced by computerised linear programming for poults' mash were presented in Table 4. The crude protein level of the least-cost diet was 28.00% in filler substituted diet and 29.89% in control diet. The control diet protein is 6.23% higher and that definitely leads to higher cost than the filler substituted diet because most proteinous feedstuffs are generally costlier than non-proteinous feedstuffs. The energy content of the filler substituted diet (2750.00 kcal kg^{-1}) was 6.78% lower than the control diet (2950.00 kcal kg^{-1}). However, the higher energy in the control diet will definitely reduce the feed consumption of the poults. So invariably birds fed the filler substituted feeds may even end up consuming more protein than those fed control diets. The lysine in the control diet (3.68%) was on the high side when compared to that of the filler substituted diet (1.60%). The methionine values of the diets fall within the recommended optimum values for both mashes. The fat in the control diet (4.30%) was higher than the filler substituted diet (4.17%). This is generally expected since the control diet contained more energy. Calcium, phosphorus fibre contents of both diets were the same.

CONCLUSIONS

The results of least cost diet formulation produced by linear programming model were presented in Table 5. Diet containing fillers had its cost at ₦48.54 kg^{-1} while the control diet gave the highest feed-cost of ₦64.68 kg^{-1} This is of great economic importance since a savings of ₦16.14 kg^{-1} would be made. The result of this study shows that utilization of diet containing fillers at 7.94% is cost effective and may reduce cost of feeding by as much as 24.95% and this will invariably improve profitability in poults' production.

Table 5: Ingredient composition of least-cost ration formulation produced by computerized linear programming for poults

Feed stuffs	Control[1]	Feed fillers[2]
Maize	520.83	454.70
Blood meal	50.00	50.00
Groundnut cake	315.36	310.62
Rice Bran	-	12.00
Fish Meal	61.52	62.97
Bone Meal	20.07	19.86
Methionine	1.44	1.53
Lysine	24.28	3.55
Vitamin mix	2.50	2.50
Salt	5.00	2.50
Feed fillers	-	79.42
Total cost (N^3 kg^{-1})	64.68	48.54
Cost per ton feed (N ton^{-1})	64687.04	48540.03

[1]Control diet. [2]Filler substituted diet, [3]1US$ = N130.00

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