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Utilization of Duckweed *(Lemna paucicostata)* in Least-cost Feed Formulation for Broiler Starter: A Linear Programming Analysis

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Abstract: This study was on the economic use of locally available and non-conventional feedstuff - Duckweed (*Lemna paucicostata)* as dietary component of feed for broilers aged between 0 and 5 weeks old using Linear Programming (LP) technique to investigate, analyse and determine the most efficient way of compounding the least-cost ration. Mathematical models were constructed, taking into consideration nutrient composition of each of the available ingredient, raw material specifications, costs and nutrient requirements of the broiler starter's mash. Simplex algorithm was used in solving the resulting linear programming models. The LP model gave least cost feed formulation containing duckweed as optimum at iteration 26. The result shows that utilization of diet containing 26.09% of duckweed is cost-effective by reducing the cost of the feed by 10.64% and this will invariably improve profitability in broiler production.

Key words: Duckweed, least-cost feed, broiler starter, linear programming, simplex algorithm

INTRODUCTION

The major problem with poultry production can be streamlined to feeds in all its ramifications[1]. The nutritional problem through inadequate consumption of qualitative feeds at affordable price can not be over emphasized. Ensminger[2] reported that feed accounts for 70% of recurrent cost of producing broiler chickens. Fetuga[3] also reported that in Nigeria, feed costs represent between 70-80% of the total cost of producing various livestock products.

Before any feed can be formulated for poultry birds, the nutritionist takes a lot of factors into consideration such as the available ingredients, nutrient composition of available ingredient, inclusion rate restriction of available ingredients and most importantly the nutrient requirements of each species of bird, doing this manually can be very cumbersome and tedious. Also at the end of the day the nutritionist may end up formulating lowest-priced feed instead of least-cost. Patrick and Schaible[4] defined least-cost feeds as the lowest-cost formular that contain all the nutritional elements needed for maximum performance while lowest-priced feeds may not be the formulation that will produce maximum performance. The maximum performance depends not only on the price of feeds but also on the efficiency of utilization of the feeds. The problem of least-cost ration formulation in poultry can be effectively managed through the application of computer using linear programming technique. Simplex method has been chosen to solve the mathematical model.

Most conventionally used protein and energy feedstuffs in poultry feeds have limited supplies and their prices are usually high because of the demands from both humans and livestock. The use of cheaper and non-conventional feedstuffs such as duckweed *Lemna paucicostata,* that grows into profusion in most tropical water bodies are aimed at minimizing the production cost of broiler starter's feeds.

Duckweed is a group of small floating aquatic plants found worldwide. It is a potentially important new crop due to its high productivity and nutritional value. The plant has a rapid growth rate and high yield, high protein content 20-40%, low fibre content, high mineral content, non toxicity and only few known pest[5]. Duckweed meal had been fed to layers at up to 40% of total feed with satisfactory results[6].

This study was therefore focussed on the use of a computer-based system which will analyze and indicate how best the available local ingredients can be combined together with duckweed to formulate least-cost feeds for broiler starters. The result of this study was aimed at helping poultry nutritionists, feed-millers and also poultry

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producers in knowing the least-cost combination of feedstuffs to meet specific nutrient requirements, acceptance or rejection of ingredients based on their cost and nutritive value.This will enhance greater supply of poultry products and by-products at lower prices to the teeming populace thereby alleviating the malnutrition problem facing the developing countries all over the world.

MATERIALS AND METHODS

Data collection: Data collections for this study were based on raw material (feedstuffs) specification, constraints imposed on the selected raw materials and the dietary nutrient requirements for broiler starter. Two models were created with one containing duckweed and the other diet without duckweed meal serving as the control.

Cost of raw materials used in the diet formulation was obtained from the prevailing market prices of feedstuffs in Nigeria through survey. Approximate 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[5,7-11]. Estimation of metabolizable energy of feedstuffs for the diets was calculated by converting the gross energy using the following equation as described by Miller and Payne[12].

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

Where:

ME = Metabolizable energy

GE = Gross Energy

N% = Dietary Nitrogen Percent

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

Restriction data on the nutrient requirements of broiler starters were obtained from literature[3,11,13,14]. These values are presented in Table 3.

Data Analysis: The method of data analysis employed in this study is 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. Patrick and Schaible[4] stated that linear programming is technically a mathematical procedure for obtaining a value-weighting solution to a set of simultaneous equations.

A linear programming model consists of three major different parts namely; an objective function, a series of equations which are alternative methods of attaining the objectives and the resources which are non negative variables. Kuester and Mize[15] stated that the classical linear programming problem has the following form:

$$\text{Optimize } F = C_1X_1 + C_2X_2 + \ldots + C_nX_n$$

$$\text{Subject to } A_{i1}X_1 + A_{i2}X_2 + \ldots + A_{i1}X_n \leq, =, \geq B_i$$
$$I = 1, 2, \ldots, m$$
$$X_1, X_2, \ldots, X_n \geq 0$$

Where, A_{ij}, B_i and C_j are given constraints and X_j are the decision variables. From the above format, we are seeking the values of the X_j which will optimize (maximize or minimize) the objective function, F.

In a more compact form, the problem can be rewritten as:

$$\text{Maximize(Minimize) } F = \sum_{j}^{n} c_j x_j$$

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

Ingredients	Cost (₦ kg^{-1})	Crude protein %	Fat %	Crude fibre %	Calcium %	% Non-phytate phosphorus	Lysine %	Methi-onine %	Energy (ME kcal kg^{-1})
Maize	35.00	10.0	4.0	2.0	0.01	0.09	0.25	0.18	3432
Groundnut cake	32.00	48.0	6.0	5.0	0.20	0.20	1.60	0.48	2640
Soybeans meal	43.00	42.0	3.5	6.5	0.20	0.20	2.80	0.59	2420
Rice bran	5.50	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	60.90	1.00	3080
Fish meal	84.00	65.0	4.5	1.0	6.10	3.00	4.50	1.80	2860
Bone meal	27.00	-	-	-	37.00	15.00	-	-	-
Oyster shell	6.00	-	-	-	35.00	.10	-	-	-
Dl-methionine	550.00	60.0	-	-	-	-	-	100.00	-
Lysine	735.00	60.0	-	-	-	-	100.00	-	-
Duckweed	5.50	25.9	5.7	12.3	1.10	.80	1.78	0.44	3450
Vitamin/Mineral Premix	320.00								
Salt	20.00								

1US$ = ₦122.00

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

	Constraints (%)	
Feedstuffs	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	0.50
Vitamin/mineral Premix	0.25	0.30

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

	Restriction (%)	
Nutrients	Minimum	Maximum
Protein (%)	23	-
Fat (%)	-	5
Metabolizable Energy (kcal g^{-1})	2800	3200
Fibre (%)	-	5
Methionine	0.50	-
Lysine	1.10	-
Calcium	1.00	1.50
Phosphorus	0.45	-

Subject to

$$\sum_{j=1}^{n} A_{ij} X_j \quad (\leq) B_i$$

$$j = 1 \quad (=)$$

$$(\geq)$$

$$x_j \geq 0$$

Where:

$j = 1,2,\ldots, N$ and $i = 1,2,\ldots, m$.

The numbers of unknowns is usually greater than the number of equations (N>M). Taha[16] 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.

Saaty[17] stated that the upper bounds on the maximum number of iterations required to solve a general problem containing N variables and M inequality constraints are determine solely by the total number of such points, or vertices. Taha[16] stated that the maximum number of iterations cannot exceed.

$$^{n}C_{m} = n! / [m!(n-m)!]$$

Model construction: Mathematical models were constructed for the two types of ration using a limited ingredients with one containing duckweed. 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 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 Eq. 1 i.e., the objective function, through Eq. 9.

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

subject to:

$$Cp_i = \sum b_{ij} X_j \text{ - Crude Protein} \quad (2)$$

$$Ee_i = \sum d_{ij} X_j \text{ - Fat} \quad (3)$$

$$Ef_i = \sum e_{ij} X_j \text{ - Crude Fibre} \quad (4)$$

$$Ca_i = \sum h_{ij} X_j \text{ - Calcium} \quad (5)$$

$$Ph_i = \sum k_{ij} X_j \text{ - Phosphorous} \quad (6)$$

$$Mt_i = \sum f_{ij} X_j \text{ - Methionine} \quad (7)$$

$$Ly_i = \sum g_{ij} X_j \text{ - Lysine} \quad (8)$$

$$Me_i = \sum a_{ij} X_j \text{ - Estimated metabolizable energy} \quad (9)$$

Where, Z = Sum of the total cost of the various feedstuffs used in the diet formulation programme such as blood meal, soybean, maize, duckweed 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 this model are the ingredients while the cost of each ingredient and the nutrient value of each ingredient is 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} = Duckweed

The following constraints for broiler starter's control and duckweed based mash are the same and is as given below:

Total weight	1000.00 kg
Crude protein	230.00 kg
Fat	50.00 kg
Fibre	50.00 kg
Calcium	15.00 kg
Calcium	10.00 kg
Phosphorus	4.00 kg

Dl-Methionine	5.00 kg
Lysine	11.00 kg
Energy	2800 ME kcal kg^{-1}
Energ	3200 ME kcal kg^{-1}
Vitamin/mineral premix	2.50 kg
Vitamin/mineral premix	3.00 kg
Salt	2.50 kg
Salt	5.00 kg
Blood meal	50.00 kg

However the objective function for the formulations differ.

Model construction for Broiler Starter's control mash: The linear programming model for broiler starter's control mash is as follows :

$$\text{Min}(-Z) = -35x_1 - 32x_2 - 43x_3 - 5.5x_4 - 12x_5 - 27x_6 - 84x_7 - 27x_8 - 6x_9 - 550x_{10} - 735x_{11} - 320x_{12} - 20x_{13}$$

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) $.1x_1 + .48x_2 + .42x_3 + .118x_4 + .18x_5 + .8x_6 + .65x_7 + .6x_{10} + .6x_{11} - s_1 = 230$
3) $.04x_1 + .06x_2 + .035x_3 + .125x_4 + .06x_5 + .01x_6 + .045x_7 + s_2 = 50$
4) $.02x_1 + .05x_2 + .065x_3 + .125x_4 + .2x_5 + .01x_6 + .01x_7 + s_5 = 50$
5) $.0001x_1 + .002x_2 + .002x_3 + .0004x_4 + .002x_5 + .0028x_6 + .0061x_7 + .37x_8 + .35x_9 + s_6 = 15$
6) $.0001x_1 + .002x_2 + .002x_3 + .0004x_4 + .002x_5 + .0028x_6 + .0061x_7 + .37x_8 + .35x_9 - s_7 = 10$
7) $.0009x_1 + .002x_2 + .002x_3 + .0046x_4 + .0016x_5 + .0009x_6 + .03x_7 + .15x_8 + .1x_9 - s_8 = 4.5$
8) $.0018x_1 + .0048x_2 + .0059x_3 + .0024x_4 + .004x_5 + .01x_6 + .018x_7 + x_{10} - s_9 = 5$
9) $.0025x_1 + .016x_2 + .028x_3 + .005x_4 + .009x_5 + .069x_6 + .045x_7 + x_{11} - s_{10} = 11$
10) $3.432x_1 + 2.64x_2 + 2.42x_3 + 2.86x_4 + 1.98x_5 + 3.08x_6 + 2.86x_7 - s_{11} = 2800$
11) $3.432x_1 + 2.64x_2 + 2.42x_3 + 2.86x_4 + 1.98x_5 + 3.08x_6 + 2.86x_7 + s_{12} = 3200$
12) $x_{12} - s_{13} = 2.5$
13) $x_{12} + s_{14} = 3.0$
14) $x_{13} - s_{15} = 2.5$
15)$x_{13} + s_{16} = 5.0$
16) $x_6 + s_{17} = 50$

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

Model construction for duckweed based Broiler Starter's mash:

$$\text{Min}(-Z) = -35x_1 - 32x_2 - 43x_3 - 5.5x_4 - 12x_5 - 27x_6 - 84x_7 - 27x_8 - 6x_9 - 550x_{10} - 735x_{11} - 320x_{12} - 20x_{13} - 5.5x_{14}$$

Subject to :

1) $x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 + x_9 + x_{10} + x_{11} + x_{12} + x_{13} + x_{14} = 1000$
2) $.1x_1 + .48x_2 + .42x_3 + .118x_4 + .18x_5 + .8x_6 + .65x_7 + .6x_{10} + .6x_{11} + .259x_{14} - s_1 = 230$
3) $.04x_1 + .06x_2 + .035x_3 + .125x_4 + .06x_5 + .01x_6 + .045x_7 + .057x_{14} + s_2 = 50$
4) $.02x_1 + .05x_2 + .065x_3 + .125x_4 + .2x_5 + .01x_6 + .01x_7 + .123x_{14} + s_5 = 50$
5) $.0001x_1 + .002x_2 + .002x_3 + .0004x_4 + .002x_5 + .0028x_6 + .0061x_7 + .37x_8 + .35x_9 + .0011x_{14} + s_6 = 15$
6) $.0001x_1 + .002x_2 + .002x_3 + .0004x_4 + .002x_5 + .0028x_6 + .0061x_7 + .37x_8 + .35x_9 + .0011x_{14} - s_7 = 10$
7) $.0009x_1 + .002x_2 + .002x_3 + .0046x_4 + .0016x_5 + .0009x_6 + .03x_7 + .15x_8 + .1x_9 + .008x_{14} - s_8 = 4.5$
8) $.0018x_1 + .0048x_2 + .0059x_3 + .0024x_4 + .004x_5 + .01x_6 + .018x_7 + x_{10} + .0044x_{14} - s_9 = 5$
9) $.0025x_1 + .016x_2 + .028x_3 + .005x_4 + .009x_5 + .069x_6 + .045x_7 + x_{11} + .0178x_{14} - s_{10} = 11$
10) $3.432x_1 + 2.64x_2 + 2.42x_3 + 2.86x_4 + 1.98x_5 + 3.08x_6 + 2.86x_7 + 3.45x_{14} - s_{11} = 2800$
11) $3.432x_1 + 2.64x_2 + 2.42x_3 + 2.86x_4 + 1.98x_5 + 3.08x_6 + 2.86x_7 + 3.45x_{14} + s_{12} = 3200$
12) $x_{12} - s_{13} = 2.5$
13) $x_{12} + s_{14} = 3.0$
14) $x_{13} - s_{15} = 2.5$
15) $x_{13} + s_{16} = 5.0$
16) $x_6 + s_{17} = 50$

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

RESULTS AND DISCUSSION

The optimum solution for the duckweed based ration was found at iteration 26 while the optimum solution for the control diet was found at iteration 23.

The crude protein level of the least-cost diet is 23% in duckweed based diet and 26.85% in control diet that definitely leads to higher cost than the duckweed based diet because most proteinous feedstuffs are generally

Table 4: Optimal nutrient analysis of least-cost diets produced by computerized linear programming for Broiler starter

	Dietary levels	
Energy/Nutrients	Control	Duckweed[x]
Protein (%)	26.85	23.00
Metabolizable Energy (kcal g^{-1})	2820.78	3155.00
Fat (%)	5.00	4.42
Fibre (%)	5.00	5.00
Methionine	0.50	0.50
Lysine	1.10	1.17
Calcium	1.50	1.50
Phosphorus	0.55	0.62

[x]Duckweed based diet

Table 5: Ingredient Composition of least-cost Ration formulation produced by computerized linear programming for Broiler Starter

	Diet composition (kg)	
Feedstuffs	Control[x1]	Duckweed[x2]
Maize	417.55	497.33
Blood meal	50.00	50.00
Groundnut cake	341.15	149.27
Rice bran	58.30	-
Brewers dried grain	84.02	-
Oyster shell	39.84	33.26
Methionine	1.63	1.74
Vit-min mix	2.50	2.50
Salt	5.00	2.50
Duckweed	-	260.89
Total cost (₦[x3] kg^{-1})	30.25	27.03
Cost ton^{-1} feed (₦ ton^{-1})	30248.28	27025.05

[x1]Control diet, [x2]Duckweed based diet, [x3]1US$ = N122.00

costlier than non-proteinous feedstuffs. The energy content of the duckweed based diet (3155.00 kcal kg^{-1}) was 11.85% higher than the control diet (2820.78 kcal kg^{-1}) (Table 4). Fetuga[3] recommended a protein level of 23 - 24% and between 2800-3000 kcal kg^{-1} energy for broilers between 0-5 weeks of age. The lysine in the control diet (1.10%) was 94.02% of the duckweed based diet lysine (1.17%). This means that the duckweed-based diet contains more of this essential amino-acid than the control diet. The methionine values of the diets fall within the recommended optimum values for broiler starter's mash[11]. Fibre contents of both diets were at the upper limit of 5%, the fibre is basically an energy diluent and it aids in digestion (Table 4).

Diet containing duckweed had its cost at ₦ 27.03 kg^{-1} while the control diet gave the highest feed-cost of ₦ 30.25 kg^{-1}(Table 5). This lower cost may be attributed to cheap cost of duckweed as substitute or replacement for the high cost groundnut cake conventionally used in the formulation of practical broiler starter's diet. Fish meal and soybean meal have been reported to account for the substantial increase in cost of fish feed[10]. Besides, there was total exclusion of soybean meal, brewer's dried grain and rice bran (Table 5) in the duckweed based diet.

The result of this study shows that utilization of diet containing duckweed (*Lemna paucicostata)* at 26.09% is cost effective and may reduce cost of feeding by as much as 10.64% and this will invariably improve profitability in broiler starter's production.

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