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Linear Programming Application to Utilization of Duckweed (*Lemna paucicostata*) in Least-cost Ration Formulation for Broiler Finisher

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Abstract: This study was on the application of linear programming to the utilization of locally available and non-conventional feedstuff - Duckweed (*Lemna paucicostata)* as dietary component of feed for broilers aged from 6 to 10 weeks old. Linear Programming (LP) technique was used 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 finisher'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 15 while the optimum for the control was at iteration 19. The result shows that utilization of diet containing 29.50% of duckweed is cost-effective by reducing the cost of the feed by 20.82% and this will invariably improve profitability in broiler production.

Key words: Linear programming, simplex algorithm, duckweed, least-cost ration, broiler finisher

INTRODUCTION

Malnutrition has been one of the major problems besetting developing countries all over the world. The bulk of food consumed by the populace of these countries are made up of carbohydrate. Morna *et al.* (1993) reported that despite the fact that a hard-working adult - a farmer, for example - needs approximately 3,500 calories and 50 grams of protein per day; a one-year-old child needs about 1,000 calories and 15 grammies of protein per day; these quantities of essentials nutrients are missing in the diets of many rural Africans, which are based on staples of grains, such as maize, or tubers, such as cassava.

The protein usually needed for growth and replacement of various cells of the body is often lacking in the diets of most Africans. Protein intake can be increased through adequate consumption of crops such as soya beans, ground nut, pigeon peas, beans; and also animal protein such as poultry products, beef, pork, mutton, goat meat and other bush meats. While proteinous crops are still affordable in most of these countries, this can not be said of animal protein whose consumption can be said to be per acutely low.

In a World Bank (1991) report on the average percentage of population food insecure each year between 1980 and 1990, 17% of Nigeria's populace were considered food insecure, that is-those who can not obtain the calories they need, either because they do not have the means or because adequate foods is not available in their area. The situation is further worsened by the deterioration in the production of livestock and crops in recent years, thereby leading to increases in price of meat and crop products. Obasanjo (1990) stated that before there can be any food security, there must be adequate access by all people at household levels to adequate food at all times. Food must not only be available, it must be cheap and affordable - particularly for low-income group.

There are many problems facing agricultural production in Nigeria. Obasanjo (1990) also stated that the basic problems of agrarian practice were compounded by insufficient and inadequate infrastructure, land tenure, poor research and extension services and suffocating marketing policy. Ilemobade (1985) reported that the problem facing livestock industry does not only lie with insufficient number of livestock, on insufficient number of specialists, but with inefficient production, cultural practices of livestock farmers, shortage of feed and water and wide-spread occurrences of animal diseases, aggravated by large human population whose percentage increase must be a matter of great concern.

A fast means of producing animal protein is through the use of monogastric animals such as pig and poultry birds because of their higher fecundity rather than ruminants. Whereas the production of pork and bacon is only limited to countries or areas where there are no religious norm against their production, but there is no known significant religious norm against poultry production hence the production of poultry products and by-products is unrestricted.

The fastest means of producing animal protein remains broiler production. The recent outbreak of bird flu (*Avian influenza*) in Nigeria (Anonymous, 2006a, b and c) has led to a very serious drop in the patronage of poultry and its allied by-products. This zoonotic disease has led to the destruction of millions of 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 by-product that are already inadequate before now.

Although the major problem with poultry production can be streamlined to feeds in all its ramifications (David-West, 1989) however this does not rule out the outbreak of contagious diseases. The nutritional problem through inadequate consumption of qualitative feeds at affordable price can not be overemphasized. Also Ensminger (1980) stated that feed accounts for 70% of the recurrent cost of producing broiler chickens. Fetuga (1989) 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 ingredients, 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 (1980) defined least-cost feeds as the lowest-cost formular that contains all the nutritional elements needed for maximum performance while lowest-priced feeds may not be the formulation that will produce maximum performance.

The problem of least-cost ration formulation can be effectively managed with the application of computer using linear programming technique (Olorunfemi *et al*., 2001, 2006). Simplex method has been chosen to solve the mathematical models.

Most conventionally used protein and energy feedstuffs in poultry feeds have limited supplies and their costs are usually high because of the demands from both humans and livestocks. 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 finisher'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 with high protein content of 20-40%, low fibre content, high mineral content, non toxicity and only few known pest (Lemna Corporation, 1992). Duckweed meal had been fed to layers at up to 40% of total feed with satisfactory results (Skillicorn *et al*., 1993).

This study is 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 finishers. The result of this study is aimed at helping poultry nutritionists, feed-millers and also poultry 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 for this study were based on raw material (feedstuffs) specification, constraints imposed on the selected raw materials and the dietary nutrient requirements for broiler finisher. Two models were created with one containing duckweed and the other diet without duckweed meal serving as the control.

Costs of raw materials used in the diet formulation were 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 (Aletor, 1986; Mbagwu *et al*., 1990; Lemna Corp, 1992; Aduku, 1993a; Skillicorn *et al*., 1993; 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 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 broiler finishers.

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

Ingredients	Cost (₦ Kg^{-1})	Crude protein (%)	Fat (%)	Calcium (%)	Crude fiber (%)	Non-phytate phosphorus (%)	Lysine (%)	Methionine (%)	Energy (Me Kcal kg^{-1})
Maize	45.00	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	2.80	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	3.00	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	-	-
Duckweed	6.00	25.9	5.7	12.3	1.10	0.80	1.78	0.44	3450
Vitamin/Mineral Premix	450.00								
Salt	20.00								

1US$ = ₦130.00

Table 2: Constraints imposed on the selection of feedstuffs by computerized linear programming for Broiler finisher'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	0.25
Vitamin/mineral Premix	0.25	0.25

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

Nutrients	Restriction (%) Minimum	Maximum
Protein (%)	20	-
Fat (%)	-	5
Metabolizable Energy (kcal kg^{-1})	3000	-
Fibre (%)	-	5
Methionine	0.38	-
Lysine	1.10	-
Calcium	0.90	-
Phosphorus	0.35	-

Restriction data on the nutrient requirements of broiler finishers were obtained from literature (Fetuga, 1989; Oluyemi, 1989; Aduku, 1993b; NRC, 1994). 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 (1980) 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 (1973) stated that the classical linear programming problem has the following form:

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

Subject to:

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

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:

$$\text{Maximize (Minimize) } F = \sum_{j=1}^{n} c_j x_j$$

Subject to:

$$\sum_{j=1}^{n} A_{ij} X_j \leq, =, \geq B_i \text{ and } x_j \geq 0$$

where j = 1, 2, …, n and i = 1, 2, …, m.

The numbers of unknown is usually greater than the number of equations (n>m). Taha (1987) stated that by setting (n - m) variables to 0, the unique solutions are called basic solutions and that if a basic solution satisfies the non negativity condition, it is called a feasible basic solution.

Saaty (1955) 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 determined solely by the total number of such points, or vertices. Taha (1987) 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 model containing duckweed and the control feed without 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.

Equation 1: Minimize $Z = \sum C_j X_j$

subject to:

Equation 2: $CP_i = \Sigma b_{ij} X_j$-Crude Protein
Equation 3: $EE_i = \Sigma d_{ij} X_j$-Fat
Equation 4: $EF_i = \Sigma e_{ij} X_j$-Crude Fibre
Equation 5: $CA_i = \Sigma h_{ij} X_j$-Calcium
Equation 6: $PH_i = \Sigma k_{ij} X_j$-Phosphorous
Equation 7: $MT_i = \Sigma f_{ij} X_j$-Methionine
Equation 8: $LY_i = \Sigma g_{ij} X_j$-Lysine
Equation 9: $ME_i = \Sigma a_{ij} X_j$-Estimated metabolizable energy

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 constraints used in the construction of model for broiler finishers' mash for both feeds are the same and is as explicitly stated below:

Crude Protein >= 200.00 kg
Fat <= 50.00 kg
Fibre <= 50.00 kg
Calcium >= 9.00 kg
Phosphorus >= 3.50 kg
Methionine>= 3.80 kg
Lysine >= 10.00 kg
Energy >= 3000ME Kcal kg^{-1}
Vitamin/Mineral Premix = 2.50 kg
Salt = 2.50 kg
Blood Meal <= 50.00 kg
Total Weight = 1,000.00 kg

However the objective function for the two formulations differs.

Model construction for broiler finisher's control mash: The linear programming model for broiler finisher's control mash is 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) $0.1x_1 + 0.48x_2 + 0.42x_3 + 0.118x_4 + 0.18x_5 + 0.8x_6 + 0.65x_7 + 0.6x_{10} + 0.6x_{11} - s_1 = 200$
3) $0.04x_1 + 0.06x_2 + 0.035x_3 + 0.125x_4 + 0.06x_5 + 0.01x_6 + 0.045x_7 + s_2 = 50$
4) $0.02x_1 + 0.05x_2 + 0.065x_3 + 0.125x_4 + 0.2x_5 + 0.01x_6 + 0.01x_7 + s_5 = 50$
5) $0.0001x_1 + 0.002x_2 + 0.002x_3 + 0.0004x_4 + 0.002x_5 + 0.0028x_6 + 0.0061x_7 + 0.37x_8 + 0.35x_9 - s_6 = 9$
6) $0.0009x_1 + 0.002x_2 + 0.002x_3 + 0.0046x_4 + 0.0016x_5 + 0.0009x_6 + 0.03x_7 + 0.15x_8 + 0.1x_9 - s_7 = 3.5$
7) $0.0018x_1 + 0.0048x_2 + 0.0059x_3 + 0.0024x_4 + 0.004x_5 + 0.01x_6 + 0.018x_7 + x_{10} - s_8 = 3.8$
8) $0.0025x_1 + 0.016x_2 + 0.028x_3 + 0.005x_4 + 0.009x_5 + 0.069x_6 + 0.045x_7 + x_{11} - s_9 = 10$
9) $3.432x_1 + 2.64x_2 + 2.42x_3 + 2.86x_4 + 1.98x_5 + 3.08x_6 + 2.86x_7 - s_{10} = 3000$
10) $x_{12} = 2.5$

11) $x_{13} = 2.5$
12) $x_6 + s_{11} = 50$

Where:

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

Model construction for duckweed based broiler finisher's mash: $Min(-Z) = -45x_1 - 39x_2 - 66x_3 - 6.5x_4 - 12x_5 - 27x_6 - 145x_7 - 23x_8 - 10.5x_9 - 700x_{10} - 650x_{11} - 450x_{12} - 20x_{13} - 6x_{14}$

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) $0.1x_1 + 0.48x_2 + 0.42x_3 + 0.118x_4 + 0.18x_5 + 0.8x_6 + 0.65x_7 + 0.6x_{10} + 0.6x_{11} + 0.259x_{14} - s_1 = 200$
3) $0.04x_1 + 0.06x_2 + 0.035x_3 + 0.125x_4 + 0.06x_5 + 0.01x_6 + 0.045x_7 + 0.057x_{14} + s_2 = 50$
4) $0.02x_1 + 0.05x_2 + 0.065x_3 + 0.125x_4 + 0.2x_5 + 0.01x_6 + 0.01x_7 + 0.123x_{14} + s_5 = 50$
5) $0.0001x_1 + 0.002x_2 + 0.002x_3 + 0.0004x_4 + 0.002x_5 + 0.0028x_6 + 0.0061x_7 + 0.37x_8 + 0.35x_9 + 0.0011x_{14} - s_6 = 9$
6) $0.0009x_1 + 0.002x_2 + 0.002x_3 + 0.0046x_4 + 0.0016x_5 + 0.0009x_6 + 0.03x_7 + 0.15x_8 + 0.1x_9 + 0.008x_{14} - s_7 = 3.5$
7) $0.0018x_1 + 0.0048x_2 + 0.0059x_3 + 0.0024x_4 + 0.004x_5 + 0.01x_6 + 0.018x_7 + x_{10} + 0.0044x_{14} - s_8 = 3.8$
8) $0.0025x_1 + 0.016x_2 + 0.028x_3 + 0.005x_4 + 0.009x_5 + 0.069x_6 + 0.045x_7 + x_{11} + 0.0178x_{14} - s_9 = 10$
9) $3.432x_1 + 2.64x_2 + 2.42x_3 + 2.86x_4 + 1.98x_5 + 3.08x_6 + 2.86x_7 + 3.45x_{14} - s_{10} = 3000$
10) $x_{12} = 2.5$
11) $x_{13} = 2.5$
12) $x_6 + s_{11} = 50$

Where:

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

RESULTS AND DISCUSSION

The optimum solution for the duckweed based ration was found at iteration 15 while the optimum solution for the control diet was found at iteration 19.

The results of optimal nutrient analysis produced by computerised linear programming for broiler finisher's mashes are presented in Table 4. The crude protein level of the least-cost diet for both diet was 20.00%. The energy content of both diet was the same (3000.00 kcal kg^{-1}). The crude protein and the energy level of both diet satisfied the minimum constraint levels set for both. The lysine in the control diet (1.00%) was 90.09% of the duckweed based diet (1.11%). This means that the duckweed-based diet contains more of this essential amino-acid than the control diet. The methionine values of both diets was the same and fall within the recommended optimum values for broiler finisher's mash (NRC, 1994). Fiber contents for the control was 4.99% while the duckweed-based diet was at the upper limit of 5.00%, the fiber is basically an energy diluent and it aids in digestion.

The results of least cost diet formulation produced by linear programming model are presented in Table 5. Diet containing duckweed had its cost at ₦30.19 kg^{-1} while the control diet gave the highest feed - cost of ₦38.13 kg^{-1}. There was total exclusion of brewer's dried grain and rice bran (Table 5) in the duckweed based diet, these ingredients are basically energy diluents. While the calcium to phosphorus ratio for this work was 2.57, the duckweed based diet gave and higher ratio of 2.98 while the control diet gave a lower ratio of 2.37 but they were still within acceptable level of inclusion.

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

	Dietary levels	
Energy/Nutrients	Control[1]	Duckweed[2]
Protein (%)	20.00	20.00
Metabolizable Energy (kcal/g)	3000.00	3000.00
Fat (%)	5.00	4.08
Fibre (%)	4.99	5.00
Methionine	0.38	0.38
Lysine	1.00	1.11
Calcium	0.9	3.84
Phosphorus	0.38	1.29

[1]Duckweed based diet

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

	Diet composition (kg)	
Feedstuffs	Control[1]	Duckweed[2]
Maize	581.99	475.76
Blood meal	50.00	50.00
Groundnut Cake	151.56	74.07
Rice bran	92.25	-
Brewers dried grain	93.24	-
Oyster shell	23.64	99.41
Methionine	0.93	0.79
Lysine	1.37	-
Vit-min mix	2.50	2.50
Salt	2.50	2.50
Duckweed	-	294.97
Total cost (₦[3] kg^{-1})	38.13	30.19
Cost per ton feed (₦ ton^{-1})	38134.05	30189.69

[1]Control diet, [2]Duckweed based diet, [3]1US$ = ₦130.00

The result of this study shows that utilization of diet containing duckweed (*Lemna paucicostata*) at 29.50% is cost effective and may reduce cost of feeding by as much as 20.82% and this will invariably improve profitability in broiler finisher's production.

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