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# A Productivity Outlook for a Multi-Criteria Animal Feed Formulation Problem: A Case Study of Nigerian Feed Mill Industry

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## Abstract

Over-formulation or under-formulation of animal feed is a major challenge in a feed milling operation .While over-feeding unnecessarily increases the feed cost; underfeeding on the other hand reduces the performance of the animal and the overall productivity of the feed milling operation. This study therefore addressed how a multi-criteria feed formulation affects the productivity of feed milling business with the use of mathematical programming in bringing about an optimal solution that is both economical and brings out the best energy yield. The solution procedure employed in this study is an iterative multi-objective optimization method. Here the optimization of the metabolizable energy and ration cost is solved iteratively using a non-differentiable interactive multi-objective bundle-based optimization method which will then result into different alternative optimal formulations. These alternatives were then evaluated using the multi-factored productivity techniques to determine the interactions between each of the optimal solutions. The performance of the four alternative optimal solutions ($C_{ingredient}$) generated were factored into the productivity model together with other input factors such as the cost of fuel ($C_{fuel}$),cost of labour ($C_{labour}$) and cost of packaging ($C_{packaging}$). The productivity index estimated from the four alternative optimal formulations includes 1.13, 1.144, 1.06, and 0.96 respectively. This shows that the optimal feed formulation generated in alternative 2 produces the highest profit (14.35%) and hence highest productivity index (1.144). Hence, the multi-factored productivity index is therefore a measure of performance in a feed mill industry when considering the impact of feed formulation on the overall cost of production in a feed mill industry.

**Keywords:** Feed; Milling; Formulation; Optimal solution; Multi-criteria; Productivity; Metabolizable energy

## Introduction

### Overview of poultry farming

Agriculture is a fast growing sector in Nigeria economy, as well as the other developing nations. This has attracted a lot of attentions because it gives food to the humanity. The categories of agriculture which involves animal rearing and growing of plant are dependent on one another. Existence of one is affected by the existence of the other and vice versa. Poultry farming is very essential for sufficient egg and meat production for human consumption and this requires the growing of ingredients needed for their feeding.

The poultry has become a popular industry for the small holders with tremendous contribution to Nigeria GDP and employment opportunities creation [1]. The Nigerian government whose campaign is centered towards agriculture as a means of delivering the jobless graduate from the menace of unemployment is yet to provide solution to the issue of the high cost involved in the feed ingredients. That is why it is important for researchers to provide solution using the mathematical programming to optimize the available ones in view of a higher gain.

It is therefore necessary that the poultry farming be carried out efficiently for high productivity and sustainability of the industry in Nigeria. The markets for the poultry products are not stable and that is why a farmer must be ready to minimize is cost for a higher return. With a costly feed ingredients and uncertain market for the products the investor needs to sustain his business and also to make profit.

World production of poultry has been increasing steadily since the sixties and shows the highest rate of increase, followed by pigs at a substantially lower rate [2]. Poultry which is the major animal grown in the south-western of Nigeria has been known for heavy consumption of certain feed ingredients which are also being consumed by human beings. This has led to the high competition in between the human and animal which like to battle for the same type of food ingredients. Poultry animals especially fouls been known for the consumption of different types of feed according to their category such as Chick Mash for Chicks, Growers for Cockerel, Layers Mash for the Laying birds, Broilers mash for the broilers etc. constitute a lot of ingredients which are also being consumed by human. Ingredients such as Soya beans, Maize, Groundnut etc. With all this involved the demand for the few grown food ingredients has become very high. Also, the rate at which people are joining the poultry business is very high and this calls for more food ingredients to make feed rations for their fouls in the respective category which they belongs to.

**Feed, feeding and feed formulation:** Feed is a material, which after ingestion by the animal is capable of being digested, absorbed and utilized i.e. before transformed into body elements of the animal. A feed is merely the carrier of nutrients [3]. While feed formulation is the process of measuring the quantity of feed ingredients that need to be put together, to form a single uniform mixture (diet) that supplies all of poultry nutrient requirements. The definition shows what is involved in formulating feeds but it goes beyond that. It entails getting the materials needed available and formulating the feed to give the

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adequate nutrient for optimum yield and also at a reasonable cost. Every investors into business are expecting return and will be happy to have it high, that is why the decision maker needs to make best use of the available ways of getting this done.

Poultry feeding takes the largest percentage of what is meant to be the farmer's profit. This has made it very difficult to have a proper projection of what the turnover of the poultry farmer could be, because of the fluctuations in the market as a result of the high cost of feeds for the birds. It has been established that feeding constitutes over 70% of the total cost of egg and broiler production [4]. This implies that efforts to increase poultry industry productivity should be directed towards improving feed formulation system.

Recently, there was a serious challenge in getting soya beans meal which is the major source of protein for the animals. In the previous years it has been maize and wheat offal which is always scarce in certain period of the year but this year proves to be another challenge. This is giving a signal that decision makers must rise up to challenges of getting an optimum mix of feed at a lesser cost and an optimum energy yield. This will help to increase the profits and sustain their poultry farming business.

Some of the commonly used methods employed in feed formulation include The Pearson Square method, Linear Programming, Non Linear Programming, and Trial and Error method. The Person Square Method is a simple, well established and popular method of determining the correct proportions of two feed ingredients necessary to obtain a desired level of a particular nutrient. The method is most often used for protein. The method permits substitution of feed ingredients without disturbing the desired protein content of the diet. It is also used for some other nutrients like amino acids. Linear programming is the common method of Least Cost Feed Formulation which compares the nutrients required by the animal to the nutrients supplied by the available feed ingredients, and combines them to obtain a balanced diet at the least possible cost [5]. Other quantitative techniques include genetic algorithm [6].

Multi-criteria modeling [7] and Goal programming [8]. However Trial and Error method is the most popular method of formulating rations for poultry in Nigeria. As the name implies, the formulation is manipulated until the nutrient requirements of the birds is arrived at.

A strict compliance to an established feed budget is a critical step to the assurance of each diet being used in its proper amount. Over-feeding a budget unnecessarily increases the feed cost, while underfeeding reduces the performance of the animal. Either of these two cases (over-formulation or under-formulation) reduces the overall productivity of the feed milling operation. Since productivity is a key factor in every business enterprise there is therefore a need to address how feed production and formulation affects the overall productivity of the feed milling operation in managing feed resources in such a way that will reduce the cost and higher profit. This study tend to address how feed formulation affects the productivity of feed milling business and the use of mathematical programming to bring about an optimal solution that is both economical and brings out the best energy yield. This research work then seeks to apply mathematical optimization techniques to the feed formulation problem of the typical Nigerian poultry farm using locally available feed ingredients.

## Literature Review

### Poultry feeds

Feed is a material, which after ingestion by the animal is capable of being digested, absorbed and utilized i.e. before transformed into body elements of the animal. A feed is merely the carrier of nutrients. No feed has been found that is nutritionally complete and balanced to the need of a given animal. It is one of the factors which play an integral role in determining a successful development of livestock production [3]. The poultry feeds are of different types varying in nutrients level, feed materials and the categories of the poultry been fed. Also, different stages of poultry may require different types of feed and these changes as they develop.

### Overview of feed mill industry

The Feed mill industry is involved in the formulation and production of different varieties of livestock feeds and these include the chick mash, grower mash, broiler starter, broiler finisher, Layer mash, and many others. There are different kinds of feed ingredients used by feed millers and these among others include maize, palm kernel cake (PKC), fish meal, bone meal, wheat offal, blood meal, oyster shell, methionine, lysine, salt etc. These are used mainly to cater for the nutrient requirements for protein, energy, mineral and vitamin needed by the animals. These nutrients are the organic or inorganic substances that nourish the body of animals.

There are six main nutrients in animal feed. They comprise; water, protein, carbohydrate, fats, mineral elements and vitamins. The six nutrients are vital to animal survival. Variations therefore exists in nutrient requirements for different farm animals, but the level of dietary energy and associated nutrient should be high enough to allow expression of animal potentials under certain environmental circumstances within the economic limitations [9]. These have to be combined in such a proportion as feed produced will contain the requirements for the different classes and ages of poultry without any waste and at the cheapest cost. This function is expected to be carried out by feed mill industry.

The major ingredient used as a source of carbohydrate is being maize, which accounts for about 60% of the total feed formulation from the 75% production cost of the overall feed formulation [5]. However, lack of maize in feed mill industry impedes the production processes and this leads to unavailability of feeds for livestock animals, and subsequently shortage in productivity of feed mill business as against the frequent demand of the feeds by livestock farmers.

### Feed formulation

Feed ration formulation involves combining different ingredients in proportions necessary to provide the animal with proper amounts of nutrients needed at a particular growth stage. The ration should be palatable to the animals and not cause any serious digestive disturbances. Different species of animals have different requirements for energy (carbohydrate and fat), proteins, minerals and vitamins in order to maintain functions like homeostasis, reproduction, egg production, lactation and growth.

Feed formulation does not merely involve mathematical calculations but factors such as cost, presence of anti-nutritional factors, texture, moisture, processing, digestibility and acceptability to the animal. One of the most important roles of animal production is to provide high quality protein for human consumption; to achieve this, animals should be fed correct proportions of high quality protein [8].

### Common practices in feed formulation

The three common practices used to formulate and manufacture animal diets include Managed Formulation, Fixed Formulation, and Least-Cost Formulation [10].

**Constant nutrition:** is a management program of diet formulation. Using this method, we are able to deliver a constant level of nutrients taking into account the biological variation of natural feedstuffs. Ingredients are assayed daily and necessary formulation refinements are made if required to minimize nutrient variation. The actual ingredients used or their order of inclusion in the diet does not change, the benefit to the scientific community is a constant baseline of nutrition to help control unwanted, nutritionally induced variables. In addition, ingredients are assayed for interfering environmental contaminants to further reduce the possibility of unwanted variables introduced through the diet.

**Fixed formulation:** is a method where the ingredient inclusion levels are fixed and do not change based on nutrient content of incoming ingredients. Extensive ingredient research has proven that formulas produced under 'Fixed Formulation', without credence to ingredient variability, will result in unknown and sometimes radical changes in nutrient concentrations. These are primarily economy minded formulated feeds that can be safely fed for production purposes to the beef, swine and dairy industries. The finished product testing on these feeds from season to season proves ingredient variability can change the nutritional composition of an animal feed.

**Least cost formulation:** The practice of ingredient interchange, known as "least-cost formulation," is widely practiced within the commercial feed industry for production animals. When the cost of one ingredient increases, a lower cost ingredient may be used as a substitute in order to produce a lower cost feed; thus providing the customer with the most economical feed. It is widely known, however, that laboratory feeds are fed to animals raised for breeding and research, not for animals used to produce food such as meat, milk and eggs. Because laboratory animal diets need to be consistent products, least cost formulation should not be used.

## Different formulation techniques in feed milling operation

There exists two approaches to feed formulation in a feed milling operation, these include the Manual approach and Mathematical linear single /multiple programming approach.

**Manual techniques of feed formulation: Pearson's Square Method (PSM):** This shows the proportion of two feed ingredients to be mixed together in order to obtain the percentage of the particular nutrient [11]. Example of this is found in the mixing of corn and soya beans to meet a 23% protein requirement. However the technique is not suitable in a complex feed mix problem [4].

**Trial and Error Method (TAE):** This is the most popular method done either manually or by using EXCEL spreadsheet [12]. For example, in choosing four ingredients combination that must meet a protein requirement between 25-30%.

The limitation of this problem is that it requires more time especially where there are a lot of ingredients and nutrients needed to be considered.

**Simultaneous Algebraic Equation (SAE):** This is used to balance two or more feed ingredients to achieve a targeted optimum nutrients value [4].

The limitation of simultaneous algebraic equation is that it can only balance for two nutrients at a time. It is not practical for solving a problem which takes many nutrients.

**Mathematical single-linear programming approach:** The first attempt on a single objective programming as a tool for solving a feed mix problem was carried out by Waugh in 1951 [13]. He optimized livestock ration in economic terms with a classical linear program. Linear programming (LP) used is for problem with a single criterion, mostly to minimize the ration cost of the feed. It is therefore an appropriate method when solving the feed mix problem provided all the prices and nutritive value of feed is known [14]. The basic concept of linear programming in all minimization or maximization problems is that of a single objective function. It means that one try to get the optimal solution in minimizing or maximizing desired objective within set of constraints imposed. From this point of view, linear programming could be a deficient method for ration formulation [15].

However, in many real life situations like livestock ration formulation, decision maker does not search for optimal solution on the basis of a single objective alone (usually cost minimization of the diet), but rather on the basis of several different objectives [16]. This is the main weakness of utilizing the linear program for least-cost ration formulation, with exclusive reliance on cost function as the most important decision criteria

However linear programming has the following drawbacks:

**Linear programming model assume nutrient level are fixed:** In real life problem nutrients level in feed ingredient are unstable and fluctuating. Therefore LP-models cannot give a satisfactory solution to nutrients variability in feed ingredients. Hence when the variability among ingredients is neglected the probability in meeting nutrient restriction is only 50%. However, nutrient level in feed ingredient are unstable and fluctuating. Lara and Romeo [16] therefore gave the drawbacks of linear programming technique in animal feed formulation as follows:

It is regularly hard to determine a good balance of nutrients in the final solution.

1. Rigidity of LP-Constraints:
2. LP-Model can only tackle for Linear Constraints, but not non-linear constraints.
3. LP-Models can handle only one Objective Function

According to Babu and Sanyal [14], the LP is a deterministic approach, and is the best method to apply in the feed mix problem, if all the prices and nutritive values of feeds are known. Moreover, it provides a solution to problem that requires solving hundreds of equations concurrently.

**Mathematical multiple-objective programming approach:** The development of multi-objective programming began in the late 50s, with significant researches beginning in the mid 1970's. Its use consequently received a wide acceptance in the 1990's [17]. This model has application in the processes such as mixing/blending processes Formulation in Chemical Processes and Optimization of Mechanical Processes.

Minimizing the nutrient (while not compromising the quality) is not common in feed formulation consideration. Thus the this model provides the solution of a multiple criteria, by allowing acceptable solutions for conflicting objectives as opposed to optimal solutions .The MOP model is thus another flexible alternative to the traditional LP approach. It is an efficient tool to assist the decision making process through solving a series of linear/non-linear programs and by interacting with the decision makers.

Zhang and Roush [18] stated the advantages of using multi-objective approach over other programming model as follows:

**Tractability:** MOP model offers more flexibility, in that it provides a compromise solution than a traditional feed formulation with a linear programming.

**Concurrent action:** MOP model has the ability to handle several conflicting objectives simultaneously as compared to the traditional linear programming model that could handle only one objective.

**Trade-off in decision making process:** The model gives best compromise solution when trade-off is made between two alternative objectives.

### The fundamentals of productivity as performance evaluation tools

Productivity is the quantitative relationship between what we produce and what we have spent on a particular product and services. It is the ratio of output to input which ensures a reduction in the wastage of resources like men, material, machine, time, space, capital etc. It can be expressed as human efforts to produce more and more with less and less inputs of resources so that there will be maximum distribution of benefits among maximum number of people.

The improvement of productivity connotes an increasing productivity index, while deploying the same amount of materials, machine time, land, labour or technology [3]. Productivity denotes relationship between output and one or all associated inputs. It is a continual effort to apply new techniques and methods to apply little input to obtain a higher output. It was described as a balance between all factors of production that will give the maximum output with the smallest effort, and this applies to an enterprise, industry or an economy as a whole [19].

An improved productivity is therefore an indication that more is being produced with the same expenditure of resource i.e. at the same cost in terms of land, materials, machine, time or labour, alternatively, it means same amount is produced at less cost in terms of land, materials, machine time or labour that is utilized [3]. The majority of the techniques were first seen in mass-production operations but the benefits they can yield in SMEs are not to be underestimated. Indeed, the absence in SMEs of many of the rigidities commonly found in large companies make it easier for them to reap the benefits of productivity improvement techniques. Hence there is an increasing pressure on manufacturing companies to exploit such methods to become agile manufacturers of mass-customized products [3].

Energy is a very important in poultry as this energy given ingredients carries over 60% of their daily feed requirements. This will help them to give a maximum yield in production be it egg or meat. Olalere [3] developed a multi-objective programme using Non-differentiable Interactive Multi-objective Bundle-based Optimization System (NIMBUS) to maximize energy variation. He came up with different alternatives at the end of his work but he didn't consider the input of the personnel in his variables. He only stopped at the tradeoff issue without factoring the productivity of the feed mill industry. This is an issue that needs to be treated very well for effectiveness and efficiency. This work tends to consider the productivity as a path way for success of the feed formulation. The feed we are formulating needs to be prepared somewhere, by some people who use it as a commercial means and as a source of livelihood. Therefore, the research will not be completed if the issue of productivity is not been considered in the feed formulation researches. So far, we have had much work on this subject matter but not to the consideration of its productivity.

Various researches have been carried out on feed formulation using linear programming and considering the available local ingredients, but little has been done in considering more than one objective and the productivity of the feed mill as a subject is yet to be given consideration. A lot of inputs come into play each time we talked about the feed formulation and that is why they need to be given consideration also. This research work extends the work of feed formulation beyond the traditional way of just minimizing the cost to its impact on the total productivity of the feed mill as a whole. The work considered the two major objectives needed for optimum yield and a guaranteed success in the business which is the cost and the energy requirement of the poultry.

## Material and Method

The procedure for developing the cost parameters and the metabolizable energy for feed ration is presented. Also, outlined are the ingredients constraints involved in the feed production, the model notation, the development process, definition and solution method to the feed optimization problem. The solution procedure employed in this study is an iterative multi-objective optimization method. Here the optimization of the metabolizable energy and ration cost is solved iteratively using this method which will then give rise to different alternative formulations. These alternatives are then evaluated using the multi-factored productivity techniques to obtained interactions between each of the optimal solutions. The problem comprises of twelve variables (x1…x12), eight constraints and two criteria.

### Identification of the feed ration nutrients and ingredients

To identify the feed ration nutrients and ingredients, the literature was reviewed, feed mills were visited, relevant staff interviewed, and farmers who are practising the poultry farming were also consulted. The ingredients that were retrieved through this means are as shown in the Table 1 while the Table 2 indicates the nutrient level required for the laying bird's optimal production.

### Model notation

$i$ = Nutrient number

$j$ = Ingredient number

n = Total number of nutrients requirements for the poultry bird

m = Total number of the available ingredients for the feed

$F$ = Objective function

$Xj$ = Percentage of the $J^{th}$ ingredient

$a_i$ = Nutrient composition of $j^{th}$ ingredient

$A_i$ = The minimum nutrient requirement of $i^{th}$ nutrients

$B_i$ = The maximum nutrient requirement of $i^{th}$ nutrients

$C_j$ = Coefficient of the criterion function of Cost for $j^{th}$ ingredient

$Q_{ij}$ = Coefficient of the criterion function of metabolizable energy for $j^{th}$ ingredient

### Model formulation

The Objective function is divided into two parts and that is why it is indicated that the work is a bi-criteria model. The first objective function is the overall cost function of making the feed. This includes the cost of ingredients and the cost of milling. Cost as a major issue, needs to be minimized for an optimum gain as a decision maker.

The second objective which is the metabolizable energy is the energy required for an optimum performance and yields of the poultry birds. While trying to minimize cost, the decision maker must not forget to maximize the metabolizable energy (ME) for a higher production and higher return on investment (ROI).

**Cost objective function:** This is the total cost (TC) involved in making a certain feed ration. The cost is in monetary value which is Naira in this study which has to be minimized. It is represented as $F_{c.}$

Fc.=CjXj ………………………………………..............………. (A)

Where, $C_j$ is the cost of the jth ingredient per kilogram

$X_j$ is the weight of the jth ingredient in kilogram

Therefore,

$F_{c.}$ (Naira) = $C_j$ (Naira/Kg) $X_j$ (Kg) ........................………………. (B)

**Metabolizable energy objective function:** Olomu, the metabolizable energy is the easiest and most convenient to derive in poultry. It is derived from the formula, ME = DE - UE, Where UE is the urinary energy and DE is the digestible energy. Hence, the objective of this model is to maximize the energy content against extreme cold. This is given as

$F_{me} = Q_j X_j$ ………………………………………………………..... (C)

Where, $Q_j$ is the quantity of energy derived per kilogram of jth ingredient

$X_j$ is the weight of the jth ingredient in kilogram

Therefore, $F_{me}(KCal) = Q_j$ (Kcal/Kg) $X_j$ (Kg)

## The model constraint

These are categorized into two and this includes the Ingredient Constraints and the compositional constraint.

### Nutrient level constraints

$$a_{11}x_1 + a_{12}x_2 + a_{13}x_3 + a_{14}x_4 + a_{15}x_5 + \ldots\ldots\ldots\ldots + a_{1n}x_{1n} \leq = \geq A_j$$

$$a_{21}x_1 + a_{22}x_2 + a_{23}x_3 + a_{24}x_4 + a_{25}x_5 + \ldots\ldots\ldots\ldots + a_{2n}x_n \leq = \geq A_j$$

$$a_{31}x_1 + a_{32}x_2 + a_{33}x_3 + a_{34}x_4 + a_{35}x_5 + \ldots\ldots\ldots\ldots + a_{3n}x_n \leq = \geq A_j$$

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$$a_{11}x_1 + a_{22}x_2 + a_{33}x_3 + a_{44}x_4 + a_{55}x_5 + \ldots\ldots\ldots\ldots + a_{mn}x_n \leq = \geq A_j$$

**Compositional constraints:** This is the constraint that shows the target of the total expected weight of the feed ration in consideration. In this case, the total expected amount of the weight of the feed ration is 1000 kg (i. e, 1 tonne). The constraint is as shown below

$$x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 \leq 1000$$

Non-Negativity Constraints; this is the constraint that all the ingredients must be available in the feed ration for a nutritious feed.

i.e., $x_1, x_2, x_3, \ldots, x_n \geq 0$

## The model

Minimize $F_C = \sum_{j=1}^{m} Cj.Xj$

Maximize $F_{me} = \sum_{j=1}^{m} Qj.Xj$

Subject to

Protein

Fat $a_{11}x_1 + a_{12}x_2 + a_{13}x_3 + a_{14}x_4 + a_{15}x_5 + a_{16}x_6 + a_{17}x_7 + a_{18}x_8 \geq A_1$

Fibre $a_{31}x_1 + a_{32}x_2 + a_{33}x_3 + a_{34}x_4 + a_{35}x_5 + a_{36}x_6 + a_{37}x_7 + a_{38}x_8 \leq A_3$

Calcium $a_{41}x_1 + a_{42}x_2 + a_{43}x_3 + a_{44}x_4 + a_{45}x_5 + a_{46}x_6 + a_{47}x_7 + a_{48}x_8 \geq A_4$

Phosphorus $a_{51}x_1 + a_{52}x_2 + a_{53}x_3 + a_{54}x_4 + a_{55}x_5 + a_{56}x_6 + a_{57}x_7 + a_{58}x_8 \geq A_5$

Methionine $a_{61}x_1 + a_{62}x_2 + a_3x_3 + a_{64}x_4 + a_5x_5 + a_{66}x_6 + a_{67}x_7 + a_{68}x_8 \geq A_6$

Lysine $a_1x_1 + a_{72}x_2 + a_{73}x_3 + a_{74}x_4 + a_{75}x_5 + a_{26}x_6 + a_{77}x_7 + a_{78}x_8 \geq A_7$

$$x_1 + x_2 + x_3 + x_4 + x_5 + x_6 + x_7 + x_8 \leq 1000$$

where, $x_1, x_2, x_3, \ldots, x_n \geq 0$

## Model application

This involves the gathering of feed data needed for study through market survey. The nutrients content of the feed ingredients, the range of values of feed, the required specification and the cost of ingredients were obtained and prepared. Feed ration cost of the ingredients were gotten from the current market price of feed ingredient in Nigeria. Different nutrients were provided with individual maximum and minimum dietary inclusions for fat, fiber, calcium, phosphorus, protein, methionine and lysine. The data gotten is presented in Tables 1-3.

## The layer mash feed formulation

The above generalized feed formulation model is a generic model that can be applied using the values from Table 3.The two objective function is drawn from Tables 1 and 2 to obtain the following sets of equations shown below. The cost and energy functions are linear in nature.

| No | Ingredients | Cost Per kg (₦/kg) | ME (Kcal/kg) |
|---|---|---|---|
| 1 | Maize (Dried) | 48 | 3432 |
| 2 | Soya Cake/Meal | 150 | 2230 |
| 3 | Wheat Offals | 40 | 1300 |
| 4 | Groundnut Cake/Meal | 140 | 2150 |
| 5 | Fish Meal | 250 | 2820 |
| 6 | Lysine | 2000 | - |
| 7 | Methionine | 850 | - |
| 8 | Oysters Shell/Limestone | 15 | - |
| 9 | Bone Meal | 60 | - |

**Table 1:** Bill of ingredients and metabolizable energy for layers feed ration.

| Ingredients | Crude Protein % | Fats % | Crude Fibre% | Ca% | P, % | Lysine % | Methionine % |
|---|---|---|---|---|---|---|---|
| Maize, $x_1$ | 8.8 | 4.0 | 2.0 | 0.01 | 0.09 | 0.25 | 0.18 |
| Soya Cake/Meal, $x_2$ | 44 | 3.5 | 6.5 | 0.2 | 0.2 | 2.8 | 0.59 |
| Wheat Offals, $x_3$ | 15.7 | - | 5.1 | 0.14 | 1.15 | 0.59 | 0.42 |
| Groundnut cake,$x_4$ | 25.2 | 48.2 | 2.10 | - | - | 0.05 | 0.05 |
| Fish Meal, $x_5$ | 60.05 | 10.0 | 0.10 | 5.11 | 2.88 | 1.50 | 1.65 |
| Lysine, $x_6$ | 60 | - | - | - | - | 100 | - |
| Methionine, $x_7$ | 60 | - | - | - | - | - | 100 |
| Oyster shell, $x_8$ | - | - | - | 21 | 18.5 | - | - |
| Bone meal, $x_9$ | - | - | - | 38 | 1.5 | - | - |

Source: Nutrient levels of feed ingredients (NRC 9th Edition)

**Table 2:** The nutrient composition of the feedstuffs.

| Nutrients | Crude Protein kg | Fats kg | Crude Fibre(kg) | Ca (kg) | P (kg) | Lysine (kg) | Methionine (kg) | ME (Kcal/kg) |
|---|---|---|---|---|---|---|---|---|
| Production Target | 16.00 | 3.51 | 7.00 | 3.60 | 0.50 | 0.08 | 0.35 | 2500-2800 |

**Table 3:** Production target of a typical feed mill.

Using the generalized model the following constraints were obtained as shown below:

## Results and Analysis

### Feed mill and data collection

The feed mill under consideration is located in Oyo state and the data were collected for a correct input value. The feed mill is into the production of all the categories of feeds according to the demand of their customers. The data collected were also verified across various feed mill and the ingredients supplier to authenticate the prices given and the body nutrients requirements.

### Results from the analysis of feed formulation data

There were four sets of new alternatives generated by the system. These alternatives were labeled Alternative1….Alternative 4, as shown in Figure 4. It produces Pareto optimal and approximation of Pareto Optimal solution based on the preferences given by the decision maker. The decision maker is free to select four that is suitable for him, before a final decision is made. The selected alternatives are given in Table 4.

From the lists of alternatives, it is clear that none of the alternatives can be better improved without impairing others. At this point, we can now make a choice from the list, based on our preference. This is done by ranking the two objectives according to the order of preference. The second alternative with criterion vector z* (69.30301 E+3, 2560.325) is therefore selected as the most Pareto optimal based on the least cost and its closeness to the set target.

The Bill of ingredients for the Alternative 1 solution ($C_{\text{ingredients})}$ = ₦ 70.31445 E+3

The Bill of ingredients of the Alternative 2 solution ($C_{\text{ingredients})}$ = ₦69.30301 E+3

### Results from other cost estimation

The other cost estimation include the total cost output, total cost of labour employed during production, cost incurred on packaging sack, depreciation cost for the mixer and grinder, cost of fuel. This estimated as follows

**The total input cost:** The following are the parameters that sum up to make the total input cost of the product;

**Cost of packaging ($C_{\text{packaging}}$):** The generally accepted bag weight is 25 kg, therefore the products are being scaled into this. This is easier to carry for an individual and easy to measure in feed ration per certain number of birds. This cost is also measured in a monetary value which is naira.

Cost incurred on packaging: This includes the cost of threading and the cost of sack given that a sack cost #40. Hence for 40 bags we procure 40 sacks. The total cost of bagging is calculated below:

($C_{\text{packaging}}$) = Cost of Sack + Cost of Thread = (35 + 40) 40 = ₦ 3000.00

**The cost of labour ($C_{\text{labour}}$) and fuel ($C_{\text{power}}$):** Total cost of labour employed during production: There were four workers employed during the production process. A worker is paid at the rate of 1,000 naira per day

For a-days of operation, the amount paid to 4-workers = 1000*4 =₦ 4,000.00

Cost on fuel is at 5 Litres of diesel per batch production. A litre of diesel is ₦150.00. Hence 5 litre is an equivalence of (5litres * 150 naira) = ₦ 750.00

**The total output cost** ($C_{\text{output}}$): The cost of buying a finished feed is 2500 naira per 25kg from the big manufacturing company. However the cost at the level of local feed millers where you start bringing every other ingredient to make the feed is at an average of 2100 naira per 25kg as at the present current market. Given that the targeted production for this batch is 1,000kg, from where we obtain 40bags each containing 25kg of the feed. Hence the cost of 40 bags is calculated as follows:

1bag of the feed is an equivalence of 25kg costing 2,100 Naira

$C_{\text{output}} = N * P$

Where,

N=Number of bags produced in a single batch =40

P = Selling Price per bag =₦ 2,100

$C_{output} = 40 \times 2{,}100 =$ ₦*84,000*

Therefore 40 bags of the feed will cost = 40 x 2, 100 = 84,000 Naira

### Estimation of performance evaluation using multi-factored productivity

The total cost incurred during production and the cost of ingredient for alternative 1 is summarized in Table 5.

The multi-factored productivity is calculated both for the current and the optimal production. The former being the production from the old data, while the latter is from the optimal solution.

From equations above;

| Generated Optimal Solutions | Criterion Vector(Z*) | |
|---|---|---|
| | **Metabolizable Energy()** | **Formulation Cost (Naira)** |
| Alternative 1 | 1772.162 | 70.31445 E+3 |
| Alternative 2 | 2560.325 | 69.30301 E+3 |
| Alternative 3 | 2838.088 | 75.36454 E+3 |
| Alternative 4 | 3031.606 | 82.92020E+3 |

**Table 4:** Generated alternatives for optimal solutions.

| | $C_{output}$ | $C_{ingredient}$ | $C_{fuel}$ | $C_{labour}$ | $C_{packaging}$ |
|---|---|---|---|---|---|
| Estimate | **₦ 84,000.00** | **₦69.3030E+3** | **₦ 750.00** | **₦ 4,000.00** | **₦3000.00** |

**Table 5:** Summary of all cost estimate involved for alternative 1.

(a) The total revenue ₦ =84,000

Total expenses for Alternative 1 formulation= $C_{\text{ingredient (current)}} + C_{fuel} + C_{labour} + C_{Packaging}$

(₦71,3145E+3)+₦ 750.00+₦ 400.00+₦ 3000.00= ₦ 75,464.50 per batch

The percentage of cost of ingredients on the overall expenses is given as: $\frac{\text{Cost of Ingredient}}{\text{Total Expense}}$

%Cost of Ingredient for Current Formulation = $\frac{71{,}314.5}{75{,}464.5} * 100 = 94.5\%$

(b) Profit from Alternative 1 Formulation = Total Revenue - Total expenses for current formulation

= 84,000 - 75,464.50 = ₦8,535.5

$$\%\text{Profit from Alt. 1 Formulation} = \frac{\text{Profit from Current Formulation}}{\text{Revenue}}$$

$$= \frac{8{,}535.50}{75{,}464.5} \times 100 = 11.3\%$$

(c) Calculating the Multi- factored productivity for alternative 1 using the formula specified in equation 16;

We have $\frac{84{,}000}{75{,}464.50} \times 100 = 111.3\%$

From the Total Output Cost which is calculated as *N * P*, we have our Unit produced per output to be,

$$\frac{\text{Number of Total output in Kg}}{\text{Total Output Cost}} = \frac{1000}{84{,}000} = 0.0119 \text{ Kg / Naira}$$

$$P_{r\,(Alt\ 1)} = \frac{\text{C output}}{\text{C Input}} = \frac{\text{Number of Total output Kg}}{\text{Total Input Cost}} = \frac{1{,}000\text{Kg}}{\text{Total Input Cost}}$$

$$\frac{1{,}000}{(₦71{,}3145E+3) + ₦750.00 + ₦400.00 + ₦3000.00}$$

$$= \frac{1{,}000 \text{ Kg}}{₦75{,}464.50} = 0.01325\, Kg N aira$$

$$= \frac{0.01325}{0{,}0119} \text{ X}100 = 111.34\%$$

(a) Total expenses for Alternative 2 formulation= $C_{\text{ingredient (optimal)}} + C_{fuel} + C_{labour} + C_{Packaging}$

= (₦ 69,3030 E+3)+₦ 750.00+₦ 400.00+₦ 3000.00 = ₦ 73,453.00

(b) %Cost of Ingredient for Alternative 2 Formulation = $\frac{69{,}303.5}{75{,}464.5} * 100 = 91.8\ \%$

(c) Profit from Alternative 2 Formulation = Total Revenue - Total expenses for optimal formulation

=84,000 - 73,453= ₦ 10, 547

$$\textbf{\%Profit for Alt. 2 Formulation} = \frac{\text{Profit from Optimal Formulation}}{\text{Cost of Production}}$$

$$= \frac{10{,}547}{73{,}453} \times 100 = 14.35\%$$

(d) Calculating the Multi- factored productivity for alternative 2 using the formula specified in equation 16;

We have $\frac{84{,}000}{73{,}453} \times 100 = 114.4\%$

From the Total Output Cost which is calculated as *N * P*, we have our Unit produced per output to be,

$$\frac{\text{Number of Total output in Kg}}{\text{Total Output Cost}} = \frac{1000}{84{,}000} = 0.0119 \text{ Kg / Naira}$$

$$P_{r\,(Alt\ 2)} = \frac{\text{C output}}{\text{C Input}} \quad \frac{\text{Number of Total output in Kg}}{\text{Total Input Cost}}$$

$$\frac{1{,}000}{(69.3030E+3) + 750.00 + 400.00 + 3000.00} = \frac{1{,}000 \text{ Kg}}{74{,}673} = 0.01339\, Kg/Naira$$

$$= \frac{0.01339}{0{,}0119} \text{ X}100 = 112.52\%$$

(a) Total expenses for Alternative 3 formulation= $C_{\text{ingredient (optimal)}} + C_{fuel} + C_{labour} + C_{Packaging}$

(₦ 75,36454 E+3)+₦ 750.00 +₦ 400.00+ 3000.00 = ₦ 79,514.50

(b) %Cost of Ingredient for Alternative 3 Formulation = $\frac{75{,}364.5}{79{,}514.5} * 100 = 94.8\ \%$

(c) Profit from Alternative 3 Formulation = Total Revenue - Total expenses for optimal formulation

= 84,000 - 79,514.5 = ₦ 4,485.5

$$\textbf{\%Profit for Alt. 3 Formulation} = \frac{\text{Profit from Optimal Formulation}}{\text{Cost of Production}}$$

$$= \frac{4{,}485}{79{,}514.5} \times 100 = 5.64\%$$

(d) Calculating the Multi- factored productivity for alternative 3 using the formula specified in equation 16;

We have $\frac{84{,}000}{79{,}514} \times 100 = 105.6\%$

From the Total Output Cost which is calculated as *N * P*, we have our Unit produced per output to be,

$$\frac{\text{Number of Total output in Kg}}{\text{Total Output Cost}} = \frac{1000}{84{,}000} = 0.0119$$

$$P_{r\,(Alt\ 3)} = \frac{\text{C output}}{\text{C Input}} \quad \frac{\text{Number of Total output in Kg}}{\text{Total Input Cost}}$$

$$\frac{1{,}000}{(₦\,75.36454\,E+3)+750.00+400.00+3000.00}$$

$$=\frac{1{,}000\ Kg}{79{,}514}=0.0126\ kg\ Naira$$

$$=\frac{0.011}{0.0119}\ X100=92.4\%$$

(a)Total expenses for Alternative 4 formulation= $C_{\text{ingredient (optimal)}} + C_{\text{fuel}} + C_{\text{labour}} + C_{\text{Packaging}}$

= (₦ 82, 92020 E+3) + ₦ 750.00 +₦ 400.00+ ₦ 3000.00 = ₦ 87, 070

(b) % Cost of Ingredient for Alternative 4 Formulation =

$$\frac{82{,}920.02}{87{,}070}*100=95.2\ \%$$

(c) Profit from Alternative 4 Formulation = Total Revenue - Total expenses for optimal formulation

=84,000 – 87, 070 = ₦-3,070

$$\textbf{\%Profit for Alt.4 Formulation}=\frac{\text{Profit from Optimal Formulation}}{\text{Cost of Production}}$$

$$=\frac{-3{,}070}{87{,}070}\times 100=-3.52\%$$

(d) Calculating the Multi- factored productivity for alternative 4 using the formula specified in equation 16;

$$\frac{\text{Number of Total output in 25 Kg}}{\text{Total Input Cost}}*\text{Market Price per 25 kg}$$

We have, $\frac{84{,}000}{87{,}070}\times 100=96.5\%$

From the Total Output Cost which is calculated as *N * P,* we have our Unit produced per output to be,

$$\frac{\text{Number of Total output in Kg}}{\text{Total Output Cost}}=\frac{1{,}000}{84{,}000}=0.0119$$

$$P_{r\,(Alt\,4)}=\frac{C\ \text{output}}{C\ \text{Input}}=\frac{\text{Number of Total output in Kg}}{\text{Total Input Cost}}$$

$$\frac{1{,}000}{(₦\,82.92020\,\mathbf{E}+3)+750.00+400.00+3000.00}=\frac{1{,}000\ Kg}{87{,}070}=0.011\ Kg/Naira$$

$$\frac{0.011}{0.0119}\times 100=92.4\%$$

## Discussion

Table 1 show the results of the model when the data gotten was applied. The results are in 4 parts which are labelled alternative 1, 2, 3 and 4. The alternative 1 which has 1772.162 for its metabolizable energy ME and 70.31445 E+3 for its cost of ingredient shows the current price of the ingredient with a metabolizable energy that is lower than the range specified by the decision maker. This tells us that the alternative 1 is not applicable for a quality feed. We should remember that though we are trying to reduce cost, the energy requirement of the birds must also be give a preference in order to avoid poor yield performance.

Alternative 2 is the optimal among the four alternatives presented by the solution. This alternative comes with a reduced cost and a metabolizable energy that is within the fair range specified by the decision maker. Giving a feed with an adequate metabolizable energy guarantees high productivity of birds. The decision maker has a lot of challenges in situations of many alternatives with two or more objectives. He must make sure he gets his preference right for the purpose of selecting the optimal. Alternative 2 has presented a greater reduction in the cost of the feed when compared to the remaining three and the metabolizable energy specified while minimizing the cost is not out of place.

Alternative 3 also is a good result within a fair range. We cannot have more than one optimal solution in real life but there are things to be considered for our selection among competing need. In a situation where the birds need more energy for optimal yield especially during the cold weather, this could rescue the decision maker to have a feed that could satisfy the requirements of bird.

Alternative 4 is totally out of the considerable solution. The metabolizable energy is too high and this can cause increase in bird mortality if fed with that. Although, we have condemned the high metabolizable energy but the cost is also at the high side when compared to the other alternatives. It is not economical to use the 4th alternative for any reason because the cost led to a negative calculation which means loss and the metabolizable energy too is out of the range specified in the Table 3.

The total expenses spent on ingredients alone when using the alternative 1 and 2 formulation are 70,314. 45 and 69,303.01 respectively. From here the percentage of ingredient cost on the total expenses spent in overall production are 94.5% and 91.8% respectively. This justifies the earliest statement that the cost of ingredient in the poultry feed production takes the largest percentage when compared to other costs involved.

From the results obtained the estimated multi-factor productivity for alternative 1 and alternative 2 productions gave 111.32% and 114.4% respectively. Also, in the Tables 6-9 shows some of the estimations on each of the alternative solutions. This gives broad knowledge on how efficient the usage of the linear optimization programme.

Also, the different ways of measuring productivity treated in this research can help to keep track on the optimization techniques

| | $C_{\text{output}}$ | $C_{\text{ingredient}}$ | $C_{\text{fuel}}$ | $C_{\text{labour}}$ | $C_{\text{packaging}}$ |
|---|---|---|---|---|---|
| Estimate | **₦ 84,000.00** | **₦ 69.3030E+3** | **₦ 750.00** | **₦ 4,000.00** | **₦ 3000.00** |

**Table 6:** Summary of all cost estimate involved for alternative 2.

| | $C_{\text{output}}$ | $C_{\text{ingredient}}$ | $C_{\text{fuel}}$ | $C_{\text{labour}}$ | $C_{\text{packaging}}$ |
|---|---|---|---|---|---|
| Estimate | **₦ 84,000.00** | **₦ 75.36454 E+3** | **₦ 750.00** | **₦ 4,000.00** | **₦3000.00** |

**Table 7:** Summary of all cost estimate involved for alternative 3.

| | $C_{\text{output}}$ | $C_{\text{ingredient}}$ | $C_{\text{fuel}}$ | $C_{\text{labour}}$ | $C_{\text{packaging}}$ |
|---|---|---|---|---|---|
| Estimate | **₦ 84,000.00** | **₦ 82.92020E+3** | **₦ 750.00** | **₦ 4,000.00** | **₦3000.00** |

**Table 8:** Summary of all cost estimate involved for alternative 4.

| | Expenses | Profit | %Profit | Productivity Index |
|---|---|---|---|---|
| Alternative 1 | **₦ 75,464.50** | **₦ 8,535.5** | **11.3%** | 1.113 |
| Alternative 2 | **₦ 73,453.00** | **₦10,547** | **14.35%** | 1.144 |
| Alternative 3 | **₦79,514.00** | **₦4,485.5** | **5.64%** | 1.06 |
| Alternative 4 | **₦87,070.00** | **₦3,070** | **- 3.52%** | 0.96 |

**Table 9:** Summary of results.

adopted for the feed formulation. This will help the decision maker to be on track each time is adopting this bi-criteria approach for the feed formulation problem.

## Conclusions

The process of feed formulation is fundamentally a problem of optimization which involves selecting the best/optimal alternative, starting from a specified set of possibilities. The sets of possibilities presented in this work enabled the decision maker to forecast in advance ingredients required for each sets of possibilities. It should be noted that the alternative 2 provide a considerable trade-off in the presence of three other sets of possibilities. This is because it presented a greater reduction in the cost of the feed when compared to the remaining three and the metabolizable energy considerably alright. The advantage of this approach is that it provides flexible alternatives of criterion vectors. The decision maker must therefore be willing to sacrifice something; this is technically called making a trade-off. At this point the decision maker will now make a choice from the list, based on his preference and can therefore pick based on what he intend to achieve.

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