

Research Article

A Pearson-Network Approach to Animals' Feed Formulation

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Abstract

Ration formulation plays a crucial role in the profitability and sustainability of animal farming, particularly in developing economies like Nigeria, where feed costs can account for 60-80% of production expenses. Traditional methods such as the Pearson Square and matrix techniques are limited in flexibility, scope, and ability to handle multiple constraints. This study introduces a novel approach by integrating graph theory (network models) with the Pearson Square method to develop diverse, cost-effective, and nutritionally balanced animal feed rations. Using secondary data from agricultural by-products sourced predominantly from Benue State, Nigeria, a directed multi-stage network was constructed with 50 vertices (ingredients) and 237 edges (ingredient interactions), representing nine stages of feed formulation, ranging from energy and protein sources to vitamins and minerals. The developed model generated over 30,000 unique feed formulations. Analytical results showed average nutritional outputs of metabolizable energy at 28g 6.86 kcal/kg, crude fibre at 8.13%, dry matter at 80.75%, nitrogen at 34.33%, and calcium at 0.28%, all within acceptable ranges for animal nutrition. The model offers flexibility to accommodate cultural and regional ingredient restrictions and addresses feed preservation concerns. This research demonstrates the potential of network optimization techniques in enhancing ration formulation processes in animal agriculture.

Keywords

Network Model, Graph Theory, Pearson Square Method, Feeds Rations, Feed Formulas, Network Analysis, Mathematical Feed Formulation

1. Introduction

Ration can be considered the summative feed given to the organisms on a systematic routine.

Ration construction/formulation can be characterized as the sequence by which diverse feed fixings are combined in a ratio needed to give an organism an appropriate sum of nutrients required at a specified phase of production. But feed cost in feeding these animals is the single important factor determining the profitability of animal farming on a com-

mercial basis. It has been projected that the cost of feeding contributes 60-80% of the variable costs of milk, meat, and poultry production. With the world's increasing population, there is an ever-increasing demand for animal proteins such as milk, meat, eggs, and other animal products. This resulted in the revolution of animal enterprises such as commercial dairy, meat, and poultry farms all over the world, including Nigeria. The commercial enterprises and the small-scale animal hold-

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Received: 6 May 2025; **Accepted:** 27 May 2025; **Published:** 19 September 2025



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ers need optimization of profit with limited investment on feeding cost as a major cost of livestock production. In other words, if a producer can reduce feed costs, it is likely to make more profit from animal agriculture [1].

The Benue state of Nigeria is the food basket of Nigeria with several crop agricultural products and their by-products are been wasted yearly which can be converted into a series of varieties of feeds for all kinds of animal agricultural and aquatic life feeds [7, 8], which is one of the reasons we carried-out this research work.

Several techniques in the past have been used to construct/formulate animal feeds such as the Pearson Square method but have a major shortcoming of not handling inequalities, ranges, also the solutions are independent of the price of the feed ingredients and can balance only two ingredients at a time and so has restricted application in diet formulation as solution demand balancing many nutrients at a time [9, 10] But in the work of [11], the Pearson Square method was used to balance more than two ingredients and yielded good results. The matrix technique was used to elucidate nutrient requirements using two different feed ingredients [12]. The simultaneous equations and matrices technique were also used but required a skillful knowledge in advanced mathematics, so it is rare among the end-users [13]. The trier-and-error technique is very common among the people who formulate poultry rations: the formulation is manipulated until the nutrient requirements are achieved, consequently, it is laborious and takes a lot of time to arrive at a fairly suitable solution [1]. The linear programming (LP) in ration formulation came into existence in the late 1960s. The experience of LP application over years proved that LP alone is not sufficient to solve the complicated demands of nutritional needs, e.g. animals not only have to be fed the least cost proteins, energy, and minerals but also the excess feeding has to be minimized to prevent excess excretion of nitrogen, minerals, and emission of potentially harmful greenhouse gases such as methane which cause environmental pollution [13]. LP is not equipped to handle such issues due to the inherent rigidity of constraint deviation and other limitations in the equation [1]. The current trend is to integrate the advantage of LP and different other optimization programming for solving the varying nutritional problems. Other mathematical programming used for feed formulation are goal programming, (multi-objective programming), multi-objective fractional programming, non-linear programming chance-constrained programming, quadratic programming, risk formulation, and genetic algorithm [1]. In this research work, we introduce the use of network model (graph theory) combined with the Pearson Square method used in work of

[11]. These two methods combined, explicitly handled the variation in ration ingredients and number of different rations formulated with a given number of ingredients.

According to [3, 4], graph $G = (V, E)$ is the pair(s) of vertices (nodes) V connected with a set(s) of edges E assuming finite i.e. $|V| = n$ and $|E| = m$, where $V(G) = \{v_1, v_2, v_3, \dots, v_n\}$ and $E(G) = \{e_1, e_2, e_3, \dots, e_n\}$. [2, 4] added that Euler started graph theory when he was asked to find a nice path across the seven Konigsberg bridges in 1735. This problem leads to the concept of the Eulerian graph. Applications of the graph cannot be enumerated due to its wide usage and demand in several spheres of life, particularly in agriculture, production, engineering, telecommunication, computer science, transportation, project management, and others. [6] stated 45 applications of the network including the fields of engineering, agriculture, education, production, telecommunication, computer science, transportation, project management, and others. [6] further added that everything is a graph, that is, whenever we look at the interactions between things, a graph is formed implicitly. There are many different employments of graph theory, although some of them are a bit unnatural. Yet, it turns out that graphs are at the very basis of many things, ideas, and procedures in everyday life.

Some studies further stated that, in both crops and animals' agriculture, graph has a lot of applications such as precision agriculture, project management, electrification, fertilizer application, locating of moving objects in the farm/fish ponds, autonomous agriculture, etc [5, 6]. With the existing applications both in agriculture and several spheres of life, we extended the graph applications to animal feed formulation by combining it with Pearson Square method in other to generate different feeds composition (network analysis).

2. Materials and Methods

The ingredients' charts used in this research work were adopted from [1, 9], where most of the ingredients were crop and animal agriculture by-products, see Table 1. These ingredients were classified according to their crude protein and energy content as shown in Table 2, which is secondary data and constitutes the data for developing the network model in Figure 1. This network model was designed using the network type of multiple sources to a single destination, a directed network model. The Pearson Square Method was combined with the network optimization; the Pearson Square Method was used to get the individual ingredient crude protein constituent in each formula, whereas the network optimization was used to react different individual ingredients with several others without repetitions.

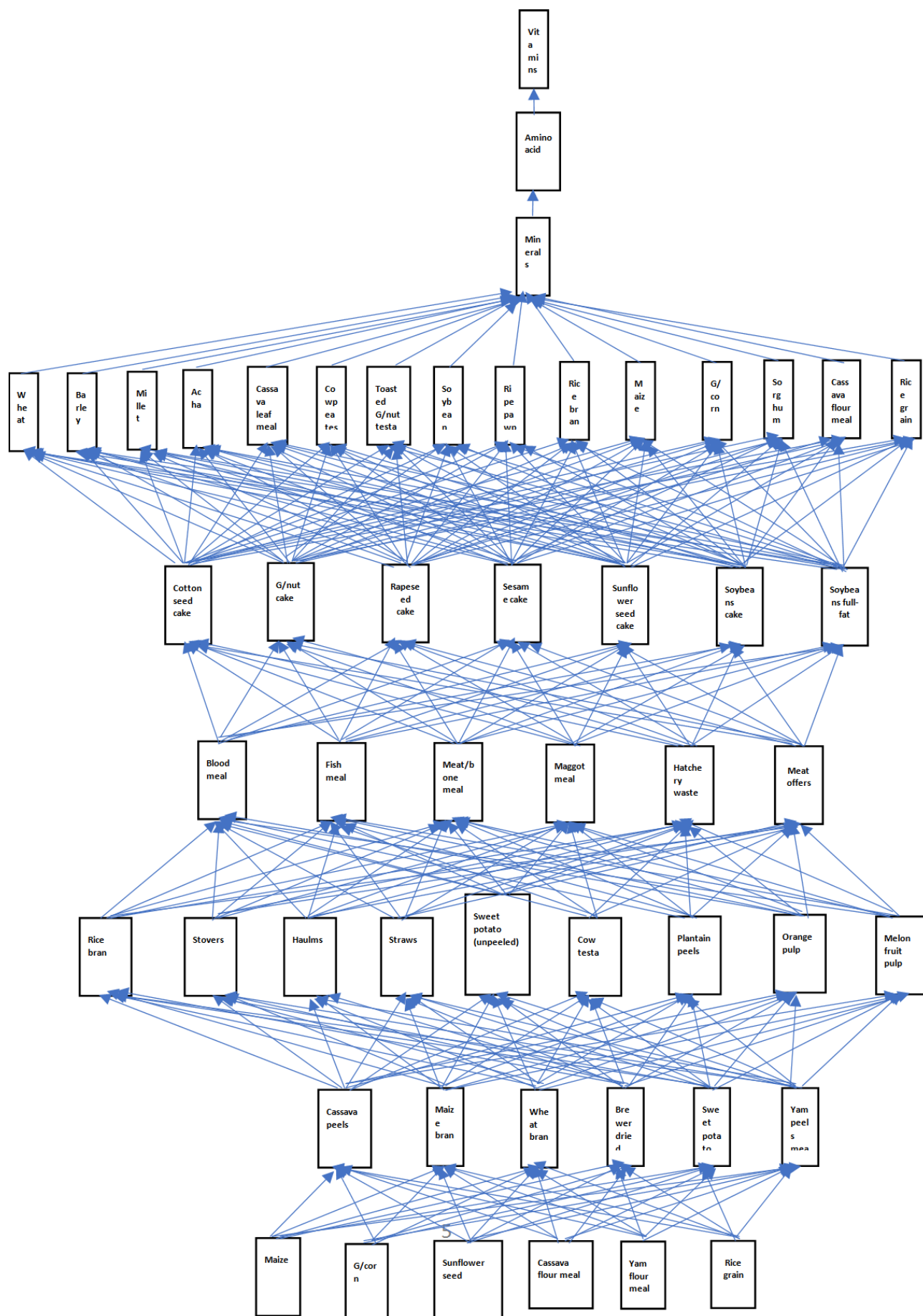


Figure 1. Animal Feeds' Ingredients Interaction Network.

Table 1. Ingredients with their compositions.

S/N	Ingredients	CP	Availabil- ity (%)	Dry Matter	Ether Extract	Crude Fibre	Nitro- gen	Energy	Ca	Phos- phorus	Hy- giene	Methi- onine
1	Maize (Yellow)	8.8	60	89.60	4.8	1.9	67.58	3333	0.02	0.27	0.20	0.15
2	Sorghum (red)	8.0	60	90.00	3.0	5.0	0	3300	0.04	0.32	0.21	0.16
3	Sunflower seed	41.0	10	93.00	7.60	21.00	4.89	2310	0.43	1.00	2.00	1. 60
4	Wheat	13.5	5	88.00	1.9	3.00	0	3035	0.05	0.41	0.40	0.25
5	Millet	12.00	5	90.0	4.2	1.8	70.07	3440	0.05	0.30	0.35	0.28
6	Cassava Flour Meal	3.10	80	89.42	0.99	3.73	89.90	3090	0.14	0.37	0.07	0
7	Rice Grain (Broken)	8.50	20	89.00	0.60	0.20	88.4	3472	0.32	0.34	0.32	0.25
8	Rice Bran	13.50	70	91.00	5.90	13.00	30.23	2040	0.10	1.70	0.50	0.17
9	Sweet Potato	2.76	20	94.25	1.87	1.20	90.68	0.60	0.02	0.03	0.23	0.09
10	Cowpea Taste	16.97	30	95.75	2.65	2035	4.58	1005	2.06	6.31	0	0
11	Plantain peels	14.03	2	91.29	5.74	4.72	10.71	1367	0.10	0.34	0	0
12	Orange Pulp	0	20	89.48	6.78	9.45	0	1049	0	0	0	0
13	Melon fruit pulp	8.48	10	93.50	4.17	31.06	14.01	1148	0	0	0	0
14	Cassava Peels	5.33	80	87.59	1.81	14.25	70.37	2807	0.65	0.25	0	0
15	Maize Bran	10.2	60	90.9	4	7.8	.	41.50	2.7	3	6.2	2
16	Wheat Bran	14.8	20	89.00	4.00	10.60	41.29	2320	0.14	1.17	0.60	0.20
17	Brewer dried grains	1.60	30	84.30	6.80	13.80	53.70	0	0.08	0.10	0.56	0.20
19	Sweet Potato Peels	5.8	20	40.0	0.54	1.20	90.68	3596	0	0	0	0
20	Yam Peels Meal	11.74	20	25.87	1.01	6.56	71.2	3009	0.38	0.1	0	0
21	Blood Meal	80.00	40	89.00	1.00	1.0	5.09	3220	0.28	0.22	6.90	1.0
22	Fish meal	65.00	20	92.00	8.50	0.40	22.35	2646	3.00	1.8	3.00	0.90
23	Meat/bone meal	52	20	92	0.	0.	0	2910	1001	04.8	1.5	2.7
24	Maggot meal (dried)	60	40	88.5	19.00	0.50	0	0	0.20	0.20	3.60	1.40
25	Meal Offals	56.5	20		8.0	0.4	4.8	1287	1.7	2.0		
26	Cottonseed	23	2	92	19	26	0	1900	1.19	0.16	0.4	1.02
27	Meal	42		90	3	8.0	21.45	2550	0.20	0.20	1.60	0.48
28	G/nut cake	40	80	90.0	6.0	8.0	17.01	2640	0.20	0.20	1.60	0.48
29	Sesame Cake	42	30	94.0	7.0	6.50	3.67	2255	2.00	1.3	1.37	1.48
30	Soybean's cake	48	70	89	1.7	3.0		4210	02	0.65	6.11	1.34
31	Soybeans	37	70	92	18	5.5	19.12	3100	0.20	4.50	2.25	0.49
32	PKC	21	30	90	4.40	17.5	0	2500	0.40	0.50	0.69	0.32
33	Cassava leaf meal	23.79	80	92.06	6.83	17.7	40.46	2856	1.24	0.6	1.04	0
34	Toasted G/nut Taste	18.98	80	99.00	10.00	10.00	0	912	0	0	0	0

Sources: [9].

Table 2. Ingredients classification based on Energy, Crude protein, Mineral, Amino Acid and Vitamins percentage level.

High Energy	Medium Energy	Low Energy	High crude Protein	Medium crude protein	Low crude protein	Minerals	Amino Acid	Vitamins
Maize, G/corn (Sorghum), Sunflower seed, Wheat, Barley, Millet, Acha, Cassava flour meal, Yam and Rice grain.	Cassava peeling, Maize bran, Wheat bran, Brewer dried grains, Sweet potato peeled and Yam peels meal	Rice bran, Stovers, Haulms, Straws, Sweet potato (un-peeled), Cow testa, Plantain peels, Orange pulp and Melon fruit pulp.	Blood meal, Fish meal, Meat/bone meal, Maggot meal, Hatchery waste (dead embryo) and Meat offers	Palm kernel cake, Cotton-seed cake, G/nut cake, Rapeseed cake, Rapeseed meal Sesame cake, Sunflower seed cake, Soybean cake and Soybean full-fat.	Cassava leaf meal, Cowpea testa, Toasted G/nut testa, Soybean testa, Ripe pawpaw seeds and Rice bran	Bone ash, Limestone, Monocalcium phosphate Salt, Shells grit, Oster shells, Di-calcium phosphate, Iron extreme and Common sand.	phenylalanine, valine, threonine, tryptophan, isoleucine, methionine, histidine, arginine, leucine and lysine.	vitamins A, C, D, E, K, and the B vitamins (thiamine, riboflavin, niacin, pantothenic acid, biotin, B ₆ , B ₁₂ , and folate)

3. Results

From the developed network in Figure 1, the analyses were carried out to determine how many variants of feed formula could be generated from the network with their constituents and also determine the best (optimal) feed among all produced. The total number of feeds formulated in the network is given in equations (1) and (2):

$$f(x) = X_1 \times X_2 \times X_3 \times \dots \times X_{n-1} \times X_n \quad (1)$$

$$f(x) = \prod_1^n X_i, \forall X_i \geq 1 \quad (2)$$

Where

$f(x)$ = total number of feed rations generated from a network

X_1 = number of states in the first stage

X_2 = number of states in the first stage

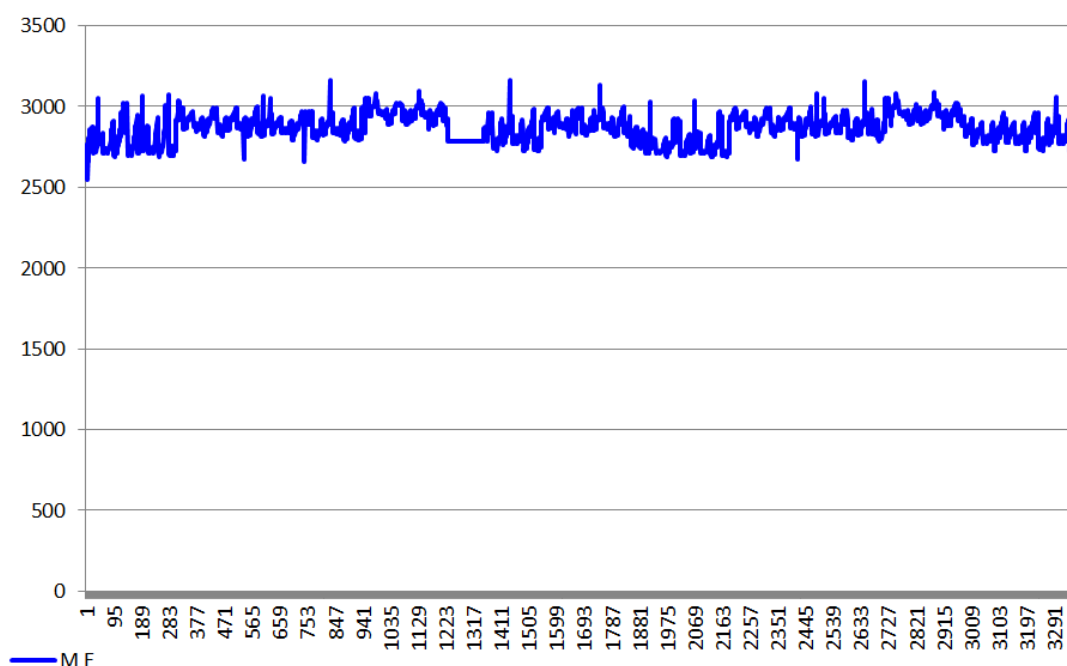
X_3 = number of states in the first stage

$\vdots$

X_{n-1} = number of states in the $(n-1)^{\text{th}}$ (second to the last) stage

X_n = number of states in the n^{th} (last) stage

The results obtained are depicted in the following tables and figures:

**Figure 2.** Metabolizable Energy Content in the Formulated Feeds.

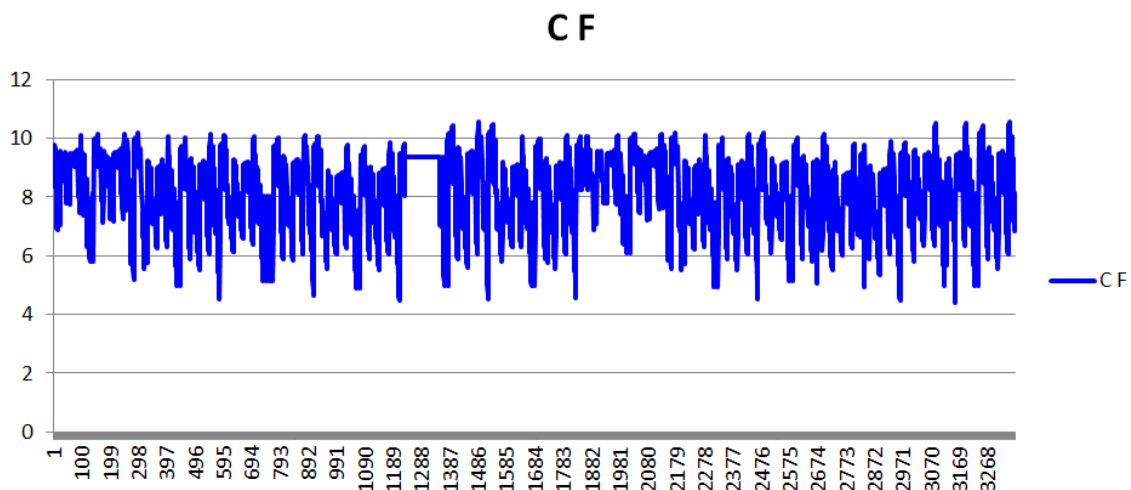


Figure 3. Crude Fibre Content in the Formulated Feeds.

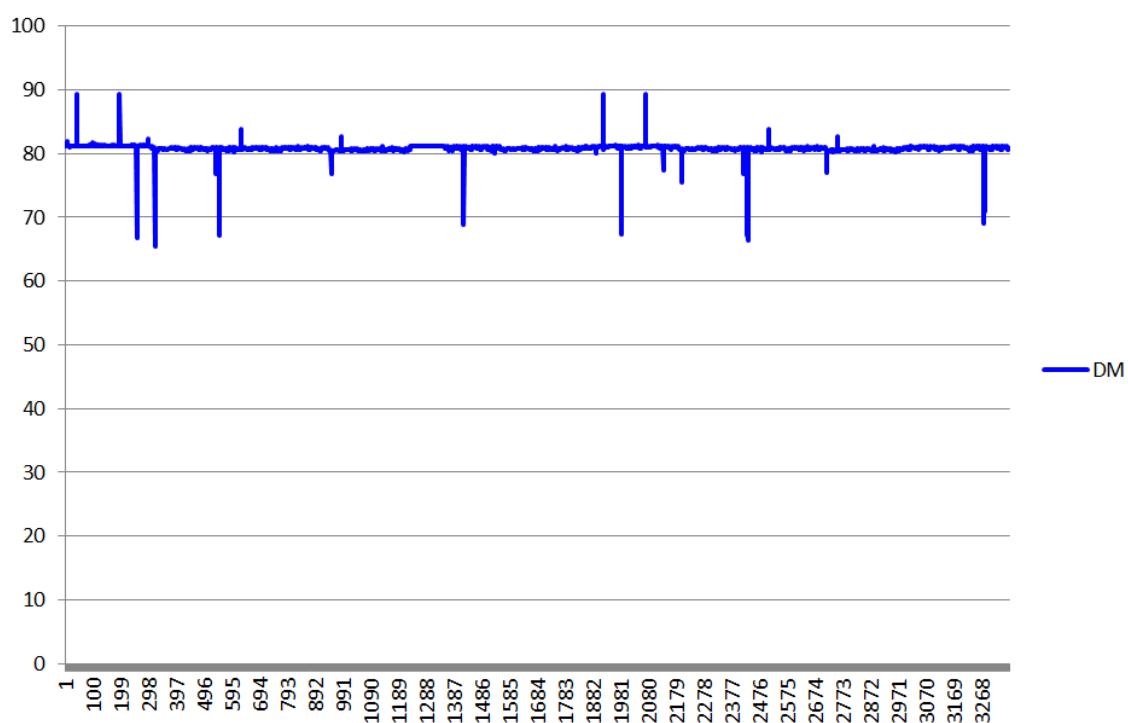


Figure 4. Dry Matter Content in the Formulated Feeds.

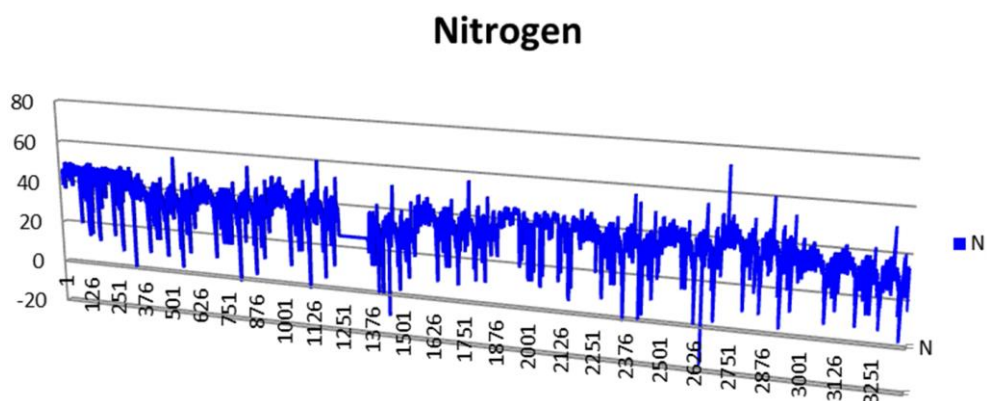


Figure 5. Nitrogen Content in the Formulated Feeds.

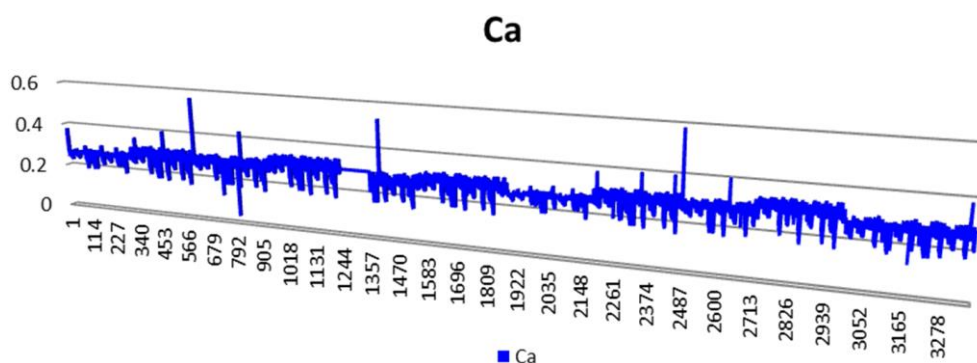


Figure 6. Calcium Content in the Formulated Feeds.

4. Discussion

From the foregoing, over 30,000 feed formulas were formulated using the single network with 50 vertices and 237 edges. The 50 vertices which are the sum of the ingredients consisting $X_1 = 6$ ingredients as the sources with high energy, $X_2 = 6$ ingredients in the second stage with average energy, $X_3 = 9$ ingredients in the third stage with low energy, $X_4 = 6$ ingredients in the fourth stage with high crude protein, $X_5 = 7$ ingredients are in the fifth stage with average crude protein, $X_6 = 15$ ingredients in the sixth stage with low crude protein and also with stages seven, eight and nine of minerals, amino acids and vitamins respectively using equation (1) and (2). The 237 edges are the sum of interactions between the ingredients.

From figure 2, figure 3, figure 4, figure 5 and figure 6, the feed rations generated using the proposed method yielded the following averagely respectively:

1. Metabolizable energy: 2866.86kcal/kg
2. Crude fibre: 8.13%
3. Dry matter: 80.75%
4. Nitrogen: 34.33%
5. Calcium: 0.28%

These outputs are all within the range as agreed in the works of Batal and Dale (2011) and Nombor (2007).

These formulae were designed bearing in mind that these ingredients vary from one location to another and in addition, they were designed bearing also that some of the ingredients are forbidden in some religions/cultures, that is, even touching them is taboo, for instance, blood meal. Therefore, where they are not forbidden, they should be used whereas other alternative formulas that do not contain them but other ingredients available should be used. Also [9] noted that, feeds that are going to be stored for a long period should avoid using ingredients such as blood meal, fish meal, etc due to it high content of fat which serves as the breeding site for harmful micro-organisms.

5. Conclusion

Conclusively, the graphical approach was combined with the Pearson square method was applied and a mathematical model

for determining the total number of feed rations in the network was developed, with over 30,000 feed formulas formulated using the single network with 50 vertices and 237 edges and also with nine stages of ingredients. The feed rations generated from the network analysis yielded the following averages:

1. Metabolizable energy: 2866.86kcal/kg
2. Crude fibre: 8.13%
3. Dry matter: 80.75%
4. Nitrogen: 34.33%
5. Calcium: 0.28%

Abbreviations

CP	Crude Protein
Ca	Calcium
G/corn	Guinea Corn
G/Nut	Ground Nut

Conflicts of Interest

The authors declare no conflicts of interest.

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