Application of Mixture Experiments in Poultry Feed Formulation

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Abstract

The quality, components, proportions and storage of feeds is critical in poultry farming. The rising prices and poor quality of feeds has constantly led to low returns due to low final weights among birds. The study applied the theory of mixture experiment designs in the formulation of feed to establish a model which farmers can apply in their formulations. D-determinant, E-Eigen value, A-average variance and T-trace optimality criterions were applied in selecting appropriate design between simplex lattice and simplex centroid mixture designs. The designs selection criterions rankings had equivalence at 1.5. Selection based on the fewer experimental runs, where SLD had 6 and SCD had 7, led to the choice of SLD. This was applied in the formulation of poultry feed. The three carbohydrate components were whole maize meal, rice and wheat each at 51.7 kg for pure blends and 25.85 kg for binary blends were being varied against the base or primary ingredient of proteins (13.3 kg, 19 % DCP) and vitamins and minerals concentrate of 5kg in a 70kg chick mash. Growers mash had the variation of the three carbohydrates each at 51.1 kg for pure blends and 25.55kg for binary blends. This was against the base ingredient of proteins (11.9kf, 17 % DCP) and concentrate of 7kg. Final weights data were analyzed using second order models as it was an optimization study. The effects of the feed proportions of the mixture on the final weights were analyzed using the mixture regression method in R software package. The mixture models were used to create contour plots of the final weights and used proportion of components. Protein bases models (soya meal, cottonseed cake and fish meal) were obtained and compared using F-statistics and R^2 of 98.74 %, 99.24 % and 99.98 % respectively. The Fish meal model (99.98 %) was selected. Under fish meal, the varied proportions of carbohydrates, demonstrated that in the single component mixtures, whole maize component gave the highest final weight while binary blends a combination of whole maize and wheat gave the highest final weights among the other mixture combinations in the experiment.

Key words: simplex lattice, feed formulation, mixture experiment, optimality criterion, simplex centroid, moment matrix, contour plots

INTRODUCTION

Poultry farming involves raising of domesticated birds such as chickens, geese, turkeys, and ducks. It is a popular business venture throughout the world, dating back to pre-historic times. It is practiced in so many parts of the world as long as the climatic conditions are in favor of their raring (Heos, 2014). Poultry provides a vast supply of food throughout the world with a steadily increasing demand. Furthermore, poultry farming is not affected by religious beliefs. The extent of poultry farming is lower in developing countries than developed countries due to the low purchasing power in developing countries (Vernooij *et al.*, 2018). Poultry farming in Africa has significantly grown over the years as a result of economic growth in the continent.

Poultry production plays a significant part of the agricultural sector in Kenya. In most developing countries, approximately all families at the village level even those who do not own land practice poultry farming. Chicken production is trending among profitable businesses due to the demand for chicken in big hotels and restaurants. In rural areas it has a significant role in reducing poverty and enhancing food security. The small-scale poultry production established in the rural areas enhances food availability .This is as a source of food in terms of consumption of eggs and the meat and also indirectly promotes women empowerment (Wong *et al.*, 2017).

To achieve satisfactory results in any field of production, the minimum cost of production leads to maximum yield. Poultry production depends on the type of feeds or feed rations that are safe and of standard quality. When farmers can formulate their feed, they save up to 80 percent of the total production costs. However, these feeds are becoming increasingly expensive, leading to farmers searching for effective methods of formulating their own acceptable and nutritious feeds.

There have been no proper policy guidelines in the feeds industry, but the department of livestock is addressing this through policy formulations and once done, farmers will reap more as the policy becomes operational (Andae, 2017)..

Feed ration formulation refers to measuring the various ingredients in amounts necessary to offer the birds with the recommended quantity of nutrients required at the different stages of growth. It involves measuring the amounts of feeds to be combined and balanced enough to supply all the required nutrients. Before feed formulation, any experimenter should consider factors such as ingredients to be used regarding nutritional value and constraints, nutrients requirements at the different growing stage, the cost and accessibility of the ingredients (Poultry Hub, 2019). Therefore, one of the importance of performing a mixture experiment is to determine the best proportion of each component and the optimum value of each process variable. Formulation of the poultry feed ration guarantees the farmer of quality because some manufacturers may not be following the recommended standards. These feeds can lead to slow growth, diseases and infections, and low production or even death. It reduces the overall cost of production since it is cheap, and the ingredients are locally available at low prices within the farms (FAO, 2010).

The use of an experimental design enables the study of the impact of different features of formulation and production method on the formulation process, thus minimizing the number of trials (Suhesti, 2016). Clear text with numerous examples has provided an all-round discussion of theory and practice (Cornell, 2011). In a given mixture problem, the main attribute that holds is that the proportion must add up to one. Three major designs that can be used during the formulation process comprise of Simplex lattice (SLD), simplex centroid (SCD), and axial designs (AD). Simplex lattice entails an ordered arrangement of uniformly spaced distribution of points referred to as a lattice.

The ultimate goal of every small and large scale poultry farmer has been rearing their chicks to a certain age then they wait for buyers who come routinely to buy their chickens. At this time, the price depends on their weight, and they realize the profit was smaller due to the low weight of their chicken. This low weight has been leading to low income to the farmers who depend on this venture as a source of income. It further translates to poor livelihoods of the farmers and middlemen who get small profits. The final consumer would not get the good value of the product, which still related to food insecurity in the long run.

There's need to regulate animal feeds traders to ensure they follow the recommended feed formulation standards when making their own formulations. Finally, there is a need to encourage greater utilization of mixture techniques in agricultural research and development. Therefore this study aimed at applying mixture experiments designs in the formulation of poultry feed for modeling the weight of chicks. Specific objectives were to compare the three-factor simplex lattice and simplex centroid mixture designs with respect to the D-, A-, E-, T- optimality criteria, to formulate poultry feed using the selected three-factor mixture design and to develop a model for optimizing chick weight based on poultry feed formulation.

METHODOLOGY

This study applied mixture experiments to poultry feed formulation. It examined the effect of varying different proportions of carbohydrates aimed at evaluating what combination would yield maximum weight gain in chicks. This involved holding the proportion of vitamins, proteins, and minerals constant but varying different types of carbohydrates. It looked at working out a model that could be recommended to farmers for their own formulations.

Methods

The researcher obtained plywood for partitioning small brooders for the different mixture types, feeder troughs, automated water drinking system, weighing scales for components and for weighing birds and the components used in formulation. The ingredients that were used in the study were wheat, whole maize, soya meal, cotton seed cake, fish meal (Omena), rice and a concentrate of vitamins and minerals. The concentrate had accretions such as vitamins and minerals, ensuring that the ration had met the recommended daily nutrient requirements. The study used 90 Rainbow Rooster type of improved indigenous chicken variety. This was because they have fast maturity, have higher resistance against many poultry diseases, and its meat has low fat hence on high demand in the market.

A poultry house was constructed following the recommended spacing of 550 cm2 per bird. Within the poultry house, 18 circular brooders were constructed of plywood for the 18 different types of mixtures. They had labels on each brooder for easy identification when giving specific feed rations of the formulated mixtures. The experiment was carried out from 2 Feb 2019 to 2 April 2019 in a poultry farm in Marura locality of Moiben sub-county of Uasin Gishu county, Kenya. It was one kilometer from the Eldoret-Iten highway, opposite Equator Flowers Company. The land had access to electricity for lighting and access to municipality water for use in the farm with a stand by water borehole.

Design Selection

The D-Determinant, E-Eigen value, A-Average Variance and T-Trace optimality criterion were applied in the selection of simplex lattice design, which was used in the study due to its efficiency in design selection. Formulations were done in two phases. First, the formulation of chick mash for the first four weeks of the study, followed by the formulation of growers mash for the last four weeks of the study. Weight in grams was recorded every seventh day of the week until the eight weeks of the study were over.

In this study, it involved varying the three easily obtained or accessed and frequently used carbohydrate components whole maize (X1), rice (X2) and wheat (X3). The criterion worked based on the determinant (D), average variance (A), Eigen value (E), and Trace (T) of the formed moment matrix. The respective experimental design forms a moment matrix by multiplying the transpose of its matrix by its initial matrix and dividing by the number of experimental runs. This is preceded by obtaining its determinant, average variance, Eigen value, and the trace of the three moment matrices of the three designs were obtained using the Microsoft Excel and R software. It was followed by ranking them whereby the design with the minimum determinant was ranked first as others follow. Similar ranking approach was used in the design with the lowest average variance, minimum Eigen value, and the minimum trace. A design with the minimum value ranking would be applied in the formulation experiment.

Ration Formulation

The recommended daily crude protein for chick mash is 18-20 %. For the 70kg bag, 19% will be a protein which was constitute of soya meal, cotton seed cake, and fish meal. Vitamins and minerals constituted 5.0 kg to make the base component to be 18.3kg. The remaining 51.7 kg is what was experimented on by varying different proportion of three carbohydrates, namely whole maize, rice, and wheat. The three ingredients were identified as variables x1 , x2 and x3 respectively and were included in the experimental design, while keeping the other ingredients at a fixed level of 18.3kg (13.3 kg proteins, 5.0kg vitamins and minerals concentrate) in the feed formulation.

The total number of birds that were used in the study was 90. Five birds for each of the 18 mixtures. The three protein bases had 6 mixture types as per the SLD design points making the up the 18 mixtures.

Table 1: 18 Chick Mash Carbohydrate Variations per Mixture in Each Protein Base Component in kgs

Cotton	seed	base	protein	Soya	Base	protein		Fish	meal	base	protein
	Maize	Rice	Wheat		Maize	Rice	Wheat		Maize	Rice	Wheat
M1	51.70	0.0	0.0	M1	51.70	0.0	0.0	M1	51.70	0.0	0.0
M2	25.85	25.85	0.0	M2	25.85	25.85	0.0	M2	28.85	25.85	0.0
M3	0.0	51.70	0.0	M3	0.0	51.70	0.0	M3	0.0	51.70	0.0
M4	25.85	0.0	25.85	M4	25.85	0.0	25.85	M4	25.85	0.0	25.85
M5	0.0	25.85	25.85	M5	0.0	25.85	25.85	M5	0.0	25.85	25.85
M6	0.0	0.0	51.70	M6	0.0	0.0	51.70	M6	0.0	0.0	51.70

Table 2: 18 Growers Mash Carbohydrate Variations per Mixture in Each Protein Base Component in kgs

Cotton	seed	base	protein	Soya	Base	protein		Fish	meal	base	protein
	Maize	Rice	Wheat		Maize	Rice	Wheat		Maize	Rice	Wheat
M1	51.10	0.0	0.0	M1	51.10	0.0	0.0	M1	51.10	0.0	0.0
M2	25.50	25.50	0.0	M2	25.50	25.50	0.0	M2	25.50	25.50	0.0
M3	0.0	51.10	0.0	M3	0.0	51.10	0.0	M3	0.0	51.10	0.0
M4	25.50	0.0	25.50	M4	25.50	0.0	25.50	M4	25.50	0.0	25.50
M5	0.0	25.50	25.50	M5	0.0	25.50	25.50	M5	0.0	25.50	25.50
M6	0.0	0.0	51.10	M6	0.0	0.0	51.10	M6	0.0	0.0	51.10

Final weight data collected was analyzed to come up with a proposed model for describing the shape of the response surface over the simplex factor space. It also determined the roles played by the individual components. The fitted model for the three components fitted was of the form,

$$\hat{y}(x) = b_1 x_1 + b_2 x_2 + b_3 x_3 + b_{12} x_1 x_2 + b_{13} x_1 x_3 + b_{23} x_2 x_3 \quad \text{.......................................(1)}$$

$\hat{y}(x)$ represented the predicted response from a mixture, i.e., final chick weight. The b's symbolizes the estimated coefficient via regression. X_1 , x_2 and x_3 were the carbohydrates proportions of whole maize, rice and wheat respectively. b_1 to b_3 were estimates of the response from feed with single ingredient. b_{12} to b_{23} represent the interaction effects for each of the two-component mixtures

The mixture model was used to create a contour plot and response trace plot of the chick weights. The optimum feed proportions in the feed mixture for maximum weight gain was estimated by response optimization analysis done using the R software package. The ANOVA of the model analysis was used to show if the components of the model were significant. If there was need for model simplifications, then it would be done by eliminating the non-significant terms in the model. Having obtained three models from the three different protein base components, they would be evaluated based on their respective R squared and adjusted R squared and F-statistics to select and recommend one model to the poultry farmers.

RESULTS AND DISCUSSION

Design Selection

When selecting a design from the two major mixture experiment designs, simplex lattice (SLD) and simplex centroid (SCD), it involved the application of D-, A-, E- and T-optimality criterions.

Simplex lattice design has six experimental runs or design points. This was used to create the 6 by 6 design matrix and a moment matrix. A moment matrix (M) is a special symmetric square matrix whose rows and columns are indexed by a polynomial with one term and plays a vital role in polynomial optimization. It is formed by multiplying the transpose of the main matrix by the initial matrix and dividing by the number of experimental runs which in this case was six.

$$M=1/96\begin{bmatrix} 24.0 & 4.0 & 4.0 & 2.0 & 2.0 & 0.0 \\ 4.0 & 24.0 & 4.0 & 2.0 & 0.0 & 2.0 \\ 4.0 & 4.0 & 24.0 & 0.0 & 2.0 & 2.0 \\ 2.0 & 2.0 & 0.0 & 1.0 & 0.0 & 0.0 \\ 2.0 & 0.0 & 2.0 & 0.0 & 1.0 & 0.0 \\ 0.0 & 2.0 & 2.0 & 0.0 & 0.0 & 1.0 \end{bmatrix}$$

Using the appropriate R software commands, the determinant, average variance, Eigen value, and trace of the moment matrix were obtained.

Table 3: Obtained Features of the Criterion

Criterion	Simplex Lattice Design	Simplex Centroid Design
D	5.232781e-09	8.169518e-26
A	0.005126973	1.431840e-17
E	0.78125	0.8292364
T	75	593.8212

This was followed by ranking of criterions as shown in Table 4.

Table 4: Ranking of Criterions

Criterion	Simplex Lattice Design	Simplex Centroid Design
D	2	1
A	2	1
E	1	2
T	1	2
Average Value	1.5	1.5

The criterions gave equivalence in ranking at 1.5 per design. However, Simplex lattice design was selected due to the fewer number of experimental runs hence less costly in implementation as compared to simplex centroid mixture design.

Application of Simplex Lattice Mixture Design in Poultry Feed Ration Formulation

Chick Mash Ration Formulation

The major constituents for the mixture design were whole maize, wheat, and rice carbohydrate sources. The protein sources were a fish meal, soya meal, and cottonseed cake. This study was based on the digestible crude protein, DCP, as the basic nutritional requisite. Given the nutritional requirements for day old to 4 weeks old chicks, its DCP should be in the range of 18% to 20%.

Growers Mash Ration Formulation

The pullets were now 4 weeks old and were supposed to be given ration with a DCP in the range of 16% to 18%. This allowed them to grow much faster towards the ideal expected market final weight. The total amount of carbohydrates, to be assembled before mixing, were whole maize, rice and wheat each at 102.2 kg. Taking the protein percentage to be 17 % in a 70 kg, there was 11.9 kg of protein with 7 kg of vitamins and minerals concentrate. Therefore the remaining 51.1 kg was what had varied proportions of carbohydrates.51.1kg for pure blends and 25.55kg for binary blends.

Exploratory Data Analysis

To get a better explanation and understanding of the features of the specific data set of final weights, summary statistics were run as follows;

(i) **Cotton Seed Cake Protein Summary Statistics**

Table 5: Cotton Seed Cake Protein Final Weights' Descriptive Statistics

Mixture	Maximum weight (g)	Minimum weight (g)	Mean weight (g)	Standard deviation	Coefficient of variation (%)
M1	1798.97	1459.15	1549.64	140.51	9.07
M2	1871.92	1277.26	1623.56	221.96	13.67
M3	1743.61	1298.88	1554.80	194.98	12.54
M4	1629.16	1346.19	1505.59	117.15	7.78
M5	1706.23	1296.5	1421.68	165.86	11.67
M6	1685.54	1162.21	1468.20	262.16	17.86

(ii) **Soya Meal Protein Summary Statistics**

Table 6 : Soya Meal Protein Descriptive Statistics

Mixture	Maximum Weight(g)	Minimum Weight(g)	Mean Weight(g)	Standard deviation	Coefficient of variation (%)
M1	1747.64	1361.04	1508.94	160.16	10.61
M2	1698.71	1342.44	1594.51	146.35	9.18
M3	1689.52	1165.66	1500.12	207.31	13.82
M4	1539.32	1343.49	1460.45	72.29	4.95
M5	1631.68	1465.63	1465.63	146.28	9.98
M6	1691	1299.52	1472.30	154.99	10.53

(iii) **Fish Meal Protein Summary Statistics**

Table 7 : Fish Meal Descriptive Statistics

Mixture	Maximum Weight(g)	Minimum Weight(g)	Mean Weight(g)	Standard deviation	Coefficient of variation (%)
M1	1396.12	1350.38	1369.26	17.20	1.26
M2	1394.36	1351.43	1376.37	19.48	1.42
M3	1399.88	1342.28	1358.70	23.87	1.76
M4	1394.15	1347.29	1382.19	19.65	1.42
M5	1399.47	1345.06	1367.47	23.27	1.70
M6	1400.05	1345.76	1379.76	22.33	1.61

Model Approximation and Evaluation

(i) Model one (Cotton Seed Cake Base Protein)

Table 8: Cotton Seed Cake Protein Model Estimates

Coefficients	Estimate	Std. Error	T value	P value	Significance
X_1	1549.64	85.05	18.221	<0.05	***
X_2	1554.80	85.05	18.282	<0.05	***
X_3	1421.68	85.05	16.716	<0.05	***
X_1X_2	285.35	416.64	0.685	0.500	
X_1X_3	-69.82	416.64	-0.168	0.868	
X_2X_3	69.40	416.64	0.167	0.869	

The pure components x_1, x_2, and x_3 were significant while the binary blends were insignificant as indicated by their respective P-Values. Table 8 further shows that the fitted model for the three components was of the form in equation 2.

$\hat{Y}(x) = 1549.64x1 + 1554.80\ x2 + 1421.68x3 + 285.35x1x2 - 69.82x1x3 + 69.40x2x3$.. (2)

The fitted model was a representation of the final weight achieved from the feed ration; hence, the following conclusions were arrived at concerning the magnitudes of the parameter estimates. b1 = 1549.64, b2 = 1554.80 and b3 = 1421.68.

$$b2 > b1 > b3$$

This indicated that from the three single component mixtures, component 2 (rice) produced chicks with the highest final weight followed by component 1 (whole maize) then component 3 (wheat). The coefficients of the model parameter estimates of the single components had synergistic effects on the final chick Weight. These single component effects were all significant. For the binary components we had b12 = 285.35, b13 = -69.82 and b23 = 69.40

$$b12 > 0\ ,b23 > 0\ ,b13 < 0$$

The components 1 and 2 and components 2 and 3 combined would give higher weights achieved than would be expected by simply averaging the weight values of their pure blends. They had binary synergistic effects. The components 1 and 3 had binary antagonistic effects. When these components were combined, the resulting chick weight had a lower average final weight than would be expected by averaging the values of the final weight of the chicks feed on the ration made of single component blends.

If chicks have to attain high final weight with a single component feed ration, then it is recommended that component 2 would be used. For a binary blend, when component 3 is not accessible, then component 1 would be used with any of the other two components.

The coefficient of determination was 0.9987(99.46%), and 0.9846(98.46%) for adjusted R^2. It implied that a greater variation of the data could be explained by the model hence a good fit to the data. The fitted model above had insignificant terms prompting, model reduction in R software, the fit of a similar model but with significant terms only.

$\hat{Y}(x) = 1564.07x1 + 1583.16x2 + 1414.51x3$... (3)

The coefficient of determination R2 gave 0.9874 (98.74%) with adjusted R2 of 0.9860 (98.6%) and an F-statistic of 703 on 3 and 27 DF. This meant the model had a good fit to the data. The model could explain a greater variation of the data.

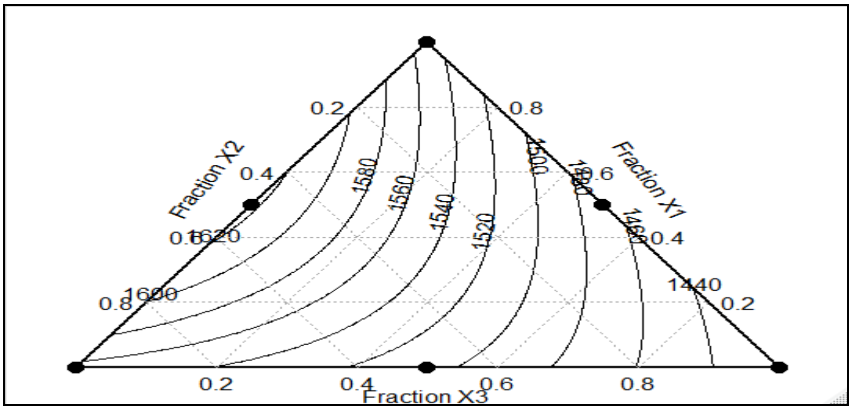

Figure 1: The Estimated Final Chicks Weight Surface with the Second-Degree Model for Cotton Seed Cake

The mixture triangular contour plots plotted illustrated the relationship between the final weights of the chicks and the amounts of components X_1, X_2, and X_3. Highest final weight of 1620g was obtained by 0.6 of component X_1 (whole maize) and 0.4 of component X_2 (rice).

(ii) Model Two (Soya Meal Protein)

Table 9: Soya Meal Protein Model Estimates

coefficients	Estimate	Std. Error	T value	P Value	Significance
X_1	1490.94	64.10	23.259	<0.05	***
X_2	1440.31	64.10	22.470	<0.05	***
X_3	1465.63	64.10	22.865	<0.05	***
X_1X_2	35.23	314.03	0.112	0.912	
X_1X_3	-23.95	314.03	-0.076	0.940	
X_2X_3	29.90	314.03	0.095	0.925	

It was evident from Table 4 that at 5% level of significance, the pure blends were significant while the binary blends were insignificant given their respective P-values.
The output had the following model in equation 4 as a representation of the data.

$$\hat{Y}(x) = 1490.94x1 + 1440.31x2 + 1465.63x3 + 35.23x1x2 - 23.95x1x3 + 29.90x2x3 \quad (4)$$

This being an adequate representation of the final weight from the feed ration formulated with soya meal as the base protein component, the following was evident. The magnitudes of the parameter estimates are b1 =1490.94 , b2 = 1440.31 and b3 = 1465.63

$$b1 > b3 > b2$$

This indicated that given the three single component mixtures, component 1 (whole maize) produced chicks with the highest final weight followed by component 3 (wheat) and finally component 2 (rice). Generally, the coefficients of model estimates in the model had synergistic effects on the final chick weight. The binary components coefficients of the model were given as b12 = 35.23 , b13 = -23.95 , and b23 = 29.90

$$b12 > 0, b23 > 0, b13 < 0$$

The components 1 and 2 and components 2 and 3 had binary synergistic effects on the final weight of the chicks. Components 1 and 2 and components 2 and 3 combined would on average lead to higher final weight records that would be expected by simply averaging the final weights of their pure blends.

The components 1 and 3 had binary antagonistic effects on the final weight of the chicks feed on this formulated ration. When these components were put together, the resulting final chick weight had a lower average final weight than would be expected from averaging the final weight values of the chicks feed on the ration formulated of their single component blends.

Given that chicks were expected to achieve a high final weight with a single carbohydrate component, then it was recommended that component 1 would be used. When binary blends are required, and component 1 is not accessible, then component 2 would be used. The coefficient of determination was 0.9924(99.24%) for multiple R2 and 0.9905(99.05%) for adjusted R2. This indicated that the model was a good fit for the data.The obtained model for the soya meal protein had its interaction terms or components being insignificant. Hence the need for model reduction with significant terms only.

$\hat{Y}(x) = 1491.0x1 + 1445.8x2 + 1465.2x3$.. (5)

The three pure components were significant at 5% level of significance hence a good fit. The coefficient of determination was at 0.9924(99.24%) for multiple R2 and 0.9916(99.16%) for adjusted R2 with an F-statistic of 1178 on 3 and 27 degrees of freedom. This implied that the model could largely explain the variations in the data.

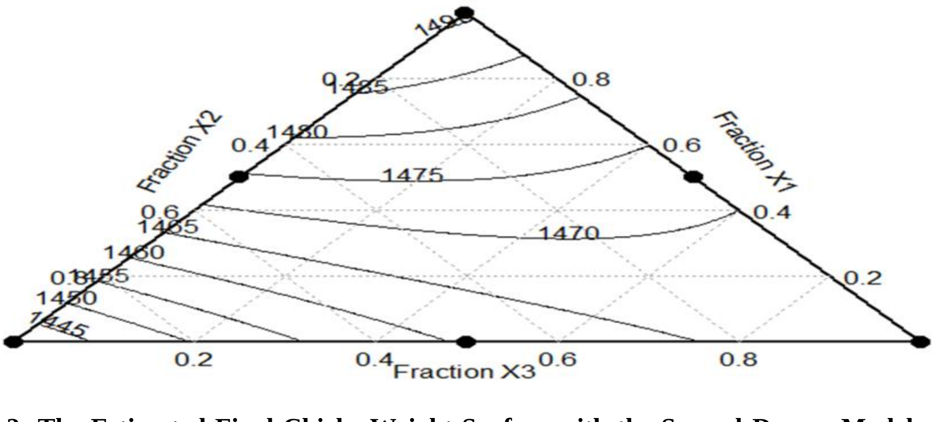

Figure 2: The Estimated Final Chicks Weight Surface with the Second-Degree Model for Soya Meal Protein

The contour plot in Figure 2 shows that when using the soya meal base protein, the maximum final weight of 1491g was achieved at the use of pure component X1 (Whole maize).

(iii) Model Three (Fish Meal Base Protein)

Table 10: Fish Meal Model Estimates

Coefficients	Estimate	Std. Error	T value	P Value	Significance
X_1	1369.256	9.436	145.117	<0.05	***
X_2	1358.704	9.436	143.999	<0.05	***
X_3	1367.472	9.436	144.928	<0.05	***
X_1X_2	49.552	46.224	1.072	0.295	
X_1X_3	45.6	46.224	0.986	0.334	
X_2X_3	76.392	46.224	1.653	0.111	

The fitted model for the three components was of the form in equation 6:

$$\hat{Y}(x) = 1369.26x_1 + 1358.7x_2 + 1367.47x_3 + 49.55x_1x_2 + 45.6x_1x_3 + 76.39x_2x_3 \quad \text{.........................} (6)$$

This being a representation of the final weight data, the following conclusions could be made concerning the magnitudes of the parameter estimates.

$b_1 > b_3 > b_2$

From the three components, the feed ration with component 1 produced chicks with the highest final weight.

$$b_{12} > 0 \text{ , } b_{13} > 0 \text{ , } b_{23} > 0$$

All the binary mixtures had synergistic effects on the final weight of the chicks. Binary components 1 and 2.components 1 and 3and binary components 2 and 3 would produce chicks with higher final weights than would be expected from averaging the final weights of chicks feed on formulations of their respective pure components blends. The coefficient of determination for the model was 0.9998(99.98%) for multiple R-squared and 0.9998(99.98%) for the adjusted R-squared. This showed that the model was good.

The fitted model had the interaction terms being insignificant hence prompting the fit of a reduced model from the only significant terms

$$\hat{Y}(x) = 1374.48x1 + 1367.01x2 + 1375.38x3 \text{.......................................} (7)$$

This model was significant, given that the p-values were all less than0.05. The Coefficient of determination was 0.9998(99.98%) for multiple R^2 and 0.9998(99.98%) for adjusted R^2 with an F-statistic of 4.115e+04 on 3 and 27 degrees of freedom. The model could explain a greater variation of the data.

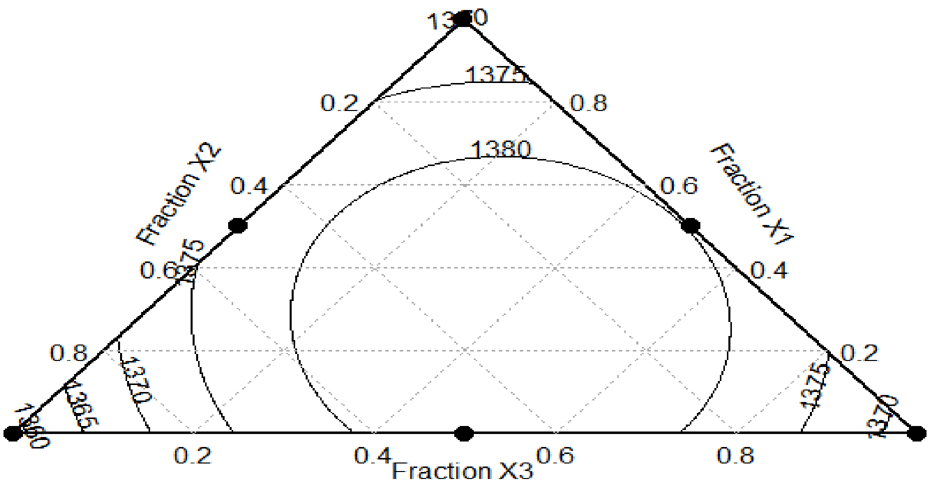

Figure 3: The Estimated Final Chicks Weight Surface with the Second-Degree Model for Fish Meal

Figure 3 shows that on a fish meal base protein, a combination of 0.5 of component X1 (Whole maize) and 0.5 of component X3 (wheat) of the feed ration would enable the chicks to achieve the highest final weight of 1380g.

The three protein models, cotton seed cake, soya meal and fish meal, had their respective second order linear models .They were compared in terms of F-statistics and coefficients of determination of 98.74%, 99.24% and 99.98% respectively with adjusted R^2 of 98.6%, 99.16% and 99.98% respectively. The Fish meal base protein with the highest R^2 of 99.98 and adjusted R^2 of 99.98 was selected the most appropriate model to be recommended.

These results were quite similar to the study by Tabeidian et al (2015). He had studied the effects of feeding semi moist diets and highly digestible carbohydrate and protein sources in pre starter feed of broilers. They used maize, soy bean, fish meal and dextrose in solid and semi moist forms. They concluded that a combination of maize, soy bean, fish meal in pre starter ration positively impacted the chicks in terms of growth and development.

CONCLUSION

The study began by comparing the two major three-factor simplex lattice and simplex centroid mixture designs. It looked at their standard design matrices, formed moment matrices using R software before obtaining their respective determinants, average variances, Eigen values and ranking the minimum values as the headmost. According to the D, A, E, T optimality criterion of $(3, 2)$ mixture experiment there was an equivalence of rankings between the two designs. In any experimental set up, the objective is to have the minimum number of experiments while gaining the maximum amount of data to achieve an efficient model with desiderate properties. In such an instance, design selection was done basing on the fewer the experimental runs, which implied less number of experiments. Hence, the choice of simplex lattice design over the simplex centroid designs for this particular study.

Simplex lattice design was applied in the formulation of poultry feed ration with six design points hence six types of mixtures. M1(pure),M2(binary),M3(pure),M4(binary),M5(pure) and M6(binary). Basing the formulation on the digestible crude protein for the birds and setting of distinct base proteins, single and binary combinations of the three carbohydrates was done. It was conclusively seen that simplex lattice mixture design could be applied in both chick mash ration and growers mash feed ration formulations.

The results of analyzing the mixture experiment data led to coming up of three models labeled equations 6, 8 and 10. These were from the cotton seed cake, soya meal and fish meal protein bases. They were evaluated based on their coefficients of determination (98.74%, 99.24% and 99.98%) and F statistics (703.9, 1178 and 4.115e+04) respectively. This concluded that fish meal protein gave the best model (99.98%) followed by Soya meal (99.24%) and cotton seedcake meal (98.74%) protein bases respectively.

In the fish meal protein model ,demonstrated that in the single component mixtures, component X_1 (whole maize) gave the highest final weight while binary blends, a combination of component X_1(whole maize) and X_3 (wheat) gave the highest final weights among the other mixture combinations in the experiment. The contour plots proved useful for establishing desirable final weights and the component combination for the highest final weight.

RECOMMENDATIONS

- ✓ This above-obtained model is recommended to the chicken farmers and from the experiment, it conclusively concurred that simplex lattice mixture design could be applied in this field of poultry production as an optimization tool.
- ✓ It would also be beneficial to apply mixture experiments in the formulation of poultry feed using 4 components to see if a much better model would be achieved given that there are more different carbohydrate sources that can be used in poultry feed ration formulation.
- ✓ It would also be recommendable if a study could be done on mixture experiments to compare varying different proportions' of proteins in place of the already done carbohydrates. This is by holding the carbohydrates, vitamins and minerals constant while varying different proportions of different proteins feed sources.
- ✓ It would also be worth to do the same study by using the other different protein feed sources as bone meal and sunflower seed cake in place of cotton seed cake meal and soya meal to compare its effects with the fish meal on the final weight of the chicken.
- ✓ These could be done to compare and contrast their outcomes, which would go a long way in reinforcing the findings of the present study. This is especially for the locally available feed raw materials.

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