AN APPLICATION OF MIXTURE EXPERIMENTS IN FORMULATION OF POULTRY FEED FOR MODELLING CHICK WEIGHT

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DECLARATION

DECLARATION BY THE STUDENT

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DEDICATION

This research thesis is dedicated to God for his wisdom, knowledge and understanding. To my family for the financial, spiritual and moral support during the period of my class and thesis work. To my colleagues in the department of Mathematics and Computer Science, for their encouragement and motivation. May God bless you.

ABSTRACT

Poultry farming in Africa has significantly grown over the years. It is highly dependent on the economy and type of feed used. The quality, components, proportions, rations and storage of feeds is quite critical in poultry farming. The rising prices of the feed and the poor quality of the feed has become a concern to the poultry farmers due to low returns brought about by the low final weights among the birds. This study investigated how the theory of mixture experiments designs would be applied in the formulation of feed to come up with a model which farmers can apply in making their formulations to cut the cost of production and raise the profit margin. This study employed D-determinant, A-Average variance, E- Eigen value, and T-Trace optimality criterions in selecting an appropriate design between two major mixture experiments designs, simplex lattice and simplex centroid designs. The designs selection based on D-determinant, E-Eigen value, A-average variance and T-trace criterions rankings had equivalence at 1.5 but selection based on the fewer experimental runs led to the choice of simplex lattice mixture design. This design was applied in the formulation of poultry feed. The three components; whole maize meal, rice and wheat were being varied against the base or primary ingredient of proteins, vitamins, and minerals. The study varied the three major components, which are largely available and used by most poultry farmers in Kenya. Final weights data were analyzed using second order models. The effects of the feed proportions of the mixture on the final weights were analyzed using mixture regression method. The second order mixture models were used to create contour plots and response trace plot of the recorded weights and the used proportion of components. The contour plots proved useful in establishing desirable final weights and operating conditions. The optimum component proportions in the feed mixture for maximum weight gain were evaluated by response optimization analysis using the R software package as 1374.48g for whole maize component ,1367.01g for rice component and 1375.38g for wheat component .Given the three soya meal, cotton seed cake and fish meal protein bases, three second order linear models were obtained and 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. The study concluded that fish meal protein gave the best model followed by Soya meal and cotton seedcake meal protein bases. Within the fish meal protein ,the varied proportions of carbohydrates, 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.

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LIST OF ABBREVIATIONS

A-Optimality	Optimality criterion named A
AD	Axial Designs
ANOVA	Analysis of Variance
CSV	Comma-Separated Values
CD-Optimality	Optimality criterion named CD
Det (M)	Determinant of the Moment Matrix
D- Optimality	Optimality criterion named D
DT-Optimality	Optimality criterion named DT
E-Optimality	Optimality criterion named E
F Value	F Statistic Value
G-Optimality	Optimality criterion named G
I-Optimality	Optimality criterion named I
KALRO	Kenya Agricultural Livestock Research Organization.
M1	Mixture label 1
M2	Mixture label 2
M3	Mixture label 3
M4	Mixture label 4
M5	Mixture label 5
M6	Mixture label 6
MS Excel	Microsoft Excel
MSS	Mean Sum of Squares
P Value	Probability Value
R software	Programming language named R
SLD	Simplex Lattice Design
SCD	Simplex Centroid Design
SS	Sum of Squares
T-Optimality	Optimality criterion based on trace
Tukey (HSD)	Tukey Honestly Significant Difference test

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CHAPTER ONE

INTRODUCTION

1.1 Introduction

This chapter contains the background of the study, statement of the problem, main objectives, justification and significance of the study.

1.2 Background Information

Poultry farming involves rearing of domesticated birds such as chickens, geese, turkeys, and ducks. Poultry products are primarily for consumption and commercial purposes. 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 where the climatic conditions are in favor of their rearing (Heos, 2014).

Poultry provides a vast supply of food throughout the world with the demand steadily increasing. Furthermore, poultry farming is not affected by religious beliefs. The extent of poultry farming in developing countries is lower than developed countries due to the low purchasing power (Vernooij, Masaki & Meijer-Willems, 2018). Poultry farming in Africa has significantly grown over the years as a result of economic growth in the continent.

The cost of poultry production in East Africa has been found to be directly related to feeds and the availability and quality of the ingredients (Elson *et al*., 2012). Kenya ranks second after Uganda with respect to accessibility of most of the feed-components used in the feed formulation process. More than 50% of poultry farming output is highly dependent on its feed management (Elson *et al*., 2012).

Poultry production plays a significant role 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. The adequacy and quality of feeds are directly proportional to the final output of the poultry farming venture.

Chicken production, particularly in the rural areas 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 meat and also indirectly promotes women empowerment (Wong *et al.,* 2017). For instance, in Uasin Gishu county, the county government established a poultry program, "*Inua Mama na Kuku initiative"* to empower women and reduce poverty in the rural areas (Ollinga, 2016). The county procured chickens, which were given to the women groups in the county. The small-scale poultry production requires little input and those farmers with limited resources especially women in rural areas can easily manage.

To achieve satisfactory results in any field of production, required minimum cost of production leading to maximum yield. Poultry production depends on the type of feeds and feed rations that are safe and of standard quality. When farmers can formulate their poultry feeds, they save up to 80 percent of the total production costs. Milling industries produce feeds that enhance growth and productivity in birds (Cornell, 2011). However, these feeds are becoming increasingly expensive, leading farmers to search for effective methods of formulating their own quality and nutritious feeds.

Following government directive that poultry feeds be packaged in 50kg bags down from 70kg, it was expected that the prices will come down. However this was not the case and the cost is still high. There have been no proper policy guidelines in the feeds industry, but the Ministry of Agriculture through the department of livestock production is addressing this through policy formulations and once done, it is hoped that farmers will reap more as the policy becomes operational (Andae, 2017).

It is therefore necessary for the farmers to be cautious when sourcing animal feeds. There had been reported cases of unscrupulous feed manufacturers who do not observe the quality and sell crushed maize cobs with aflatoxins as maize germ. The use of rotten maize should be avoided when preparing poultry feeds because of its sensitivity to feed contamination, especially with aflatoxins (Andae, 2017).

This study was conducted to evaluate the impact of varying the proportions of the feed ingredients on the average weight gain of the birds over a given period.

1.2.1. Feed Formulation

To achieve optimization, apart from suitable housing and following up-to-date vaccination schedules, good feed in regard to quantity and quality is essential (Poultry feed, 2019).

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).

A mixture comprises adding two or more ingredients, for example, a fruit juice, which varies depending on the quantities of watermelon, oranges, and orange juice in the mixture. Responses of mixture experiment are further determined by the settings of variables when making the mixture. 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.

Feed ration formulation refers to measuring the various ingredients in amounts necessary to offer the birds with the recommended quantity of nutrients required at different stages of growth. Therefore mixture experiment was the best approach to use in the study since our interest was in determining how changes in the proportion of an experimental component affect the response. It involved measuring the amounts of feeds to be mixed to provide a feed that would supply all the required nutrients combined and balanced enough to supply all the required nutrients.

Before doing any formulation, an experimenter should have a thorough understanding of vital aspects and this includes the 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).

The process of formulation required the farmer to have the correct and approved formulation, the required ingredients, and finally the services of a farm hand was necessary so as to assist with the mixing of components with a spade or home-made drum mixer or an electric mixer.

1.2.2. Mixture Designs

The use of mixture experimental designs has been of importance in the formulation process of animal feeds (chicken feeds) and thus minimizing the number of trials by farmers. (Suhesti, 2016)

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 (Lachman, 2009).

Other researchers elsewhere have 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. The settings for these various factors satisfy the constraints in equations 1 and 2.

$$X_i \geq 0, \qquad i = 1, 2, 3\ldots\ldots q \qquad (1)$$

$$\sum_{i=1}^{q} X_i = x_1 + x_2 + \cdots + x_q = 1.0 \qquad (2)$$

Where x_i is the mixture component and q is the number of components.

The observed and measured responses of interest for optimization purposes were presumed to be functionally linked to proportions or percentages of the mixture components rather than to the quantity of the mixture. The q components of this system, namely the mixture variables (X_i), are not independent due to the above restrictions, being the primary feature of the mixture problems. A change in one component of a mixture involves a change in the proportion of the other elements in the mixture. The level of the q^{th} element therefore may be estimated when the remaining q-1 components are known (Tauler, Walczak and Brown, 2009)

When described by a polynomial equation the lattice can be denoted as {q, m}, where, q represents the number of components, m is the degree of the polynomial or the proportions assumed by each part. It is advantageous for a small number of components with response surfaces that require polynomial equation of order at least two providing an accurate description. The points are distributed evenly over the whole simplex in the design. The coordinates of the points are estimated by combining components that take m+1 evenly spaced values between 0 and 1 (Cornell, 2011; Prenscia, 2019).

$$X_i = 0, \frac{1}{m}, \frac{2}{m} \ldots\ 1. \qquad (3)$$

The mixture approach recommended by Scheffe´ presents some advantages. For instance, it is easy to design mixture experimentation despite the number of experiments being few. The number of experimental points is similar to the number of terms in the related polynomial model. Thus, the coefficients may be estimated without the use of a computer program for multiple linear regressions (Cornell, 2002;Prenscia, 2019).

The validity of the model can be tested by including additional checkpoints, which are not designed points, and their coordinates are the ones presented. A simplex lattice (SLD) has an order of equally spaced points on a simplex (Lachman *et al*., 1970). The simplex centroid design is not far much different from the simplex lattice design, except that the design points are equally spaced and appear in equal proportions or zero. The design points are acquired using $2q - 1$ equation.

However, the approach has some disadvantages; for instance, SCD is expensive regarding the number of points when the model degree increases. Also, the model coefficients are measured based on the experimental data where only simple mixtures with components (q^9 - q) are involved.

A q-component is where the number of points is acquired using $2q - 1$. The simplex centroid is described as the design points related to the q-permutations of $(1, 0, 0, 0$ ... 0). SCD design is based on the same rules as the simplex lattice design, with the exception that the design points are not only equally spaced but also appear in equal proportions or zero. These mixtures are located at the centroid of the $(q - 1)$ dimensional simplex and the centroids of all the lower dimensional simplex contained in the $(q - 1)$ dimensional simplex. The above designs are boundary designs implying the design points are located in the boundaries such as vertices, edges, and so forth. (Cornell, 2011; Prenscia, 2019).

Axial designs refer to complete mixtures or q-component blends whereby a majority of the points are situated inside the simplex and usually recommended when component effects are examined. It is primarily used to distinguish significant components in the mixtures that comprise a large number of components.

1.3 Statement of the Problem

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 them. At this time, the price depends on their weight, and they realized the profit was smaller due to the low weight of their chicken. Poultry farmers who depend on this venture as the main source of income realized smaller profits due to the low weights of the birds at end of production period or at the point of sale. This was attributed to the high prices of commercial feeds . 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. This prompted the need to formulate own acceptable and nutritional rations to reduce the cost of production.

Further, given the rising cases of cancer and chronic diseases, the use of wrong components in feed formulation to get quick money by animal feed traders may lead to health-related issues to the birds and eventually to the consumer. There’s need to regulate animal feeds traders who formulate their own feeds to ensure they follow the recommended feed formulation standards. Finally, there is a need to encourage greater utilization of mixture techniques in agricultural research and development in the country.

1.4 Main Objectives

This study aimed at applying mixture experiments designs in the formulation of poultry feed for modeling the weight of chicks.

1.5 Specific Objectives

The specific objectives were;

a) To compare the three-factor simplex lattice and simplex centroid mixture designs with respect to the D-Determinant, A-Average variance, E-Eigen value, and T-Trace optimality criteria of design selection for experimentations.

b) To formulate poultry feed ration using the selected three-factor mixture experiment design.

c) To develop a model for optimizing chick weight based on poultry feed ration formulation.

1.6 Research Questions

By the end, this research was seeking to answer the following questions.

1. Which is the best three-factor design of mixture experiments that can be used in the formulation of poultry feed?
2. How would a selected three-factor design of mixture experiments be applied in the formulation of poultry feed?
3. What type of model can be obtained that will optimize final weight of birds through the formulation of their poultry feed?

1.7 Justification of the Study

To come to an agreeable output in any business venture, the minimum cost of production is required to achieve highest level of returns. Poultry production depends on the type of feeds or feed rations that are safe and of standard quality. This has not been the case due to the rising prices of commercial feeds. This has led the birds attaining low weights at maturity fetching low prices in the market.

Bett *et al*,.(2015) did a study on the impact of poultry feed prices on commercial production. It showed the need for poultry feed traders to adjust the prices temperately if the farmers are to be pertinent. When farmers can formulate their own feed, they save up to 80 percent of the total production costs thereby raising the profit margin. Farmers have been seeking alternatives to the commercial rations which may not be meeting the standard nutritional requirement of the birds.

Animal feed traders have also been formulating their own rations without accurately following the recommended standards leading to low final weights and low returns. There is need to have a poultry ration formulation model that meets the nutritional requirement of the birds at their respective ages of growth. It should also have positive outcomes in terms of growth and development of the birds and also that the birds fed on this ration can attain higher final weights to fetch high market prices for the venture to be successful.

However, these feeds are becoming increasingly expensive, leading to farmers searching for effective methods of formulating own acceptable and nutritious feeds.

1.8 Significance of the Study

The findings of this study are important to poultry farmers and society at large in the country. The high demand for graduates with knowledge and skills, especially in the current state of low employment would encourage self-employment ventures such as poultry farming.

Whatever the venture, it should seek to maximize on returns so as to progress. Therefore the need to develop new ways that would reduce the cost of production and increase income would be very vital. In poultry production, farmers who would apply the recommended model and optimal settings in feed formulation would be able to train fellow farmers in poultry farming. This would lower the cost of production to make it a profitable and affordable business. For the researcher, by the end of the mixture experiment, it would aid in implementing acquired class knowledge to the field hence a greater understanding of the study area.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

This chapter reviews related literature to provide a framework of answering the research questions identified in the study.

2.2 Optimality Criterion

Optimal designs are experimental designs arising from a given optimality criterion that becomes optimal in specific statistical models. The clamor for optimality designs was actualized in 1918 when researchers applied optimality criterion with regression designs The foremost authors who refined optimality criteria were Kiefer and Wolfowitz (1959). The advancement of the computational statistical inference procedures for optimum designs has made their application in regression problems feasible. The optimality criterion used will determine the best design. (Kiefer and Wolfowitz ,1959)

In fitting a response surface to a group of designs, it is necessary to have selection criteria for selecting the best design. From the many criteria for design selection, it is of importance to look at a design that would work well with the objectives of the study. While the concept of optimality is useful, the aspect of its ability to handle missing data is quite important. In this regard, graphical methods have been used parallel to optimality criterions in design selection (Anderson-Cook, Borror & Montgomery, 2009).

El-monsef, Seyam and Rady (2009) did a comparative study to evaluate the relationship among the several optimality criteria. They looked at their distinct definitions and how different criteria could be applied in different life sciences. They did an elliptical survey on the criteria with their classifications. They were able to distinguish the criterions. G-, D-, A-, E- and I- Information based criteria were related to the information matrix for the design and were classified according to the number of parameters. The C- Optimality criterion minimized the variance of the estimates of the parameters. The following A-, D- and E- optimality criteria would be combined to work as U- criterion to multiply an experimental set. A criterion that worked towards maximizing the mean distance between design points was named S-, also known as maximum spread design. The two designs namely DT- and CD- criteria were distinguished as two compounded criteria. There were criteria that didn't fit in the previous descriptions and the T- criterion defined as a criterion discriminating between a number of models.

Harman, Bachrata and Filova (2015) constructed efficient experimental designs under multiple resource constraints. They brought out a clear definition of resource constraints and looked at how D- optimality criterion would work with computed efficient designs to block the models with limits. Their working alongside quadratic regression models and non- linear regression models. This approach was able to invoke better results as compared to algorithms under less general constraints (Harman *et al*,. 2015)

Kiplagat *et al* (2015) investigated mixture experiments in the second-degree Kronecker model. The parameter subspace of interest in the study was maximal parameter subsystem. Optimal designs were obtained of mixture experiments and were derived by employing the Kronecker model approach and applying the various optimality criteria. They showed that A- and D- optimal weighted exists for two and three ingredients and further obtained D- optimal designs for four and more ingredients respectively (Kiplagat *et al.,* 2015).

Goo's *et al* (2016) did a study that looked at mixture experiments with I- optimal designs. The I- Optimal designs were used to minimize the average variance of prediction. This approach was more befitting in blending experiments than D- optimal designs in terms of accurate forecast. Further, the performance of D- optimal design on I- optimality criterion were very dependent on each other.

Ruseckaite *et al*,. (2016) selected a design using Bayesian D- opt imality. It elaborated a mixture coordinate-exchange algorithm that is competent enough to construct designs for several mixture components. It was evident that the resulting design was highly effectual and practically applicable in many mixture experiments. That same algorithm still could be used further for obtaining optimal designs as in case of A-, G-, and V- optimality criterions. The extensive use of coordinate-exchange algorithms in the optimal experimental design literature, however, indicates that the resulting designs are highly efficient and practically useful. Another issue worth mentioning was that, while they focused on the D-optimality criterion, their algorithm could be used for generating designs that are optimal concerning other criteria as well, such as the A-, G- and V-optimality criteria. Further, to avoid the challenging work of ranking of large numbers, it was suggested that the use of choice sets of two or three comparisons for respondents to select from would be much easier.

Maronge *et al* (2017) investigated the optimal design problem for some wavelet regression models. Optimal designs came in as a way of increasing experimental precision.. The C-optimal designs and *I*-optimal designs constructed were different from the *D*-optimal designs. The study showed that a significant saving of resources might be realized by employing an optimal design. They also obtained *C*-optimal designs. Optimal (*D*- and *I*-) quadratic spline wavelet designs were constructed, both analytically and numerically. The case study showed that a significant saving of resources might be realized by employing an optimal design.

Roelof and Haines (2017) did a study on construction of D- and I- optimal designs for mixture experiments that involved the use of constraints in its components. This was a case where the design space is a polytope inside a regular simplex. Another study looked at the construction of D- and I-optimal designs for the scheffe` model in three and four component mixtures and this advanced the whole idea of barycentric coordinates (Coetzer and Haines, 2017)

A study was done to show that the estimation of the slope could be obtained by using mixture experiments given that it gives a good response for all possible formulations of a mixture with optimal proportions for each component at unique positions (Mwaniki *et al,* 2017). It focused on slope optimal mixture designs for third-degree Kronecker model. Weighted Simplex Centroid Designs and Uniformly Weighted Simplex Centroid Designs mixture experiments were presented to get the optimal proportion for every given ingredients formulation. After looking at the slope information matrices for the four ingredients, maximal parameters of interest for third-degree Kronecker model were considered. Therefore the D-, E-, A-, and T-optimal criteria and their efficiencies for both Weighted Simplex Centroid Designs and Uniformly Weighted Simplex Centroid Designs were obtained. Uniformly Weighted Simplex Centroid Designs was found to perform better than Weighted Simplex Centroid Designs in terms of slope and average prediction variance with most formulations satisfying general equivalent theorem for I-optimality. Further, it recommended that to achieve optimal results; the researcher would allocate weights in mixture ingredients evenly (Mwaniki *et al*., 2017).

Limmun *et al* (2018) proposed a technique to generate robust A-optimal designs for mixture experiments using genetic algorithms. It was a case when the experimental region was an irregularly shaped polyhedral region and it had been formed by constraints on the mixture ingredient proportions. The approach sought the design, which minimized the weighted average of the sum of the variances of the estimated coefficients across the set of potential mixture models that occurred due to initial model misspecification. This approach provided an alternative option when the experimenter was uncertain about which final model was to be selected (Limmun *et al*,. 2018).

2.3 Experiments with Mixtures

The mixture design has also been applied in the construction sector, for instance, a study conducted on bridge decks in the United States. In the study, the primary cause of breakage in bridge decks was believed to be caused by premature cracking. Therefore, a mix design was used to reduce the shrinking that caused the cracking. Different sources and sizes of the concrete mixtures were considered in the research and their properties tested. The study supported that an ideal mixture design helped reduce the early cracking on the bridge deck. Therefore, It was an effective strategy to mitigate shrinkage cracking and improve its quality (Qiao *et al*,. 2010).

Experiments with mixtures involve combining two or more ingredients in varying proportions to come up with an end product. The quality characteristics of the end product are studied for each blend to assess the quality changes across the combinations (Cornell, 2011).

For example, (Cornell ,2011) used the illustrations of when determining the effectiveness and durability of a pesticide prepared by mixing several chemicals or when interested in enhancing brightness and strength of railroad flares, which are the end product of mixing proportions of magnesium, strontium nitrate, binder, and sodium nitrate respectively. From the above scenarios, the value of each response under study that is the brightness and durability of railroad flares, the end product is somewhat dependent on the relative proportions of the mixture constituents than the quantity of the final product.

The mixing of the ingredients aims at determining whether the combining of the ingredients in the experiment will produce a desirable end product compared to the use of a single ingredient. It is assumed that the characteristics of interest functionally correlate to the product composition. Therefore, varying the composition by altering ingredient amounts, the quality of the end product will also be altered (Cornell, 2011).

According to the existing literature (Cornell, 2011), the design of a mixture experiment comprises 4-5 steps explained in detail as follows:

(a) Describe the goals of the experiment.

(b) Choose the mixture components and all the other factors under study

(c) Identifying any limiting factors affecting the mixture components to identify the experimental region and the response variables(s) to be assessed

(d) Recommend a suitable model for the response data as functions of the mixture constituents and the other features preferred for the experiment

(e) Chose an experimental design appropriate for the suggested model and permits a test of model capability.

The D-, E-, A- and T- optimality criterion were applied in the selection of simplex lattice design, which was used in the study due to its efficiency in design model selection. The mixture design to be selected had to follow the recommended characteristics. According to (Cornell, 2011), a good design should meet the following features,

(a) Create a satisfying distribution of information across the triangle or experimental region.

(b) Ensure that the fitted model predicts a value, $\hat{y}(x)$ at all points in the experimental region that is as close as possible to the true values of the response.

(c) Provide good detectability of model lack of fit.

(d) Establish an internal estimate of the error variance.

In any given experiment that investigates the functional relationship between the measured property or response such as brightness and durability of railroad flares and the controllable variables such as the proportions of magnesium, strontium nitrate, binder, and sodium nitrate in the case of the railroad, it aims to determine if the mixing of the ingredients is reasonable. Furthermore, it focuses on gaining a better understanding of the whole system by examining the roles of each ingredient. Therefore, the best outcome would be a combination that would produce the best and strongest railroad flares without incurring further costs.

Experiments on mixtures have been used extensively in various fields of research including cosmetics, pharmacology, and the food and beverage industry to agricultural research. In an attempt to ascertain the best combination of ingredients, more than often it results in trial and error. (Cornell, 2011).

The simplex-centroid mixture design was applied in a research aimed at obtaining an ideal formulation for stabilizers used in the production of ice cream. The stabilizers are essential in the production of ice cream as they increase velocity and control meltdown. Each stabilizer had specific beneficial characteristics, and combining them would be more effective as it can be used in low amounts as well as minimizing the cost. The study utilized guar gum, carboxymethyl cellulose, and basil seed gum as the stabilizers using the mixture design. It concluded that to obtain an ideal mixture, a combination consisting of 15.57 % of guar gum and 84.43 % of basil seed gum level of 0.15 % was suitable. The authors further mentioned that the design model was a reliable method for obtaining an optimum mixture and that the combination produced desirable features in ice (Bahramparvar *et al*,. 2013).

The simplex lattice mixture design was used to prepare nanosuspension of piroxicam drug. Piroxicam is an oral medication under the anti-inflammatory drug group prescribed for the management of arthritis. In the study, nanosuspension of the drug was prepared using evaporative antisolvent method established to be effective in enhancing the bioavailability of the drug. Simplex lattice design was used to optimize the ingredients, namely Polivinylpirolidon PVP K30 (X_2) , Chitosan (X_1) and Sodium Tripoliposphat STPP (X_3) .The paper concluded that a combination in the ratio of X_1 : X_2 : X_3 whereby 0.333 amount of $X_{1,}$, 0.333 of X_2 and 0.333 of X_3 as the optimum mixture of piroxicam nanoparticles. The design influences the different aspect of the manufacturing process (Suhesti *et al*,. 2016).

Mixture design was used to enhance low-calorie juice made from oranges, pineapples, and persimmon based on the sensory and nutritional properties. They found out that juice made from the combination of the named fruits had a sweeter taste and a less intense red color preferred by majority of the customers. (Curi *et al*, 2017)

In a similar research, a four-component simplex centroid was applied in the formulation of a tropical beverage. It combined juices of watermelon, orange, pineapple, and grapefruit. The response of interest was the fruitiness flavor score of beverage. The results showed that the orange was the single fruit with most flavors, followed by watermelon and pineapple for the binary fruit with fruity flavor. Watermelon, orange, and pineapple for the ternary blend and finally watermelon, orange, pineapple, and grapefruit was the combination of all fruits together .The quaternary mixture was the best combination of the fruits with the finest fruity flavor (Kipkoech *et al*,. 2017).

To develop the buoyant matrices of,metformin, a drug for treating diabetes, Patel & others applied simplex centroid design method (2017). The study used direct compression method using mixture design as an optimization technique with simplex centroid design. The formulation M-SCD 7 was found to be the optimum having good floating lag time and matching the desirability criteria for drug release. The formulation also gave a reasonably high adhesion retention period and swelling index desirable for securing the retention of formulation in the abdomen. It established that one could use simplex centroid design in the development of floating matrix tablets with minimum experimentation (Patel *et al*, 2017).

Kashi *et al*. (2017) in their research also utilized simplex lattice mixture design where they looked at the anaerobic digestion of waste particularly organic as an approach proved to be effective in minimizing environmental pollution. It is of importance due to the need to come up with strategies to manage the increasing waste production globally. The study was investigated under kinetic modeling and mesophilic temperature. The mixture design selected was used to develop an ideal waste ratio and establish the antagonistic effect of the waste materials interactions. The study found out that the interaction proved to be antagonistic and resulted in the minimal production of methane gas (Kashi *et al*., 2017)

Oussaid *et al* (2017) applied simplex-centroid mixture design to select the best solvent for the extraction of the phenolic compounds from L. rhizome. This extraction used simplex centroid, S.C, for optimization, which showed that acetone was effective among the other components. This was regarding antioxidant and antibacterial properties. Antagonistic and synergistic relations were also studied. The study recommended further research to be done on the extracts to distinguish individual components.

To establish the appropriate combination of essential oils with effective antioxidant features, a research used simplex-lattice mixture design. It combined the essential oil mixtures and to establish the potential effect of the interaction between the essential oils. Rosemary, basil, and marjoram were the ingredients (essential oils) utilized in the study. Baj *et al* concluded that the mixture made of a composition of 8% basil, 75% of marjoram and 17% of rosemary had the highest antioxidant activity. Therefore, the simplex-lattice design was reported to be efficient in the preparation of essential oils mixtures. Furthermore, the mixture optimization method would be applied to the food industry in the extraction of vital compounds (Baj *et al*,. 2018).

Another study was done on herbal mixtures focusing on modeling extraction of Total Phenolic (TPC) and Flavonoid Content (TFC) from mixtures of *Cnestis palala*, *Urceola micrantha*, *Labisia pumila*, and *Microporous xanthopus*. The study assessed the optimal formulation of the herbal blend. The dried plant materials were extracted using hot boiling water extraction. Samples of $(0.1\ g)$ were infused in 200 mL boiling distilled water $(100°C)$, stirred for 3 min using a magnetic stirrer, left to cool for 5 min and filtered using filter paper. Design-Expert 9.0 Software was used to generate the required 24 herbal formulations. It was found that Quadratic and linear model was the best model for describing the relationship between the proportion of polyherbal with the TPC and TFC. After validating the formulations experimentally, the maximum TPC and TFC were shown by a single formulation. The study proved that one could use a statistical mixture design to analyze the optimal formulations of any herbal mixture (Amalina *et al*., 2018).

Belay *et al*. in 2019 used the simplex lattice mixture design approach to identify the ideal gas composition. The optimum gas composition would be used in pomegranate arils stored under modified atmosphere. Pomegranate arils contain health benefits such as antioxidant and anti-inflammatory properties. The use of oxygen and carbon dioxide under modified atmosphere would increase the shelve life of fruits and vegetables highly perishable. The research aimed at establishing the optimum concentration of the two gases to ensure its ideal benefits are not destroyed during the process. The study paper identified that a gas mixture of $6\times10^{7} kPa$ (Kilopascal) of oxygen and $7\times10^{8}\ kPa$ of carbon dioxide was the ideal combination in addition to other ingredients such as sugars, ascorbic acid organic acid concentration among others in the commercial production of pomegranate arils. (Belay *et al*, 2019)

2.3. Poultry Feed Formulation

In Nigeria, a research was conducted on the requirements of design for poultry feed formulation software. It focused on features such as digestibility, the acceptability of the feed, cost, palatability, and presence of anti-nutritional factors and toxins. Methods such as Trial and Error, Stochastic Method, Linear Programming, Pearson Square were used in the study. The adoption of the software would increase independence in the poultry feeds productions in Nigeria since the cost of producing poultry products in the country is approximately 70%. Further, the study resulted in the collapse of several commercial farms in the country due to the high cost of poultry feeds.The application of the methods such as Trial and Error,Stochastic Method, Linear Programming and Pearson Square Methods were used in the study (Afolayan, Olatunde & Afolayan, 2008).

Studies have been carried out to improve poultry feed formulation using various strategies. Alhotan (2008), applied several approaches, for instance, the non-linear formulation and a simulation analysis method using Excel Spread Sheet package. He further implemented a meta-analysis to assess the balance of protein content (dlys & true protein (TP) levels) in the broiler feeds. The non-linear formulation was to measure the cost of production of the feeds in which according to his study,it significantly reduced the cost. The meta-analysis resulted in an optimal balance between the dlys & true protein (TP) levels in the feeds.

Tabeidian *et al* (2015) studied the effects of feeding semi-moist diets and highly digestible carbohydrate and protein sources in pre starter feed for broilers. They used maize, soy bean, fish meal and dextrose in solid and semi moist forms. By the end of the study period, irrespective of the varying feed conversion rates, chicks feed on maize, soy bean and fish meal recorded highest final weights as compared to those feed on a combinations of maize, soy bean and dextrose or maize, soy bean, case in or maize starch and maize, soy bean, maize gluten and maize starch diets respectively. They concluded that a combination of maize, soy bean, fish meal in pre starter ration positively impacted the chicks in terms of weight and growth (Tabeidian *et al*, 2015)
A study was also done to look at the nutritional content of the poultry feed and it was acknowledged that feeds with adequate nutrients and in the correct amounts ensured optimum growth. It considered mixing various feed ingredients to come out with a balanced ration. In this case Linear programming was used, which lowered the cost of feed formulation by approximately 7.5% for broiler starter feeds in comparison to other models. The study concluded that broiler feed rations should be a balance of minerals, proteins, carbohydrates, vitamins, and essential fatty acids respectively. Furthermore, Linear programming approach assured a cost-effective decision in terms of nutrient intake for broilers. It is essential to mention that this program was availed to Nigerian poultry farmers via the basic excel package (Olugbenga *et al*., 2015).

In Kenya, several methods have been published concerning feed formulation. The common one is by use of Pearson’s Square method. This works on the aspect of consuming Digestible Crude Protein (DCP) as the fundamental nutritional requirement for any feed preparation for animals and birds. However, Farmers are advised that whatever method they use in the formulation process; the end product sample should be compared with a commercial ration to assess its performance (Obwogo, 2018)

It is necessary to enhance the knowledge on the utilization of locally available agricultural product formulating. This will result in a significant decrease in the cost of production and since poultry feeds constitute about 70 % of the total cost. It can be done by utilizing products such as wheat, cowpeas leave brewery waste, sunflower seeds and so forth incorporated in the poultry feed in such a way that it does not have adverse effects on the birds. These products are also considered rich in vital nutrients such as carbohydrates, proteins, and water-soluble vitamins. The traditional sources of the above nutrients may be expensive. However, the availability of these products is limited due to their use for human consumption (Swain, 2019)

2.5 Model Fitting with Optimal Settings

The objective of any mixture experiment is to fit a suitable mathematical model which will show response variables as functions of the proportions of the mixture components. Establishing the blending surface such that estimates of the response for a mixture component, whether a combination or single can be made empirically (Bondari, 2005).

Testing the suitability of the model will be necessary. The primary objective of this study was to determine the application of the mixture experiment in the agricultural sector among small holder farmers in the country.

2.6 Research Gap

From the literature above, there has been many studies done on various applications of mixture experiments, but none had been done on the formulation of poultry feed. Several studies have also shown methods such as Pearson's square method that can be used in poultry feed formulation but none has used mixture experiments. This study applies 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. The study employs a design with optimal settings that could be recommended to farmers for their poultry feed formulation.

CHAPTER THREE

RESEARCH METHODOLOGY

3.1 Introduction

This section gives a detailed account of how the study was carried out from preparation to having data ready for analysis.

3.2 Materials

A poultry house was constructed following the recommended spacing of 550 cm^2 per bird. Within the poultry house, 18 circular brooders were constructed of plywood for the 18 different types of mixtures. Each brooder was labeled for easy identification when giving specific feed rations of the formulated mixtures. It was within the brooders that adequate lighting for 24 hours and recommended temperatures of 32 degrees centigrade were maintained. This temperature was maintained for the first seven days then reduced by 4 degrees centigrade per week in the next three weeks. Temperatures were maintained by close observations of the birds' behavior around the heat sources. This is where the closeness to the heat source indicates the temperatures are low and needs an increase while moving far from the heat source are an indication of high temperatures and needs to be reduced. Fresh air was maintained in the brooders and dampness was avoided at all costs by regular change of wood shaving beddings. The location faced the leeward side with good drainage in place.

A clean and disinfected feed store was constructed to assure the quality of the feeds and avoid contaminations. It was rodent proof, well ventilated, rainproof and fitted with palates for placing the feeds. It was stocked with new gunny bags that were used to store the formulated feed.

The materials required for the experiment were the plywood's for partitioning 18 small brooders for the 18 different mixture types of the feed rations, the feeder troughs for each brooder, three buckets for the automated drinking systems with nipples and the components used in feed ration formulation. Spades were used in mixing of the components. Two weighing scales were used to record weights of the birds during the entire period of study to be analyzed and to measure the components during formulation.

The ingredients that were used in the study were wheat, whole maize, soya meal, cotton seed cake, fish meal (Omena), rice and vitamins and minerals concentrate. The concentrate had accretions such as vitamins and minerals, ensuring that the ration had met the recommended daily nutrient requirements. Due to the season of study, some of the materials were cheaply available along with the previous maize harvest in Uasin Gishu County. Some of the components were purchased from an animal feed retail outlet within Eldoret town while others were obtained from the host farm 8km from the poultry farm under study. It was essential to include mycotoxin binders found in the concentrate so that when blended with any other components it prevents aflatoxins contamination. Since the birds were susceptible to aflatoxins poisoning, the poisoning would lower the production quality of the egg and the meat obtained later on.

The other materials were a guaranteed source of clean drinking water for the bird's water for daily cleaning of the water drinkers, for preparation of footbath for the personnel to avoid contamination and making the disinfectant solution for sanitizing the whole poultry unit $3-4$ days before bringing the birds. The study used ultraxide disinfectant for proper sanitation.

There are several varieties of improved Kienyeji chicken as Kroiler breed, KARI breed, Kenbro breed and Rainbow rooster breed. The study used 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. They were brought in as day olds and already vaccinated against Marek's disease at the hatchery. The chicks were given liquid paraffin and water as the first feed to prepare the digestive system before starting them on the chick mash. The room temperature for their house was maintained at the recommended temperatures.

Feeders and drinkers installation for the birds as well as traditional *jiko* warmers were purchased from an agrovet store in Marura shopping centre. The 18 *jiko* warmers were used to warm their brooders at night during rainy days. A digital weighing scale was also obtained for weekly weighing of the birds throughout study. The veterinary for Kuku chick limited in Eldoret town confirmed that the day-old chicks had received the Marek's disease vaccine.

3.2.1 Labor

The personnel assisted in receiving, proper timing of feed and clean water to the birds daily. There were two farm hands one for daily cleaning and the other for feeding and record keeping. The services of an extension officer were sought to confirm the house standard and other requirements before, during, and after the study. The officer administered fowl typhoid, deworming, and new castles disease vaccines during the entire period of research study.

3.2.2 Research Site

The experiment was carried out for two months beginning 2nd Feb 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 and a stand by water borehole in case of water deficiency during the period of study.

3.2.1 The Experiment

The feeds ingredients and the mixers were sourced as well as the farmhands were trained before the experiment was done. When the poultry house was ready, the 90 day-old chicks for the study were delivered. Kuku Chick Limited supplied the day-old chicks in Eldoret and their weight recorded. The chicks were put in labeled brooders in the poultry unit from where they were given their respective feed mixtures.

There was an assurance of the extension officer concerning the records of the stock to be delivered, and the prepared destination will allow the birds to be delivered at the farm, which was done by the supplier using the appropriate means of transport. On arrival, their initial weights were recorded as they were placed at specific brooders labeled for easy record keeping. 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. They were given the formulated chick mash following the approved time intervals with clean water supply for drinking. Weight in grams was recorded every seventh day of the week until the eight weeks of the study were over. These records had to be as accurate as possible, and the data collected was entered in Microsoft Excel before being exported to R programming software.

This was followed by different analysis for fitting appropriate model that can be used by farmers to formulate their own feed rations. The three different protein bases led to three models, which were evaluated for an appropriate one. The following tips were considered during the entire process of the feed ration formulation

(a) Caution was taken with the quality of ingredients, as mentioned earlier, to avoid aflatoxins poisoning.
(b) The fish meal was brought from reputable sellers and not from open-air markets, which would otherwise be contaminated.
(c) It was essential to mix the micronutrients (amino acids) before combining with the other feed ingredients.

3.3 Mixture Designs and Optimality Criterions

In this study, it involved varying the three easily accessible and frequently used carbohydrate components whole maize (X_1), rice (X_2) and wheat (X_3) respectively hence three factor. The criterion worked based on the determinant (D), average variance (A), Eigen value (E), and Trace (T) of the formed moment matrix.

The two major mixture designs in MS Excel led to the formation of respective moment matrices. This was followed by obtaining its determinant, average variance, Eigen value, and the trace of the three moment matrices of the three designs were obtained. 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 ranking value was selected and applied in the feed formulation experiment as it would imply less cost implications.

3.4 Mixture Design in Feed Formulation

After the selection of experimental design, the next step was grouping the ingredients purchased as per the components or variables. The components comprised of whole maize, wheat and rice as carbohydrate sources. Fish meal, soya meal, and cotton seed cake as protein sources .The components were ground to increase palatability. Omena fish meal or locally known as *ochogaa* was used in the correct proportion. The right type of soya meal containing low-fat content was selected being specific to the supplier that it was for making poultry feed since there were several varieties in the market. It was also roasted to increase the amount of fat in the diet.It would thus improve energy density of the diet.

It was ensured that all the feed made would last a month only and that the feeds remain fresh and safe for consumption by the chicken. It is because formulating large volumes of feed rations for feeding much longer periods may deteriorate in quality and eventually affect the chicken. This was because there was no use of animal feed preservatives .The vitamins and minerals concentrate was obtained from Sirikwa animal feeds and agro vet in Eldoret town.

The recommended daily crude protein for poultry feed is $18-20$ % for chick mash and $16-18$ % for growers mash. For the 70kg bag, 17% and 19% of DCP was used in respective feed mashes formulations. The protein sources were constituted of soya meal, cotton seed cake, and fish meal. Vitamins and minerals will take up 5.0 kg to make the base component to be 18.3kg. The remaining 51.7 kg is what will be experimented on by varying different proportion of three carbohydrates, namely whole maize, rice, and wheat. The three ingredients will be identified as variables x_1, x_2 and x_3 respectively and will be included in the experimental design, while keeping the other ingredients at a fixed level of 18.3kg (5.0 kg vitamins and minerals concentrate, 13.3 kg protein) 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. This number allowed close and easy observation since they occupied a small space and were manageable in terms of cost to the researcher.

Table 1 shows the mixing of the selected mixture experimental design for the three components used in the study as per the experimental runs of the mixture design.

Table 1: Proportions of Components X_1 X_2 and X_3 for the Mixtures.

Mixture number	Components in mixture	X_1	X_2	X_3
1	1	1	0	0
2	1	0	1	0
3	1	0	0	1
4	2	0.5	0.5	0
5	2	0.5	0	0.5
6	2	0	0.5	0.5

3.4.1 Simplex Lattice

This involves an ordered arrangement of uniformly spaced distribution of points called a lattice. For degree m and q components, it is denoted as $\{q, m\}$ simplex lattice. The coordinates of the points are defined by the combination of components combinations that take $m + 1$ evenly spaced values between 0 and 1.

Table 2 shows the experimental design points for simplex lattice mixture design for the three feed components.

Table 2: SLD Design Points

Mixture no.	X_1	X_2	X_3
1	1	0	0
2	0	1	0
3	0	0	1
4	0.5	0.5	0
5	0.5	0	0.5
6	0	0.5	0.5

3.4.2 Simplex Centroid

This is a q-component design where the number of points is obtained using 2q-1 formulae. The design points correspond to the q-permutations of $(1, 0, 0, 0, .., 0)$ and so on. These mixtures are located at the centroid of the $(q - 1)$ dimensional simplex and at the centroids of all the lower dimensional simplexes contained in the $(q - 1)$ dimensional simplex.

Table 3 shows the experimental design points for the simplex centroid mixture design.

Table 3: SCD Design Points

Mixture no.	X_1	X_2	X_3
1	1	0	0
2	0	1	0
3	0	0	1
4	0.5	0.5	0
5	0.5	0	0.5
6	0	0.5	0.5
7	0.3333	0.3333	0.3333

The experiment was carried out in replicates of 5 which was economical since it involved 18 mixtures.

3.5 The Appropriate Model for Feed Formulation

This study aimed at modeling the response surface for predicting response to all blends. The study investigated the blending properties of the three components as well as to measure the effects of separate components on the response.

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. Given the data, an average of the responses was made for each design point. The effects of the feed proportions in the feed mixture on total weight gain were analyzed using the mixture regression method . The fitted model for the three components was of the form in equation 4

$$\hat{y}(X) = b_1 X_1 + b_2X_2 + b_3X_3 + b_{12}X_1X_2 + b_{13}X_1X_3 + b_{23}X_2X_3 \qquad (4)$$

$\hat{y}(x)$ 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. The parameter coefficients b_1 to b_3 were estimates of the response from feed with single ingredient. Also the parameter coefficients b_{12} to b_{23} represent the interaction effects for each of the three 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 technique. The Analysis of Variance, ANOVA was used to show if the components of the fitted model a significant effect with the response and also the proportion of the variability that would be explained by the model.

The contour plots that were derived from the model were fitted to the actual experimental data. The model's goodness of fit was assessed from the lack of fit analysis by checking the P-value if it was significant. The adjusted R^2 was checked to see if the model fits well to the data.

The estimates of the b`s were obtained followed by an estimate of the error variance from the replicate observations at the lattice points. The variances of the parameter estimates were obtained whose positive square root gave the estimated standard error of each parameter estimate.

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 would recommend one model to the poultry farmers in the region. From the data analysis and model selection, optimal settings that yielded maximum weight in chicks was obtained and recommended for future feed formulation.

3.6 Assumptions

- Price of components was fixed
- Adequate mentorship from the self-help group
- Political stability during the period of the study.
- The errors were independent and identically distributed with zero mean and common variance.
- The underlying response surface was continuous over the region being studied.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This chapter gives the findings and results of the design selection used, data analysis and model estimation and evaluation procedures.

4.2 Design Selection

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

4.2.1 Simplex Lattice Design

Simplex lattice design has six experimental runs or design points. Table 4 displays the experimental design points for the mixture design.

Table 4: Design Points for Simplex Lattice Mixture Design

Mixture number	X_1	X_2	X_3
1	1	0	0
2	0	1	0
3	0	0	1
4	0.5	0.5	0
5	0.5	0	0.5
6	0	0.5	0.5

Table 4 was used to create the 6 by 6 design matrix as illustrated in Table 5

Table 5: SLD Experimental Design in MS Excel

X_1	X_2	X_3	X_1X_2	X_1X_3	X_2X_3
1	0	0	0	0	0
0	1	0	0	0	0
0	0	1	0	0	0
0.5	0.5	0	0.25	0	0
0.5	0	0.5	0	0.25	0
0	0.5	0.5	0	0	0.25

The SLD experimental design in Excel looks

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 optimi zation. It is formed by multiplying the transpose of the main matrix by the initial matri x and dividing by the number of experimental runs which in this case was six.

$M=\frac{1}{N} X^{I} X$

$M=\frac{1}{6} X^{1}X$

$$= \begin{bmatrix} 0.2500000 & 0.04166667 & 0.04166667 & 0.02083333 & 0.02083333 & 0.00000000 \\ 0.04166667 & 0.25000000 & 0.04166667 & 0.02083333 & 0.00000000 & 0.02083333 \\ 0.04166667 & 0.04166667 & 0.25000000 & 0.00000000 & 0.02083333 & 0.02083333 \\ 0.02083333 & 0.02083333 & 0.00000000 & 0.01041667 & 0.00000000 & 0.00000000 \\ 0.02083333 & 0.00000000 & 0.02083333 & 0.00000000 & 0.01041667 & 0.00000000 \\ 0.0000000 & 0.02083333 & 0.02083333 & 0.0000000 & 0.00000000 & 0.01041667 \end{bmatrix}$$

The moment matrix was reduced by factoring out $\frac{1}{96}$.

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

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

(i) Determinant.

This scalar value can be computed from the elements of a square matrix and encodes certain properties of the linear transformation described by the matrix.

$$Det\ (M)\ = 5.232781e - 09$$

(ii) Eigen value

These are a special set of scalars associated with a linear system of equations that are sometimes also known as characteristic roots, characteristic *values* (Hoffman and Kunze , 1971). For this design, the output values are displayed below.

$$0.338623027 \quad 0.210502541 \quad 0.210502541 \quad 0.008247459$$
$$0.008247459 \quad 0.005126973$$

The minimum of the above set of scalars was taken as the Eigen value of the moment matrix.

$$Eigen\ value = 0.005126973$$

(iii) Trace

It is the sum of the (complex) eigenvalues, and it is invariant concerning a change of basis.

$$Trace = 0.78125$$

(iv) Average variance

It involves the averaging the measure of the variability or spread in a set of data.

$$Average\ variance\ = 75$$

4.2.2 Simplex Centroid Design

The seven experimental design points of the SCD is as shown in Table 6.

Table 6: Design Points for Simplex Centroid

Mixture number	X_1	X_2	X_3
1	1	0	0
2	0	1	0
3	0	0	1
4	0.5	0.5	0
5	0.5	0	0.5
6	0	0.5	0.5
7	0.3333	0.3333	0.3333

A matrix was formed in MS Excel as shown in Table 7.

Table 7: SCD Design Points in Excel

X_1	X_2	X_3	X_1X_2	X_1X_3	X_2X_3
1	0	0	0	0	0
0	1	0	0	0	0
0	0	1	0	0	0
0.5	0.5	0	0.25	0	0
0.5	0	0.5	0	0.25	0
0	0.5	0.5	0	0	0.25
0.33	0.33	0.33	0.1089	0.1089	0.1089

The moment matrix for simplex centroid, SCD, was as illustrated.

$M= \{\frac{1}{N} X'X\}$

$M=\frac{1}{6}X'X$

=

$$\begin{bmatrix} 0.25000000 & 0.09666667 & 0.16666667 & 0.08333333 & 0.05074167 & 0.00907500 \\ 0.09666667 & 0.22648333 & 0.11083333 & 0.08250000 & 0.01375000 & 0.05074167 \\ 0.16666667 & 0.11083333 & 0.22648333 & 0.06916667 & 0.02083333 & 0.01815000 \\ 0.08333333 & 0.08250000 & 0.06916667 & 0.10148333 & 0.02083333 & 0.01375000 \\ 0.05074167 & 0.01375000 & 0.02083333 & 0.02083333 & 0.01239320 & 0.00000000 \\ 0.00907500 & 0.05074167 & 0.01815000 & 0.01375000 & 0.00000000 & 0.01239320 \end{bmatrix}$$

The matrix is reduced by factoring out $\frac{1}{110}$.

$$M=1/110\begin{bmatrix} 27.5000 & 10.6333 & 18.3333 & 9.1667 & 5.5820 & 0.9983 \\ 10.6333 & 24.9132 & 12.1917 & 9.0750 & 1.5125 & 5.5816 \\ 18.3333 & 12.1917 & 24.9132 & 7.6083 & 2.2917 & 1.9965 \\ 9.1667 & 9.0750 & 7.6083 & 11.1632 & 2.2917 & 1.5125 \\ 5.5820 & 1.5125 & 2.2917 & 2.2917 & 1.3633 & 0.0000 \\ 0.9983 & 5.5816 & 1.9965 & 1.5125 & 0.0000 & 1.3633 \end{bmatrix}$$

The following features of the moment matrix were obtained as listed below.

(i) Determinant

$$Det\ (M)\ = 8.169518e - 26$$

(ii) Eigen value.

Eigen values obtained were as follows.

$$5.392932e - 01, 1.595143e - 01, 7.992626e - 02, 5.021873e - 02, 2.838990e - 04\ and\ 1.431840e - 17$$

The minimum of the displayed scalars was the Eigen value.

Eigen value = $1.431840e - 17$

(iii) Average variance

Average variance obtained was 0.8292364

(iv) Trace

The trace obtained was 593.8212

4.2.3 Optimality Criterion

This is the technique that was used in design selection. The process involved ranking t he obtained features of the formed moment matrices of the two experimental designs i n question. This was done as illustrated in Table 8.

Table 8: 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 9.

Table 9: 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.

4.3 Application of Simplex Lattice Mixture Design in Poultry Feed Ration Formulation.

The feed components were assembled and formulated using the selected simplex lattice design. There was the formulation of chick mash feed ration for the first part of the experiment followed by the formulation of growers mash feed ration for the final part of the experiment.

4.3.1 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 meal. This study was based on the digestible crude protein, DCP, as the basic nutritional requisite. Given the nutritional requirements for this age of the chicks, its DCP should be in the range of 18% to 20%. A single chick is expected to averagely feed on 13g of feed ration per day for the first week, 18g for the second week and 30g and 50 g per day for the third and fourth weeks respectively.

The following ingredients were assembled before the blending. Whole maize, rice and wheat each at 99.4 kg, soya meal, cotton seed cake and fish meal each at 59.85 kg (13.3kg × 4.5 bags). For the entire study 105 kg of the vitamins and minerals concentrate was needed which meant 2 bags since each bag was of 70 kg capacity.

The 70kg bag had 19% being the protein which is equivalent to 13.3kg. The recommended amount of concentrate is $5kg$. The remaining 51.7 kg was the total amount of varied proportions of the three energy sources. The bases were Soya meal protein and concentrate Fish meal protein and finally, cotton seed cake protein and concentrate. In each of these bases, the remaining 51.7 kg was added varying proportions of the energy sources as per the experimental design points. Each experimental design had six types of mixtures. Therefore, a total of 18 mixtures were formulated for the entire study. There were three types of protein used singularly in the base component with the vitamins and minerals concentrate.

The blending of the components is as shown in the experimental design in Table 10.

Table 10: Chick Mash Ration Formulation

	Coded	Variables		Actual	Variables	
Mixture	X_1	X_2	X_3	Whole Maize (kg)	Rice (kg)	Wheat (kg)
M1	1	0	0	51.70	0.00	0.00
M2	0.5	0.5	0	25.85	25.85	0.00
M3	0	1	0	0.00	51.70	0.00
M4	0.5	0	0.5	25.85	0.00	25.85
M5	0	0.5	0.5	0.00	25.85	25.85
M6	0	0	1	0.00	0.00	51.70

They were ground to increase palatability given the age of the chicks.

4.3.2 Growers Mash Ration Formulation

This was formulated in the final stage of the study. The pullets were now grown 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. Similarly, for a single chick, it needs 70 g of feed ration per day, 90 g, 110 g and 130 g per day for the $5th, 6th$,$7th$and $8th$ week respectively. The weight of carbohydrates to be assembled before mixing was 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. The constitution of components as per the experimental design was as indicated in Table 11.

Table 11: Growers Mash Ration Formulation

	Coded	Variables		Actual	Variables	
Mixture	X_1	X_2	X_3	Whole Maize (kg)	Rice (kg)	Wheat (kg)
M1	1	0	0	51.10	0.00	0.00
M2	0.5	0.5	0	25.55	25.55	0.00
M3	0	1	0	0.00	51.10	0.00
M4	0.5	0	0.5	25.55	0.00	25.55
M5	0	0.5	0.5	0.00	25.55	25.55
M6	0	0	1	0.00	0.00	51.10

A total of 6 mixtures were formulated in each of the three protein base components totaling to 18 mixture types. Kuku Chick Limited in Eldoret supplied day old chicks and their weight recorded. The chicks were put in labeled compartments in the poultry unit being given their respective feed mixtures.

4.4. Analysis of Mixture Data

The final weights of the birds from the three distinct groups were exported from MS Excel to R software. This was for analysis as mixture experiment data. Summary statistics are presented for each group as shown in Section 4.3.1.

4.4.1 Exploratory Data Analysis

The summary statistics for each protein base data set of the final weights of the chicks was analyzed to get the summary statistics per mixture. Each formulation had 30 final weights summing to 90 for the entire study. This aided in giving a better explanation and understanding of the features of the specific data set of final weights for the entire period of study.

4.4.2 Cotton Seed Cake Protein Summary Statistics

Each of the six mixtures formulated using cotton seed cake base protein were feed to the six mixture types labeled M1, M2, M3, M4, M5, and M6 each having 5 birds. The weights of the birds were recorded statistical descriptive obtained were as shown in Table12.

Table 12: 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

Mixture labeled M2 had the highest maximum final weight of 1871.92g of the chick while Mixture M1 had the highest minimum weight value of 1459.15g as shown on Table 12 above. On the other hand, the mixture labeled M2 had the highest mean weight (1623.56g) of all chicks in fish meal protein-based formulation. It meant that 1623.56g would be used to describe the entire sample since it is a measure of central tendency. The mixture component labeled M6 had the highest standard deviation of 262.16 among the other mixture labels. Further, mixture label M6 still had the highest coefficient of variation value of 17.86. The large value meant that the mixture label M6 had more variation in the final weights of the birds.

Figure 1 shows a box plot of the distributions of the final weights under different mixture formulations. It gave the overall pattern of the final weights of the birds.

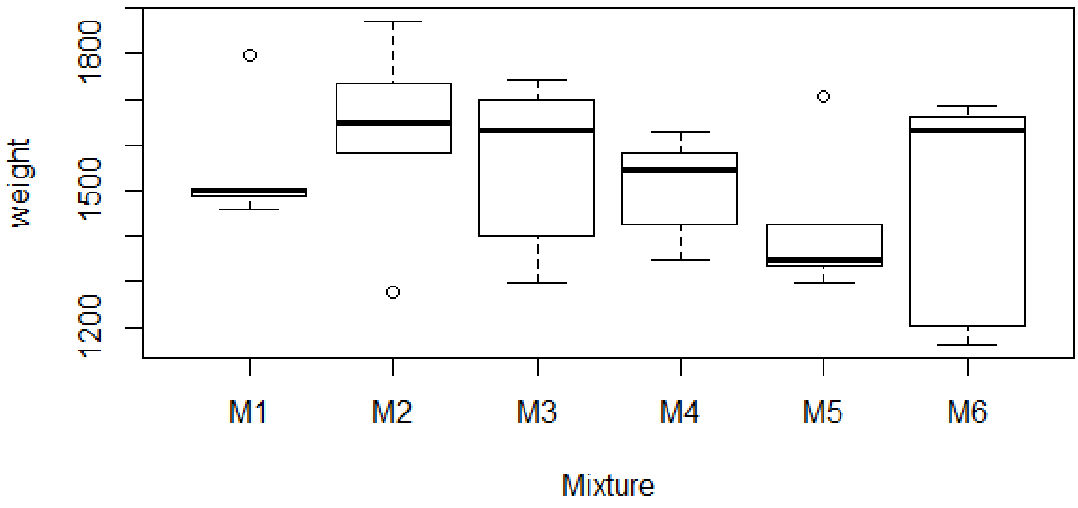

Figure 1: Box Plots for the Chicks' Final Weight for Cotton Seed Cake Protein

From the plots in Figure 1, it is evident that mixture M1 had its final weights having a high level of agreement with each other. Mixture label M6 had its weights with greatest variation while M1 and M2 mixtures displayed the major difference between mixture groups.

4.4.3 Soya Meal Protein Summary Statistics

The next formulation of ration made of soya meal as the base protein had their final weights recorded and descriptive statistics evaluated as displayed in Table 13.

Table 13: 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

Mixture labeled M1 had the highest maximum weight recorded among the six mixture labels M1, M2, M3, M4, M5, and M6, further, the largest minimum value among all the mixtures was recorded in mixture component labelled M5.

Mixture M2 also had the highest mean final weight ($1594.51g$). However, Mixture labelled M3 recorded the highest standard deviation ($207.31g$) and coefficient of variation (13.82) value of its weights at mixture label M3. This implied that a greater spread of the final weights was achieved in this mixture label. Figure 2 is a box plot of the final weights of the whole group of mixtures under this formulation.

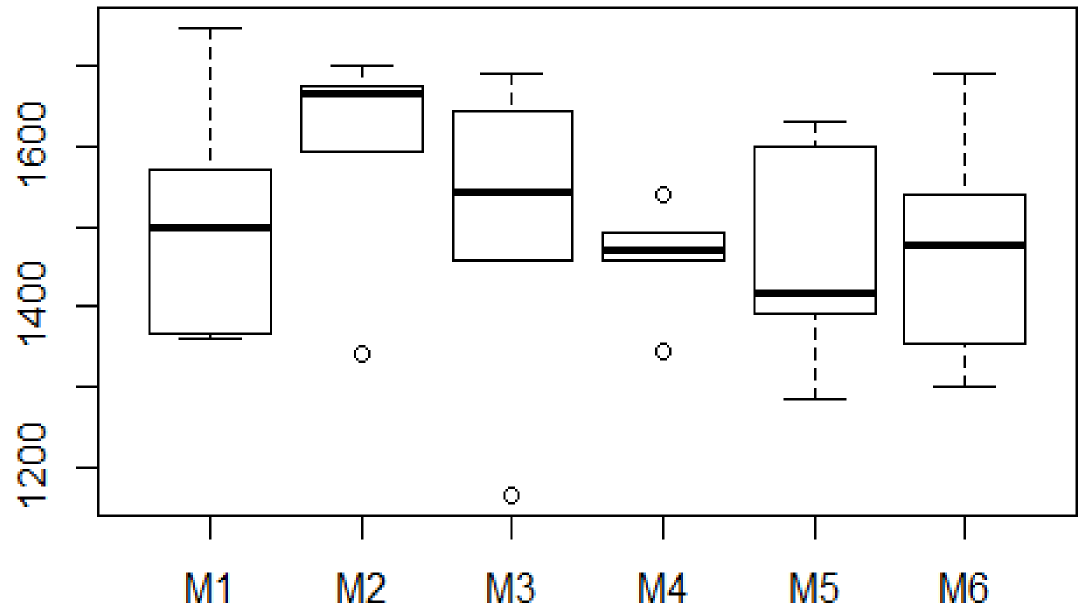

Figure 2: Box Plot for the Chicks Weight of Soya Meal Protein

Figure 2 plots clearly showed that mixture label M4 had its chick weights with a high agreement with each other while mixture M6 had its chicks with most dispersed final weights.

4.4.4 Fish Meal Protein Summary Statistics

The final chick weights of this formulation were estimated for descriptive statistics as seen on Table 14.

Table 14: 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

Table 14 shows that mixture label M6 had the highest maximum final weight record of 1400.05g. The highest minimum weight record of 1351.43g was observed in mixture label M2. The highest chick means the weight of 1382.19g was found in mixture label M4. A greater spread of the data was evident in mixture label M3. This was shown by the highest values of the standard deviations and coefficient of variations of 23.87 and 1.76, respectively. In order to make an efficient comparison between measures of the final weights of the chicks, box plots were plotted as shown in Figure 3.

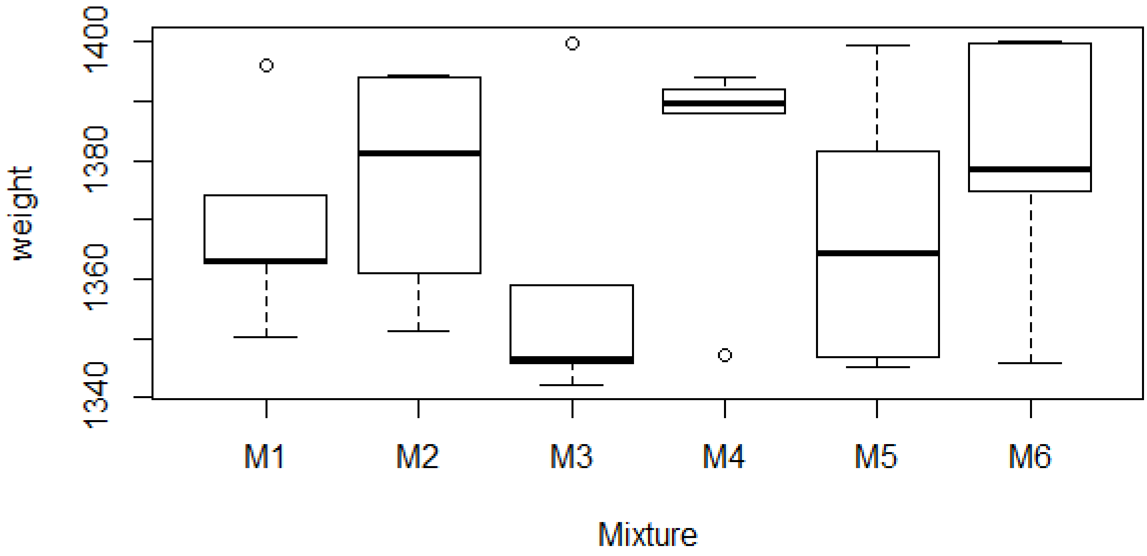

Figure 3: Box Plot for the Chicks Final Weights of Fishmeal Protein

Figure 3 plots show that mixture labelled M4 had its chick weights being less varied. Mixture label M6 had its chicks record the higher final weight while mixture label M3 had the greatest spread or deviation of its final weights.

4.5 Model Approximation and Evaluation

In any experiment on mixtures, model fitting is done to show the relationship between the responses. A set of measurable variables in this study was the final weight. The several poultry rations formulations gave distinct weight data sets, which were analyzed to get different models. The models were later evaluated and compared to come up with an appropriate model that would be recommended to the poultry farmers in the country and Africa at large.

4.5.1 Model one (Cotton Seed Cake Base Protein)

These 30 final weight entries were from the first formulation that had cotton seed cake as the main protein component. This is as displayed in Table 15.

Table 15: Data from Cotton Seed Cake Base Protein Formulation

		Components			Final
Run	Blend	X_1	X_2	X_3	Weight(g)
1	Pure	1	0	0	1459.15
2	Pure	1	0	0	1798.97
3	Pure	1	0	0	1505.69
4	Pure	1	0	0	1398.98
5	Pure	1	0	0	1485.69
6	Binary	0.5	0.5	0	1650.81
7	Binary	0.5	0.5	0	1580.76
8	Binary	0.5	0.5	0	1277.26
9	Binary	0.5	0.5	0	1737.04
10	Binary	0.5	0.5	0	1871.92
11	Pure	0	1	0	1743.61
12	Pure	0	1	0	1399.42
13	Pure	0	1	0	1298.88
14	Pure	0	1	0	1634.24
15	Pure	0	1	0	1697.87
16	Binary	0.5	0	0.5	1583.33
17	Binary	0.5	0	0.5	1545.02
18	Binary	0.5	0	0.5	1629.16
19	Binary	0.5	0	0.5	1424.25
20	Binary	0.5	0	0.5	1346.19
21	Binary	0	0.5	0.5	1425.30
22	Binary	0	0.5	0.5	1347.53
23	Binary	0	0.5	0.5	1332.83

24	Binary	0	0.5	0.5	1296.5
25	Binary	0	0.5	0.5	1706.23
26	Pure	0	0	1	1162.21
27	Pure	0	0	1	1685.54
28	Pure	0	0	1	1202.17
29	Pure	0	0	1	1631.76
30	Pure	0	0	1	1659.33

The 30 final weight records for the chicks feed on this ration were uploaded to MS Excel and exported to R software for data analysis. It was followed by model fitting using the installed mixexp package: Library (mixexp). The regression models showing the effect of variables on the responses were estimated. The effects of the mixture components on the weight response were summarized as shown on the Table 16.

Table 16: Cotton Seed Cake Protein Model Estimates

Coefficients	Estimate	Std. Error	T value	P value	Significance
X_1	1549.64	85.05	18.221	1.47×10^{-15}	***
X_2	1554.80	85.05	18.282	1.36×10^{-15}	***
X_3	1421.68	85.05	16.716	1.0×10^{-14}	***
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 15 further shows that the fitted model for the three components was of the form in equation 5.

$$\hat{Y}(x) = 1549.64x_1 + 1554.80\,x_2 + 1421.68x_3 + 285.35x_1x_2 - 69.82x_1x_3 + 69.40x_2x_3 \quad (5)$$

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 from equation 5. $b_1 = 1549.64$, $b_2 = 1554.80$ and $b_3 = 1421.68$ respectively.

$$b_2 > b_1 > b_3$$

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 $b_{12} = 285.35$, $b_{13} = -69.82$ and $b_{23} = 69.40$ as values of the parameter estimates respectively.

$$b_{12} > 0 , b_{23} > 0 , b_{13} < 0$$

This implied that component 1 and 2 and component 2 and 3 combined would give higher final weights 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 (rice) would be used. For a binary blend, when component 3 (wheat) 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. This implied that a greater variation of the data could be explained by the model hence a good fit to the data. The Analysis of variance (ANOVA) results of the final chick weight is summarized as shown in the Table 17. The P- value for the pure effects showed a statistical significance effect as compared to the interaction terms which remained insignificant.

Table 17: Analysis of Variance for Cotton Seed cake Protein

Source of variation	Degree of freedom	Sum of Squares	Mean Square	F Value	P Value	Significance.
X_1	1	31940772	31940772	883.2016	2.0×10^{-16}	***
X_2	1	23238841	23238841	642.5825	2.0×10^{-16}	***
X_3	1	14291748	14291748	395.1844	2.0×10^{-16}	***
X_1X_2	1	17819	17819	0.4927	0.4895	
X_1X_3	1	1419	1419	0.0393	0.8446	
X_2X_3	1	1003	1003	0.0277	0.8691	
Residuals	24	867954	36165			

It could not be concluded that there was a statistically significant association between the response and the terms. This affected the need for model reduction to get a model with only the significant term.

4.5.2 Cotton Seed Cake Protein Model Reduction

The fitted model above had insignificant terms prompting the fit of a similar model but with significant terms only. It gave the output in Table 18.

Table 18: Cotton Seed Cake Protein Model Reduction

Coefficients	Estimate	Std. Error	t value	P value	Significance
X_1	1564.07	67.86	23.05	2.0×10^{-16}	***
X_2	1583.16	67.86	23.33	2.0×10^{-16}	***
X_3	1414.51	67.86	20.84	2.0×10^{-16}	***

The output above gives a significant model of the form in equation 6.

$$\hat{Y}(x) = 1564.07x_1 + 1583.16x_2 + 1414.51x_3 \qquad (6)$$

Generally, if coefficients have a positive sign, then there is proof of the ability of the variables to increase the response while a negative sign indicates an ability to decrease the response. Further, the model had all its terms being significant; hence an indication of significant linear model fit. It was the recommended model for the cotton seed cake protein, given the varying proportions of the three carbohydrate components.

The coefficient of determination R^2 gave 0.9874 (98.74%) with adjusted R^2 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.

In order to get graphical representation, contours were plotted in Figure 1 to see how the fitted final weight values relate to protein type and mixture type based on the model equation. This provided a two-dimensional view where all points were connected.

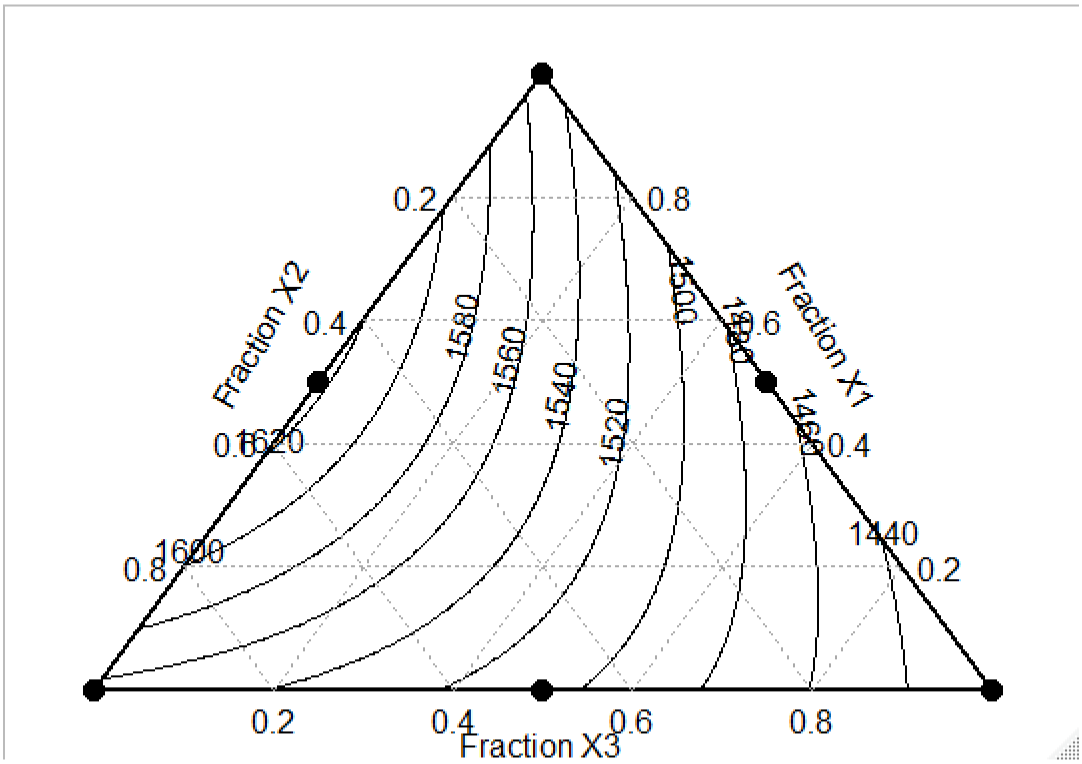

Figure 4: The Estimated Final Chicks Weight Surface with the Second-Degree Model for Cotton Seed Cake

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).

4.5.3 Model Two (Soya Meal Protein)

The second batch of birds were fed on the feed ration formulated using the base protein component of soya meal. They had their final weights as shown in Table 19.

Table 19: Soya Meal Protein Base Final Weight

			Components		
Run	Blend	X_1	X_2	X_3	Final weight(g)
1	Pure	1	0	0	1367.45
2	Pure	1	0	0	1361.04
3	Pure	1	0	0	1499.29
4	Pure	1	0	0	1569.28
5	Pure	1	0	0	1747.64
6	Binary	0.5	0.5	0	1342.44
7	Binary	0.5	0.5	0	1674.73
8	Binary	0.5	0.5	0	1664.04
9	Binary	0.5	0.5	0	1592.61
10	Binary	0.5	0.5	0	1698.71
11	Pure	0	1	0	1165.66
12	Pure	0	1	0	1459.38
13	Pure	0	1	0	1541.73
14	Pure	0	1	0	1644.31
15	Pure	0	1	0	1689.52
16	Binary	0.5	0	0.5	1343.49
17	Binary	0.5	0	0.5	1459.39
18	Binary	0.5	0	0.5	1469.17
19	Binary	0.5	0	0.5	1490.88
20	Binary	0.5	0	0.5	1539.32
21	Binary	0	0.5	0.5	1418.07
22	Binary	0	0.5	0.5	1631.68

23	Binary	0	0.5	0.5	1599.96
24	Binary	0	0.5	0.5	1285.58
25	Binary	0	0.5	0.5	1392.88
26	Pure	0	0	1	1355.12
27	Pure	0	0	1	1475.19
28	Pure	0	0	1	1299.52
29	Pure	0	0	1	1540.66
30	Pure	0	0	1	1691.00

These final weights of the birds were analyzed using R software. Estimating the regression effects of the model gave the output in Table 20.

Table 20: Soya Meal Protein Model Estimates

coefficients	Estimate	Std. Error	T value	P Value	Significance
X_1	1490.94	64.10	23.259	2.0×10^{-16}	***
X_2	1440.31	64.10	22.470	2.0×10^{-16}	***
X_3	1465.63	64.10	22.865	2.0×10^{-16}	***
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 20 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 7 as a representation of the data.

$$\hat{Y}(x) = 1490.94x_1 + 1440.31x_2 + 1465.63x_3 + 35.23x_1x_2 - 23.95x_1x3 + 29.90x_2x_3 \quad (7)$$

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 b_1 =1490.94 , b_2 = 1440.31 and b_3 = 1465.63 respectively.

$$b_1 > b_3 > b_2$$

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 obtained were b_{12} = 35.23 , b_{13} = -23.95 , and b_{23} = 29.90 respectively.

$$b_{12} > 0, b23 > 0, b_{13} < 0$$

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 R^2 and 0.9905(99.05%) for adjusted R^2 . This indicated that the model was a good fit for the data.

Table 21: Analysis of Variance for Soya Meal Protein

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	F-Value	P Value	Significance
X_1	1	29290327	29290327	1425.7065	2.0×10^{-16}	***
X_2	1	19974766	19974766	972.2716	2.0×10^{-16}	***
X_3	1	15334356	15334356	746.3997	2.0×10^{-16}	***
X_1X_2	1	259	259	0.0126	0.9116	
X_1X_3	1	179	179	0.0087	0.9263	
X_2X_3	1	186	186	0.0091	0.9249	
Residuals	24	493066	20544			

The analysis of variance for the second fitted model gave the output in Table 21. The single component mixtures were significant at 5% level of significance. Their P-values were less than 0.05. The initial model had non-significant terms hence the need to fit again with the significant terms only.

4.5.4 Soya Meal Protein Model Reduction

The obtained model for the soya meal protein had its interaction terms or components being insignificant. This prompted the fitting of a final model with only the significant terms as shown in Table 22.

Table 22: Soya Meal Protein Model Reduction

Coefficients	Estimate	Std. Error	t value	P value	Significant
X_1	1491.0	50.6	29.47	2.0×10^{-16}	***
X_2	1445.8	50.6	29.47	2.0×10^{-16}	***
X_3	1465.2	50.6	29.47	2.0×10^{-16}	***

The above output altered the model to be such as in equation 8.

$$\hat{Y}(x) = 1491.0x_1 + 1445.8x_2 + 1465.2x_3 \qquad (8)$$

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 R^2 and 0.9916(99.16%) for adjusted R^2 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.

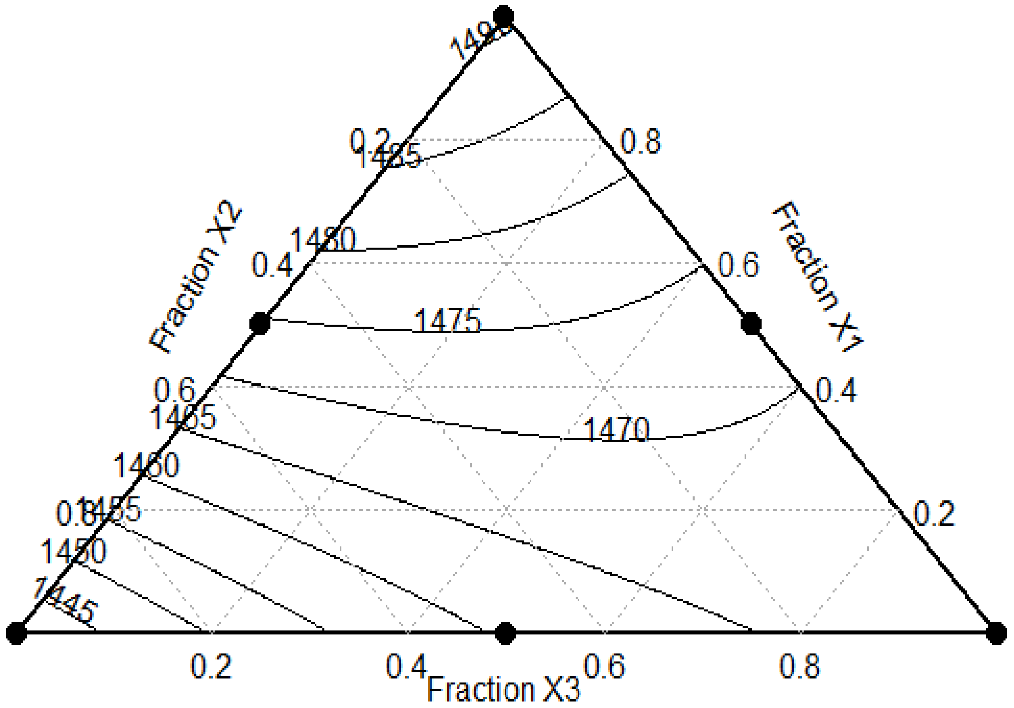

Figure 5: The Estimated Final Chicks Weight Surface with the Second-Degree Model for Soya Meal Protein

The contour plot in Figure 5 shows that when using the soya meal base protein, the maximum final weight of 1491g was achieved at the use of pure component X_1 (Whole maize).

4.5.5 Model Three (Fish Meal Base Protein)

The third batch of 30 birds was fed on the Fish meal protein-based component, and their final weights were recorded as shown in Table 23 below.

Table 23: Fish Meal Protein Base Final Weight

		Components			
Run	Blend	X_1	X_2	X_3	Final weight
1	Pure	1	0	0	1363.05
2	Pure	1	0	0	1374.05
3	Pure	1	0	0	1350.38
4	Pure	1	0	0	1396.02
5	Pure	1	0	0	1362.68
6	Binary	0.5	0.5	0	1351.43
7	Binary	0.5	0.5	0	1394.36
8	Binary	0.5	0.5	0	1381.25
9	Binary	0.5	0.5	0	1393.92
10	Binary	0.5	0.5	0	1360.88
11	Pure	0	1	0	1358.97
12	Pure	0	1	0	1342.28
13	Pure	0	1	0	1346.52
14	Pure	0	1	0	1399.88
15	Pure	0	1	0	1345.87
16	Binary	0.5	0	0.5	1347.29
17	Binary	0.5	0	0.5	1387.85
18	Binary	0.5	0	0.5	1394.15
19	Binary	0.5	0	0.5	1392.04
20	Binary	0.5	0	0.5	1389.60
21	Binary	0	0.5	0.5	1346.74
22	Binary	0	0.5	0.5	1399.47
23	Binary	0	0.5	0.5	1381.63
24	Binary	0	0.5	0.5	1364.46
25	Binary	0	0.5	0.5	1345.06
26	Pure	0	0	1	1345.76
27	Pure	0	0	1	1400.05
28	Pure	0	0	1	1378.37
29	Pure	0	0	1	1399.78
30	Pure	0	0	1	1374.86

Table 24: Fish Meal Model Estimates

Coefficients	Estimate	Std. Error	T value	P Value	Significance
X_1	1369.256	9.436	145.117	2.0×10^{-16}	***
X_2	1358.704	9.436	143.999	2.0×10^{-16}	***
X_3	1367.472	9.436	144.928	2.0×10^{-16}	***
X_1X_2	49.552	46.224	1.072	0.294	
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 is shown in equation 9:

$$\hat{Y}(x) = 1369.26x_1 + 1358.7x_2 + 1367.47x_3 + 49.55x_1x_2 + 45.6x_1x_3 + 76.39x_2x_3 \qquad (9)$$

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.

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

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 analysis of variance for this formulation had the output in Table 25.

Table 25: Analysis of Variance for Fish Meal Protein

Source of variation	Degree of freedom	Sum of squares	mean sum of squares	F value	P value	Significance
X_1	1	25159261	25159261	56519.073	2.0×10^{-16}	***
X_2	1	17824555	17824555	40042.0093	2.0×10^{-16}	***
X_3	1	13511981	13511981	30354.0170	2.0×10^{-16}	***
X_1X_2	1	226	226	0.5071	0.4832	
X_1X_3	1	231	231	0.5200	0.4778	
X_2X_3	1	1216	1216	2.7312	0.1114	
Residual	24	10684	10684			

The single component mixtures were significant at 5% level of significance.

4.5.6 Fish Meal Protein Model Reduction

The fitted model had the interaction terms being insignificant hence prompting the fit of a reduced model from the only significant terms. The output was as shown in Table 26.

Table 26: Fish Meal Protein Model Reduction

Coefficients	Estimate	Std. Error	T value	P Value	Significant
X_1	1374.483	8.004	171.7	2.0×10^{-16}	***
X_2	1367.01	8.004	170.8	2.0×10^{-16}	***
X_3	1375.383	8.004	171.8	2.0×10^{-16}	***

The output in Table 26 can be summarized using the equation 10 below.

$$\hat{Y}(x) = 1374.48x_1 + 1367.01x_2 + 1375.38x_3 \qquad (10)$$

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 larger variation of the measured data.

The contour plot for fish meal protein is as displayed in Figure 6.

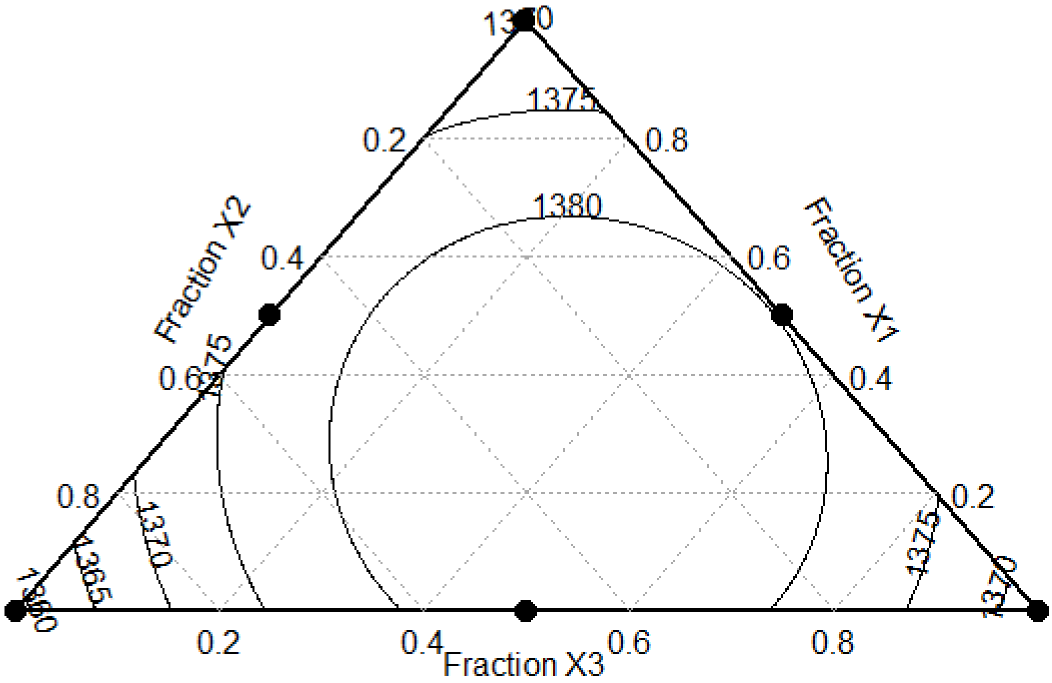

Figure 6: The Estimated Final Chicks Weight Surface with the Second-Degree Model for Fish Meal

Figure 6 shows that using fish meal base protein, a combination of 0.5 of component X_1 (Whole maize) and 0.5 of component X_3 (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 and to be used by small scale farmers in the county and the country at large.

The study concluded that fish meal protein gave the best model followed by Soya meal and cotton seedcake meal protein bases. Within the fish meal protein ,the varied proportions of carbohydrates, 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.

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 as the main components in their formulations. They concluded that a combination of maize, soy bean, fish meal in pre starter ration positively impacted the growth and development and development of chicks.

4.6 Test for Normality

In a given data set, it is of the essence to test for normality of distribution before running certain statistical tests. This is to check if the data agrees with the assumption of normality test, then other methods like non-parametric tests will be recommended. Also transformations can be performed on the specific variables before final analysis.

4.6.1 Soya Meal Test for Normality

The final weight data for the different mixture types were recorded and summarized before model fitting. Normality test was done using the Shapiro-Wilks test. The weight record was uploaded to R, followed by running the Shapiro. Test command. The output gave a P-value of 0.07546. It was greater than 0.05 hence failed to reject the null hypothesis for non-normality. It was therefore concluded that the distribution of the data was not significantly different from the normal distribution. It was normally distributed data.

4.6.2 Cotton Seed Cake Test for Normality

The chicks feed on the ration of soya meal base protein had their final weight tested for normality. It gave a P value of 0.159, which was greater than 0.05 hence failed to reject the null hypothesis to conclude that it was not significantly different from the normal distribution.

4.6.3 Fish Meal Test for Normality

Given the final weights of the chicks fed on the cotton seed cake protein base ration data, it was tested for normality before further analysis. Shapiro-Wilks test gave a P-value of 0.03942, which was less than 0.05 hence, we reject the null hypothesis. It meant that the distribution of the weights is significantly different from the normal distribution. This led to doing of non -parametric one way ANOVA.

Kruskal-Wallis test was done to decide whether the median weight distributions are identical without them following normality. This test gave a chi-squared value of 3.1523 and a P value of 0.6765 hence we accept the null hypothesis and a conclusion that there was no significant difference in the median final weights.

4.7 One-Way Analysis of Variance

One way analysis of variance was done to test the equality of means for the different groups. This was as per the hypothesis below.

Ho: $\mu_1 = \mu_2 = \mu_3 = \mu_4 = \mu_5 = \mu_6$

H1: $\mu_i \neq \mu_j$ for at least one i.j

4.7.1 One Way ANOVA Soya Meal Protein

Given the final weights of the chicks feed on the fish meal base protein ration the different mixtures were tested for equality of means as shown in Table 27.

Table 27: One-way ANOVA for the Soya Meal Protein Final Weights

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	F value	P value
Mixture	5	62617	12523	0.534	0.748
Residual	24	562782	23449		

The P-value was 0.748. This was greater than 0.05 hence we accept the null hypothesis. This meant that there was no difference in mean final weights for the different feed ration mixture types M1 to M6 respectively.

4.7.2 One Way ANOVA Cotton Seed Cake Meal

The different weights of the distinct mixtures of this ration were tested for equality of means to give the output presented in Table 28.

Table 28: One-Way ANOVA for Cotton Seed Cake Meal Protein

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	F value	P value
Mixture	5	160611	32122	1.693	0.175
Residual	24	455431	18976		

The P value of 0.175 was greater than 0.05 hence we accept the null hypothesis for the difference of means. This meant that there was no difference between the means.

4.7.3 One Way ANOVA for Fish Meal Base Protein

The final weights of the chicks fed on this ration were recorded and tested for equality of means as shown on the output in Table 29.

Table 29: One-Way ANOVA for Fish Meal Protein

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	F value	P value
Mixture	5	1937	387.4	0.87	0.515
Residual	24	10684	445.1		

Table 29 indicates a P value of 0.515 which was similarly greater than 0.05 accepting the null hypothesis of no difference among the means for the fish meal protein.

4.8 Two Way Analysis of Variance.

This study had two sets of treatments as proteins and mixtures. Two-way ANOVA was done to evaluate concurrently the effect of proteins and mixtures on the final weight of the chick as listed.

1. There is no difference in the means of proteins
2. There is no difference in means of mixtures
3. There is no interaction between proteins and mixtures

Table 30 was the obtained output for the two way Analysis of Variance.

Table 30: Two-Way ANOVA for Proteins and Mixtures

Source of variation	Degree of freedom	Sum of squares	Mean sum of squares	F value	P value
Protein	2	382827	191414	9.769	0.000176
Mixture	5	112969	22594	1.153	0.340729
Protein:mixture	10	78079	7808	0.398	0.943197
Residuals	72	1410830	19595		

The P values indicated that the protein effects were significant. The mixture and interaction effects were insignificant leading to performing post hoc analysis using Tukey HSD test. This would show the actual difference or the significance of the difference in mixture means as shown in the output in Table 31.

Table 31: Tukey (HSD) Multiple Comparisons of Means

	P Value	Significance at 5% level of significance.	
Cotton-Soya	0.2656	>0.05	
Fish-Soya	0.0001	<0.05	**
Fish-Cotton	0.017	<0.05	**

The output in Table 31 shows the significance of the P values which implies that Fish-Soya and Fish-Cotton proteins had significant difference while Cotton-Soya had insignificant difference at 0.05 level of significance. It was evident that there was significant difference of mean weight of the chicken under study when feed between fish meal and cotton seed cake proteins and between fish meal and soya meal proteins. There was no significant difference of mean weights of the chicken under study when feed on cotton seed cake and soya meal proteins.

4.9 Analysis of Covariance

The birds from the three proteins based formulations had their initial weights recorded at the beginning of the experiment. This led to initial weight variable (X). Analysis of Covariance was done to check if the initial weight could have had an effect on the final weight of the chicks. The output was as shown in Table 32.

Table 32: Analysis of Covariance

Source of variation	Degree of Freedom	Sum of Squares	Mean sum of Squares	F Value	P Value	Significance
Protein	2	328140	164070	9.842	0.000142	***
X	1	84365	84365	5.061	0.027025	*
Residuals	86	1433626	16670			

Their P Values were significant at 0.5level of significance. This implied that there was a linear relationship between the initial and final weights of the chicks in the study.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This Chapter is organized as conclusions on the three objectives. It evaluated mixture experiments design selection based on D-, A-, E-, T- optimality criterions. Poultry feed formulation was done using the selected three factor simplex lattice mixture design and model evaluation to select one that could be recommended to the farmers with suggestions for further research.

5.2 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 before obtaining their respective determinants, average variances, Eigen values and ranking the minimum values as the best. 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 desiderable properties. In such an instance, design selection was done basing on the fewer number of experimental runs, which implied less number of experiments. Hence, the choice of simplex lattice design over the simplex centroid designs for this particular study was recommended.

Simplex lattice design was applied in the formulation of poultry feed ration with six design points hence six types of mixtures. 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 seen that simplex lattice mixture design could be applied in both chick mash ration and growers mash feed ration formulations respectively.

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 ,the varied proportions of carbohydrates, 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.

5.3 Recommendations

The fish meal protein model is recommended to the chicken farmers and from the experiment, it is conclusive that simplex lattice mixture design could be applied in this field of poultry production as an important 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 significant 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.

The same study can also be done 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.

5.4 Suggestions for Further Research

The study suggests that research could be done on the application of mixture experiments in the formulation of the dairy meal and pig feed rations as an optimization tool.

It further suggests formulation of poultry feed in a different location as the coastal region of Kenya where the majority of the main feed raw materials are different from those used in the study to compare and contrast the outcomes.

Finally if more funds could be accessed, simplex centroid mixture design could be applied in formulation of poultry feed using the duplicate feed components to compare their final weights and compare the resulting appropriate models.

Further research into appropriate combinations of these ingredients for optimum growth and feed utilization by broilers is highly recommended.

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APPENDICES

APPENDIX I : Final Weights of the Chicks

1. Table of periodic weight records for cotton seedcake base protein formulation.

Mixture label	Mixture proportions	Bird no	Day 1	WK 1	WK 2	WK 3	WK 4	WK 5	WK 6	WK 7	WK 8
M1	(1,0,0)	1	40.04	99.41	173.24	300.21	492.99	624.97	806.22	1313.24	1459.15
M1	(1,0,0)	2	46.61	97.15	163.13	368.48	442.56	726.9	1078.47	1477.66	1798.97
M1	(1,0,0)	3	41.22	100.56	171.95	336.43	492.84	717.63	944.07	1374.07	1505.69
M1	(1,0,0)	4	38.52	101.19	167.78	309.93	459	660.52	876.9	1214.36	1498.98
M1	(1,0,0)	5	40.71	99.96	173.85	315.02	453.4	707.56	981.83	1224.18	1485.69
M2	(0.5,0.5,0)	6	39.96	95.82	178.80	322.07	531.25	699.47	1103.86	1145.84	1650.81
M2	(0.5,0.5,0)	7	43.11	101.53	182.86	362.64	495.61	597.1	996.53	1356.69	1580.76
M2	(0.5,0.5,0)	8	43.02	100.84	159.12	303.51	470.69	634.15	1048.4	1001.96	1277.26
M2	(0.5,0.5,0)	9	47.07	94.79	181.42	359.29	469.31	679.43	859.31	1105.14	1737.04
M2	(0.5,0.5,0)	10	47.44	95.23	170.09	288.30	530.92	620.04	969.54	1356.60	1751.91
M3	(0,1,0)	11	47.23	96.58	174.67	293.11	467.65	659.17	1022.99	1256.07	1743.61
M3	(0,1,0)	12	43.18	94.63	171.31	339.23	460.68	727.18	963.61	1134.57	1399.42

M3	(0,1,0)	13	35.99	101.13	167.41	278.52	456.83	681.61	981.29	1323.01	1298.88
M3	(0,1,0)	14	41.94	97.18	165.88	335.16	518.80	593.79	1083.34	1058.96	1634.24
M3	(0,1,0)	15	46.07	102.29	171.34	286.48	504.79	665.15	901.75	1031.86	1697.87
M4	(0.5,0,0.5)	16	43.18	99.27	182.00	371.34	520.28	630.43	815.7	1364.76	1583.33
M4	(0.5,0,0.5)	17	37.15	93.71	161.97	338.75	486.77	609.19	1044.54	1031.75	1545.02
M4	(0.5,0,0.5)	18	44.34	97.70	170.97	337.14	447.23	598.91	1076.21	1405.48	1629.16
M4	(0.5,0,0.5)	19	36.63	101.17	160.34	363.98	470.9	626.92	870.71	1268.49	1424.25
M4	(0.5,0,0.5)	20	37.18	100.53	176.08	329.93	503.4	720.21	818.82	1363.14	1346.19
M5	(0,0.5,0.5)	21	39.18	98.56	179.83	299.61	511.37	616.72	906.36	1319.49	1425.30
M5	(0,0.5,0.5)	22	42.27	101.44	171.27	278.01	528.35	665.53	1063.39	1393.44	1347.53
M5	(0,0.5,0.5)	23	36.85	97.13	179.47	275.92	485.85	598.75	877.43	1133.68	1332.83
M5	(0,0.5,0.5)	24	43.51	94.18	174.35	317.96	483.73	681.01	1021.19	1269.69	1296.5
M5	(0,0.5,0.5)	25	46.29	102.29	168.16	364.01	481.10	683.16	863.67	1241.61	1706.23
M6	(0,0,1)	26	47.70	98.88	158.96	357.36	415.54	643.09	842.82	1340.32	1762.21
M6	(0,0,1)	27	45.76	93.64	183.19	347.89	460.89	667.78	1083.31	1271.53	1685.54
M6	(0,0,1)	28	41.13	97.53	164.9	329.15	434.67	634.88	951.58	1137.87	1202.17
M6	(0,0,1)	29	46.9	95.1	164.	336.	537.	683.	911.	1360	1631

			1	8	51	02	84	96	61.	.19	.76
M6	(0,0,1)	30	45.1010	101.21	175.85	341.41	538.92	726.84	917.64	1084.39	1659.33

1. Table of weight records for fish meal base protein formulation

Mixture label	Mixture proportions	Bird no	Day 1	WK 1	WK 2	WK 3	WK 4	WK 5	WK 6	WK 7	WK 8
M1	(1,0,0)	1	40.33	101.82	186.82	280.95	470.00	616.19	968.33	1077.29	1363.05
M1	(1,0,0)	2	48.00	97.60	195.27	284.04	502.36	709.12	856.15	1074.07	1374.05
M1	(1,0,0)	3	39.65	100.77	196.58	302.94	497.82	707.26	958.62	1039.47	1350.38
M1	(1,0,0)	4	41.09	98.44	162.92	291.69	512.12	653.73	965.94	1066.72	1396.02
M1	(1,0,0)	5	46.93	103.25	198.08	333.84	496.44	703.25	921.49	1094.22	1362.68
M2	(0.5,0.5,0)	6	48.51	111.29	194.38	346.01	483.19	616.28	902.74	1095.45	1351.43
M2	(0.5,0.5,0)	7	42.15	102.09	175.40	286.27	419.15	672.02	871.96	1035.67	1394.36
M2	(0.5,0.5,0)	8	39.22	97.61	158.21	293.76	424.68	681.68	953.86	1100.43	1381.25
M2	(0.5,0.5,0)	9	46.58	105.81	187.02	341.10	493.35	688.72	982.30	1042.86	1393.92
M2	(0.5,0.5,0)	10	37.54	99.31	192.31	325.98	501.08	715.90	969.29	1073.48	1360.88
M3	(0,1,0)	11	42.20	97.53	188.82	293.27	512.35	618.04	979.50	1056.15	1358.97
M3	(0,1,0)	12	39.	99.6	169.	301.	495.	728.	928.	1052.	1342.

			87	9	45	50	59	14	72	97	28
M3	(0,1,0)	13	44.94	112.18	187.64	330.01	504.47	704.13	872.80	1058.43	1346.52
M3	(0,1,0)	14	47.25	115.05	175.48	293.63	510.26	639.23	906.76	1026.63	1399.88
M3	(0,1,0)	15	40.57	118.07	159.90	316.60	414.00	689.49	939.62	1089.18	1345.87
M4	(0.5,0,0.5)	16	46.23	99.89	187.77	324.98	435.90	681.39	968.99	1072.85	1347.29
M4	(0.5,0,0.5)	17	39.18	104.11	184.24	327.32	438.18	720.42	954.48	1016.93	1387.85
M4	(0.5,0,0.5)	18	36.69	112.38	173.99	349.73	511.00	725.91	977.32	1069.04	1394.15
M4	(0.5,0,0.5)	19	37.83	114.51	173.60	345.27	497.32	654.29	916.03	1070.68	1392.04
M4	(0.5,0,0.5)	20	37.42	105.77	185.65	331.47	514.69	673.73	985.63	1011.96	1389.60
M5	(0,0.5,0.5)	21	35.32	114.51	186.24	304.13	478.39	692.26	853.58	1022.96	1346.74
M5	(0,0.5,0.5)	22	41.50	115.21	184.47	334.98	426.31	637.18	908.78	1095.63	1399.47
M5	(0,0.5,0.5)	23	36.57	100.21	174.99	316.36	463.79	692.48	873.62	1095.59	1381.63
M5	(0,0.5,0.5)	24	36.83	103.76	173.79	315.72	416.10	716.14	860.62	1036.09	1364.46
M5	(0,0.5,0.5)	25	37.15	103.60	173.15	300.45	467.39	612.87	977.83	1018.60	1345.06
M6	(0,0,1)	26	42.33	102.43	188.85	313.44	477.46	657.15	878.49	1080.74	1345.76
M6	(0,0,1)	27	49.09	110.41	168.73	331.53	519.59	696.72	966.27	1021.16	1400.05
M6	(0,0,1)	28	36.77	113.60	171.98	345.55	456.59	641.77	877.66	1075.47	1378.37

M6	(0,0,1)	29	36.33	113.15	175.73	320.87	516.22	678.77	956.15	1019.16	1399.78
M6	(0,0,1)	30	41.05	112.60	195.44	339.55	464.61	728.16	876.51	1026.24	1374.86

g

2. Table of weight records for soya meal base protein formulation

Mixture label	Mixture proportions	Bird no	Day 1	WK 1	WK 2	WK 3	WK 4	WK 5	WK 6	WK 7	WK 8
M1	(1,0,0)	1	45.86	99.36	150.48	311.94	441.46	680.40	964.29	1224.65	1367.45
M1	(1,0,0)	2	42.84	95.45	176.75	350.31	429.39	626.43	816.96	1186.01	1361.04
M1	(1,0,0)	3	42.88	97.90	151.60	341.60	413.57	560.50	849.97	1116.15	1499.29
M1	(1,0,0)	4	42.68	100.71	154.84	348.13	427.27	702.81	948.33	1271.13	1569.28
M1	(1,0,0)	5	44.79	90.37	154.13	278.96	496.10	629.18	965.22	1232.38	1747.64
M2	(0.5,0.5,0)	6	3921	96.87	165.69	336.42	436.64	630.50	820.59	1146.77	1342.44
M2	(0.5,0.5,0)	7	46.16	96.04	169.34	341.98	472.07	694.84	881.47	1240.90	1474.37
M2	(0.5,0.5,0)	8	39.02	92.20	151.73	283.24	459.39	703.01	883.70	1135.27	1664.04
M2	(0.5,0.5,0)	9	47.82	91.96	178.17	270.81	416.02	697.07	819.86	1200.71	1592.61
M2	(0.5,0.5,0)	10	38.66	100.38	165.50	295.19	476.33	652.47	902.21	1253.14	1698.71
M3	(0,1,0)	11	40.94	99.29	168.41	290.17	448.13	641.91	783.18	1195.96	1165.66
M3	(0,1,0)	12	39.	92.5	155.	285.	430.	660.	970.	1163.	1459.

			65	1	46	00	91	17	27	56	38
M3	(0,1,0)	13	38.24	92.66	158.03	328.89	445.44	626.31	836.23	1197.54	1541.73
M3	(0,1,0)	14	45.74	90.83	160.60	341.40	475.07	684.37	985.09	1220.06	1644.31
M3	(0,1,0)	15	44.50	95.40	160.38	274.15	448.78	622.92	943.81	1273.92	1689.52
M4	(0.5,0,0.5)	16	39.21	94.73	183.66	311.25	426.76	594.30	827.69	1131.84	1343.49
M4	(0.5,0,0.5)	17	40.52	98.09	161.49	354.77	427.11	698.16	879.12	1224.79	1459.39
M4	(0.5,0,0.5)	18	48.50	101.09	175.25	322.94	420.59	631.27	858.54	1259.12	1469.17
M4	(0.5,0,0.5)	19	38.64	99.51	153.92	327.85	421.62	608.84	926.30	1161.01	1490.88
M4	(0.5,0,0.5)	20	41.85	99.14	160.81	300.53	478.10	646.12	911.60	1273.61	1539.32
M5	(0,0.5,0.5)	21	39.14	97.34	156.71	334.65	452.30	578.16	910.84	1200.80	1418.07
M5	(0,0.5,0.5)	22	45.95	94.85	170.39	301.79	477.35	681.51	819.42	1176.27	1631.68
M5	(0,0.5,0.5)	23	39.27	91.44	168.23	314.92	479.12	699.97	956.68	1241.14	1599.96
M5	(0,0.5,0.5)	24	39.77	92.72	162.19	312.81	466.77	636.60	976.39	1177.44	1285.58
M5	(0,0.5,0.5)	25	38.63	94.18	167.34	354.17	468.83	625.28	869.30	1271.22	1392.88
M6	(0,0,1)	26	45.47	92.30	163.44	272.31	504.15	583.91	873.06	1271.47	1355.12
M6	(0,0,1)	27	40.57	95.92	154.39	323.59	480.41	600.95	965.26	1249.23	1475.19
M6	(0,0,1)	28	39.84	94.95	166.61	330.85	507.54	572.52	956.80	1225.74	1299.52

M6	(0,0,1)	29	46.04	98.25	179.65	359.72	442.95	683.84	900.67	1219.05	1540.66
M6	(0,0,1)	30	47.70	100.71	162.09	304.22	455.84	570.34	948.92	1128.44	1691.00

APPENDIX II: Composition of the Vitamins and Minerals Concentrate.

This was an imported product from Koudijs Animal Nutrition, P.O. BOX 396, 6710 BJ Eden, The Netherlands. It was then sold in Sirikwa agro vet in Eldoret town.

CALCULATED ANALYSIS

ME	2050 kcal/kg
Crude protein	39.00 %
Crude fat	2.80 %
Crude fiber	7.70 %
Crude ash	17.30 %
Lysine	3.21 %
Methionine	2.05 %
Calcium	3.00 %
Phosphorus	1.72 %
Sodium	1.40 %
Anti-oxidant	Added
Phytase	Added
Mold Inhibitor	Added
Vitamins	Added

APPENDIX III: R Software Commands

These were used in data analysis with their respective outputs in the study.

Analysis of mixture data

```
weight <-read.csv("C:\\Users\\Admin\\Desktop\\weight.csv")

attach(weight)

weight

library(mixexp)

model<-lm(Y~-1+X1+X2+X3+X1:X2+X1:X3+X2:X3,data=weight)

summary(model)

anova(model)

library(mixexp)

MixturePlot(X3,X2,X1,Y,constrts=FALSE,contrs=TRUE,cols=FALSE,mod=2,n.brea
ks=9)

MixturePlot(X3,X2,X1,Y,constrts = FALSE,contrs = TRUE,cols = FALSE,mod =
2,n.breaks = 9)
```

Model reduction.

```
model<-lm(Y~-1+X1+X2+X3,data=weight)
```

Summary statistics

```
rm(list=ls())

weight <-read.csv("C:\\Users\\Admin\\Desktop\\weight.csv")

attach(weight)

weight

max(Y)

min(Y)

mean(Y)

sd(Y)
```

range(Y)

quantile(Y)

boxplot(Y)

Summary outputs

```
> max(M1)
[1] 1798.97
> max(M2)
[1] 1871.92
> max(M3)
[1] 1743.61
> max(M4)
[1] 1629.16
> max(M5)
[1] 1706.23
> min(M1)
[1] 1459.15
> min(M2)
[1] 1277.26
> min(M3)
[1] 1298.88
> min(M4)
[1] 1346.19
> min(M5)
[1] 1296.5
> mean(M1)
[1] 1549.638
> mean(M2)
[1] 1623.558
> mean(M3)
[1] 1554.804
> mean(M4)
[1] 1505.59
> mean(M5)
[1] 1421.678
> sd(M1)
[1] 140.5089
> sd(M2)
[1] 221.9564
> sd(M3)
[1] 194.9788
> sd(M4)
[1] 117.1456
> sd(M5)
[1] 165.8647
> range(M1)
[1] 1459.15 1798.97
```

```
> range(M2)
[1] 1277.26 1871.92
> range(M3)
[1] 1298.88 1743.61
> range(M4)
[1] 1346.19 1629.16
> range(M5)
[1] 1296.50 1706.23
> cv<-function(mean,sd){(sd/mean)*100}
> cv(mean=mean(M1),sd=sd(M1))
[1] 9.067208
> cv(mean=mean(M2),sd=sd(M2))
[1] 13.67098
> cv(mean=mean(M3),sd=sd(M3))
[1] 12.54041
> cv(mean=mean(M4),sd=sd(M4))
[1] 7.780708
> cv(mean=mean(M5),sd=sd(M5))
[1] 11.66683
```

```
> range(M1)
[1] 1459.15 1798.97
> range(M2)
[1] 1277.26 1871.92
> range(M3)
[1] 1298.88 1743.61
> range(M4)
[1] 1346.19 1629.16
> range(M5)
[1] 1296.50 1706.23
> cv<-function(mean,sd){(sd/mean)*100}
> cv(mean=mean(M1),sd=sd(M1))
[1] 9.067208
> cv(mean=mean(M2),sd=sd(M2))
[1] 13.67098

> cv(mean=mean(M3),sd=sd(M3))
[1] 12.54041
> cv(mean=mean(M4),sd=sd(M4))
[1] 7.780708
> cv(mean=mean(M5),sd=sd(M5))
[1] 11.66683


>
```

Protein 2 summary output

```
max(M1)
[1] 1699.19
> max(M2)
```

```
[1] 1664.04
> max(M3)
[1] 1644.31
> max(M4)
[1] 1539.32
> max(M5)
[1] 1631.68
> min(M1)
[1] 1347.64
> min(M2)
[1] 1298.71
> min(M3)
[1] 1266.65
> min(M4)
[1] 1343.49
> min(M5)
[1] 1285.58
> mean(M1)
[1] 1490.938
> mean(M2)
[1] 1474.434
> mean(M3)
[1] 1440.314
> mean(M4)
[1] 1460.45
> mean(M5)
[1] 1465.634
> sd(M1)
[1] 147.5582
> sd(M2)
[1] 156.6982
> sd(M3)
[1] 162.1474
> sd(M4)
[1] 72.28981
> sd(M5)
[1] 146.2786
> range(M1)
[1] 1347.64 1699.19
> range(M2)
[1] 1298.71 1664.04
> range(M3)
[1] 1266.65 1644.31
> range(M4)
[1] 1343.49 1539.32
> range(M5)
[1] 1285.58 1631.68
> cv<-function(mean,sd){(sd/mean)*100}
> cv(mean=mean(M1),sd=sd(M1))
[1] 9.897004
```

```
> cv(mean=mean(M2),sd=sd(M2))
[1] 10.62769
> cv(mean=mean(M3),sd=sd(M3))
[1] 11.25778
> cv(mean=mean(M4),sd=sd(M4))
[1] 4.949831
> cv(mean=mean(M5),sd=sd(M5))
[1] 9.980565
```

Protein 3 summary output

```
max(M1)
[1] 1396.12
> max(M2)
[1] 1394.36
> max(M3)
[1] 1399.88
> max(M4)
[1] 1394.15
> max(M5)
[1] 1399.47
> min(M1)
[1] 1350.38
> min(M2)
[1] 1351.43
> min(M3)
[1] 1342.28
> min(M4)
[1] 1347.29
> min(M5)
[1] 1345.06
> mean(M1)
[1] 1369.256
> mean(M2)
[1] 1376.368
> mean(M3)
[1] 1358.704
> mean(M4)
[1] 1382.186
> mean(M5)
[1] 1367.472
> sd(M1)
[1] 17.19534
> sd(M2)
[1] 19.47691
> sd(M3)
```

```
[1] 23.86652
> sd(M4)
[1] 19.65336
> sd(M5)
[1] 23.2675
> range(M1)
[1] 1350.38 1396.12
> range(M2)
[1] 1351.43 1394.36
> range(M3)
[1] 1342.28 1399.88
> range(M5)
[1] 1345.06 1399.47
> range(M4)
[1] 1347.29 1394.15
> cv<-function(mean,sd){(sd/mean)*100}
> cv(mean=mean(M1),sd=sd(M1))
[1] 1.255816
> cv(mean=mean(M2),sd=sd(M2))
[1] 1.415095
> cv(mean=mean(M3),sd=sd(M3))
[1] 1.756565
> cv(mean=mean(M4),sd=sd(M4))
[1] 1.421904
> cv(mean=mean(M5),sd=sd(M5))
[1] 1.701498
```

Test for normality using Shapiro-Wilks and output

```
data:  fish
W = 0.93698, p-value = 0.07546
```

One way ANOVA with output

```
> avsamplefish<-aov(weight~mixture,data=samplefish)
> summary(avsamplefish)
            Df Sum Sq Mean Sq F value Pr(>F)
mixture      5 126864   25373   0.702  0.628
Residuals   24 867920   36163
```

```
avsy<-aov(weight2~mixture2,data=onewaysy)
> summary(avsy)
            Df Sum Sq Mean Sq F value Pr(>F)
mixture2     5  62617   12523   0.534  0.748
Residuals   24 562782   23449
```

Two way ANOVA commands and output

```
Twoway<-aov(weight~protein*mixture)
```

```
> summary(Twoway)
                Df  Sum Sq Mean Sq F value  Pr(>F)
protein          2  338616  169308   9.973 0.00013 ***
mixture          5   29465   29465   1.736 0.19128
protein:mixture  2   52024   26012   1.532 0.22203
Residuals       84 1426045   16977
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Model reduction 1 output

```
Call:
lm(formula = Y ~ -1 + X1 + X2 + X3, data = Weight)

Residuals:
    Min      1Q  Median      3Q     Max
-250.72 -112.99   14.33  126.28  201.73

Coefficients:
   Estimate Std. Error t value Pr(>|t|)
X1  1592.28      55.91   28.48   <2e-16 ***
X2  1549.60      55.91   27.71   <2e-16 ***
X3  1528.68      55.91   27.34   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 149.4 on 27 degrees of freedom
Multiple R-squared:  0.9918,              Adjusted R-squared:  0.9909
F-statistic:  1086 on 3 and 27 DF,  p-value: < 2.2e-16
```

Model 2 output

```
Call:
lm(formula = Y ~ -1 + X1 + X2 + X3 + X1:X2 + X1:X3 + X2:X3, data = weight2)

Residuals:
     Min       1Q   Median       3Q      Max
-180.054 -126.718    1.414   95.779  218.702

Coefficients:
      Estimate Std. Error t value Pr(>|t|)
X1     1490.94      64.10  23.259   <2e-16 ***
X2     1440.31      64.10  22.470   <2e-16 ***
```

```
X3     1465.63      64.10  22.865   <2e-16 ***
X1:X2    35.23     314.03   0.112    0.912
X1:X3   -23.95     314.03  -0.076    0.940
X2:X3    29.90     314.03   0.095    0.925
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 143.3 on 24 degrees of freedom
Multiple R-squared:  0.9924,	Adjusted R-squared:  0.9905
F-statistic: 524.1 on 6 and 24 DF,  p-value: < 2.2e-16
```

Model 2 ANOVA

```
Analysis of Variance Table

Response: Y
          Df   Sum Sq  Mean Sq   F value Pr(>F)
X1         1 29290327 29290327 1425.7065 <2e-16 ***
X2         1 19974766 19974766  972.2716 <2e-16 ***
X3         1 15334356 15334356  746.3997 <2e-16 ***
X1:X2      1      259      259    0.0126 0.9116
X1:X3      1      179      179    0.0087 0.9263
X2:X3      1      186      186    0.0091 0.9249
Residuals 24   493066    20544
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

Model 2 reduced output

```
Call:
lm(formula = Y ~ -1 + X1 + X2 + X3, data = weight2)

Residuals:
     Min       1Q   Median       3Q      Max
-179.620 -125.232    4.922   92.904  212.882

Coefficients:
   Estimate Std. Error t value Pr(>|t|)
X1   1491.0       50.6   29.47   <2e-16 ***
X2   1445.8       50.6   28.58   <2e-16 ***
X3   1465.2       50.6   28.96   <2e-16 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 135.2 on 27 degrees of freedom
Multiple R-squared:  0.9924,	Adjusted R-squared:  0.9916
F-statistic:  1178 on 3 and 27 DF,  p-value: < 2.2e-16
```

One way ANOVA and Tukey HSD test with output

```
tukey
onewayprotein<-aov(weight~protein,data=onewayprotein)
> summary(onewayprotein)
            Df  Sum Sq Mean Sq F value   Pr(>F)    
protein      2  338616  169308   9.771 0.000149 ***
Residuals   87 1507534   17328                     
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
> TukeyHSD(onewayprotein)
  Tukey multiple comparisons of means
    95% family-wise confidence level

Fit: aov(formula = weight ~ protein, data = onewayprotein)

$protein
       diff       lwr       upr     p adj
B-A  -53.243 -134.2872  27.80119 0.2655936
C-A -148.296 -229.3402 -67.25181 0.0001034
C-B  -95.053 -176.0972 -14.00881 0.0173042
```

Model 3 output

```
Call:
lm(formula = Y ~ -1 + X1 + X2 + X3 + X1:X2 + X1:X3 + X2:X3, data = weight3)

Residuals:
    Min      1Q  Median      3Q     Max 
-34.896 -14.824  -0.564  13.610  41.176 

Coefficients:
      Estimate Std. Error t value Pr(>|t|)    
X1    1369.256      9.436 145.117   <2e-16 ***
X2    1358.704      9.436 143.999   <2e-16 ***
X3    1367.472      9.436 144.928   <2e-16 ***
X1:X2   49.552     46.224   1.072    0.294    
X1:X3   45.600     46.224   0.986    0.334    
X2:X3   76.392     46.224   1.653    0.111    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 21.1 on 24 degrees of freedom
Multiple R-squared:  0.9998,	Adjusted R-squared:  0.9998 
```

```
F-statistic: 2.115e+04 on 6 and 24 DF,  p-value: < 2.2e-16

> anova(model3)
Analysis of Variance Table

Response: Y
          Df   Sum Sq  Mean Sq    F value Pr(>F)
X1         1 25159261 25159261 56519.0730 <2e-16 ***
X2         1 17824555 17824555 40042.0093 <2e-16 ***
X3         1 13511981 13511981 30354.0170 <2e-16 ***
X1:X2      1      226      226     0.5071 0.4832
X1:X3      1      231      231     0.5200 0.4778
X2:X3      1     1216     1216     2.7312 0.1114
Residuals 24    10684      445
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Model reduction 3

```
Call:
lm(formula = Y ~ -1 + X1 + X2 + X3, data = weight3)

Residuals:
    Min      1Q  Median      3Q     Max 
-30.323 -20.196  -0.253  21.439  32.870 

Coefficients:
   Estimate Std. Error t value Pr(>|t|)    
X1 1374.483      8.004   171.7   <2e-16 ***
X2 1367.010      8.004   170.8   <2e-16 ***
X3 1375.383      8.004   171.8   <2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Residual standard error: 21.39 on 27 degrees of freedom
Multiple R-squared:  0.9998,     Adjusted R-squared:  0.9998 
F-statistic: 4.115e+04 on 3 and 27 DF,  p-value: < 2.2e-16

> anova(model)
Analysis of Variance Table

Response: Y
          Df   Sum Sq  Mean Sq F value    Pr(>F)    
X1         1 25159261 25159261   54975 < 2.2e-16 ***
X2         1 17824555 17824555   38948 < 2.2e-16 ***
X3         1 13511981 13511981   29525 < 2.2e-16 ***
Residuals 27    12357      458
```

```
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

>
```

One way anova fish

```
rm(list=ls())

onewayfish <-read.csv("C:\\Users\\Admin\\Desktop\\excells data\\onewayfish.csv")

attach(onewayfish)

onewayfish

avfish<-aov(mixture~weight,data=onewayfish)

summary(avfish)
```

One way fish output

```
avfish<-aov(weight~mixture,data=onewayfish)
> summary(avfish)
            Df Sum Sq Mean Sq F value Pr(>F)
mixture      5 160611   32122   1.693  0.175
Residuals   24 455431   18976
```

FISH NORMALITY

```
Shapiro-Wilk normality test

data:  fish
W = 0.93698, p-value = 0.07546

>

>
```

Oneway soya with test for normality

```
rm(list=ls())

onewaysoya <-read.csv("C:\\Users\\Admin\\Desktop\\excells data\\onewaysoya.csv")

attach(onewaysoya)
```

```
onewaysoya

shapiro.test(soya)

avsoya<-aov(mixture2~weight2,data=onewaysoya)

summary(avsoya)

shapiro.test(soya)

        Shapiro-Wilk normality test

data:  soya
W = 0.94901, p-value = 0.159


> avsoya<-aov(weight~mixture,data=onewaysoya)
> summary(avsoya)
          Df Sum Sq Mean Sq F value Pr(>F)
mixture    5 160611   32122   1.693  0.175
Residuals 24 455431   18976
```

Kruskal-wallis test output

```
Kruskal-Wallis rank sum test

data:  weight by mixture
Kruskal-Wallis chi-squared = 3.1523, df = 5, p-value = 0.6765
```

APPENDIX IV: Plates

(a) Day old chicks at the beginning of experiment

(Source: Author, 2019)

(b) Eight-week old chicks in a brooder at the end of the study

(Source: Author, 2019)

(c) Initial mixing of ingredients

(Source: Author, 2019)

(d) Vitamin and Minerals Concentrate

(Source: Author, 2019)

(e) Mixing of Components

(Source: Author,2019)

(f) Weighing Scale for the chicks

(Source: Author,2019)

(g) Weighing scale for the mixture components

(Source: Author, 2019)

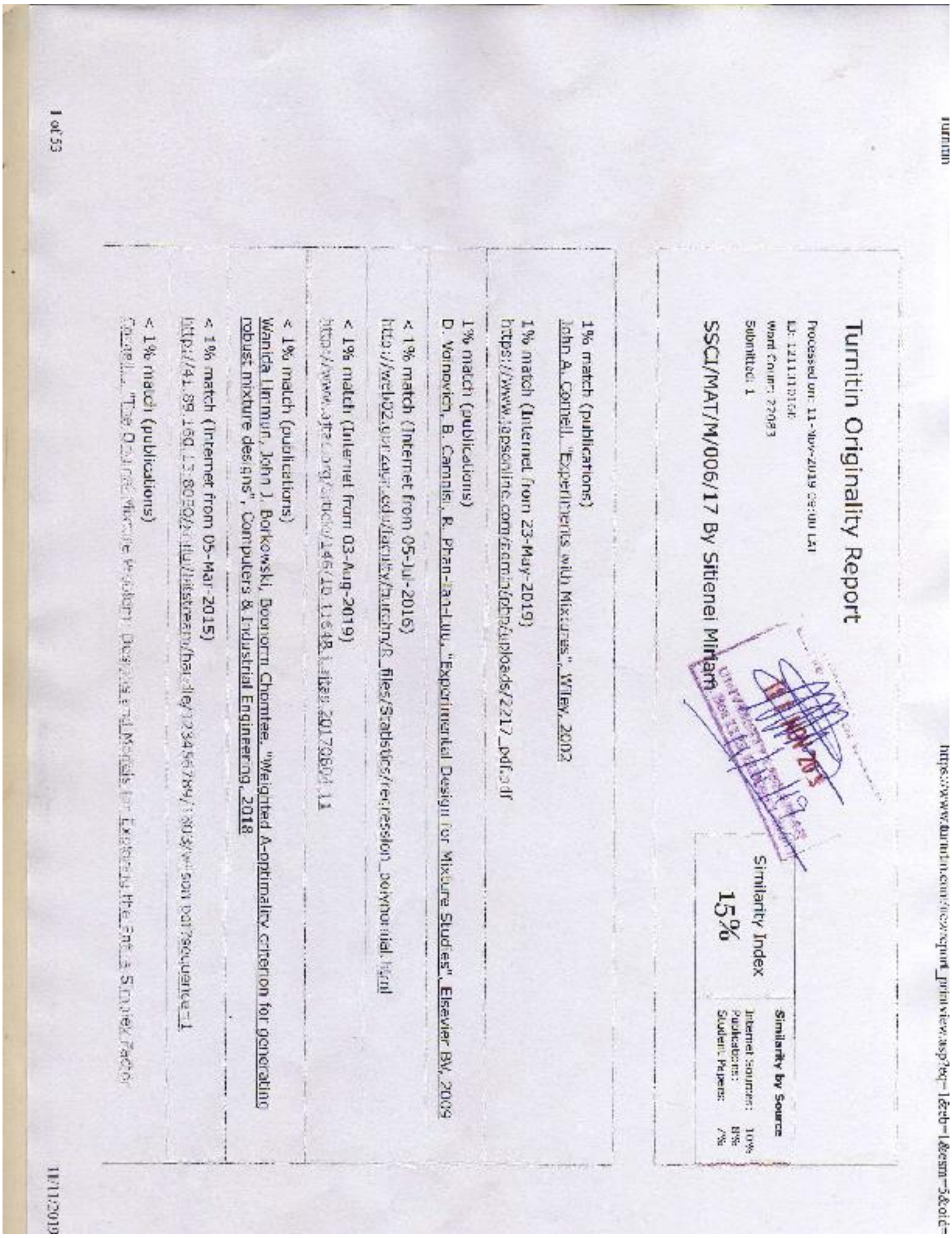
(h) Weighing of single component before mixing

(Source: Author, 2019)

(i) Mid-way Through with one mixture ration

(Source: Author, 2019)

APPENDIX V: Similarity Index/Anti-Plagiarism Report



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