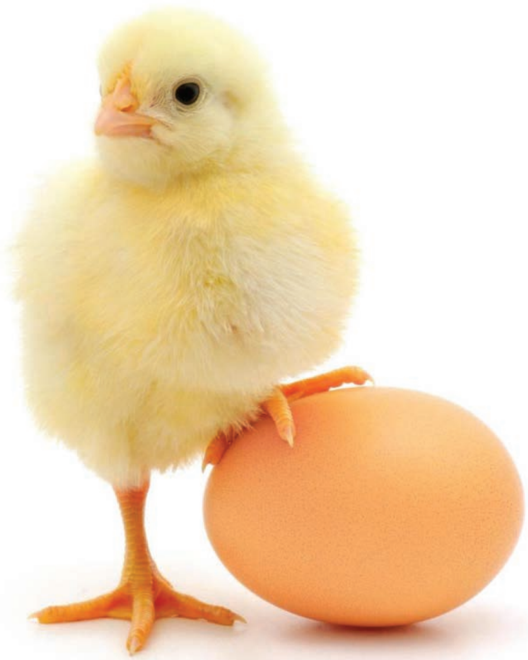
ISSN 1682-8356
ansinet.com/ijps



# INTERNATIONAL JOURNAL OF POULTRY SCIENCE

Science Alert
scialert.net

ANSInet
an open access publisher
http://ansinet.com

OPEN ACCESS International Journal of Poultry Science

ISSN 1682-8356
DOI: 10.3923/ijps.2021.59.66

# Research Article
# Optimization of Poultry Feed Formulation Using Experimental Design Methodology

[1,2]Inoussa KY, [2]Charles PARKOUDA, [1]Marius K. SOMDA, [2]Bréhima DIAWARA and [1]Mamoudou H. DICKO

[1]University Joseph Ki-Zerbo, UFR/SVT, LABIOTAN 09 BP 848 Ouagadougou 09, Burkina Faso
[2]Department of Food Technology (DTA), Institute of Research in Sciences Applied and Technology (IRSAT), Scientific and National Technological Research Center (CNRST), Ouagadougou 03 BP 7047, Kadiogo, Burkina Faso

## Abstract
**Objective:** This study was carried out to deal with reducing feed cost and provide high quality poultry feed for the local breed of chickens "Poulet du Faso". **Materials and Methods:** In this study the modeling based on the mixed design technique was used. The local raw materials used for this feed were selected on the basis of their biochemical composition, availability and accessibility. **Results:** The optimization of first degree polynomial equation yielded an optimal formulation composed of corn (40%, w/w), cottonseed meal (5%, w/w), soybean meal (15%, w/w), wheat bran (5%, w/w), rice bran (11.63%, w/w), fish meal (13.12%, w/w), oyster shell (2.5%, w/w), bi-calcium phosphate (2.5%, w/w), iodized salt (0.25%, w/w) and mineral-vitamin-nitrogen concentrate (CMVA) (5%, w/w). This formula has increased the average daily gain from 9.23-29.97 g and lowered the feed cost to 30%, with an overall desirability index of 88.05%. **Conclusion:** The obtained optimal formulation will considerably reduce the rearing time, minimize the cost of production and consequently increase the profit margin.

Key words: Feed formulation, experimental design, poultry feed, average daily gain, Poulet du Faso

Citation: Inoussa KY, Charles PARKOUDA, Marius K. SOMDA, Bréhima DIAWARA and Mamoudou H. DICKO, 2021. Optimization of poultry feed formulation using experimental design methodology. Int. J. Poult. Sci., 20: 59-66.

Corresponding Author: Inoussa KY, Department of Food Technology (DTA), Institute of Research in Sciences Applied and Technology (IRSAT), Scientific and National Technological Research Center (CNRST), Ouagadougou 03 BP 7047, Kadiogo, Burkina Faso Tel: +226 78-65-35-91/+226 71-84-59-84



Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

## INTRODUCTION

In Burkina Faso, a large part of the population is involved in livestock farming[1]. It accounts for about 10-20% of the country's gross domestic product and it is the second largest contributor to agricultural value added, after cotton[1]. In the case of poultry farming, it is widespread in Burkina Faso and provides livelihoods for about 1.6 million producers and households, particularly rural women[1,2].

Rearing of local breeds of poultry is widespread in Burkina Faso (the traditional or extensive system), which account for more than 98% of the national poultry population[3]. The local hen is an important source of income for farmers[1] and is also used in several ritual sacrifices and religious ceremonies such as weddings and baptisms[4]. However, local breeds of poultry have low productivity. This is due to low quality and insufficient quantity of feed and high mortality rate due to poor sanitation and inadequate health management system[3]. In poultry farming, feed is the main factor affecting the productivity and economic profitability of farmers. In poultry farming, feed cost accounts for 70% of the total cost of egg or meat production, therefore, attention must be paid to this factor to increase the profitability of farmers[5].

Poultry feed formulation is of particular interest for the optimization of production costs and profitability of the activity. Poultry feed formulation is the process of collection of raw materials and quantifying the amount of feed ingredients to form a uniform mixture that supplies all of their nutrient requirements[6].

Some poultry farmers use inefficient manual methods, while others improvise approaches to solve poultry feed formulation problems. Moreover, in early 1950s, the specialists in computer programming developed methods to formulate feed for livestock and poultry at low cost[7]. These methods minimize the cost of food production. Despite the importance of these methods, their application in the field of poultry feed formulation is limited due to the variability and quality of raw materials. The development of a rigorous mathematical approach becomes a permanent challenge in the field.

The aim of this study was to improve feed formulations for local poultry in Burkina Faso commonly known as "Poulet du Faso"[8] through experimental design including mixed plans.

## MATERIALS AND METHODS

**Study site:** The study was conducted on a farm in Toécé (Latitude 11°49 46"North, Longitude: -1°15 44" West), a rural commune located in the Centre-South region of Burkina Faso. In the Sudano-Sahelian zone the rainy season start from May to October and a dry season from November to April. The average annual rainfall is between 500 and 1200 mm[9].

**Materials:** The biological material, laboratory equipment, breeding material and 11 day-old chicks of the local breed "Poulet du Faso" were used in this study. Nutrients were kernels of maize, soybean cake, cotton seed cake; brans from rice and wheat; fishmeal, di-calcium phosphate, iodized salt and concentrated mineral-vitamin-nitrogenous cake (CMVA). These raw materials were selected on the basis of their biochemical composition, availability and affordability. The laboratory equipment consisted of an AUHUS brand mixer, an AUHUS brand precision balance, weighing equipment and a MICHELIN brand mill. As for the breeding equipment, it was composed of birdcages, feeders and watering troughs.

### Methodology

**Objectives and experimental approach:** The practice of raising "Poulet du Faso" is characterized by a long rearing time and a high cost of feed in the local market. According to the zootechnical monitoring sheet of this breed, the average rearing time is 105 days for an average daily gain (ADG) in weight of 9.23 g $day^{-1}$ with average feed cost 300 FCFA $kg^{-1}$ (1 FCFA is approximately 0.00181 US dollar or 0.00152 euros). The objective of this newly developed feed formula was to double the average daily weight gain and to reduce the feed cost by at least 25%. In order to do so, target was maximize the ADG and minimize the feed cost (Fig. 1). The modeling was based on the mixing design technique[10-13].

**Experimental field:** Mixture designs[10,14] differ from other designs in that the factors are proportions of constituents (their sum is equal to unity) and the values of the proportions are dimensionless, perfectly comparable numbers.

The factors of the study were selected based on their biochemical composition, availability and cost. Factors include maize kernel ($X_1$), cottonseed cake ($X_2$), soybean cake ($X_3$), wheat bran ($X_4$), rice bran ($X_5$), fishmeal ($X_6$), oyster shell ($X_7$), di-calcium phosphate ($X_8$), sodium chloride referred as salt ($X_9$) and CMVA ($X_{10}$). The levels of these factors were fixed using the method described by Cornell[15] taking into account the recommended incorporation thresholds as described by Ndoye[16]. The experiment therefore consisted of a combination of these factors on the response.

The approach consisted in combining the proportions of the constituents so that their sum is equal to 100 (Table 1). The purchase cost considered for each raw material was according to the market at the time of the study.

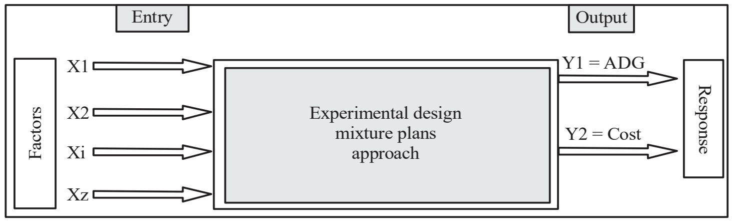



Fig. 1: Experimental design approach
X1: Factors 1, X2: Factors 2, Xi: Factors i, Xz: Factors z, ADG: Average daily gain

Table 1: Experimental field

| Factors (raw materials) | Lower level (g/100 g) | Higher level (g/100 g) | Cost of purchase (FCFA $kg^{-1}$) |
|---|---|---|---|
| Corn | 40 | 44.75 | 130 |
| Cottonseed cake (CakeCott) | 5 | 9.75 | 125 |
| Soya kernel cake (CakeSoy) | 15 | 19.79 | 300 |
| Wheat bran (Wheat bran) | 5 | 9.75 | 98 |
| Rice bran (Ricebran) | 10 | 14.75 | 51 |
| Fish meal (Fishmeal) | 10 | 14.75 | 300 |
| Oyster Shell (OysterS) | 2.5 | 7.25 | 100 |
| Dicalcium Phosphate (DicPhos) | 2.5 | 7.25 | 800 |
| Iodized Salt (IodizedS) | 0.25 | 5.00 | 90 |
| Minéralo-Vitamino-Nitrogenized Concentrate (CMVA) | 5 | 9.75 | 700 |

Table 2: Experimental matrix (%, w/w)

| N° Formulate | Corn | CakeCott | CakeSoy | Wheatbran | Ricebran | Fishmeal | OysterS | DicPhos | IodizedS | CMVA |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 44.75 | 5 | 15 | 5 | 10 | 10 | 2.5 | 2.5 | 0.25 | 5 |
| 2 | 40 | 9.75 | 15 | 5 | 10 | 10 | 2.5 | 2.5 | 0.25 | 5 |
| 3 | 40 | 5 | 19.75 | 5 | 10 | 10 | 2.5 | 2.5 | 0.25 | 5 |
| 4 | 40 | 5 | 15 | 9.75 | 10 | 10 | 2.5 | 2.5 | 0.25 | 5 |
| 5 | 40 | 5 | 15 | 5 | 14.75 | 10 | 2.5 | 2.5 | 0.25 | 5 |
| 6 | 40 | 5 | 15 | 5 | 10 | 14.75 | 2.5 | 2.5 | 0.25 | 5 |
| 7 | 40 | 5 | 15 | 5 | 10 | 10 | 7.25 | 2.5 | 0.25 | 5 |
| 8 | 40 | 5 | 15 | 5 | 10 | 10 | 2.5 | 7.25 | 0.25 | 5 |
| 9 | 40 | 5 | 15 | 5 | 10 | 10 | 2.5 | 2.5 | 5 | 5 |
| 10 | 40 | 5 | 15 | 5 | 10 | 10 | 2.5 | 2.5 | 0.25 | 9.75 |

CakeCott: Cottonseed cake, CakeSoy: Soya kernel cake, Wheatbran: Wheat bran, Ricebran: Rice bran, Fishmeal: Fishmeal, OysterS: Oyster Shell, DicPhos: Dicalcium Phosphate, IodizedS: Iodized Salt, CMVA: Minéralo-Vitamino-Nitrogenized Concentrate

**Selected model:** The mathematical model of the phenomenon was unknown. Therefore, without being able to study the theoretical model, which requires knowledge of all the dependencies between the variables, an empirical model was postulated[17]. In this formulation, ingredients were mixed using a blender without any heat treatment. The first-degree model[5] was therefore retained using a first degree polynomial equation:

$$Y_1 = a_1X_1+a_2X_2+a_3X_3+a_4X_4+a_5X_5+a_6X_6+a_7X_7+a_8X_8+a_9X_9+a_{10}X_{10}$$

where, $Y_1$ is the average daily gain (ADG), $a_1$, $a_2$, $a_3$, $a_4$, $a_5$, $a_6$, $a_7$, $a_8$, $a_9$ $a_{10}$ are the effects of the constituents. Minitab version 18.1 software was used to estimate the coefficients.

**Experimental matrix:** The experimental diet was prepared using simplex lattice design with a mesh size 1 m in order to reduce the number of experimental tests[18]. A design of ten experimental mixtures was generated by the software (Minitab version 18.1) with well-defined proportions of the constituents. The upper level of each factor was combined with the lower level of the nine other factors. This allowed to observe the variation of the response according to the levels of the factors (Table 2).

**Experimental procedure and observation of responses:** The mixtures were prepared with mixer (AUHUS) at a speed of 100 rpm at room temperature. A total of one hundred (100) eleven (11) day old chicks (Poulet du Faso) were divided into ten (10) batches. Each batch was fed with experimental mixture for sixty (60) days under the same conditions. The average weight of the chicks was 140.1 g at the beginning of the experiment. The feed was distributed twice a day at 8 am and 7 pm[16]. Feed and water were provided *ad libitum*; water in the drinkers was changed three times during the day, in the morning, evening and before the feed at 1:00 p.m.

All the poultry underwent the national medical prophylaxis protocol[19] against pseudo fowl plague, gumboro disease, fowl pox, coccidiosis, helminthosis and parasitic diseases.

For each formulation submitted to the experiment, ADG response (Y1) was evaluated at the end of each week and a mean was inferred at the end of the experiment. To avoid any subjective evaluation, the average ADG of the ten heads of poultry fed with each formulation was considered.

**Checking the validity of the model:** The values of the ADG were calculated from the coefficients of the model equation. For residual estimation the difference between observed and estimated values was calculated. These residuals were used as the basis for assessing the predictive quality of the model for restoring the value of the measured responses and for their validation as described by Goupy and Creighton[10].

**Optimization of the formula:** The objective was to find high quality feed at a lower cost. It means that $Y_1$ (ADG of the food), must be maximized and a second response $Y_2$ (the cost) must be minimized. $Y_2$ was calculated using the following equation:

$$Y_2 = b_1X_1+b_2X_2+b_3X_3+b_4X_4+b_5X_5+b_6X_6+b_7X_7+b_8X_8+b_9X_9+b_{10}X_{10}$$

where, $b_1$, $b_2$, $b_3$, $b_4$, $b_5$, $b_6$, $b_7$, $b_8$, $b_9$, $b_{10}$ are the purchase prices of the raw materials obtained from the local market noted in Table 2. In other words, a combination of the constituents must be found that allows maximum ADG at a minimum formula cost.

To formulate such an optimal poultry feed, the principle of multi-criteria optimization was used as previously described by Derringer and Suich[20]. The mathematical function applied to optimize feed mixtures is the desirability function developed in the study of Park and Park[21], Das[22] and Pal and Gauri[23]. This desirability function transforms each response into dimensionless variables called desirability index (di). The range of this index is [0, 1].

For the response $Y_1$ (ADG) which must be maximized, the required minimum value is 18.46 g day$^{-1}$. This value will have a desirability index equal to 0. All ADG values below 18.46 g day$^{-1}$ will have a desirability index equal to zero. On the other hand, the ideal ADG value is 30 g day$^{-1}$ corresponding to a desirability index equal to 1. A high desirability index, for a given response, means that it contributes significantly to the optimal feed formula for poultry. As for the response $Y_2$ which must be minimized, the required value is 220 FCFA kg$^{-1}$, so it will have a desirability index equal to 1, while the maximum value is 225 FCFA kg$^{-1}$. Its desirability index is thus equal to 0.

The multiplication of all the desirability indices allows to calculate the global desirability (D), between 0 and 1. The formula is considered satisfactory if desirability index is 70%.

## RESULTS

**Average daily gain (ADG) responses and the cost of formulas:** The average daily gain ranges from 22.81-31.92 g day$^{-1}$ with an average of 26.19 g day$^{-1}$ (Table 3). This is higher than the expected target of doubling the initial ADG of the local breed of chicken "Poulet du Faso" (18.46 g day$^{-1}$).

These results also showed that the ADG increased with the increase in the proportions of certain raw materials. This increase was observed in formulas No. 2, 3 and 6. On the other

Table 3: Observed responses: Average daily gain (ADG) and formula cost

| | Factors (%, w/w) | | | | | | | | | | Responses | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| N° Formulate | Corn | Cakecott | Cakesoy | Wheatbran | Ricebran | Fishmeal | OysterS | DicPhos | IodizedS | CMVA | ADG (g/j) | Cost (FCFA kg$^{-1}$) |
| 1 | 44.75 | 5 | 15 | 5 | 10 | 10 | 2.5 | 2.5 | 0.25 | 5 | 25.81 | 207.150 |
| 2 | 40 | 9.75 | 15 | 5 | 10 | 10 | 2.5 | 2.5 | 0.25 | 5 | 27.06 | 206.910 |
| 3 | 40 | 5 | 19.75 | 5 | 10 | 10 | 2.5 | 2.5 | 0.25 | 5 | 28.51 | 215.230 |
| 4 | 40 | 5 | 15 | 9.75 | 10 | 10 | 2.5 | 2.5 | 0.25 | 5 | 26.21 | 205.630 |
| 5 | 40 | 5 | 15 | 5 | 14.75 | 10 | 2.5 | 2.5 | 0.25 | 5 | 26.27 | 203.400 |
| 6 | 40 | 5 | 15 | 5 | 10 | 14.75 | 2.5 | 2.5 | 0.25 | 5 | 31.92 | 215.230 |
| 7 | 40 | 5 | 15 | 5 | 10 | 10 | 7.25 | 2.5 | 0.25 | 5 | 22.81 | 205.730 |
| 8 | 40 | 5 | 15 | 5 | 10 | 10 | 2.5 | 7.25 | 0.25 | 5 | 23.9 | 238.980 |
| 9 | 40 | 5 | 15 | 5 | 10 | 10 | 2.5 | 2.5 | 5.00 | 5 | 23.39 | 205.250 |
| 10 | 40 | 5 | 15 | 5 | 10 | 10 | 2.5 | 2.5 | 0.25 | 9.75 | 26.03 | 234.230 |
| Average | | | | | | | | | | | 26.191 | 213.774 |
| Standard deviation | | | | | | | | | | | 2.65 | 12.730 |

CakeCott: Cottonseed cake, CakeSoy: Soya kernel cake, Wheatbran: Wheat bran, Ricebran: Rice bran, Fishmeal: Fishmeal, OysterS: Oyster shell, DicPhos: Dicalcium Phosphate, IodizedS: Iodized Salt, CMVA: Minéralo-Vitamino-Nitrogenized Concentrate, ADG: Average daily gain

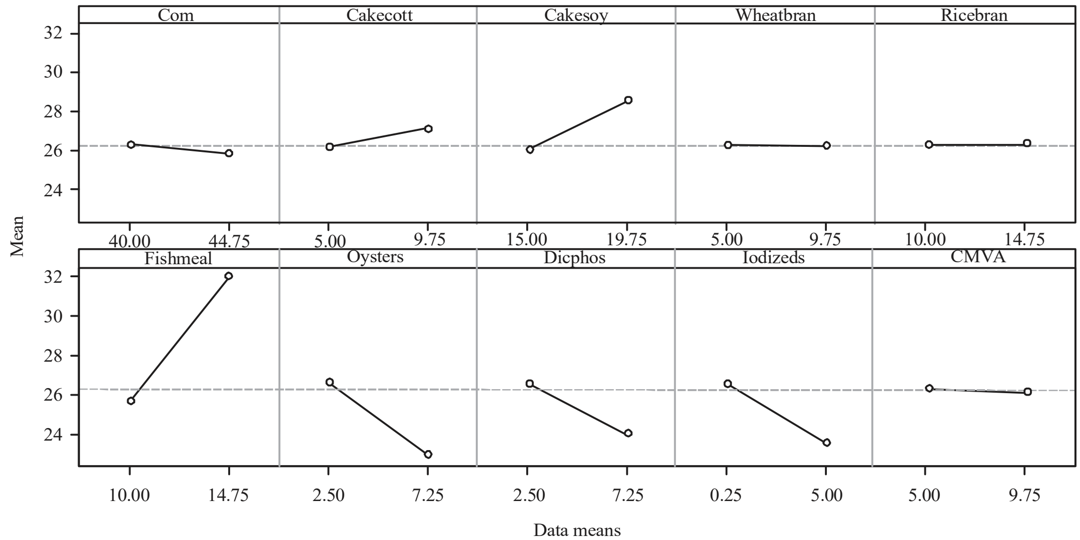



Fig. 2: Main effects plot for ADG

CakeCott: Cottonseed cake, CakeSoy: Soya kernel cake, Wheatbran: Wheat bran, Ricebran: Rice bran, Fishmeal: Fishmeal, OysterS: Oyster Shell, DicPhos: Dicalcium Phosphate, IodizedS: Iodized Salt, CMVA: Minéralo-Vitamino-Nitrogenized Concentrate, ADG: Average daily gain

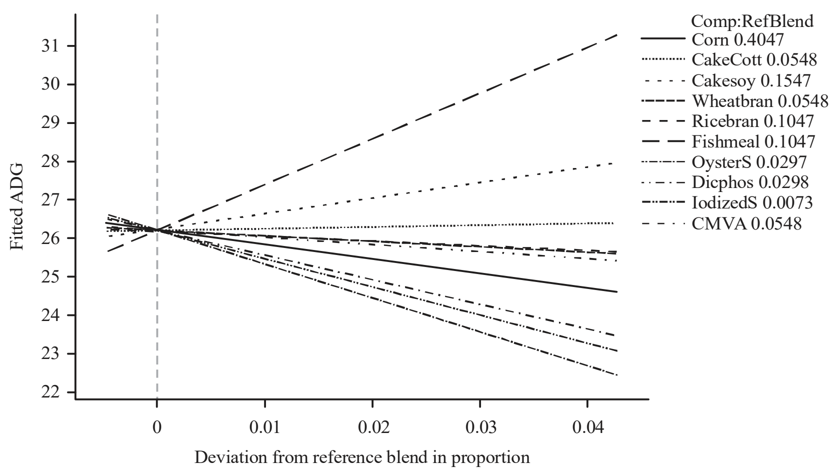



Fig. 3: ADG Response Plot Diagram

CakeCott: Cottonseed cake, CakeSoy: Soya kernel cake, Wheatbran: Wheat bran, Ricebran: Rice bran, Fishmeal: Fishmeal OysterS: Oyster Shell, DicPhos: Dicalcium Phosphate, IodizedS: Iodized Salt, CMVA: Minéralo-Vitamino-Nitrogenized Concentrate, ADG: Average daily gain

hand, the increase in the proportion of certain raw materials had no effect on the evolution of the ADG but increased the formula cost as shown in the results of formulas No. 8 and 10. The cost increased from 203.40 to 238.98 FCFA $kg^{-1}$ with an average of 213.77 FCFA $kg^{-1}$. This cost is also higher than the expected objective of reducing the feed cost to at least 225 FCFA $kg^{-1}$.

These observations showed that two formulas are remarkable, formula No. 6 with an ADG of 31.92 g $day^{-1}$ (the highest) for a formula cost of 215.23 FCFA $kg^{-1}$ and formula No. 8 with an ADG of 23.90 g $day^{-1}$ for a cost of 238.98 FCFA $kg^{-1}$ (the most expensive).

**Diagrams of traces and main effects:** Figure 2 shows that soybean cake and fishmeal had a positive effect on ADG. Wheat bran, rice bran and CMVA had a minimum effect on the ADG. On the other hand, oyster shell, di-calcium phosphate and salt had a negative effect on ADG.

Figure 3 shows that the ADG increases proportionally with the quantity of fishmeal, soybean cake and to a lesser extent cottonseed cake.

**Model equation:** The model equation was:

$$Y1 = 0.04X1+0.31X2+0.61X3+0.13X4+0.14X5+1.33X6-0.49X7-0.36X8-0.47X9+0.09X10$$

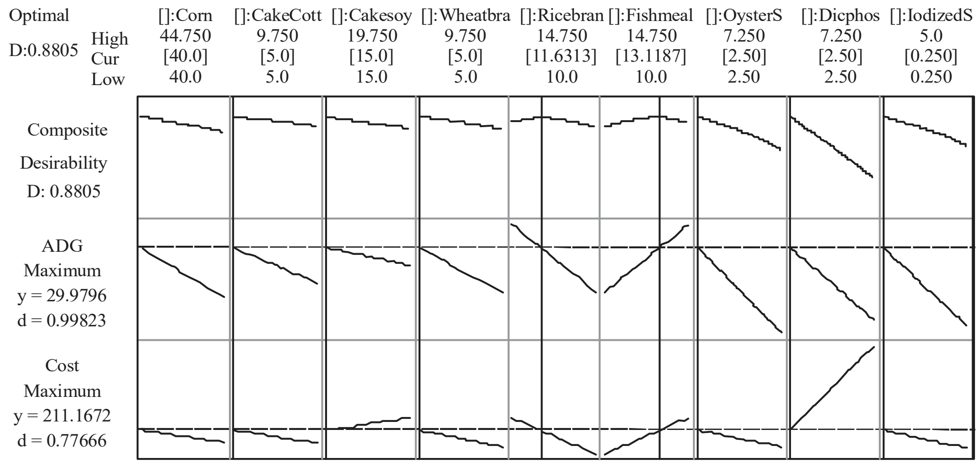



Fig. 4: Optimization of ADG response and cost formula

CakeCott: Cottonseed cake, CakeSoy: Soya kernel cake, Wheatbran: Wheat bran, Ricebran: Rice bran, Fishmeal: Fishmeal, OysterS: Oyster shell, DicPhos: Dicalcium Phosphate, IodizedS: Iodized Salt, CMVA: Minéralo-Vitamino-Nitrogenized Concentrate, ADG: Average daily gain, D: Composite desirability, d: Desirability

Table 4: Estimated regression coefficients for ADG (Component quantities)

| Term | Coefficients |
|---|---|
| Corn | 0.04195 |
| CakeCott | 0.30511 |
| CakeSoy | 0.61037 |
| Wheatbran | 0.12616 |
| Ricebran | 0.13879 |
| Fishmeal | 1.32827 |
| OysterS | -0.58963 |
| DicPhos | -0.36015 |
| IodizedS | -0.46752 |
| CMVA | 0.08827 |

CakeCott: Cottonseed cake, CakeSoy: Soya kernel cake, Wheatbran: Wheat bran, Ricebran: Rice bran, Fishmeal: Fishmeal, OysterS: Oyster Shell, DicPhos: Dicalcium Phosphate, IodizedS: Iodized Salt, CMVA: Minéralo-Vitamino-Nitrogenized Concentrate

where coefficients 0.04195; 0.30511; 0.61037; 0.12616; 0.13879; 1.32827; -0.58963; -0.36015; -0.46752; 0.08827 were for maize, cottonseed cake, soybean cake, wheat bran, rice bran, fishmeal, oyster shell, dicalcium phosphate, salt and CMVA, respectively (Table 4).

The model restituted exactly the observed value of the ADG response. The residual value of the model is zero for all formulas (Table 5).

**Model optimization:** The results obtained after the optimization allowed to determine the optimum proportions of the raw materials for the optimum formula. These proportions were 40, 5, 15, 5, 11.63, 13.12, 2.5, 2.5, 0.25 and 5%, w/w for corn, cottonseed cake, soya cake, wheat bran, rice bran, fishmeal, oyster shell, di-calcium phosphate, salt and CMVA, respectively. The combination of its proportions would result in ADG responses of 29.97 g day$^{-1}$ with a desirability index of 0.9982 and a formula cost of 211.2 FCFA kg$^{-1}$ with a desirability index of 0.7776 (Fig. 4). The overall desirability index is 0.8805. This is much higher than the satisfactory index D (0.70) predicted.

## DISCUSSION

The ADG obtained in this study are close to the value (27 g day$^{-1}$) found by Ouedraogo *et al.*[24] and are much higher (7.8 and 7.8 g day$^{-1}$) than those reported by Pousga *et al.*[25]. This difference in growth expresses the effectiveness of the nutritional value of our formulas, especially with respect to protein content[26,27].

The average cost (213.77 FCFA kg$^{-1}$) of the feed recorded in this study is lower (219.05 FCFA kg$^{-1}$) than those reported by Ouattara *et al.*[26] and the national market price for poultry feed which varied from 240-300 FCFA kg$^{-1}$ [26]. This decrease can be attributed to the rational use of raw materials in the feed formulation by the adequate formulation method.

ADG are positively influenced by soybean meal and fishmeal and grow according to the quantity of these raw materials. This can be explained by the high protein content of these two raw materials[27,28].

The residual value of the model is zero for all tests. This means that the model has accurately restituted the observed value of the ADG response. This predictive quality of the model is comparable to the model described by Oladokun and Johnson[5].

The optimal formulation would increase the ADG from 9.23-29.97 g day$^{-1}$ (225% increase) and reduce the feed cost from 300-211.2 FCFA kg$^{-1}$ (42% reduction). Interestingly these

Table 5: Residual values of the model

| Formula No. | ADG Responses observed | ADG Responses predicted by model | Residual value for ADG |
|---|---|---|---|
| 1 | 25.81 | 25.81 | 0 |
| 2 | 27.06 | 27.06 | 0 |
| 3 | 28.51 | 28.51 | 0 |
| 4 | 26.21 | 26.21 | 0 |
| 5 | 26.27 | 26.27 | 0 |
| 6 | 31.92 | 31.92 | 0 |
| 7 | 22.81 | 22.81 | 0 |
| 8 | 23.9 | 23.9 | 0 |
| 9 | 23.39 | 23.39 | 0 |
| 10 | 26.03 | 26.03 | 0 |

ADG: Average daily gain

findings are higher than the targeted objectives set at the beginning of the study and the cost reduction is much better than the model described by Oladokun and Johnson[5].

## CONCLUSION

The importance of poultry feed formulation in socio-economic life is highlighted throughout this study. The newly developed formulation method increased the nutritional quality of chicken feed at a minimum cost. The study revealed that combination of optimal proportion of local raw materials would allow to increase ADG with a desirability index under controlled rearing conditions.

This optimal proportion will reduce rearing time by half and reduce feed costs by more than a quarter. The proposed formulation model could be used to rationalize the cost of chicken production in order to increase the profit margin.

## ACKNOWLEDGMENTS

The author would like to thank the Upssala University for funding this research through ISP/IPICS/RABIOTECH, upssala university project at UJKZ, The authors would like to thank TAPSOBA Ambroise and whole staff at "Expertise For Sens and Empowerment" for their efforts during the conduct of this experiment.

## REFERENCES

1. FAO., 2018. Le développement durable de l'élevage africain: approche «Une Seule Santé» au Burkina Faso. Food and Agriculture Organization, Rome, Pages: 85.
2. Ayssiwede S.B., A. Dieng, M.R.B. Houinato, C.A.A.M. Chrysostome, Issay, J.-L. Hornick, A. Missohou, 2013. Elevage des poulets traditionnels ou indigènes au Sénégal et en Afrique Subsaharienne : état des lieux et contrainte. Ann. Méd. Vét., 157: 103-119.
3. Vincent, A., F. Grande, E. Compaoré, G.A. Annor and P.A. Addy *et al*., 2020. Table de composition des aliments FAO/INFOODS pour l'Afrique de l'Ouest (2019): Guide d'utilisation & table de composition des aliments condensée. [FAO/INFOODS Food Composition Table for Western Africa (2019): User Guide & Condensed Food Composition Table.]. Food and Agriculture Organization, Rome, Pages: 543 (in French).
4. Richard, K.S., 2007. Revue du Secteur Avicole. Food and Agriculture Organization, Ouagadougou, Burkina Faso, Pages: 34.
5. Oladokun, V.O. and A. Johnson, 2012. Feed formulation problem in Nigerian poultry farms: A mathematical programming approach. Am. J. Sci. Ind. Res., 3: 14-20.
6. Saxena, P., 2011. Comparison of linear and nonlinear programming techniques for animal diet. Applied Math., 1: 106-108.
7. Brah, N., M.F. Houndonougbo and S. Issa, 2016. Etapes et méthodes de formulation d'aliment de volaille : Une synthèse bibliographique. Int. J. Biol. Chem. Sci., 9: 2924-2931.
8. Kondombo, S.R., 2005. Improvement of village chicken production in a mixed (chicken-ram) farming system in Burkina Faso. Ph.D. Thesis, Wageningen Institute of Animal Sciences, Wageningen University, Netherlands.
9. Institut National de la Statistique et de la Démographie (INSD) 2014. Tableau de bord 2013 de la région du Centre-Sud. https://bit.ly/3bT82rg
10. Goupy, J. and L. Creighton, 2006. Introduction Aux Plans D'experiences. 3rd Edn., Dunod, Pages: 324.
11. Montgomery, D.C., 2012. Design and Analysis of Experiments. 8th Edn., John Wiley and Son Inc., New York, USA., Pages: 724.
12. Raza, I., M.A. Masood and R. Mahmood, 2013. Mixture experiments and their application in agricultural research. Asian J. Agric. Rural Dev., 3: 951-959.
13. Sahin, Y.B., E.A. Demirtaş and N. Burnak, 2017. Mixture design: A review of recent applications in the food industry. Pamukkale Univ. J. Eng. Sci., 22: 297-304.
14. Lal, K., 2014. Experiments with mixtures. https://bit.ly/3p1vF4k

15. Cornell, J.A., 2002. Experiments with Mixtures: Designs, Models and the Analysis of Mixture Data. 3rd Edn., John Wiley and Sons Ltd., New York, USA., ISBN-13: 9780471393672, Pages: 649.
16. Ndoye, M.N., 1996. Etude de la Qualite Nutritionnelle des Aliments de Volaille Vendus au Senegal et de L'effet de :Leur Supplementation en Lysine, en Methionine et en Lipides Sur Les Performances Zootechniques du Poulet de Chair. Ph.D., Thesis Universite Cheikh Anta Diop.
17. Hellal, F., 2003. Application d'un plan d'expériences mixte à l'étude de l'optimistion de la formulation d'une poudre de détergent. J. Soc. Chimique Tunisie, 5: 335-348.
18. Scheffé, H., 2018. Experiments with mixtures. J. R. Stat. Soc., 20: 344-360.
19. Hamadé, O., 2013. Influence de la substitution *du Glycine max*(soja) par *Vigna unguiculata* (niébé) comme source de protéines, sur les performances zootechniques et la rentabilité économique des poussins (*Gallus domesticus*) de race locale. Institut du Developpement Rural. https://bit.ly/3qAHyPd.
20. Derringer, G. and R. Suich, 2018. Simultaneous optimization of several response variables. J. Qual. Technol., 12: 214-219.
21. Park, S.H. and J.O. Park, 1998. Simultaneous Optimization of Multiple Responses Using a Weighted Desirability Function. In: Quality Improvement Through Statistical Methods, Abraham B., (Ed.). Birkhäuser, Boston, Massachusetts, pp: 299-311,
22. Das, P., 2010. Hybridization of artificial neural network using desirability functions for process optimization. Int. J. Qual. Res., 4: 37-50.
23. Pal, S. and S.K. Gauri, 2018. A desirability functions-based approach for simultaneous optimization of quantitative and ordinal response variables in industrial processes. Int. J. Eng. Sci. Technol., 10: 76-87.
24. Ouedraogo, B., B. Bale, S.J. Zoundi and L. Sawadogo, 2015. Caractéristiques de l'aviculture villageoise et influence des techniques d'amélioration sur ses performances zootechniques dans la province du Sourou, région Nord-Ouest Burkinabè. Int. J. Biol. Chem. Sci., 9: 1528-1543.
25. Pousga, S., F. Sankara, K. Coulibaly, J.P. Nacoulma and S. Ouedraogo *et al*., 2019. Effets du remplacement de la farine de poisson par les termites (*Macrotermes* sp.) sur l'evolution ponderale et les caracteristiques de carcasse de la volaille locale au Burkina Faso. Afr. J. Food Agric. Nutr. Dev., 19: 14354-14371.
26. Ouattara, S., V.M.C. Bougouma-Yameogo, A.J. Nianogo and A. Al Bachir, 2015. Effets des graines torréfiées de Vigna unguiculata (niébé) comme source de protéines, dans l'alimentation des poules locales en ponte au Burkina Faso, sur leurs performances zootechniques et la rentabilité économique des régimes. Int. J. Bio. Chem. Sci., 8: 1990-1999.
27. Lombo, Y., K. Tona, E. Talaki and B. Bonfoh, 2019. Effet de l'alimentation sur la croissance des pintadeaux au nord du togo. Int. J. Bio. Chem. Sci., 12: 2109-2118.
28. Fomekong, T.A.M., J.R. Kana, T.R. Ngouana, K.H. Mube and A. Teguia, 2018. Effets du taux de la lysine et de la méthionine de la ration sur les performances de croissance de la poule Barrée du Cameroun. Int. J. Bio. Chem. Sci., 12: 927-939.