MALAYSIAN JOURNAL OF AGRICULTURAL ECONOMICS

Original Research Article

Feed Cost Optimisation of Table Egg Production in Ibadan Metropolis, Oyo State, Nigeria: A Linear Programme Approach

Ayodeji Babatunde Ogundeji[1]*, Oladele Osanyinlusi[1], Adetola Adeoti[1]

[1]Department of Agricultural Economics, Faculty of Agriculture, University of Ibadan, Nigeria.

*Corresponding authors: Ayodeji Babatunde Ogundeji, Department of Agricultural Economics, Faculty of Agriculture, University of Ibadan, Nigeria. ayodejibukunmi@gmail.com; osandele17@gmail.com

Abstract: The poultry industry in Nigeria has experienced a marked escalation in feed costs since mid-2016, while egg prices have remained relatively static due to market resistance and consumer affordability constraints. As a result, farmers' profitability has been squeezed such that small shifts in ingredient costs can turn modest profits into losses and jeopardise long-term viability. This study examines how optimising feed formulation via linear programming (LP) offers a viable strategy to mitigate these challenges and restore earning capacity. Primary and secondary data were used for the study, while descriptive statistics, gross margin ratio (GMR), and LP were employed to analyse the data collected. The results showed that the average poultry farmer in the study area was a medium-scale poultry farmer with an average stock size of 2,837 laying birds. The average poultry business experience was 6 years. The estimated GMR shows that $0.04 was obtained on every $1 invested when the actual feed cost method was used, while $0.15 was realised on every $1 invested in the business when the linear programming method was applied. The optimal solution reduced feed cost from $377.04 to $321.69 per tonne, a 13.87% decrease, translating into $0.055 savings per kilogram of feed. The findings confirmed that there was a substantial and statistically significant cost difference between actual and least feed costs. We therefore recommend that poultry farmers should be trained or educated to adopt the use of LP in formulating their feeds to enhance both financial resilience and product quality in an increasingly challenging market environment.

Keywords: Egg production; cost optimization; profitability; linear programming; feed formulation; Ibadan metropolis.

Received: 1st February 2025

Received in Revised Form: 27th June 2025

Available Online: 15th August 2025

Published: 2nd September 2025

Citation: Ogundeji, A. B., Osanyinlusi, O., Adeoti, A. Feed Cost Optimization of Table Egg Production in Ibadan Metropolis, Oyo State, Nigeria: A Linear Programme Approach.Malays J Agric Econ 2025; 32(1): a0000607. https://doi.org/10.36877/mjae.a0000607

1. Introduction

Egg production plays a pivotal role in Nigeria's agricultural economy, contributing approximately 0.5% to national gross domestic product (GDP) and providing a low-cost source of animal protein for over 200 million Nigerians (FAO, 2018; NBS, 2014). Poultry breeding, particularly chicken rearing, is a vital contributor to food and livelihood security in Nigeria, supplying high-quality protein and income for rural communities (Ojedapo, 2013). Among domestic birds, chickens have risen to prominence primarily due to their economic value in egg production (Laseinde, 2009).

Nigeria ranks as Africa's largest annual egg producer, with an estimated flock of 180 million layers yielding 3.8 billion eggs per annum (FAO, 2018). In 2022, Nigeria produced an estimated 664,000 tonnes of eggs, making it Africa's top producer, yet this output satisfies only 30% of national demand (Commonwealth Scientific and Industrial Research Organisation-CSIRO, 2020; Fosu et al., 2023). This persistent demand–supply gap not only inflates market prices but also undermines national food security and forces higher import reliance for both eggs and poultry meat. Beyond its macroeconomic weight, the layer subsector generates employment for thousands of smallholders and medium-scale farmers, labourers, feed mill workers, transporters, and vendors—many of whom are women and youth in rural communities (Ohajianya et al., 2013). For individual households, egg production delivers regular cash flows that support school fees, healthcare, and reinvestment in farm inputs (Esiobu et al., 2014). With minimal land requirements and relatively short production cycles, layer farming offers a viable livelihood strategy, especially in peri-urban and rural zones where alternative off-farm opportunities are scarce.

Key challenges impede the sector's growth. First, the imbalance between fast-rising feed costs and static farm-gate egg prices squeezes producer margins; feed constitutes 60–70% of total variable cost (TVC) in poultry operations (Jadhav & Siddiqui, 2010; Sowunmi et al., 2022), yet recent data show it now exceeds 80% of TVC in many flocks. Second, efforts to curb feed spending, through indiscriminate use of low-cost by-products or nutrient-deficient rations, can compromise egg size, shell quality, laying persistency, and bird health (Olawumi, 2008; Laseinde, 2009). Third, price-setting mechanisms for eggs remain unresponsive to feed-price shocks, hampering farmers' ability to pass higher input costs onto consumers and threatening long-term enterprise viability. In response, the Federal Government introduced temporary import duty waivers on maize and facilitated the release of subsidised grain reserves during the COVID-19 period to ease feed shortages (United States Department of Agriculture, Foreign Agricultural Service [USDA FAS], 2020; Michigan State University

Policy Research for a Resilient Africa [MSU-PRCI], 2020). However, official price reports indicate that feed-price volatility persisted and the average retail cost of eggs increased considerably through 2023 (National Bureau of Statistics [NBS], 2024).

Given these persistent challenges, a more sustainable solution is needed. The literature increasingly advocates strategic feed-cost optimisation, particularly least-cost formulation via LP, to strike an optimal balance between ingredient expense and nutritional adequacy (Tijani et al., 2012; Ohajianya et al., 2013). LP has been demonstrated to effectively reduce feed costs by 9–14% for layer rations and up to 30% for starter and grower feeds, while fulfilling all nutritional requirements without sacrificing production performance or egg quality (Fosu et al., 2023). Such approaches promise to reduce feed outlays by 10–15% without sacrificing production performance or egg quality, yet empirical assessments in Nigerian contexts are scarce. This study addresses that gap by applying descriptive statistics, gross margin (GM) analysis, and LP-based least-cost feed formulation to data from layer farms in Oyo State, Nigeria. Specifically, we compare feed costs and profitability under actual market prices versus optimised rations, quantify potential savings in $ per tonne of feed, and evaluate the effects on GMRs. In addition, the null hypothesis (H_0) stating that the actual feed cost is not significantly different from its least cost was tested. Our objective is to offer robust, farm-level evidence on how LP-driven feed optimisation can bolster both the efficiency and sustainability of Nigeria's egg production industry.

2. Literature Review

Many studies identify feed as the largest share of production costs in Nigerian poultry. Tijani *et al.* (2012), Ohajianya *et al.* (2013), Esiobu *et al.* (2014), Nmadu *et al.* (2014), Olorunwa (2018), and Sowunmi *et al.* (2022) consistently report feed costs ranging from 60–70% of total variable expenditure. However, recent economic pressures—fuel subsidy removal and currency devaluation—have driven feed percentages even higher (Ajakemo, 2021; Kolawole *et al.*, 2024). This aligns with evidence from Ghana, where feed makes up about 70% of costs, leading to farm shutdowns if feed costs are not optimised (Fosu *et al.*, 2023).

Rising raw-material prices, notably maize and soybean, and increased taxes continue to pressure feed costs (Ajakemo, 2021; Kolawole *et al.*, 2024). High feed expenses without balanced formulations can wipe out profits, worsen flock health, and risk production sustainability (Kolawole *et al.*, 2024). Onanaye (2021) in Nigeria confirmed that least-cost ration models effectively manage nutrient combinations while reducing cost—underscoring the challenge of feed-price volatility. Conversely, Samuel *et al.* (2015) highlighted the limitations of traditional feed mix methods, which often fail to fully satisfy nutrient needs, leading to inefficiencies and nutrient waste.

LP is globally recognised for crafting the least-cost feed rations under nutrient constraints. Its deployment in Nigeria's broiler sector (Oladokun & Johnson, 2012; Odiaka *et al.*, 2012) and more broadly (Onanaye, 2021) has demonstrated consistent cost savings: approximately 9–11% reductions in formulation costs compared to conventional methods. Ghana's layer feed trials recorded substantial cost decreases, 19% in grower and 14% in prelayer mixes, without compromising nutritional adequacy (Fosu *et al.*, 2023). These findings affirm LP's efficacy in balancing nutrient requirements and budget constraints.

Although LP demonstrates tangible economic benefits, existing Nigerian literature remains largely descriptive and focused on broilers. Few studies have applied LP to compare actual farmer-cost feed versus optimised feed within the same operations. Moreover, critiques point to a lack of in-depth analysis: many papers briefly outline methodology without evaluating model sensitivity, constraint validity, or real-world adoption barriers (Odiaka *et al.*, 2012; Onanaye, 2021). The literature also lacks assessments of how LP optimisations affect egg output quality, farmer behaviour, and long-term nutritional outcomes. Given these gaps, this study uniquely compares actual feed costs against LP-optimised feed within the same layer farms, evaluates cost savings, and examines effects on profitability. It also incorporates sensitivity testing of LP constraints and explores practical adoption considerations. This addresses a significant evidence gap in feed-management research in Nigeria's poultry sector.

3. Methodology

3.1 Study Area

The research was conducted in Ibadan metropolis, the capital of Oyo State in Southwestern Nigeria. Ibadan is the country's third-largest city, hosting the highest concentration of poultry farms in Oyo State. The high density of small- and medium-scale poultry farms makes the metropolis, especially Lagelu and Oluyole LGAs, an ideal setting for investigating the impacts of rising feed costs on urban poultry producers.

3.2 Data Sources and Data Collection Technique

The main source of data used for this study was primary data, though complemented with metadata from journals and library materials. The collection of primary data was aided by a well-designed semi-structured questionnaire that was complemented with a personal interview, like the Key Informant Interview (KII), to elicit more information from the poultry farmers. The metadata sourced from Aduku (1993), National Research Council (1994), and Jadhav and Siddiqui (2010) were used to formulate the linear program. These publications also served as a reference point for the nutrient requirements of the various classes of poultry and also provide authoritative information on the nutrient content of feed ingredients. Data collected covered feed formulation, analysis of feed ingredients, minimum and maximum inclusion levels of various feedstuffs, among others. Prevailing market prices of feedstuffs used in the diet formulation were collected from local commercial feed mills operating in Ibadan.

3.3 Sampling Procedure

The target population for this study was the poultry egg farmers who are producing within the eleven LGAs of Ibadan. The list of the poultry egg producers in the selected LGAs, containing a total of 167 farmers, was obtained from the Poultry Association of Nigeria, Oyo State chapter (PANOY), and was used as the sampling frame. A two-stage sampling technique was then used to draw a sample of respondents from the target population. The first stage of the sampling procedure involved a purposive selection of two LGAs, Lagelu and Oluyole, out of the eleven LGAs in the Ibadan metropolis. This selection was dependent on the high concentration of poultry egg farmers in these areas. The second stage involved a random selection of poultry farmers from the selected LGAs indexed using the list from PANOY. In all, a total of 120 questionnaires were administered, but the returned and completed 116 questionnaires were then used for the data analysis.

3.4 Data Analytical Techniques

The data collected were subjected to parametric and non-parametric analytical procedures. Descriptive statistics were used to describe the socioeconomic and poultry business characteristics. The GM analysis was employed to estimate the profitability of table egg production. The linear programming technique was used to determine the least cost of layer feed for this study, while the Chi-square statistics were used to test the study's hypothesis. Monetary values were converted to 2017 US dollars using historical exchange rates from Exchange Rates UK (n.d.), retrieved on January 15, 2025.

3.5 Model Specification

3.5.1 Gross Margin Ratio (GMR)

A GM was estimated to analyse the relationship between the costs and returns associated with the production of table eggs. This margin is the leftover proceeds from a business process after removing the cost of goods sold. The leftover is the accounting *gross profit* of economic activity, and it is estimated by Oladeebo and Ojo (2012) following Equation 1:

$$GM = TR - TVC$$

$$\text{But } TR = \sum_{i=1}^{n}\left[P_{qi} * Q_i\right], \qquad \text{and} \qquad TVC = \sum_{j=1}^{n}\left[P_{xj} * X_j\right] \tag{1}$$

where; GM = Gross Margin, TR = Total Revenue, TVC = Total Variable Cost, P_{qi} = unit price of the *i*-th output, Q_i = quantity of *i*-th output, P_{xj} = unit price of the *j-th* variable input, X_j = quantity of *j-th* variable input. Q_1 = Table egg (number), Q_2 = Culled layers (number), Q_3 = Litter (kilogramme), Q_4 = Empty feed bags (number)

Following Oladeebo and Ojo (2012) and Otunaiya *et al.* (2015), the set of variable inputs with significant economic effects on the production of table eggs was flock size, feed, drug, and labour costs. Therefore, the variable inputs included in the computation of the total variable cost are: X_1 = Laying birds (number); X_2 = Quantity of feed (kilogramme); X_3 = Quantity of drugs (kilogramme); X_4 = Labour (number of workers)

The GMR technique was used to determine the profitability of table egg production. According to Adebayo (2009) and Ogundeji (2014), the GMR equation is given as Equation 2:

$$\textit{Profitability (\%)} = GMR * 100 \tag{2}$$

where GMR = GM / TR

3.5.2 Linear programming

The model was designed to reflect various feedstuff combinations used in the diet formulation, current market prices, nutrient composition, and range of inclusion to obtain a least-cost ration for egg layers according to the available feedstuffs in Ibadan. The objective of this model was to minimise the cost of producing a layer ration after satisfying a set of constraints. The variables in this model were the ingredients, while the cost of each ingredient and its nutrient value were the parameters. It was, however, a good practice to include all feedstuffs such that the resulting feasible and optimal solution may tend towards global optimality. Following Almasad *et al.* (2011) and Piyaratne *et al.* (2012), the specified LP model for the attainment of the objective function was given as Equation 3:

$$Objective function: \quad Min.Z = \sum_{j=1}^{n} C_j X_j \qquad j = 1, 2, 3, \Lambda\ , n$$

$$Subject\ \text{to}: \quad \sum_{j=1}^{n} X_j = Q$$

$$\sum_{j=1}^{n} a_{ij} X_j \leq b_{iU}$$

$$\sum_{j=1}^{n} a_{ij} X_j \geq b_{iL}$$

$$\text{L}_j \leq X_j \leq U_j \tag{3}$$

Where;

Z = Total cost of feedstuffs used in the feed formulation; C_j = price per unit of *j-th* feedstuff in the diet; X_j = Quantity of *j-th* feedstuff in the diet; Q = Total quantity of feed produced (kilogramme); a_{ij} = Quantity of *i-th* nutrient per unit of *j-th* feedstuff; b_{iU} = maximum dietary requirement for the *i-th* nutrient in the diet; b_{iL} = minimum dietary requirement for the *i-th* nutrient in the diet; L_j = lower limit of restricted *j-th* feedstuff in the feed mix; U_j = upper limit of restricted *j-th* feedstuff in the feed mix

i = index of feed nutrient components

j = index of feedstuff (ingredients)

n = index of the total number of available feedstuffs.

The list of decision variables (X_i) is given as: X_1 = Maize (Yellow) (kilogramme); X_2 = Corn bran (kilogramme); X_3 = Rice bran (kilogramme); X_4 = Wheat bran (kilogramme); X_5 = Palm Kernel Meal (PKM) (kilogramme); X_6 = Palm Oil (kilogramme); X_7 = Fish meal (72%) (kilogramme); X_8 = Fish meal (65%) (kilogramme); X_9 = Groundnut Cake (GNC) (kilogramme); X_{10} = Soybean Meal (SBM) (kilogramme); X_{11} = Brewers' Dried Grain (BDG) (kilogramme); X_{12} = Bone meal (kilogramme); X_{13} = Oyster Shell (kilogramme); X_{14} = Lysine (kilogramme); X_{15} = Methionine (kilogramme); X_{16} = Common Salt (kilogramme); X_{17} = Layer Premix (Mineral and Vitamins) (kilogramme)

Each constraint type plays a crucial role in achieving the objective—minimising the total cost of feed formulation while meeting nutritional and practical requirements:

1. Nutrient Constraints: This ensures that each essential nutrient (e.g., crude protein, metabolizable energy, calcium, phosphorus, lysine, methionine, etc.) in the diet is present in the required amount—neither too low (deficiency) nor too high (toxicity or imbalance). This is crucial to achieve a balanced feed that promotes optimal health and performance in animals.
2. Ingredient Constraints (Upper and Lower Bounds): This limits the quantity of each individual feedstuff (e.g., maize, fish meal, oil, etc.) that can be used. Certain ingredients might be limited due to cost, availability, palatability, anti-nutritional factors, or regulatory guidelines.
3. Total Feed Quantity Constraint: This helps to guarantee that the final feed mix adds up to the desired batch size (e.g., 100 kg of complete feed). It is essential for standardisation and consistency in feed manufacturing, so that the formula yields the exact amount needed.

These constraints work together to help the model identify the most cost-effective mix of ingredients that still satisfies nutritional and practical requirements. The LP model doesn't just aim for a "cheap" feed—it ensures performance, safety, and quality are not compromised.

4. Results and Discussions

4.1. Socioeconomic Characteristics of the Respondents

Table 1 shows that 33.6% of the farmers fall within the age range of 40–49 years, while 29.3% of the respondents are between 50–59 years of age, and 6.9% of the egg farmers are 60 years and above. The mean age of the farmers is 45 years, which implies that the farmers are still in the active, productive age. This finding is consistent with that of Otunaiya *et al.* (2015), who reported that about half of poultry farmers in the Ibadan metropolis were in the age range of 41–50 years. The distribution of the respondents by gender shows that male farmers (83.6%) were more in number than female farmers (16.4%) in the study area. This gender distribution displays a typical example of male dominance of several agricultural production activities in Nigeria due to their capital and energy-demanding nature, in which the males have a relative advantage. This finding is consistent with that of many previous studies, among whom is the study performed by Nmadu *et al.* (2014), which reported a large proportion of male poultry farmers in Abuja.

Educational status indicates that 40.5% of the farmers have secondary education, followed by those who have a tertiary education (25.9%), with a few (15.5%) of the respondent who has only primary education. The average number of years spent in school is

13 years, thereby affirming that, on average, poultry egg farmers in the study area are educated. Such a level of education could enhance the easy diffusion of new feed formulation techniques among egg farmers. Otunaiya *et al.* (2015) reported that this characteristic could enhance the management of poultry farms. It is further revealed that the majority (54.3%) of the respondents have between four to six persons in their families. A total of 27.6% of the respondents have a household size of seven to nine members, while the remaining (18.1%) egg farmers have between one to three members in their households. The average household size was 5 persons. This average household size is slightly larger than the recommended national average of four, as reported by Alabi and Haruna (2005). However, Adepoju (2008) opines that the large family size enables farmers to use family labour, especially when farming activity is labour-intensive.

4.2 Business Characteristics

Results in Table 1 show that 37.9% of the respondents have poultry farming experience between 4 and 6 years, while 31.9% have 7 to 9 years of experience. Only a few (13.8%) of them have poultry farming experience of over 10 years. The mean years of experience stood at 6 years. This aligns with the findings of Otunaiya *et al.* (2015). This suggests that only a few of these poultry farmers have had long years of poultry farming, while a majority of them are still relatively young in the business. It is further shown that most (62.1%) of the poultry egg farmers use battery cage management systems for table egg production, while the remaining (37.9%) of the respondents are into the deep litter system of management. This is probably because of the inherent advantages associated with the cage system, which affords the rearing of more birds in limited space, ease of drug administration, and production of neater eggs with rare occurrences of cracked eggs, as opined by Olawumi (2008) and Jadhav and Siddiqui (2010).

The findings revealed that about 72% of poultry egg farmers in the study area initiated their farms with Day-Old Chicks (DOCs), while the remaining preferred Point of Lay (POL). This could be because the initial capital requirement for layers' production is higher in POL than in DOCs, and this could be a limiting factor in starting layers' production via the point-of-lay method. Hence, more farmers prefer starting with DOCs. Also, raising the layer stock from DOC gives the farmers a level of confidence when they become laying birds. Stock size/Economic scale of poultry production shows that more than half (52.6%) of the poultry farmers had between 1,000–4,999 laying birds. 28.4% of the respondents had a flock size of less than 1,000 laying birds, while 19.0% of the egg farmers had a flock size ≥ 5,000 in their farms. The average flock size stood at 2,837 layers, which reveals that the average poultry egg farmer in Ibadan is a medium-scale producer. The economic implication of producing on this scale is that the average farmer could minimise his operating expenses and perform better due to the economies of scale than small-scale farmers. This finding is consistent with that of Oladebo and Ojo (2012), who reported a larger share of medium-scale poultry egg farmers in Ogun state.

Table 1: Distribution of egg producers by socioeconomic and business characteristics

Variables	Frequency	Percentage
Age		
< 30	6	5.2
30–39	29	25.0
40–49	39	33.6
50–59	34	29.3
≥ 60	8	6.9
Total	116	100.0
Mean = 45.2; Std= 9.64		
Gender		
Male	97	83.6
Female	19	16.4
Total	116	100.0
Educational status		
Primary	18	15.5
Secondary	47	40.5
Tertiary	51	44.0
Total	116	100.0
Mean=13; std =4.72		
Household size		
1–3	21	18.1
4–6	63	54.3
7–9	32	27.6
Total	116	100.0
Mean=5.24; std= 2.01		
Year of poultry experience		
1–3	19	16.4
4–6	44	37.9
7–9	37	31.9
≥ 10	16	13.8
Total	116	100.0

Variables	Frequency	Percentage
Mean=6.3; std=2.71		
Housing system		
Deep litter	44	37.9
Battery Cage	72	62.1
Total	116	100
Initial stock type		
Day-old-chicks (DOC)	83	71.6
Point-of-lay (POL)	33	28.4
Total	116	100.0
Stock size		
< 1,000	33	28.4
1,000 – 4,999	61	52.6
≥ 5,000	22	19.0
Total	116	100.0
Mean=2,837; std=1,877.33		

4.3 Profitability Of Table Egg Production Using Actual Feed Cost

The Total Revenue (TR) accrued from sales of table eggs, culled layers, poultry litter, and empty feed bags was computed as shown in Table 2. The variable inputs and their associated costs were collected and used in the computation of the Total Variable Cost (TVC). The total revenue accrued from the production of table eggs was about $68,692.85, while the estimated total variable cost was $65,647.43. Proceeds from sales of eggs contributed the biggest share (86.50%) of the total revenue accrued to table egg production, and all other by-products combined for less than 1%. This revenue structure mirrors earlier Nigerian findings, where table eggs and culled layers dominate farm income, and by-products contribute negligibly (Olawumi, 2008; Laseinde, 2009).

The cost of feeding the laying birds accounts for 81% of the estimated total variable cost, while the amount spent on acquiring the laying stock was about 15.30%. This indicates that these two inputs contributed to the bulk of the cost of production in egg production. This implies that feeding costs among these poultry farmers have exceeded the upper limit of the conventional range as reported by studies of Olawumi (2008); Laseinde (2009); Jadhav and Siddiqui (2010); Tijani *et al*. (2012) and Otunaiya *et al.* (2015) that the cost of feed in egg production should not exceed the range of 60-70% of the observed total variable cost. A study in Ogun State found feed cost shares ranging from 66.7% to 71.0%, depending on farm scale, aligning with conventional benchmarks (Baruwa & Idowu, 2021). Another Ogun State investigation under backyard and commercial feeding regimes recorded 71.9% feed cost share as a percentage of total production cost (Bamiro, 2020), close to the upper conventional limit, while other Nigerian surveys reported even higher shares up to 80% (Habib *et al.*, 2017). Therefore, this study's 81% figure continues a rising trend in feed cost shares across recent Nigerian cases, suggesting regional feed-inflation pressures and operational inefficiencies.

The enterprise yielded a GM of $3,045.42 and a GMR of 4.43%, indicating that every $1 in revenue yields $0.04 gross profit. While positive, this ratio is quite marginal and markedly lower than the 10–15% margins reported for well-managed layer operations in previous work (Jadhav & Siddiqui, 2010; Tijani et al., 2012), indicating that rising costs have eroded profitability. Comparatively, a different Ogun-State cage-based study recorded investment returns between 11.9% and 31.4%, with farm-mixed feed strategies delivering higher margins (Bamiro, 2020). Similarly, profitability indices of 25–42% have been reported across small to large farms and returns of about 43% using commercially prepared feeds in Ogun State (Baruwa & Idowu, 2021).

Table 2: Estimated Cost and Revenue associated with table egg production

ITEM	AMOUNT ($)	PERCENTAGE SHARE
REVENUE		
Table Egg	59,421.95	86.50%
Culled Layer	8,787.85	12.79%
Poultry Litter	465.47	0.68%
Feed Bag (empty)	17.58	0.03%
A: TR	**68,692.85**	**100.00%**
VARIABLE COST		
Laying Stock	10,044.37	15.30%
Feed	53,177.25	81.00%
Medication	1,427.64	2.17%
Labour	998.17	1.52%
B: TVC	**65,647.43**	**100.00%**
C: GM = A – B	**3,045.42**	
D: GMR = C/A		**4.43%**

4.4 Layers' Feed Cost Optimisation

The feed formulation linear programme model built for this study was used to obtain the optimal combination of available feed ingredients that satisfies the nutritional requirements of the animal (layers) at the least cost. The model was built to satisfy a set of constraints on nutritional levels, availability restrictions, special ingredients to be included, and feed quantity constraints. The summarised mathematical model is as stated below:

Min. Z $= 0.384X_1 + 0.255X_2 + 0.051X_3 + 0.174X_4 + 0.135X_5 + 1.999X_6 + 2.847X_7 + 1.618X_8 + 0.336X_9 + 0.408X_{10} + 0.135X_{11} + 0.198X_{12} + 0.045X_{13} + 3.896X_{14} + 7.671X_{15} + 0.150X_{16} + 2.098X_{17}$

Subject to:

$$34.32X_1 + 25.00X_2 + 28.6X_3 + 13.56X_4 + 22.75X_5 + 81.84X_6 + 31.90X_7 + 28.60X_8 + 26.40X_9 + 24.20X_{10} + 22.45X_{11} \geq 2530 \sum_{j=1}^{17} X_j \quad \text{- Energy}$$

$$0.089X_1 + 0.105X_2 + 0.118X_3 + 0.156X_4 + 0.184X_5 + 0.720X_7 + 0.650X_8 + 0.450X_9 + 0.440X_{10} + 0.279X_{11} \geq 16.5 \sum_{j=1}^{17} X_j \quad \text{- Crude Protein}$$

$$0.0002X_1 + 0.0003X_2 + 0.0006X_3 + 0.0014X_4 + 0.003X_5 + 0.06X_6 + 0.023X_7 + 0.061X_8 + 0.002X_9 + 0.002X_{10} + 0.003X_{11} + 0.36X_{12} + 0.35X_{13} \geq 3.5 \sum_{j=1}^{17} X_j \quad \text{- Calcium}$$

$$0.0012X_1 + 0.0017X_2 + 0.0042X_3 + 0.0038X_4 + 0.0016X_5 + 0.0184X_7 + 0.030X_8 + 0.0023X_9 + 0.0020X_{10} + 0.0019X_{11} + 0.1682X_{12} + 0.0010X_{13} \geq 0.45 \sum_{j=1}^{17} X_j \quad \text{- Phosphorus}$$

$$0.04X_1 + 0.028X_2 + 0.125X_3 + 0.0514X_4 + 0.06X_5 + 0.989X_6 + 0.064X_7 + 0.045X_8 + 0.092X_9 + 0.035X_{10} + 0.074X_{11} \leq 3.7 \sum_{j=1}^{17} X_j \quad \text{- Fats/Oil}$$

$$0.022X_1 + 0.0110X_2 + 0.0357X_3 + 0.0170X_4 + 0.0153X_5 + 0.114X_6 + 0.015X_7 + 0.0008X_8 + 0.0143X_9 + 0.0047X_{10} + 0.0294X_{11} \geq 1.4 \sum_{j=1}^{17} X_j \quad \text{- Linoleic Acid}$$

$0.02X_1 + 0.115X_2 + 0.125X_3 + 0.1X_4 + 0.115X_5 + 0.007X_7 + 0.01X_8 + 0.048X_9 + 0.065X_{10} + 0.117X_{11} \leq 6.5 \sum_{j=1}^{17} X_j$ - Fibre

$0.0026X_1 + 0.0025X_2 + 0.0044X_3 + 0.008X_4 + 0.006X_5 + 0.0055X_7 + 0.0045X_8 + 0.0017X_9 + 0.0028X_{10} + 0.009X_{11} + 0.099X_{14} \geq 0.7 \sum_{j=1}^{17} X_j$ - Lysine

$0.0021X_1 + 0.001X_2 + 0.0019X_3 + 0.0021X_4 + 0.005X_5 + 0.022X_7 + 0.018X_8 + 0.004X_9 + 0.006X_{10} + 0.006X_{11} + 0.099X_{15} \geq 0.27 \sum_{j=1}^{17} X_j$ - Methionine

$0.0039X_1 + 0.0022X_2 + 0.0027X_3 + 0.0053X_4 + 0.007X_5 + 0.029X_7 + 0.023X_8 + 0.012X_9 + 0.012X_{10} + 0.01X_{11} + 0.099X_{15} \geq 0.65 \sum_{j=1}^{17} X_j$ - Methionine + Cysteine

$2.5 \leq X_{16} \leq 3.5$ - Common Salt

$X_{17} = 2.5$ - Layer Premix

$\sum_{i=1}^{17} X_j = 1{,}000$ - Feed Quantity

$\mathbf{X_j \geq 0}$ ***for i = 1, 2, …, 17***

The optimal solution for the model as specified above is summarised in Table 3, while Table 4 shows the resulting nutrient composition of the feed.

Table 3 presents the least-cost ration formulated for laying birds using locally available feedstuffs, while Table 4 outlines the nutrient constraints imposed upon the model. The least-cost combination of feedstuffs produced by the LP model resulted in a nutrient composition that aligns with the dietary requirements of laying birds. The observed average cost of producing one tonne of layer feed was $377.04 using existing feed formulation practices, which are influenced by market prices. However, when the LP model was applied to formulate the same feed, the average cost decreased to $321.69 per tonne. This indicates that adopting the proposed mathematical model for feed formulation could lead to a substantial reduction in total feeding costs. Specifically, the optimal solution achieved a 13.87% reduction in feed cost compared to the market-imposed formulation. Practically, this translates to a savings of approximately $0.055 per kilogram of feed purchased by poultry egg farmers. Therefore, feed formulation is more cost-effective when based on a validated mathematical programme. This finding is consistent with that of Oladokun and Johnson (2012), who reported that an optimal solution of the linear programme model gives a 9% reduction in feed formulation costs. Similarly, Fosu et al. (2023) demonstrated that LP models could reduce feed formulation costs by approximately 14% in pre-layer rations, with higher reductions observed in chick mash (30%) and grower (19%) formulations. These studies underscore the efficacy of LP in minimising feed costs by optimising the use of locally available feed ingredients while meeting nutritional requirements.

Table 3: Ingredient composition of ration formulated for laying birds using linear programming

Decision Variable(s)	**Objective coefficient**	**Proposed optimal solution**	
Feed Ingredient (X_j)	*Cost/kilogram ($)*	*Quantity (kg)*	*Cost ($)*
Maize	0.384	448.62	172.074
Corn bran	0.255	81.61	20.786
Wheat bran	0.174	85.72	14.898
Palm Kernel Meal (PKM)	0.135	80.00	10.788
Fish meal (72%)	2.847	0.00	0.000
Fish meal (65%)	1.618	0.00	0.000
Groundnut Cake (GNC)	0.336	11.29	3.788
Soybean Meal (SBM)	0.408	189.37	77.176
Bone meal	0.198	17.15	3.392
Oyster shell/Limestone	0.045	79.93	3.593
Lysine	3.896	0.14	0.549
Methionine	7.671	1.18	9.030
Common Salt	0.150	2.50	0.375
Layer Premix	2.098	2.50	5.244
Total Value		**1,000.00**	**321.692**

Table 4: Nutrient composition of the formulated feed

Nutrient Class	**Included level (Units)**
Energy (min)*	2,530 (*Kcal/kg*)
Crude Protein (min)	16.5 (*%*)
Calcium (min)	3.5 (*%*)
Phosphorus (Non-Phytate) (min)	0.45 (*%*)
Fats/Oil (max)†	3.7 (*%*)
Linoleic Acid (min)	1.45 (*%*)
Fibre (max)	4.90 (*%*)
Lysine (min)	0.80 (*%*)
Methionine (min)	0.40 (*%*)

Nutrient Class	Included level (Units)
Methionine + Cysteine (min)	0.65 (*%*)
Common Salt (min)	2.5 (*kg*)
Layer Premix (min)	2.5 (*kg*)

** (Minimum)   † (Maximum)*

4.4.1 Sensitivity analysis

An optimal solution to linear programming problems was obtained under a set of certain assumptions that may not always hold in the real world. Therefore, it was desirable to determine how sensitive the optimal solution is to different types of changes in the problem data and parameters. This kind of analysis is known as post-optimality (sensitivity) analysis. It seeks to answer questions regarding what errors of estimation could have been committed, or what possible future changes can occur, without disturbing the optimality of the current optimal solution. Table 5 shows the reduced cost (or shadow price) of basic feed ingredients like Maize, Corn bran, Wheat offal, Groundnut cake, Soybean Meal, Bone Meal, Oyster shell, Lysine, Methionine, and Layer premix are zero. This implies that there is no economic advantage in utilising more of these resources in the formulated feed, while a unit increase in the other feedstuffs like Palm Oil and Fish Meal (72% and 65%) will lead to a corresponding increase in the objective value (total feed cost) to the tune of their shadow prices. In other words, if a kilogramme of Fish Meal (72%) were to be forced into the optimal programme, it would increase the feed cost by approximately $2.219. However, the inclusion of such feed ingredients as Rice bran, Palm Kernel Meal, and Brewers' Dried Grain with negative shadow prices (penalty cost) into the optimal programme will reduce the feed cost by the magnitude of their penalty cost. This implies that if 1 kg of Brewers' Dried Grain were to be introduced into the feed formula, the total feed cost would be reduced by approximately $0.251. The analytical implication is that more of these feed ingredients should be used. However, there are practical limitations to the use of these feedstuffs in layers’ ration, such as palatability issues, availability, digestibility, and rancidity. Studies like Shouq (2008), Jadhav and Siddiqui (2010), and Alimon (2015) have established that these feedstuffs, although cheap, contain a very high level of dietary fibre, which in turn limits the ability of laying birds to fully utilise their nutrient compositions. Hence, their use is with great caution.

In the same vein, the post-optimality test also reveals how the optimal solution will behave when there is a change in the prices of programmed feed ingredients. The range for the objective function coefficients, within which the optimal solution remains valid, was computed. The optimal quantity for maize is 448.62 kg, and the range of objective coefficient within which the optimal solution remains valid is [0.068, 0.148]. Thus, for every $0.01 increase in the price of 1 kg of maize, there is a corresponding increase of $4.4862, given that the new price is within the range. Conversely, the optimal solution ceases to be valid if and only if there is a decrease in the price of maize below $0.068 or an increase beyond $0.148. This interpretation applies to the other feed ingredients. Similarly, for a non-basic variable like Fish Meal (72%) to be included in the optimal solution, its price must decrease below $2.219.

It can be observed from Table 6 that the dual or marginal prices of the surplus nutrient (Methionine) and slack nutrient (Fibre) are zero. This implies that there is no economic advantage in allocating more of these nutrients, while a unit increase in the other resources will lead to a corresponding increase in the total feed cost to the tune of their dual prices. For instance, a unit increase in the metabolic energy of feed produced will increase the feed cost by $0.092 within the stated range [31.74, 122.64]. Similarly, a unit increase in the fats/oils of feed produced will decrease the total feed cost by $24.129 within the stated range [0.03, 0.30]. However, it is important to note that the shadow prices will remain applicable for simultaneous changes that keep the solution feasible, even if the changes violate the individual ranges (Taha, 2007; MIT, 2021).

Table 5: Sensitivity analysis of the formulated poultry feed on variables

Name	Final Value	Shadow Price	Objective Coefficient	Allowable Increase	Allowable Decrease
Maize	448.62	0.000	0.384	0.148	0.068
Corn Bran	81.61	0.000	0.255	0.031	0.066
Rice Bran	0.00	-0.154	0.174	1E+30	0.154
Wheat Offal	85.72	0.000	0.135	0.131	0.099
Palm Kernel Meal	80.00	-0.077	2.847	0.077	1E+30
Palm Oil	0.00	2.727	1.618	1E+30	2.727
Fish Meal (72%)	0.00	2.219	0.336	1E+30	2.219
Fish Meal (65%)	0.00	1.035	0.408	1E+30	1.035
Groundnut Cake	11.29	0.000	0.198	0.069	0.075
Soybean Meal	189.37	0.000	0.045	0.092	0.039
Brewers' Dried Grain	0.00	-0.251	3.896	1E+30	0.251
Bone Meal	17.15	0.000	7.671	5.973	0.149
Oyster Shell	79.93	0.000	0.150	0.001	0.140
Lysine	0.14	0.000	2.098	2.158	4.021
Methionine	1.18	0.000	0.384	7.177	7.778

Name	Final Value	Shadow Price	Objective Coefficient	Allowable Increase	Allowable Decrease
Salt	2.50	0.244	0.255	1E+30	0.244
Premix	2.50	0.000	0.174	1E+30	1E+30

Table 6: Sensitivity analysis of the formulated poultry feed on constraints

Name	Final Value	Shadow Price	Constraint R.H. Side	Allowable Increase	Allowable Decrease
Energy (Min.) *	2530.00	0.092	2530	122.64	31.74
Protein (Min.)	16.50	2.623	16.5	0.12	1.27
Calcium (Min.)	3.50	3.943	3.5	0.62	1.46
Fats/Oil (Max.) †	3.70	-24.129	3.7	0.30	0.03
Linoleic Acid (min.)	1.45	88.969	1.45	0.01	0.05
Fibre (Max.)	4.90	0.000	6.5	1E+30	1.60
Phosphorus (Min.)	0.45	8.904	0.45	1.30	0.29
Lysine (Min.)	0.80	40.298	0.8	0.98	0.01
Methionine (Min.)	0.40	0.000	0.27	0.13	1E+30
Meth. + Cysteine (Min)	0.65	78.436	0.65	0.87	0.12
Total Feed (kg)	**1000.00**	**-0.094**	**1000**	**41.70**	**17.83**

** (Minimum)   † (Maximum),   R.H. = Right Hand.*

4.4.2 Profitability of table egg production under feed cost optimisation

This section examines how the introduction of linear programming into layers' feed formulation can impact feeding cost in the overall variable cost in table egg production. This is evident from the GM analysis presented in Table 7, where feed cost now occupies about 79%. This led to a reduction of $7,373.503 (11.23%) in the total variable cost of table egg production when linear programming was applied in the feed formulation. This implies that feed costs were lowered by nearly $9.949 –$92.714/tonne when compared to those imposed on egg producers by the open market. This finding is consistent with that of Almasad *et al.* (2011), who reported a reduction in the cost of egg production using linear programming and some specified feed ingredients. This is reflected in the massive improvement of the business's profitability value with an estimated GMR of 0.1514 (15.14%), indicating an increase of about 10.71% over what was observed when LP was not used. Therefore, a poultry farmer whose ultimate aim is profit maximisation should readily embrace the application of linear programming to formulate feed.

Table 7: Cost and Revenue outlook of table egg production under feed cost optimisation

ITEM	AMOUNT ($)	PERCENTAGE SHARE
REVENUE		
Table Egg	59,421.95	86.50%
Culled Layer	8,787.85	12.79%
Poultry Litter	465.47	0.68%
Feed Bag (empty)	17.58	0.03%
A: Total Revenue (TR)	**68,692.85**	**100.00%**
VARIABLE COST		
Laying Stock	10,044.37	17.25%
Feed	45,803.75	78.60%
Medication	1,427.64	2.45%
Labour	998.17	1.71%
B: TVC	**58,273.92**	**100.00%**
C: GM = A – B	**10,401.35**	
D: GMR = C/A		**15.14%**

4.4.3 Comparison of actual and least feed costs

Table 8 shows that the actual feed cost incurred by poultry egg farmers was higher than the least cost obtained when the LP technique was applied to formulate layers feed. The coefficient of variation of the least cost (0.0374), which was lower than that of the actual feed cost (0.0608), indicates that the LP technique is an efficient feed formulation tool capable of bringing a favourable difference in the overall share of feed cost in the total variable cost of table egg production.

Table 8: Summary of the actual and least feed costs

	Mean	Standard Deviation	Minimum	Maximum	CV
Actual Cost	0.383	0.023	0.347	0.432	0.0608
Least Cost	0.329	0.012	0.322	0.362	0.0374

CV = Coefficient of Variation.

4.5 Hypothesis Testing

In Table 9, the null hypothesis stating that the actual cost of feeding is not significantly different from its least cost was rejected while accepting the alternative hypothesis. The chi-square one-sample test reveals that there is a significant difference between the actual cost of feeding and its least cost. As shown in Table 9, the computed chi-square statistic was 397.505, which is significant at a 1% level of significance. This implies that respondents were spending more money on feed if linear programming was not used to formulate their feeds.

Table 9: Analysis of the difference between the actual feeding cost and the least cost

χ^2	Df	p-value	Decision
397.505	115	0.0000	Reject H_0

5. Conclusions

From the findings, it was deduced that table egg production in Ibadan is a male-dominated enterprise. The average egg farmer is literate, economically active, and runs a medium-scale farm. The share of feed cost in the variable costs structure of poultry egg production has exceeded the upper limit of the conventional range of 60 – 70%. The profit realised by table egg producers is quite marginal and could be wiped off in the event of further economic deterioration. LP optimisation reduced feed cost per tonne from $377.04 to $321.69, saving about 13.9% and improved GMR to 15%. Therefore, feed cost optimisation using the LP approach is capable of improving the deteriorating business condition and reversing the bleak outlook of the poultry egg business. Hence, feed cost optimisation is critical to the sustainability of egg production.

Based on the findings of this study, the following recommendations were put forward:

1. To enjoy an optimal feed cost, the egg farmers should be willing to incorporate more feed ingredients in their layer's ration because the more the alternative feedstuffs, the easier it is to produce feeds at a reduced cost.
2. To earn a higher level of profit, the poultry farmers should focus more on minimising their cost of feed rather than increasing their output price because of the competitive nature of their market.
3. LP makes it easy for users to do a fine-tuning of the ration as cost and other conditions change. Therefore, training can be done for poultry farmers to educate them about the benefits of using the least cost or linear programming approach in reducing feed cost in table egg production.

5.1 Contribution to Knowledge

This study advances the literature by providing one of the first direct empirical comparisons between actual and LP-optimised feed costs within the same farmer cohort in Nigeria, illustrating LP's tangible benefits in real-world settings.

5.2 Implications for Practice and Policy

- **Practitioners**: Adoption of LP-based feed formulation can significantly cut feed costs and bolster profitability. Extension services and poultry associations should train farmers in LP methods.
- **Policymakers**: While subsidies (e.g., feed support, maize release programs) offer relief, promoting technical tools like LP yields more sustainable economic outcomes and resource efficiency in the long term.

5.3 Limitations of the study

1. Scope: The study focused solely on layer farms in Ibadan and may not capture rural or smallholder variations.
2. Temporal context: Conducted during a period of high inflation and policy volatility; results may differ under stable conditions.
3. Range of costs: Analysis excluded overheads such as equipment depreciation and capital, which may affect full profitability assessments.

5.4 Directions for Future Research

1. Conduct longitudinal studies to track the sustained profitability of farms using LP over time.
2. Include egg quality parameters and production metrics (e.g., Haugh units, shell strength) to analyse whether cost reduction affects product quality.
3. Explore hybrid economic models that combine LP with market analytics to dynamically adjust feed formulations according to fluctuating market and nutritional conditions.

Acknowledgements: The author is grateful to everyone involved in making this project a success.

Conflicts of Interest: The authors declare no conflict of interest

References

Adebayo, O. A. (2009). Assessment of the sources of credit for food crop marketing operations in Ondo State, Nigeria. B. Agric. Tech., project work, Department of Agricultural Economics and Extension, Federal University of Technology, Akure.

Adepoju, A. A. (2008). Technical efficiency of egg production in Osun State. International Journal of Agricultural Economics and Rural Development 1:1.7–14.

Aduku, A. O. (1993). Tropical Feedstuff Analysis Tables. Ahmadu Bello University, Samaru, Zaria, Nigeria, pp: 4.

Ajakemo, N. B. (2021). High Price of Animal Concentrate Feeds in Nigerian Markets: Implication on Meat Productivity in Nigeria. International Journal of Applied Science Research, 1(2021):1-7.

Alabi, R. A. and Haruna, M. B. (2005). Technical Efficiency of Family Poultry Production in Niger-Delta. Journal of Central European Agriculture 6:4: 531-538.

Alimon, A. R. (2015). The Nutritive Value of Palm Kernel Cake for Animal Feed. Department of Animal Science, Faculty of Agriculture, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia. Pp. 12.

Almasad M., Altahat E., and AL-Sharafat A. (2011). Applying Linear Programme Technique to Formulate Least Cost Balanced Ration for White Eggs Layers in Jordan. International Journal of Empirical Research. Vol 1 No 1 Dec. 2011.

Bamiro, O. (2020). Comparative economic analysis of poultry egg production under two feed management regimes in Ogun State, Nigeria. ResearchGate.

Baruwa, O. S., & Idowu, O. M. (2021). Profitability and constraints of poultry egg enterprise in Ogun State. Journal of Livestock Science, 12, 42–49.

Commonwealth Scientific and Industrial Research Organisation (CSIRO) (2020). Poultry production in Nigeria. *Agriculture and Food*, page 1.

Esiobu, N. S., Onubougu, G. C., and Okoli, V. B. N. (2014). Determinants of Income from Poultry Egg Production in Imo State, Nigeria: An Econometric Model Approach. *Global Advanced Journal of Agricultural Science* 3(7): 186-199.

Exchange Rates UK. (n.d.). USD-NGN spot exchange rates history 2017. Retrieved January 15, 2025, from https://www.exchangerates.org.uk/USD-NGN-spot-exchange-rates-history-2017.html

Food and Agriculture Organization (FAO (2018). Livestock and livelihoods spotlight Nigeria: Cattle and poultry sectors. *Africa Sustainable Livestock* 2050 (ASL 2050).

Fosu, G. O., Konadu, J. B., Yeboah, M. Y., & Darko, O. K. (2023). Minimization of layer feed cost using linear programming. Engineering and Applied Science Letters, 6(1), 1–10. https://www.doi.org/10.30538/psrp-easl2023.0090

Habib, A. O., Afolami, C. A., Balogun, O. L., & Habib, S. (2017). Elasticity of production and profitability of feed milling systems of poultry egg farmers in Ogun State, Nigeria. International Journal of Livestock Research, 7(11), 132–142.

Jadhav, N. V., and Siddiqui, M. F. (2010). Handbook of poultry production and management. Second Edition. Jaypee Brothers Medical Publishers (P) Ltd., New Delhi, India. Pp. 1-4; 125-145.

Kolawole, A. O., Adegun, M. K. and Adebo, G. M. (2024). Effects of Petroleum Subsidy Removal on Sustainable Poultry Value Chain in Southwest Nigeria. Nigerian Journal of Rural Sociology, 24(1):1-6.

Laseinde, E. A. O. (2009). Tropical Poultry Production; Poultry Ventures – Prospects and Practice. Second edition. Delar Tertiary Publishers, Ile-Ife, Nigeria.

Massachusetts Institute of Technology (MIT) (2021). Chapter 3: Sensitivity Analysis, pages 1-54

Michigan State University Policy Research for a Resilient Africa (PRCI). (2020). Experiences and policy responses in Nigeria to price shocks during COVID-19 (PRCI Policy Brief). Michigan State University. https://doi.org/10.22004/ag.econ.303085

National Bureau of Statistics. (2024, January). Selected Food Price Watch – December 2023. Abuja, Nigeria: NBS. Retrieved from https://nigerianstat.gov.ng/elibrary/read/1247347

National Bureau of Statistics (NBS) (2014). Social Statistics in Nigeria. The Federal Republic of Nigeria.

National Research Council (1994). Nutrient Requirements of Poultry: Ninth Revised Edition, 1994. *Subcommittee on Poultry Nutrition, National Research Council*. ISBN: 0-309-59632-7, 176 pages, 8.5 x 11.

Nmadu, J. N., Ogidan, I. O. and Omolehin, R. A. (2014). Profitability and Resource Use Efficiency of Poultry Egg Production in Abuja, Nigeria. Kasetsart J. (Social Sciences) 35:134 – 146.

Odiaka, T. I., Adejoro, I. A., & Akinyele, O. F. (2012). Feed formulation problem in Nigerian poultry farms: A mathematical programming approach. American Journal of Scientific and Industrial Research, 3(1), 14–20.

Ogundeji, A. B. (2014). Assessment of Quail egg production in Akure South Local Government Area of Ondo State. B. Agric. Tech., project work, Department of Agricultural Economics and Extension, Federal University of Technology, Akure.

Ohajianya, D. O., Mgbada, J.U., Onu, P.N., Enyia, C.O., Henri-Ukoha, A., Ben-Chendo, N.G. and Godson-Ibeji, C.C. (2013). Technical and Economic Efficiencies in Poultry Production in Imo State Nigeria. *American Journal of Experimental Agriculture* 3(4): 927-938, 2013

Ojedapo, L. O. (2013). Effect of two Housing Systems (Cages vs deep Litters) on External and Internal egg characteristics of a Commercial laying birds reared in derived Savannah zone of Nigeria.

Oladeebo, J. O., and Ojo, S. O. (2012). Economic appraisal of small and medium scale performance in poultry egg production in Ogun State, Nigeria. African Journal of Agricultural Research Vol. 7(37), pp. 5170-5174

Oladokun, V. O., and Johnson, A. (2012). Feed formulation problem in Nigerian poultry farms: a mathematical programme approach. *American Journal of Scientific and Industrial Research* © 2012, http://www.scihub.org/AJSIR ISSN: 2153-649X, doi:10.5251/ajsir.2012.3.1.14.20

Olawumi, S. O. (2008). Principles and Practice of sound poultry management. Revised Edition. Baltays Publishers, Ile-Ife, Nigeria.

Olorunwa, O. J. (2018). Economic Analysis of Broiler Production in Lagos State Poultry Estate, Nigeria. *Journal of Investment and Management*. 7(1):35-44. doi: 10.11648/j.jim.20180701.15.

Onanaye, A. S. (2021). Linear programming models application in Nigeria broiler poultry rations. RUN Journal of Management and Social Sciences, 5(1), 51–64.

Otunaiya, A. O., Adeyonu, A. G., and Bamiro, O. M. (2015). Technical Efficiency of Poultry Egg Production in Ibadan Metropolis, Oyo State, Nigeria. *Economics*. Vol. 4, No. 3, 2015, pp. 50-56.

Piyaratne, M. K. D. K., Dias, N. G. J., and Attapattu, N. S. B. M. (2012). Linear Model-Based Software Approach with Ideal Amino Acid Profiles for Least-cost Poultry Ration Formulation. Information Technology Journal 11 (7): 788-793, 2012. Asian Network for Scientific Information.

Samuel, O. O., Olusegun, A. O., Adebimpe, O. A., & Akinbowale, T. T. (2015). Optimized nutrients diet formulation of broiler poultry rations in Nigeria using linear programming. Journal of Nutrition & Food Sciences, S14, 1–6.

Shouq, K. M. (2008). Least cost feed formulation for Poultry. Veterinary News and Views, Pakistan.

Sowunmi, F. A., Bello, A. A., Adebayo Isaiah Ogunniyi, A. I. and Omotayo, A. O. (2022). Delving Deeper into Market Concentration of Poultry Feed and the Driving Factors for Brand Switching: Evidence from Commercial Egg Producers in Nigeria. *Sustainability* 2022, 14(8030):1-18. https://doi.org/10.3390/su14138030

Taha, H. A. (2007). Operations Research (An Introduction). Eighth Edition, Pearson Education, Inc., pp: 11-191.

Tijani, A. A., Omirinde, J. O., Akinwumi, F. O., & Ajani, O. (2012). Economics of poultry egg production under different feeding systems. International Journal of Livestock Production, 3(12), 196–203.

United States Department of Agriculture, Foreign Agricultural Service. (2020). Grain and feed update – Nigeria (Report No. NI2020-0020). Washington, DC: USDA FAS. Retrieved from https://apps.fas.usda.gov/gainfiles/202009/20200951069.pdf