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Broiler Poultry Feed Cost Optimization Using Linear Programming Technique

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Abstract

Demand for poultry meat and eggs is increasing at a faster pace due to its good quality, nutritive values, and reasonable price. With the growing demand for egg and poultry meat, the demand for poultry feed is also increasing. Most of the feed ingredients which are used in poultry feed are also used for human nutrition. So these major feed ingredients and cumulatively poultry feed are facing market competition with increased cost. This study proposed linear programming (LP) technique to minimize the feed cost for small scale poultry farms. It employs locally available feed ingredients to formulate the broiler starter and finisher feed mix. The dietary nutrient requirement for broiler starter and finisher stage were determined from the prescribed standard specifications by Indian standard institutes and National Research Centers, Indian Council of Agricultural Research (ICAR). Sixteen feed ingredients were selected to formulate the optimal feed mix to minimize the total cost of feed mix subject to the essential nutrient constraints. Microsoft excel solver was used for the formulation of liner programming model and optimal feed mix for broiler starter and finisher were obtained.

Keywords

Poultry feed cost, optimization, linear programming

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Introduction

Poultry industry has emerged as the fastest growing segment not only in the livestock sector but also in the agriculture sector as a whole. The production of agricultural crops has been increasing at the rate of 1.5–2 percent per annum while that of eggs and broilers has been increasing at the rate of 8–10 percent per annum. Poultry farming is defined as ‘raising different types of domestic birds commercially for the purpose of meat, eggs and feather production’. However, the most common and widely raised poultry birds are chicken. Around 5,000 million chickens are being raised every year as a source of food (both meat and eggs of chicken). Broiler poultry are the most preferred type of poultry which are raised for meat consumption and also for business purposes. Broiler poultry farming industry is a well-known industry with proven economic potential. Broilers grow very fast since their feed conversion capacity is fast. They convert feed into food products quickly and efficiently within a short period of time, approximately 1.5–2 months duration. Their high rate of productivity results in relatively high nutrient needs. Poultry feeding is one of the important branches of poultry industry, since feed cost accounts for 70–80 percent of the total farm expenses (Gunasekar, 2007; Olugbenga, Abayomi, Oluseye, & Taiwo, 2015). It is in the interest of every poultry man to be able to get as much chicken meat or as many egg for every rupee that he spends on the feed as possible. For economic reasons, this supply of nutrients should be at least cost. So broiler feed must be designed in such a way that it meets the entire essential nutrients requirement for the growth and development of birds.

Various methods have been employed by industrialists and agriculturists for the formulation of the best poultry feed mix with the aim of minimizing costs or maximizing profits as well as working within the dietary requirements of these birds as proposed by researchers and experts in veterinary and/or animal nutrition fields. Methods employed include the trial and error method, Pearson square method, simultaneous equation method, two-by-two matrix method, linear programming method, etc. All these methods have similar guiding principles and employed within the dietary requirements to achieve the best feed mix.

The article is organized as follows. The second section provides problem statement followed by third section which is dedicated to review of past literature. The fourth section discusses the methodology adopted. The fifth section analyzes the results. Few implications of this research for the practitioners have been discussed in the sixth section, while the seventh section provides concluding remarks and scope of future research.

Problem Statement

Feed is an essential element in the poultry business as well as other livestock business. According to international market analysis research and consulting (IMARC) report the Indian animal feed market was worth ₹817 billion in 2018. The market is further projected to reach ₹1,683 billion by 2024. This increasing growth in feed market is due to the increasing demand for animal protein food and dairy products, which also had resulted in a growing livestock population in India. Most of the ingredients which are used in poultry feed are also used for human nutrition. So these major poultry ingredients have been facing market competition with human food as well. So the demand for feed ingredients goes up for which feed manufacturers use artificial feed additives, amino acids, and vitamins which are way costly than the normal feed ingredients. So the cost of feeds which are manufactured by modern feed manufacturers goes up in this regard. The feed cost incurs about 60–65 percent of the total cost of poultry production. So this increased feed cost highly affects the farmers who run small scale poultry farming and due to this they have started using locally available feed ingredients as feed for their birds. Using this type of feed may adversely affect the birds' health and growth, which leads to affect the overall farming business. For these reasons it is necessary that investments that go into rearing of these poultry birds are optimized to give the very best outcome. This can thus be achieved by optimizing the feed formulation of broiler starter and finisher.

Literature Survey

The survey explores various studies pertaining to broiler poultry production as pertains to nutrition and diet formulation. It discusses about various factors and considerations that affect poultry growth and development. It explores various nutrients and ingredients that make up the broiler feed, highlighting their significances and effects on broiler poultry diet. The review considers various attempts made in the formulation of poultry diet optimization models and successful attempts in achieving optimal animal feed diet. It highlights how the earlier discussed dietary information are utilized alongside animal growth and development factors as well as economic considerations such as feed ingredients price.

Food Competition and Food Production

As per the National action plan for egg and poultry by 2022 report, the 2017 broiler production is projected at 4.5 million tons which is approximately 7 percent more from the year 2016 possibly because of rising domestic demand for poultry meat. The growth in the broiler segment is expected to remain strong due to consumer preference for poultry, increasing income levels, and changing food habits. More than 80 percent of India's poultry output is produced by organized commercial poultry farms. Major poultry companies have vertically integrated operations which comprise approximately 60–70 percent of the total chicken production. Major companies/integrators, own hatcheries, feed mills, and primary processing facilities and often provide credit, extension services, and veterinary medicine to the contractual farmers. Integrators contract with multiple smaller farmers who rear the chicks to slaughter weight. Kryger, Thomsen, Whyte, and Dissing (2010) reported also that approximately 80 percent of rural households in developing countries engage in smallholder poultry production (village systems). The live birds are then purchased either by the integrators for slaughter and further processing or by a wholesaler who distributes them via live markets. According to Food and Agriculture Organization (FAO) (2009) report, chicken is usually the cheapest of all domestic livestock meats.

Poultry meat and eggs are highly nutritious, cheapest, and efficient feed utilized products (FAO, 2010; Farrell, 2010; Mengesha, 2011).

Feed Production

According to FAO (1995) reports, increment of mono-gastric animal production and the more intensive feeding systems with improved genotypes resulted in relatively greater demand for higher quality concentrate feeds. Moreover, mass production of pigs and poultry needs a larger proportion of the production of feed crops (Madan, 2005). As cereal products are increasingly used as feeds for animals, its share is projected to reach nearly 45–50 percent by 2050 in the world (FAO, 2003). Further, major poultry ingredients have been facing market competition with human food demands. Similarly, Gura (2008) reported that the competition between food, feed, and agrofuels is expected to aggravate prices of poultry feeds that enforce producers to look for alternative and locally available feed sources.

Feed price constitutes around 60–70 percent of the total production cost and therefore is the major component in changing production and marketing scenario of poultry and poultry products. At lesser feed prices, more farmers are willing to enter into the business and most of them would want to place more birds. Since feed is the main cost item in any system of poultry production, the beneficiaries of poultry development have been few in undeveloped countries (Reddy & Qudratullah, 1996). However, UNEP (2011) reported that chicken production is among the most energy-efficient sector in the world.

Poultry Feed Resources

As per the report of extension for feed by Dr Jacquie Jacob, the major ingredients in poultry diets provide energy and protein for poultry to maintain health, growth, and produce eggs. Common energy sources in poultry feeds include cereals and fats. Cereals are grasses that produce edible starchy grains, many of which can be used in poultry diets as an energy source. Barley, maize (also called corn), sorghum, and wheat are cereals often used in poultry diets.

Fats and oils provide a concentrated source of energy, which include tallow, poultry fat (derived from poultry offals), feed grade animal feed, etc. However, inclusion of fat in poultry diet is not necessary since fat percentage can be covered up by the cereals and protein supplements used in the diet.

The possible protein sources for poultry feeds include soybean, cottonseed meal, groundnut cake, fishmeal, meat and bone meal, cereal by-products, etc., many cereal grains which are used for human consumption are also used for poultry feed. The grains are cleaned and then either dry or wet milled. Many of the by-products of both wet and dry milling are suitable for inclusion in poultry feeds. Common cereal by-products are grain hulls, bran, middlings, rice polishing, etc.

Dietary Nutrient Requirements in Poultry Diet

Dietary nutrient requirements for broiler starter and finisher poultry are necessary for the determination of optimal feed formulation. These form the basis of the constraints that make up the linear programming models. The ingredients used in poultry feed are different in the context of source, nutrient contents, and significance. These ingredients fall within the classification based on the nutrients of which they have the greatest extent (Table 1).

Pond et al. (2005) has highlighted the nutrients of interest in the formulation of poultry feed as crude protein, metabolizable energy, fat, and calcium and phosphorous as major macro minerals and lysine and methionine as major amino acids of interest. These nutrient selections are found to be generic and are applied in most studies on the development, analysis, and optimization of broiler poultry feed.

Energy by itself is not a nutrient but a property of energy yielding nutrients, primarily carbohydrates, lipids, and proteins when they are oxidized during metabolism. Energy is very critical in poultry feed, in fact, the more energy loaded in the diet, the less feed the birds would consume (Larbier & Leclercq, 1994). Plavnik, Wax, Sklan, Bartov, and Hurwitz (1997) and Nahashon, Adefope, Amenyenu, and Wright (2006) reported that as dietary energy level increases, birds satisfy their energy needs by decreasing feed intake. Decreases in feed intake with high energy levels in the diets of broiler chickens have also been reported by Leeson et al. (1995) and Veldkamp, Kwakkel, Ferket, and Verstegen (2005).

In formulating poultry diets, the nutrient requirements of broilers have frequently been expressed per unit of dietary metabolizable energy (Gonzalez-a & Pesti, 1993). This practice is based on the theory that birds will adjust their feed intake according to their metabolizable energy requirements. Daily energy consumption of birds will vary with age, stage of production, and environmental temperature.

Protein is essential in all animal life. Proteins make up a large part of the muscle, skin, beak, feathers, cartilage, and internal organs of animals and are needed for growth, egg production, reproduction, production of antibodies to fight diseases, etc. Dietary requirements for protein are actually requirement of amino acids content in the protein. Two essential and critical amino acids for poultry are lysine and methionine. Thus, stating dietary requirements for both protein and essential amino acids are an appropriate way to ensure that all amino acids needed physiologically are provided. This is why methionine and lysine are chosen as the amino acids used in the formulation of feed as they are essential amino acids from which others are synthesized.

Table 1. Common Ingredients for Typical Poultry Feed

Nutrients	Sources
Carbohydrates	Cereals, cereal by-products, animal fats, vegetable oils
Protein	Plant protein (by-products of oilseed crops), animal protein (meat, bone, feather meal, etc.)
Mineral	Calcium supplements (limestone, shell grit), calcium and phosphorous supplements ($CaHPO_4$, bone meal), trace minerals (Cu, Fe, Mn, Zn, Co, I, Mo, etc.), and sodium sources (NaCl, $NaHCO_3$)
Vitamins	Vitamin premixes
Amino acids	Lysine, methionine, therionine
Feed additives	Enzymes, antibiotics, etc.

Source: Banerjee (A textbook of animal husbandry [18th edition, Reprint-2010]).

However, since protein sources are expensive, so protein levels are usually stated in precise terms to be closer to the minimum requirement than other nutrients. Protein sources can be of plant origin like soybean, groundnut cake, cotton seed meal, sunflower oil cake, safflower oil cake, de-oiled mustard cake, coconut cake, etc., or of animal origin such as fishmeal, meat and bone meal, blood meal, etc.

Mineral supplement also plays a vital role in preparation of poultry diet. Minerals are classified into two types, such as macro elements (which are individually considered in feed diet) and micro elements (supplied as proprietary feed mix).

According to FAO poultry require relatively large amount of some minerals, such as calcium, phosphorous, and sodium. Calcium and phosphorous are required for normal growth and skeletal development. Limestone powder can be used to supplement the calcium requirement and for phosphorous fishmeal or meat and bone meal can be used, which are also supplements for protein as well. Common salt is included in every diet as a source of sodium and appetite stimulant. It is added at a level of 0.2–0.4 percent in the diet since excess consumption of salt leads to excess water retention in the body.

Importance of Feed in Poultry

Feed represents the major cost of poultry production, constituting up to 70 percent of the total. Of total feed cost, about 95 percent is used to meet energy and protein requirements, about 3–4 percent for major mineral, trace mineral and vitamin requirements, and 1–2 percent for various feed additives. Poultry diets are formulated from a mixture of ingredients, including cereal grains, cereal byproducts, fats, plant protein sources, animal byproducts, vitamin and mineral supplements, crystalline amino acids and feed additives. These are assembled on a least-cost basis, taking into consideration their nutrient contents as well as their unit prices. Energy sources constitute the largest component of poultry diets, followed by plant protein sources and animal protein sources. Table 2 shows common feed ingredients used in poultry feed formulations in most parts of the world.

Table 2. Key Nutrient Composition of Cereal Grains and By-products of Cereal Grains

Ingredients	ME (kcal/kg)	Protein (%)	Calcium (%)	Phosphorous (%)	Lysine (%)
Maize	3350	13.6	0.22	0.35	1.01
Wheat	3100	13	0.05	0.20	0.5
Sorghum	3263	9.0	0.02	0.15	0.3
Barley	2795	11.5	0.10	0.20	0.4
Rye	2734	12.5	0.05	0.18	0.5
Triticale	3110	15.4	0.05	0.19	0.4
Oats	2756	12.0	0.10	0.20	0.4
Bajra	2642	12.7	0.13	0.72	0.42
Broken rice	2345	7.9	0.11	0.48	0.06
Wheat bran	1069	14.7	0.19	1.12	0.50
Rice bran	2937	12.7	0.27	1.37	0.40
Maize bran	—	8.5	0.07	0.13	—
Molasses	2400	2.8	1.51	0.66	—
Rice polish	2937	12.7	0.27	1.37	0.40

Source: Banerjee (*A textbook of animal husbandry, poultry nutrition*).

Protein Meals

Protein is provided from both plant and animal sources, such as oilseed meals and fish processing by-products (Table 3).

Table 3. Key Nutrient Composition of Protein Sources

Ingredients	ME (kcal/kg)	Protein (%)	Calcium (%)	Phosphorous (%)	Lysine (%)
Soybean meal	2557	48.0	0.20	0.37	3.2
Groundnut cake	2328	58.0	2.2	0.31	0.67
Cottonseed cake	2350	41.0	0.15	0.48	1.7
Sunflower oil cake	2205	46.8	0.30	0.50	1.6
Canola	2000	37.5	0.66	0.47	2.2
Coconut cake	1190	22.6	—	—	0.70
Mustard cake	2373	35.1	0.89	1.78	0.99
Linseed cake	—	29.6	—	—	0.94
Seasame seed cake	1882	39.1	2.46	1.42	1.04
Safflower oil cake	—	25.4	0.37	0.33	—

(Table 3 Continued)

(Table 3 Continued)

Ingredients	ME (kcal/kg)	Protein (%)	Calcium (%)	Phosphorous (%)	Lysine (%)
Fish meal	2720	60.0	6.50	3.50	5.3
Meat meal	2319	56.2	2.68	2.06	3.73
Meat and bone meal	2680	50.4	10.3	5.1	2.6
Blood meal	1420	73.4	0.32	0.31	4.79

Source: Banerjee (*A textbook of animal husbandry, poultry nutrition*).

Mineral Supplements

Minerals are vital for normal growth and development in poultry, such as bone formation and body processes such as enzyme activation. Some minerals, such as calcium and phosphorus, are required in large quantities. Other minerals, such as copper, iron, manganese, zinc, selenium, cobalt, iodine, and molybdenum, are required in milligram quantities but deficiency of these minerals will lead to serious health problems in mild cases and death in severe cases. Usually the grains and vegetable protein ingredients are relatively poor in mineral contents when compared with those of animal protein feed stuffs. The common mineral supplements in poultry diet are as follows:

1. Limestone powder
2. Bone meal
3. Oyster shell
4. Sodium chloride
5. Di-calcium phosphate.

The calcium supplements commonly used in poultry feeding are limestone, crushed sea shells, or sea-shell flour. Limestone powder can be included at no more than 3 percent, because higher levels will lower feed intake. To meet the phosphorus needs of poultry, formulations must be supplemented with inorganic phosphorus sources. In diets containing fishmeal and meat and bone meal, supplementation with inorganic sources may not be necessary. The inorganic phosphates used in poultry diets are di-calcium phosphate, bone meal, rock phosphate, defluorinated phosphate, and tricalcium phosphate, all of which supply both calcium and phosphorus. It is important that the inorganic phosphates are obtained from reliable sources, as contamination with fluorine can be a problem in some regions. Excess levels of fluorine in the phosphate source can adversely affect bird performance.

Common salt is included in all diets as a source of sodium and an appetite stimulant. Salt is added in poultry diets at levels of 0.2–0.4 percent. Excessive salt increases water consumption and leads to wet excreta. The use of salt can be lowered or even omitted if more than 5 percent fishmeal is used in the diet.

Feed Formulation

'Feed formulation is the process of quantifying the amount of feed ingredients that need to be combined to form a single uniform mixture (diet) for poultry, which supplies all of their nutrient requirements.' Since, feed accounts for 65–70 percent of total production cost, a simple mistake in feed formulation can be extremely expensive for a poultry producer. So, feed formulation requires thorough understanding of the following:

- Dietary nutrient requirements of the class of poultry (layers, broilers, etc.).
- Feed ingredients in terms of nutrient composition.
- Cost of feed ingredients.
- Availability of feed ingredients.

Feed formulation, often referred as least cost formulation, is the process of matching the nutrient requirements of a class of animals with the nutrient contents of the available ingredients (raw materials) in an economic manner. Typical formulations indicate the amounts of each ingredient that should be included in the diet, and then provide the concentration of nutrients (composition) in the diet. The nutrient composition of the diet will indicate the adequacy of the diet for the particular class of poultry for which it is prepared.

With this knowledge, mathematical formulas are used to derive the amounts of each ingredient that need to be included in the diet. When using only a few ingredients, the formulas are simple. However, when there are numerous ingredients available in different amounts and at different costs, more complex formulas are required.

Methodology

Linear programming is the most widely and popularly used optimization model employed in operation research. This technique helps to allocate resources to strategic alternatives in the best possible way. Linear programming is a mathematical technique for finding optimal solutions to problems that can be expressed using linear equations and inequalities. If a real-world problem can be represented accurately by the mathematical equations of a linear program, the method will find the best solution to the problem. To achieve a viable linear programming model for the optimization of the cost of broiler starter and finisher feed diet, it is necessary to develop various model equations and constraints that would govern the optimization process. This includes developing objective function, demand constraints, nutrient requirement constraints, and non-negativity constraints. Also information on the prices of locally available feed ingredients, their availability, and nutrient composition are presented here for the development of linear programming model equations.

Linear Programming: Importance and Popularity

Kelly & Potter, (1971) advocated that application of LP technique to solve feed formulation problem in small poultry units is uneconomical due to involvement of large initial expenditure. However, Enochean et al. (1971) contradicted this idea and suggested that efficient use of computers and LP is the most effective means of attaining minimum feed cost. Davies et al. (1972) also supported the claim of Enochean et al. (1971) and suggested the use of LP technique to solve feed formulation problems. Use of LP technique in feed formulation problem concept was further strengthened by Olentine who opined that ration formulation has now become finely tuned through the use of large computer matrices. The computer programs perform highly defined value-based ingredients analysis and delicate ingredient combinations. Thus it is not the same old ration formulation, wherein only protein and energy values were balanced first and later on some adjustments were made for few minerals and vitamins.

Al-Deseit (2009) carried out a similar study on the economic use of the locally available feedstuffs to formulate least cost rations for broilers using linear programming (LP) technique to determine how available ingredients can be combined efficiently and effectively toward achieving a least cost formulation. In a similar kind of study conducted in Nigeria. Oladokun and Johnson (2012) analyzed feed formulation problems in poultries using a mathematical programming approach to formulate a viably cheaper feed mix for layer poultry. They identified that many farmers within the Nigerian context still rely on older methods of formulation, such as intuition, experience, and rule of thumb amongst others. The optimal solution of the linear programming model gave 9 percent reduction in feed formulation costs compared to the existing method on the commercial farm utilized as a case study. Post optimality analysis also gave useful insight into the impact of changes in costs of feed inputs. They were able to achieve a formulation that not only satisfied all requirements and constraints but also proffered a comparatively cheaper price than the existing formulation. Olugbenga et al. (2015) carried out optimization of broiler feed rations at least cost with a case study of Nigerian poultries. A linear programming model was also applied for this study.

Use of Linear Programming in Feed Formulation

1. Product mix problem (deciding the combination of products/services leading to maximum profit)
2. Ingredient mix problem (deciding the quantity of ingredients to be used in the product leading to minimum cost)
3. Transportation problem (deciding the distribution plan of goods/services leading to minimum transportation cost)
4. Aggregate production planning (deciding the quantity of products/services to be produced so that overall cost will be minimum)
5. Assignment problem (to assign man or machine resources to various activities to minimize the total cost or maximize the profit)

The linear programming problems follow the following conditions:

1. The decision variables involved in the problem are non-negative.
2. The criterion for selecting the best values of decision variables can be described by a linear function of these variables, that is, the objective function should be a linear function of decision variables.
3. The operating rules governing the process can be expressed as a set of linear equations or linear inequalities. This set is known as the constraint set.

Dietary Nutrient Requirement of Broiler Poultry

Broiler diets are especially formulated in such a way that they promote an early rapid growth. Usually broiler diets are prepared in such a way so that the feed contains relatively high energy and high protein when compared with the feed of chickens other than broilers. A protein percent between 22 and 24 are fed to broilers for the first 4 weeks to obtain rapid early growth. These are called broiler starter diets. After this period, broilers are fed with a different type of diet having relatively less protein and more energy for fattening. Such a feed is known as broiler finisher diet.

For making a balanced feed for broilers, feed ingredients have to be mixed in proper ratio. Feeding strategies for broiler chickens will vary depending on the target market for the final product. Strategies for feeding broilers destined for the whole bird market will differ from strategies for broilers destined to be sold as pieces.
Table 4 shows the dietary nutrient requirement for broiler starter and finisher diet.

Nutrient Composition of Broiler Feed Ingredients

Based on data retrieved from the National Research Council (NRC), Indian Standard Institutions (ISI), as well as other nutritionist information and nutrient requirement specifications from Local farms, the following nutrient composition of feed ingredients and nutrient requirements for broiler starter and finisher are derived.

Table 4. Dietary Nutrient Requirement for Broiler Starter and Finisher Diet

	Broiler Starter		Broiler Finisher	
Nutrients	Max Value	Min Value	Max Value	Min Value
Metabolizable energy (kcal/kg)	3,500	2,800	4,000	3,050
Protein (%)	40.0	15.0	22.0	13.0
Fat (%)	2.5	1.0	6.0	1.0
Calcium (%)	1.5	0.5	1.0	0.3
Phosphorous (%)	0.7	0.1	0.6	0.1
Lysine (%)	2.5	0.5	2	0.5
Methionine (%)	0.7	0.2	0.7	0.2
Sodium (%)	0.3	0.02	0.3	0.02
Chloride (%)	0.5	0.05	0.5	0.05

Source: Banerjee (A textbook of animal husbandry [18th edition, Reprint-2010]).

The ingredients listed here are ingredients applied for this particular study. The selection of ingredients is based on the following:

1. The availability: ingredients are selected as per their local availability.
2. The prices: available ingredients are selected according to their prices.
3. The nutrient composition: which are the ingredients that can be selected as per their nutrient composition to meet the nutrient requirements of broiler poultry.
4. The palatability: ingredients should be palatable to eat otherwise feed intake will be less.

The essential nutrients are selected by consulting poultry nutritionists and from extensive literature survey.

The figures presented in Tables 5–7 are typical values for ingredients listed and nutrient requirements for broiler starter and finisher. They are sometimes average values or approximate values, especially in case of major ingredients and in case of lesser used ingredients the figures listed are only the values available in literature.

Table 5. Energy Supplements for Broiler Diet

Ingredients Nutrients (%)	Maize (x1)	Bajra (x2)	Wheat (x3)	Sorghum (x4)	Broken Rice (x5)	Rice Bran (x6)	Wheat Bran (x7)
ME (kcal/kg)	3,350	2,642	3,100	3,263	2,345	2,937	1,069
Protein	13.6	12.7	13.0	9.0	7.9	12.7	14.7
Fat	2.1	4.9	2.3	4.6	1.7	13.9	3.8
Calcium	0.22	0.13	0.05	0.02	0.11	0.27	0.19
Phosphorous	0.35	0.72	0.20	0.15	0.48	1.37	1.12
Lysine	1.01	0.42	0.5	0.3	0.06	0.40	0.50
Methionine	0.2	0.24	—	0.1	—	0.44	0.16
Sodium (g/kg)	0.1	—	0.6	0.1	—	0.7	0.6
Chloride (g/kg)	0.7	0.2	0.8	0.8	0.3	0.7	0.9
Cost/kg	15	16	22	18	12	9	15

Source: Banerjee (A textbook of animal husbandry [18th edition, Reprint-2010]).

Table 6. Protein Supplements for Broiler Diet

Ingredients Nutrients (%)	Soybean Meal (x8)	Cotton Seed Meal (x9)	Groundnut Cake (x10)	Sunflower Oil Cake (x11)	Fish Meal (x12)	Meat and Bone Meal (x13)
ME(kcal/kg)	2,557	2,350	2,328	2,205	2,720	2,680
Protein	48.0	41.0	58.0	46.8	60.0	50.4
Fat	21.2	8.6	2.2	10.9	4.3	10.0
Calcium	0.20	0.15	0.31	0.30	6.50	10.3
Phosphorous	0.37	0.48	0.67	0.50	3.50	5.1

(Table 6 Continued)

(Table 6 Continued)

Ingredients Nutrients (%)	Soybean Meal (x8)	Cotton Seed Meal (x9)	Groundnut Cake (x10)	Sunflower Oil Cake (x11)	Fish Meal (x12)	Meat and Bone Meal (x13)
Lysine	3.2	1.7	1.51	1.6	5.3	2.6
Methionine	0.72	0.45	0.43	—	1.19	0.71
Sodium(g/kg)	2.9	0.6	0.8	0.2	8.0	7.0
Chloride(g/kg)	0.3	0.4	0.3	1.9	3.0	14.0
Cost/kg	33	27	24	23	19	34

Source: Banerjee (A textbook of animal husbandry [18th edition, Reprint-2010]).

Table 7. Mineral Supplements for Broiler Diet

Ingredient Nutrient (%)	Limestone Powder (x14)	Di-Calcium Phosphate (x15)	Salt (NaCl) (x16)
Calcium	34.42	28.0	—
Phosphorous	0.02	19.0	—
Sodium	—	—	39.5
Chloride	—	—	60.5
Cost/kg	3	28	4

Source: Banerjee (A textbook of animal husbandry [18th edition, Reprint-2010]).

Feed Composition of Selected Feed Ingredients

Table 8 shows the selected feed ingredients, their prices, and nutrient composition.

Linear Programming Model Formulation

Formulation of linear programming model involves the following steps.

Let, i = Nutrient components of feed ingredients, where $i = 1, 2, 3\ldots., m$ and j = Number of feed ingredients, where $j = 1, 2, 3\ldots., n$

$$X_j = Quantity\ of feed\ ingredients\ j\ in\ the\ feedmix\left(Decision\ variable\right)$$

$$X_t = Total\ quantity\ of\ feed\ to\ be\ produced\ in\ Kg\ \left(Subject\ to\ the\ demand\right)$$

$$Z = Total\ cost\ of\ feed\ ingredients\ used\ in\ feed\ formulation$$

$$C_j = Unit\ cost\ of\ feed\ ingredient\ j\left(in rupees\right)$$

$$a_{ij} = Amount\ of\ nutrient\ i\ available\ in feed\ ingredient\ j$$

$$B_i = Requirement\ of dietary\ nutrient\ i\ for\ Broiler\ poultry$$

Objective Function

The objective function is to minimize the total feed mix cost and it is in the form of

Table 8. Feed Composition Table for Selected Feed Ingredients

Ingredients	Optimal Amount in Diet	Cost per kg	ME (kcal/kg)	Protein (%)	Fat (%)	Ca (%)	P (%)	Lys (%)	Meth (%)	Na (%)	Cl (%)
Maize	x_1	15	3,350	13.6	2.1	0.22	0.35	1.01	0.2	0.1	0.7
Bajra	x_2	16	2,642	12.7	4.9	0.13	0.72	0.42	0.24	—	0.2
Wheat	x_3	22	3,100	13.0	2.3	0.05	0.20	0.5	—	0.6	0.8
Sorghum	x_4	18	3,263	9.0	4.6	0.02	0.15	0.3	0.1	0.1	0.8
Broken rice	x_5	12	2,345	7.9	1.7	0.11	0.48	0.06	—	—	0.3
Rice bran	x_6	9	2,937	12.7	13.9	0.27	1.37	0.40	0.44	0.7	0.7
Wheat bran	x_7	15	1,069	14.7	3.8	0.19	1.12	0.50	0.16	0.6	0.9
Soybean meal	x_8	33	2,557	48.0	21.2	0.20	0.37	3.2	0.72	2.9	0.3
Cottonseed meal	x_9	27	2,350	41.0	8.6	0.15	0.48	1.7	0.45	0.6	0.4
Groundnut cake	x_{10}	24	2,328	58.0	2.2	0.31	0.67	1.51	0.43	0.8	0.3
Sunflower oil cake	x_{11}	23	2,205	46.8	10.9	0.30	0.50	1.6	—	0.2	1.9
Fish meal	x_{12}	19	2,720	60.0	4.3	6.50	3.50	5.3	1.19	8.0	3.0
Meat and bone meal	x_{13}	34	2,680	50.4	10	10.3	5.1	2.6	0.71	7.0	14.0
Limestone powder	x_{14}	3	—	—	—	34.42	0.02	—	—	—	—
Di-calcium phosphate	x_{15}	28	—	—	—	28	19	—	—	—	—
Salt	x_{16}	4	—	—	—	—	—	—	—	39.5	60.5

Source: The authors.

$$Minimize\,Z = \sum_{j=1}^{n} C_j X_j$$

$$Z = C_1X_1 + C_2X_2 + \ldots C_nX_n$$

Constraints

The objective function is subject to the following constraints.

Demand requirements: The demand requirement is an indication of the total amount of feed mix required based on the requirement of broilers at different stages according to their ages.

$$X_t = \sum_{j=1}^{n} X_j$$

$$X_t = X_1 + X_2 + \ldots X_n$$

where

$$X_j = Quantity\ of\ feed\ ingredient\ j\ in\ the\ feedmix$$

Minimum requirement: These constraints serve to limit the amount of a certain feed nutrient (a_i) to the minimum requirement of the Broiler poultry for that nutrient. It is the lower limit of the deviation of the nutrient amount during optimization.

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

where

$$a_{ij} = Amount\ of\ nutrient\ i\ in\ feed\ ingredient\ j$$

$$B_i = Requirement\ of\ dietary\ nutrient\ i\ for\ Broiler$$

Maximum requirement: These constraints serve to limit the amount of a certain feed nutrient (a_i) to the maximum requirements of the Broiler poultry. It is the upper limit of the deviation of the nutrient amount during optimization.

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

where

$$a_{ij} = Amount\ of\ nutrient\ i\ in\ feed\ ingredient\ j$$

$$B_i = Requirement\ of\ dietary\ nutrient\ i\ for\ Broiler$$

Non-negativity constraints: The non-negativity constraints serve to ensure that in the process of optimization, no optimal value falls into the negativity range.

$$X_j \geq 0, j = 1, 2, \ldots.., n$$

Excel Solver Application for Linear Programming

Excel solver belongs to a special set of commands often referred as what-if analysis tools. It is primarily purposed for simulation and optimization of various business and engineering models. The excel solver add-in is especially useful for solving linear programming optimization problems; hence it is sometimes called a linear programming solver. Apart from linear programming optimization problems, it also solves non-linear and non-smooth problems.

Solver is a simple yet effective tool to solve optimization problem. Solver approach makes solving optimization problems fairly a simple task. It offers a quick way to build a model, and the user can easily explain the model and results to the other users. Linear programming is a model in which the objective function and all of the constraints are linear function of decision variables. With the help of excel solver it is always possible to determine that a linear programming has no feasible solution or has unbounded solution or has a globally optimal solution.

Conventional excel formulas process straight forward calculation, whereas solver takes excel's math engine much further and runs advanced problem solving algorithms to discover results for multiple variables at a time. The Microsoft excel solver is a common linear programming tool chosen for its accessibility and its easy use to achieve better economies of production by minimizing costs.

Necessary information regarding the feed ingredients, their per kg prices, nutrient components of each feed ingredients and nutrient requirements for starter broiler diet and finisher broiler diet for this study were entered as input values into the Microsoft excel sheets as shown below in the figures.

Calculation of Error

Error is calculated to check the deviation of observed nutrient values from the required values. Weights are assigned to each nutrient as per the expert's opinion and weighted values are derived.

Results and Discussion

The data presented in this article are the results and analysis of the formulated linear programming model for the optimization of feed cost for broiler poultry. The models for broiler starter diet and broiler finisher diet were solved using linear programming method in Microsoft excel solver. If the solver is able to find a feasible solution that satisfies all the constraints and optimality conditions then it generates several reports based on the feasible optimal solution. The reports generated by solver were answer report, sensitivity report, and limits report.

Then the comparison between the existing formulation and proposed formulation was performed. Comparison was done on the basis of optimized cost, deviation of optimal nutrient value from the required nutrient level and feasibility or suitability of the proposed feed mix as per the cost requirement of poultry farmer and as per the growth, development, and palatability of poultry birds.

The errors were calculated for nutrient requirement of broiler to check the deviation of proposed formulation from the required value and finally conclusion was drawn from the results.

Result of Broiler Starter Diet

The proposed diet formulation result produced by linear programming model has shown that for approximately 1 kg of starter feed mix the diet consists of 0.45 kg of maize, 0.12 kg of bajra, 0.1 kg of wheat, 0.1 kg of broken rice, 0.075 kg of groundnut cake, and 0.097 kg of fishmeal. This feed mix costs approximately ₹16 per kg.

Sensitivity Analysis for Broiler Starter Diet

The sensitivity report is divided into two parts. The first part is named 'Adjustable cells' corresponding to objective function coefficients. The allowable increase and allowable decrease values of each decision variable specifies that how much the objective function coefficient can change within the specified limits without changing the optimal solution. For example per kg cost of bajra can be increased by ₹6.97 and decreased by ₹1.32 without changing the optimal solution corresponding to bajra.

The second part of the table titled 'Constraints' addresses the range of feasibility which is the range for right-hand side of constraint, where the shadow price remains unchanged. A shadow price value is associated with each constraint of the model. Shadow price gives the net impact in the total maximum profit or minimum cost if additional unit of certain resources can be obtained. It is the instantaneous change in the objective function value of the optimal solution obtained by changing the right-hand side value of the constraint by one unit. One unit increase or one unit decrease has net impact on the objective function value. But the changed RHS values of constraints should be within the allowable limits without affecting the shadow price values. For example for metabolizable energy the RHS value can be increased by 300 kcal or decreased by 25.91 kcal with a resulting increase or decrease of ₹0.0148. In cost minimization problem a negative shadow price means that an increase in the corresponding RHS value of constraint results in a decreased cost and a decrease in corresponding constraint RHS value results in an increased cost.

Answer Report Analysis for Broiler Starter Diet

Answer report shows the optimal solution of decision variables $x_1 = 0.45, x_2 = 0.116, x_3 = 0.1, x_5 = 0.1, x_{10} = 0.075, x_{12} = 0.097$ and optimal value. *Minimum cost* = ₹15.67

In constraint section it shows the binding and non-binding constraints. A constraint is binding if after optimal solution the LHS value of the constraint is equal to its RHS value. Binding constraint is a limiting constraint since it restricts the possible changes from that point. So it prevents us from improving the objective function (in case of minimization improve means reducing cost). But non-binding constraint does not restrict the possible changes from that point. It shows we have not used all the available resources but which can be used to improve the objective function value.

Result of Boiler Finisher Diet

The proposed diet formulation result produced by linear programming model has shown that for approximately 1 kg of finisher feed mix the diet consists of 0.45 kg of maize, 0.17 kg of bajra, 0.1 kg of wheat, 0.1 kg of broken rice, 0.179 kg of rice bran, 0.005 kg of groundnut cake, 0.003 kg of limestone powder. This feed mix costs approximately ₹15 per kg.

Sensitivity Analysis for Broiler Finisher Diet

The sensitivity report is divided into two parts. The first part is named 'Adjustable cells' corresponding to objective function coefficients. The allowable increase and allowable decrease values of each decision variable specifies that how much the objective function coefficient can change within the specified limits without changing the optimal solution. For example per kg cost of Bajra can be increased by ₹4.688 and decreased by ₹2.38 without changing the optimal solution corresponding to Bajra.

The second part of the table titled 'Constraints' addresses the range of feasibility which is the range for right-hand side of constraint, where the shadow price remains unchanged. A shadow price value is associated with each constraint of the model. Shadow price gives the net impact in the total maximum profit or minimum cost if additional unit of certain resources can be obtained. It is the instantaneous change in the objective function value of the optimal solution obtained by changing the right-hand side value of the constraint by one unit. One unit increase or one unit decrease has net impact on the objective function value. But the changed RHS values of constraints should be within the allowable limits without affecting the shadow price values. For example for metabolizable energy the RHS value can be increased by 45.16 kcal or decreased by 43.41 kcal with a resulting increase or decrease of ₹0.009. In cost minimization problem a negative shadow price means that an increase in the corresponding RHS value of constraint results in a decreased cost and a decrease in corresponding constraint RHS value results in an increased cost.

Answer Report Analysis for Broiler Finisher Diet

Answer report shows the optimal solution of decision variables $x_1 = 0.45, x_2 = 0.17, x_3 = 0.1, x_5 = 0.1, x_6 = 0.179, x_{10} = 0.005, x_{14} = 0.003$ and optimal value. *Minimum cost* = ₹14.678

In constraint section it shows the binding and nonbinding constraints. A constraint is binding if after optimal solution the LHS value of the constraint is equal to its RHS value. Binding constraint is a limiting constraint since it restricts the possible changes from that point. So it prevents us from improving the objective function (in case of minimization improve means reducing cost). But non-binding constraint does not restrict the possible changes from that point. It shows we have not used all the available resources but which can be used to improve the objective function value.

Comparison Between Existing Diet Formulation and Proposed Diet Formulation

Tables 9 and 10 show the comparison between existing feed formulation and proposed feed formulation.

From the comparison it was derived that the number of ingredients and quantity of each ingredient has been decreased as compared to the existing formulation. So accordingly the total cost of feed mix has decreased.

Also the existing formulation contains certain ingredients which were not taken into consideration while performing the feed formulation using linear programming model. According to nutritionist the use of ingredients like oil, baking soda, lysine, and methionine mixture can be omitted, since the required nutrients which are obtained from these ingredients can also be obtained from available cereal grains and protein meals.

For example oil is used for fat content in the diet, but fat content can also be obtained from rice bran, groundnut cake, sunflower oil cake, etc. Lysine and methionine content can also be obtained from protein meals like soybean, cottonseed meal, groundnut cake, etc. Limestone powder and di-calcium phosphate could be used in place of baking soda. A comparison of proposed broiler feed formulation with the existing feed formulation for starter and finisher feed is provided in Tables 9 and 10, respectively.

For Broiler Starter

Comparison of proposed broiler starter feed formulation with the existing feed formulation (Table 9) shows that the cost of proposed feed mix for broiler starter is ₹1,567.09 for 100 kg of feed mix and ₹15.67 (approximately ₹16) for 1 kg of feed mix. Based on the information received from a local farm, it was recorded that on an average monthly feed consumption of 100 birds (broiler) is 199.3 kg. Starter feed is fed to the birds for 4 weeks. So, the total cost of feed for 4 weeks (a month) will be 199.3 × ₹15.67 = ₹3,123.

Whereas, the existing feed mix which costs ₹2,270.67 for 100 kg and ₹22.70 for 1 kg, the total cost for 4 weeks consumption is 199.3 × ₹22.70 = ₹4,524. So, the decrease in total starter feed cost can be clearly visible here.

For Broiler Finisher

Comparison of proposed broiler finisher feed formulation with the existing feed formulation (Table 10) shows that the cost of proposed feed mix for broiler

Table 9. Comparison of Proposed Broiler Starter Feed Formulation with the Existing Feed Formulation

Existing Broiler Diet Formulation (for 100 kg)				Proposed Broiler Starter Diet Formulation (for 100 kg)			
Ingredients	Quantity (kg)	Cost/kg	Total Ingredient Cost	Ingredients	Quantity (kg)	Cost/kg	Total Ingredient Cost
Maize	63.2	15	949.2	Maize	45	15	675
Soybean meal	27.7	33	914.76	Bajra	11.65	16	186.4
Meat and bone meal	4	34	136	Wheat	10	22	220
Oil	2.32	75	174.67	Broken rice	10	12	120
Di-calcium phosphate	0.38	28	10.64	Groundnut cake	7.55	24	181.2
Limestone powder	1.207	3	3.621	Fish meal	9.71	19	184.49
Salt	0.164	4	0.656		Total feed cost = ₹1,567.09		
Soda	0.187	23	4.30				
Lysine	0.226	230	51.98				
Methionine	0.124	200	24.8				
Total feed cost = ₹2,270.63							

Source: The authors.

finisher is ₹1,467.8 for 100 kg of feed mix and ₹14.67 (approximately ₹15) for 1 kg of feed mix. Data collected from a local farm reveal on an average for 100 birds (broiler) 211.3 kg of finisher feed is required. And this is fed for 2 weeks to a broiler live weight of 2 kg. So, the proposed finisher feed mix will cost 211.3 × ₹14.67 = ₹3,100. Whereas, the existing feed mix which costs ₹2,270.67 for 100 kg and ₹22.70 for 1 kg, the total cost for 2 weeks consumption is 211.3 × ₹22.70 = ₹4,796. This indicates the proposed feed mix will reduce cost of finisher feed.

Our results are in line with the findings of Oladokun and Johnson (2012) and Olugbenga et al. (2015). Both the studies demonstrated that a reduction in cost of broiler feed could be achieved without compromising the nutrient content through the application of linear programming techniques.

Deviation of Proposed Feed Diet from the Nutrient Requirements

After the proposed diet is formulated, it is then required to check that up to what extent the formulated diet satisfies the nutrient requirement of broiler feed. Therefore, the observed value and target value of each nutrient was compared and subsequent error was calculated to determine the deviation. Finally the total error was calculated to check the acceptability of the proposed feed mix. Calculated error for broiler starter and finisher feed is provided in Tables 11 and 12, respectively.

For Broiler Starter

Calculated error for broiler starter (Table 11) indicates that starter diet lacks the required protein nutrient. A rich in protein diet is required for broiler starter for the first 4 weeks to obtain rapid early growth. Lack in protein content can affect the growth of birds and can take more time to achieve the required weight. So, a good source of protein meal like soybean or cotton seed meal should be included in the diet to meet the required protein requirement. Otherwise the proposed feed mix cannot be practiced by the farmers for their birds.

For Broiler Finisher

Calculated error for broiler finisher feed formulation with the existing feed formulation (Table 12) reveals that the observed value of metabolizable energy in proposed diet is 3,050 kcal/kg whereas its required value is 3,225 kcal/kg. In case of finisher diet metabolizable energy is required more for fattening of birds at finisher stage. So, it is necessary that energy supplements should be balanced well in the diet to meet the required value. It is also seen that fat content is very high in the proposed diet than the required value; this could be due to the inclusion of rice bran, which has higher fat content. So, rice bran can be omitted or quantity of rice bran can be reduced to meet up the required fat content. Again sodium is an important nutrient which the proposed finisher diet lacks, and sodium content can be supplemented by adding salt in the diet.

Table 10. Comparison of Proposed Broiler Finisher Diet with the Existing Formulation

Existing Broiler Diet Formulation (for 100 kg)				Proposed Broiler Finisher Diet Formulation (for 100 kg)			
Ingredients	Quantity (kg)	Cost/kg	Total Ingredients Cost	Ingredients	Quantity (kg)	Cost/kg	Total Ingredients Cost
Maize	63.2	15	949.2	Maize	45	15	675
Soybean meal	27.7	33	914.76	Bajra	17.35	16	277.6
Meat and bone meal	4	34	136	Wheat	10	22	220
Oil	2.32	75	174.67	Broken rice	10	12	120
Di-calcium phosphate	0.38	28	10.64	Rice bran	17.95	9	161.55
Limestone powder	1.207	3	3.621	Groundnut cake	0.528	24	12.672
Salt	0.164	4	0.656	Limestone powder	0.326	3	0.978
Soda	0.187	23	4.30	Total feed cost = 1,467.8			
Lysine	0.226	230	51.98				
Methionine	0.124	200	24.8				
Total feed cost = ₹2,270.63							

Source: The authors.

Table 11. Calculated Error for Broiler Starter

Essential Nutrients	Required Value	Observed Value	Fractional Deviation	Square of Fractional Deviation	Weightage	Weighted Value
ME (kcal/kg)	3,010	2,800	−0.0697	0.0048	0.05	0.00024
Protein (g/kg)	250	198.99	−0.2040	0.0416	0.01	0.00208
Fat (g/kg)	20	25	0.25	0.0625	0.01	0.00625
Calcium (g/kg)	10	7.849	−0.2150	0.0462	0.15	0.00462
Phosphorous (g/kg)	5	7	0.4	0.16	0.15	0.016
Lysine (g/kg)	12.7	11.88	−0.0643	0.0041	0.1	0.00082
Methionine (g/kg)	5	2.66	−0.4679	0.2189	0.1	0.02189
Sodium (g/kg)	1.5	0.94	−0.3716	0.1381	0.15	0.02762
Chloride (g/kg)	1.5	0.76	−0.4917	0.2418	0.1	0.02418
Total error = 0.103730 × 100 = 10.373%						

Source: The authors.

Table 12. Calculated Error for Broiler Finisher Diet

Essential Nutrients	Required Value	Observed Value	Fractional Deviation	Square of Fractional Deviation	Weightage	Weighted Value
ME (kcal/kg)	3,225	3,050	−0.0542	0.0029	0.05	0.0001
Protein (g/kg)	190.0	130.0	−0.3157	0.0997	0.01	0.0049
Fat (g/kg)	25.0	47.0244	0.8809	0.7761	0.01	0.0776
Calcium (g/kg)	6.5	3.0	−0.5384	0.2899	0.15	0.0289
Phosphorous (g/kg)	4.2	6.0	0.4285	0.1836	0.15	0.0183
Lysine (g/kg)	10.5	6.6316	−0.3684	0.1357	0.1	0.0271
Methionine (g/kg)	3.9	2.1291	−0.4540	0.2061	0.1	0.0206
Sodium (g/kg)	1.5	0.2349	−0.8433	0.7113	0.15	0.1422
Chloride (g/kg)	1.5	0.5869	−0.6086	0.3705	0.1	0.0370
Total error = 0.35718 × 100 = 35.718%						

Source: The authors.

Implications

This research has the following implications for the practitioners and researchers:

- This research has collected and provided information on various nutrients required for proper growth of broilers at different stages and the sources of these nutrients. This will be helpful for the practitioners to provide proper diet to the birds from the locally available food sources.
- The LP methodology used could be helpful for the academicians and practitioners in developing a proper feed mix with low cost.
- In rural areas of our country where farming is the sole source of income for people, the issues of poor feed formulation as well as high cost of feed are two prevailing problems that can be solved simultaneously.

Conclusion and Scope for Further Research

This study employed a linear programming technique for reasons of accuracy and ease of doing calculation in comparison to other manual techniques of feed formulation employed by local farms. Also Microsoft excel solver was used in this study for solving optimization problem since solver is a simple yet effective tool which gives best outcome subject to the necessary constraints. The proposed result of broiler starter and finisher diets are realistic according to the economic prospective but these diets are not viable for the use in poultry farms according to dietary nutrient requirement.

The proposed broiler starter and finisher diets are not having enough of some essential nutrients. This could be due to the sourcing of nutrient composition of feed ingredients data from various animal nutrition text books and publication that in some cases they have wide variations on feed composition information. So, these proposed diets cannot be practiced by the farmers without the improvement in the nutrients requirement. For future work to be carried out on this project, samples of locally available feed ingredients can be collected and tested to ascertain the nutrient composition of the feed ingredients. From such analysis, feed ingredients nutrient compositions that are more practical to the prevailing environment and the quality of feed ingredients can be employed to the study. So that when the feed will be formulated greater accuracy can be obtained. Further, the optimization techniques other than the linear programming technique can be carried out with the help of Microsoft excel solver and results can be compared with the linear programming result to get a better feed mix.

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