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Linear Model Based Software Approach with Ideal Amino Acid Profiles for Least-cost Poultry Ration Formulation

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Abstract: This study was on the development of linear model based software with inclusion of digestible amino acids for least-cost poultry ration formulation. The software model developed in this project used recent advancements in the field of poultry nutrition and feeding, information technology and provided facilities to incorporate commonly used feed ingredients and ideal amino acid profiles. Sixty (60) feed ingredients, thirty (30) nutrients and 1800 (60×30) constraints were considered. Standard Linear Programming (LP) model with incorporating lp_solve (Mixed integer linear programming solver) was used to analyze and determine the most efficient and effective way of compounding the least-cost ration with analyzing ideal amino acid profiles. Taking nutrient composition of each of the available ingredients, cost of ingredients, nutrient requirements of the birds, standard restrictions for formulation and ideal amino acids into consideration a mathematical model was constructed. Lp_solve methods were used in linear model algorithm at the program execution. Facilities were made available to formulate broiler rations based on National Research Council (NRC) standards and Ideal Illinois Chick Protein (IICP) (published by Illinois University) profiles. The model gave rations with equalizing major nutrient requirements at the average inclusion level of commercial Lysine 0.05% and Methionine 0.02%. Equal nutrient requirement gave up to 12 major nutrients with ideal amino acid profiles. The formulation was optimum at 15 iterations.

Key words: Linear programming, optimization, software, least-cost ration, ideal amino acids, poultry ration

INTRODUCTION

The poultry industry in Sri Lanka which was started as a backyard domestic operation in 1980s has now graduated to a high level of sophistication in compliance with international best practices. When compared to other meat industries, the production of poultry and the consumption of poultry meat and egg are less regulated by ethno-religious taboos. Consequently, the poultry industry in Sri Lanka experienced a rapid expansion during last two decades (Central Bank of Sri Lanka, 2004). However, during last few years, the profit margin of the poultry industry has narrowed forcing many small and medium scale farmers to leave out of the industry, mainly due to the high feed cost.

With the rapid growth of the poultry sector, the demand for quality feed is also growing. The current poultry feed production of Sri Lanka is 38,000 MT per month (Samarasinghe, 2007). Firman (2010) also reported that provision of some nutrients like energy, phosphorus and amino acids can cost over 90% of total diet cost. The objective of the modern nutrition and feeding management programs is to deliver an exact quantity of nutrient to the birds at lowest financial and environmental costs. In formulating such a diet for poultry, a range of aspects such as birds nutrient requirements, available feed resources, their costs, nutrient composition and digestibility and ideal amino acids has to be considered. Nutrient requirements of broilers and layers depend on many factors and continuous research has established the requirements of more than 30 nutrients for different age classes of broilers and layers (NRC, 1994). Similarly, nutrient compositions and their digestibility values in broilers and layers have also been established for hundreds of feedstuffs. If effectively used, above advancements formulates highly efficient diets at the lowest financial and environmental cost. When considered the environmental cost, several issues become with the pollution of nitrogen (N) excretion and sometimes phosphorus excretion which is due to

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inefficiency of protein and other nutrients utilization (Schutte and De Jong, 1999; Coon, 2004; Diarra *et al*., 2010). The practical feed formulation based on an ideal protein and amino acid level set at exact requirements is a difficult task. As the first limiting amino acids are methionine and lysine (Si *et al*., 2004; Babiker *et al*., 2009) the present formulators use commercially available amino acids like DL methionine and L lysine to reduce the utilization of protein as the requirements for methionine, methionine plus cystine and lysine (Coon, 2004). This will leads to increase the production cost again. Several attempts have been done to analyze the effects of ideal amino acids in poultry industry (Adeola and Sands, 2004; Si *et al*., 2004; Firman, 2010; Zaefarian *et al*., 2008). Mbajiorgu *et al*. (2011) reported the uses and importance of protein and amino acids in detail. Since, the formulation of a precise ration requires considering an enormous amount of information, this can be best handled by using a computerized system. A range of software is available for poultry ration formulations, though expensive. Winfeed (www.winfeed.com) is one of popular software which can be used for ruminants, poultry and fish. Udo *et al*. (2011) has reported successful research findings in formulation of least-cost ration for African catfish using Winfeed software.

Square method, Simultaneous equation method, Two-by-two matrix method and Trial-and-error method (Omenka and Anyasor, 2010) are among most commonly used simple methods. These rations are laborious and can consider only a limited amount of constraints in the ration formulation. Furthermore quick and fine alterations cannot be done easily. At present many farmers and nutritionists balance their poultry feeds from using simple computer programs such as spreadsheet applications to mathematical models developed with linear programming technology. Though several methods are available for ration calculation, all of them have the same objectives of providing the required balanced nutrients at the least possible cost and most of the time they use total amino acid requirements (Coon, 2004). Several experiments have been conducted to formulate least-cost ration using linear programming technique in the livestock industry (Olorunfemi, 2006, 2007; Olorunfemi *et al*., 2006; Al-Deseit, 2009; Pathumnakul *et al*., 2011; Udo *et al*., 2012). Mamat *et al*. (2011, 2012) have also used linear programming technique for human ration formulations. With the assistance of computers and linear programming methods feed formulators can consider more nutrients and feed ingredients to formulate rations at lowest possible cost. Also linear programming makes it easy for users to do fine tuning the rations as the cost and other conditions change. The software developed in this project uses recent advancements such as ideal protein concept in broiler nutrition and feeding.

MATERIALS AND METHODS

The system design phase was based on structured programming approach. According to design methodology, there were three layers in the system. Those layers can be designed in order to structured programming approach. Hence, the stages of the system design phase are interface design, process design and database design.

The design methodology: Waterfall Model (Somerville 1997), with minor changes was used as the system development model for this software development. According to the Somerville (1997), this model has five fundamental stages; requirements analysis and definition, system and software design implementation and unit testing, integration and system testing, operation and maintenance.

System architecture: The software system architecture designed based on the Three-tier architecture (Whitten and Diffman, 2001). Three layers of the system are represents as System User Interfaces (Application Layer) (Galitz, 2007), Process Management (Business Logic Layer) and Database Management (Data Storage Layer) (Ramez and Navathe, 2004).

The design technology: Overall application implementation was done in the. NET platform (Microsoft, 2003). Visual Studio.NET (Microsoft, 2003) was used to implement the GUI interfaces. Visual Basic.NET 2003 (Microsoft, 2003) was used to implement codes by considering the user requirements. The major analytical part of this software was the linear model (http://www.sce.carleton.ca/faculty/chinneck/po.html). The linear model was developed integrating the solving methods of lp_solve (Sourceforge, 2007) (mixed integer linear solver) into Visual Basic.NET. Due to compatibility and easiness of handling, MS Access 2003 (Microsoft, 2003) was used as the database management system and database connectivity was the OLE DB (Microsoft, 2003) connection and it was done with ADO.NET (Microsoft, 2003). According to the Dobson (2003), creating database connection and opening of the connection were done as follows:

```
Dim string As New String ("Provider = Microsoft.Jet.OLEDB.4.0;")
    string + = "Data Source =<database name>.mdb"
    cnnection.ConnectionString = string
    cnnection.Open ()
```

Data collection: This study was totally based on secondary data. NRC (1994) standards on feedstuffs specifications, constraints imposed on the selected feedstuffs including maximum and minimum inclusion levels and the dietary nutrient requirements for poultry were used. NRC (1994) and IICP (Emmert and Baker, 1997) ideal amino acid profiles (Table 1) were used to set constraints on the model algorithm to evaluate amino acid levels. Actual market prices were used as cost of feed ingredients. Table 2 shows the ingredients and their nutrient compositions which are only used in verification trials.

Linear model: Linear programming is a computational approach which can be used to select, allocate and evaluate limited resources with constraints to obtain an optimal solution for an objective function. A linear program model consists of three major different parts namely; an objective function, a series of equations and the resources which are non negative variables (Olorunfemi, 2006, 2007). A standard linear programming model for ration formulation with the objective function to minimize cost can be stated as follows (http://www.sce.carleton.ca/faculty/chinneck/po.html):

Table 1: University of Illinois ideal rations for selected amino acids at three growth periods

	Lysine ideal ratio (%)		
Amino acids	0-21 days	21-42 days	42-56 days
Lysine	100	100	100
Methionine+Cystine	72	75	75
Methionine	36	37	37
Cystine	36	38	38
Threonine	67	70	70
Valine	77	80	80
Arginine	105	108	108

Emmert and Baker (1997)

$$\text{Minimize} \quad < \sum_{j=1}^{n} c_j x_j$$

$$\sum_{j=1}^{n} a_{ij} x_j \leq b_i$$

$$\sum_{j=1}^{n} a_{ij} x_j \geq b_i$$

$$\sum_{j=1}^{n} x_j = 1$$

$$x_j \geq 0$$

Where:

c_j = Cost per unit for jth ingredient
x_j = Quantity of jth ingredient
a_{ij} = Quantity of ith nutrient per unit of jth ingredient
b_i = Requirement for ith nutrient in the diet

Model construction: Mathematical model was constructed for maximum 60 variables (feed ingredients). Number of constraints, mainly about nutrient requirements of the bird and maximum and minimum ingredient inclusion levels (upper and lower limits) were also used. The objective of the model was to minimize cost of producing a particular ration after satisfying a set of constraints. The variables in this model were the ingredients while the cost of each ingredients and the nutrient value of each ingredient was the parameter. Nutrients compositions of the ingredient and nutrient requirements are called from the database into the model using lp_solve methodologies.

Objective function for 60 variables:

min: +p1x1 +p2x2 +p3x3 …………..+p60

where, p1, p2 …p60 are unit cost of each ingredient and x1, x2…..x60 are amounts of each ingredients.

Subject to:

Total weight = 1000: (Total ration weight is 1000 kg)
+x1+x2+x3…..X60 = 1000

Table 2: Cost implication of feedstuffs used for trials and their nutrient levels

Ingredients	Cost (LKR kg^{-1})	Crude protein (%)	Crude fibre (%)	Calcium (%)	Non-phytate phosphorus (%)	Lysine (%)	Methionine (%)	Energy (MEkcal kg^{-1})
Coru grain (maize)	30.00	8.50	2.20	0.02	0.08	0.26	0.18	3,350.00
Copra meal	19.00	19.20	14.40	0.17	0.00	0.50	0.28	1,525.00
Fish meal	255.00	64.20	1.00	3.73	0.00	5.07	1.59	2,580.00
Rice bran	25.00	12.90	11.40	0.07	0.22	0.59	0.26	2,980.00
Sesame seeds meal	34.00	43.80	7.00	1.99	0.34	0.91	1.22	2,210.00
Soybean seeds meal	55.00	44.00	7.00	0.29	0.27	2.69	0.62	2,230.00
Coconut oil	80.00	0.00	0.00	0.00	0.00	0.00	0.00	8,800.00
Shell powder	4.00	0.00	0.00	38.00	0.00	0.00	0.00	0.00
Di-calcium phosphate	70.00	0.00	0.00	22.00	13.09	0.00	0.00	0.00
Limestone	45.00	0.00	0.00	38.00	0.00	0.00	0.00	0.00
Common salt	20.00	0.00	0.00	0	0.00	0.00	0.00	0.00
Vitamin mineral premix	400.00	0.00	0.00	0	0.00	0.00	0.00	0.00
DL methionine	475.00	0.00	0.00	0	0.00	100.00	0.00	0.00
L lysine	300.00	0.00	0.00	0	0.00	0.00	100.00	0.00

NRC (1994)

Requirement constraint for nutrient requirement:

$$+q1x1 + q2x2 + q3x3 \ldots\ldots\ldots + q60x60 = \text{Nutrient requirement}$$

where, q1, q2 …q60 are amount of each nutrient and x1, x2… x60 are amount of each ingredient.

The requirement constraint model was applied into 30 nutrient requirements.

Ingredient constraints as follows:

+Minimum<= +Feed Ingredient<= Maximum

This was applied to 60 ingredients accordingly.

All standard constraints on maximum and minimum ingredients inclusion levels and nutrients requirements are set as defaults. But these are customizable and user can change accordingly at run time. Ration formulation was done with 3 major steps with the software including bird selection (17 categories are available), ingredient selection (60 ingredients are available) and amino acid profile selection. Amino acid selection step was done with 5 selections including no profile, no profile with changing lysine ratio, NRC profile with total amino acid basis, NRC profile with digestible amino acid profile and IICP profile with digestible amino acid profile.

RESULTS AND DISCUSSION

Seventeen rations types formulated successfully for seventeen birds types including white and brown egg immature layer birds with 4 age categories, white and brown egg mature birds with 3 age categories and 3 broiler categories. Avoiding huge number of tables, a limited number of formulated rations (3 to 6 weeks age broiler category) and nutrient compositions of those are displayed. Commonly available practical rations calculated by hand at the Department of Animal Science, Faculty of Agriculture, University of Ruhuna are considered for integrity analysis, the model calculated ration was totally depended on the hand calculated values and constraints are set accordingly. All the time, the model gave the similar rations and nutrient compositions as well. One comparison of those rations and nutrient compositions is displayed in Table 3 and 4.

Normally, when formulating rations by hand, only a limited number of nutrients and feed ingredients can be considered due to the complexity. Table 5 shows a comparison of hand calculated practical ration and model calculated ration with considering equal nutrient requirements. It shows the ingredient amounts of the two rations are totally different because the model calculated ration was totally based on equal nutrient requirements (not depended on hand calculated values). Model calculated ration consists 59.8% of corn grain, the highest amount in the ration. When compared to hand calculated ration, rice bran, copra meal, limestone, DL methionine and L lysine amounts were 0% in model calculated ration. Table 6 shows the comparison of nutrient composition of the two rations. The ration formulated by the software exactly matched with the nutrient requirements whereas hand calculated ration showed deviation from standard nutrient levels. Particularly, the level of non phytate phosphorus and methionine levels exceeded the

Table 3: Comparison of rations calculated by hand and linear model for broilers (3 to 6 weeks age)

Ingredient name	Hand calculation	Linear model
Corn grain	314.50	314.50
Fish meal	3.30	3.30
Rice bran	200.00	200.00
Sesame seeds meal	173.00	173.00
Soybean seeds meal	130.00	130.00
Copra meal	64.60	64.60
Coconut oil	87.50	87.50
Di-calcium phosphate	14.00	14.44
Limestone	4.60	4.23
Common salt	2.50	2.50
Vitamin mineral premix	2.50	2.50
L lysine	2.50	2.43
DL methionine	0.00	0.00
Total	999.00	999.00

Constraints of model calculation were totally depended on the hand calculated values

Table 4: Comparison of nutrient composition of the ration in Table 3

Nutrient name	Hand calculation	Linear model	Standard requirement
Protein	200.2960	200.2962	200.0
Energy	3200.8470	3200.8470	3200.0
Lysine	10.0636	10.0000	10.0
Methionine	4.2548	4.2548	3.8
Methionine+cystine	7.6692	7.6692	7.2
Calcium	9.1254	9.0000	9.0
Non-phytate phosphorus	3.5129	3.5600	3.5
Fibre	60.2545	60.2545	<50

Table 5: Comparison of rations calculated by hand and linear model for broilers (3 to 6 weeks age) constraints of model calculation were not depended on the hand calculated values

Ingredient name	Hand calculation	Linear model
Corn grain	198.00	597.87
Fish meal	3.60	26.13
Rice bran	400.00	0.00
Sesame seeds meal	144.00	53.68
Soybean seeds meal	150.00	242.66
Copra meal	0.00	0.00
Coconut oil	77.50	51.59
Di-calcium phosphate	13.00	14.14
Limestone	6.30	0.00
Common salt	2.50	2.50
Vitamin mineral premix	2.50	2.50
L lysine	1.60	0.00
DL methionine	0.00	0.00
Total	999.00	1000.00

Table 6: Comparison of nutrient composition of the ration in Table 5

Nutrient name	Hand calculation	Linear model	Standard requirement
Protein	200.10	200.00	200.0
Energy	3201.52	3200.00	3200.0
Lysine	10.01	10.00	10.0
Methionine	4.16	3.80	3.8
Methionine+cystine	7.65	7.10	7.2
Calcium	9.05	9.00	9.0
Non-phytate phosphorus	3.68	3.50	3.5
Fibre	70.56	34.07	<50.0

Table 7: Rations formulated with considering amino acid profiles for Broilers (3 to 6 weeks age)

	Amino acid profiles (%)		
Ingredients	NRC-TR	NRC-DR	IICP-DR
Coru grain (maize)	40.00	40.00	40.00
Fish meal	4.07	5.99	5.99
Rice bran	23.85	26.12	26.11
Sesame seeds meal	8.12	5.04	1.60
Soybean seeds meal	15.95	15.21	18.64
Coconut oil	5.50	5.00	5.00
Shell powder	0.88	1.00	1.14
Di-calcium phosphate	1.09	0.96	0.98
Common salt	0.25	0.25	0.25
Vitamin mineral premix	0.25	0.25	0.25
DL methionine	0.00	0.08	0.00
L lysine	0.03	0.10	0.04

TR: Total requirement, DR: Digestible requirement

Table 8: Nutrient compositions of three rations in Table 7

	Amino acid profiles (%)		
Nutrients	NRC-TR	NRC-DR	IICP-DR
Crude protein	200.0	200.00	200.00
Lysine	10.0	10.00	10.00
Methionine	4.2	4.60	3.60
Calcium	9.0	9.00	9.00
Nonphytate phosphorus	3.5	3.50	3.50
Energy	3200.0	3200.00	3200.00
Fibre	53.13	53.17	53.15

TR: Total requirement, DR: Digestible requirement

recommended levels. Fibre level of model calculated ration was 3.4% while the hand calculated one was 7%. Inclusion of high fibre levels reduces the animal performance while more non phytate phosphorus and methionine levels increase the excretion of phosphorus and nitrogen, respectively. Therefore, the ration formulated with software can assumed to be environmentally more friendly.

The ideal protein concept of broiler ration formulation attempts to match the amino acid profile of the ration with the required amino acid profile. It has been shown that this method maximizes the performance while minimizing the excretion on amino acids. Theoretically, when ideal amino acid profiles are used in ration formulation all amino acids are utilized at 100% efficiency. However, formulation of broiler diets considering ideal amino acid profile by hand calculation of using spreadsheet is extremely difficult. This software has introduced the ideal protein concept to formulate rations to meet the ideal amino acid profiles. Two ideal proteins NRC (1994) and Illinois University ideal ration) were used. Sample rations prepared to meet the ideal amino acid profiles are shown in Table 7 and the comparison of nutrient compositions of those sample rations is shown in Table 8.

CONCLUSION

The critical evaluation point of this system was the linear model because many of software model developers use linear programming to resolve linear problems in less time. Therefore, the performance testing was in high percentage of total evaluation process. The linear model analyzing time period is less than a second (optimum ration gives at less than 15 iterations). That is the very successful performance of the system. In order to testing results, ration formulation results are more accurate and informative than hand calculation results. Least cost rations can be formulated equalizing up to 10-12 major nutrients. It provides exhaustive information on nutritive values for a wide range of feed ingredients (up to 60) along with the maximum and minimum inclusion levels for each ingredient. The ideal protein concept of broiler ration formulation can also be considered and it allows users to change Ideal Protein (IP) levels based on NRC and IICP profiles. Changing of IP levels shows a significant improvement of the rations. The standard nutrient requirement levels can be customized and user can change the nutrient requirements. The software can be run under Microsoft Windows environment and users are able to print and save results as well as initial database information. The software has been successfully installed, tested and evaluated successfully with several research projects at the Department of Animal Science of the Faculty of Agriculture, University of Ruhuna. Result comparison between hand and model calculation proved that the developed model was accurate, saves time, formulates environmentally friendly and economic rations and could handle the complex situations considering the higher number of feed ingredients, nutrients and constraints.

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