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A Hybrid Model of Uniform Design and Artificial Neural Network for The Optimization of Dietary Metabolizable Energy, Digestible Lysine, and Methionine in Quail Chicks

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ABSTRACT

A uniform design (UD) was used to construct models to explain the growth response of Japanese quails to dietary metabolizable energy (ME), and digestible methionine (dMet) and lysine (dLys) under tropical condition. In total, 100 floor pens with seven birds each were fed 25 UD different diets containing 25 ME (2808-3092 kcal/kg), dMet (0.31-0.49% of diet), and dLys (0.91-1.39% of diet) levels from 7 to 14 d of age. A platform of artificial neural network based on UD (ANN-UD) was generated to describe the growth response of the birds to dietary inputs using random search. Artificial neural networks of body weight gain (BWG) and feed conversion ratio (FCR) were optimized using random search algorithm. The optimization the ANN-UD results showed that maximum BWG may be achieved with 2995 kcal ME/kg, 0.45% dMet, and 1.18% dLys of diet; and minimum FCR may be obtained with 3000 kcal ME/kg, 0.45% dMet, and 1.17% dLys of diet. The result of this study showed that a ANN and UD hybrid model can be used successfully to optimize the nutritional requirements of quail chicks.

INTRODUCTION

There is no increasingly trend for research activity on Japanese quails (*Coturnix coturnix japonica*) as a biological model (Minvielle, 2004) and little information is available on the nutritional requirements of modern quails, especially on digestible amino acid requirements. Some reports were recently published on the metabolizable energy:crude protein (ME:CP) ratio in growing (Ghazaghi *et al*., 2012; Siyadati *et al*., 2011) and adult quails (Tarasewicz *et al*., 2006). The ME content of diet may control feed intake and, therefore, the digestible intake of each amino acid (NRC, 1994; Richards and Proszkowiec-Weglarz, 2007). However, it has been shown that the protein intake in monogastric animals is regulated separately from energy intake and that both controlling mechanisms interact to determine overall feed intake (Henry, 1985).

The main limitation of factorial experiments with more than two factors and different levels of each factor is the need for several experiments, followed by the complexity of multivariable analyses. In order to solve this problem some experimental designs such as Box-Behnken Design (De Leon *et al*., 2010; Ferreira *et al*., 2007), Central Composite Design (Mehri, 2012; Mehri *et al*., 2012; Montgomery, 2008), and Uniform Design (Fang, 1980) were suggested. Uniform design was initially proposed by Fang (1980) and it is becoming increasingly popular both in the industry and the academia (Cheng & Li, 2009; Fang & Lin, 2003). Uniform design has the distinct features: 1) it allows for multiple optimization with moderate number of experiments, reducing costs; 2) since there is no assumption about the underlying function, the more uniform points which are spread within the domain result in a good representation of the underlying function by the model; 3) it can be used for more possible numbers of levels of each factor among all experimental designs (Zhang *et al*., 1998). The most important features of these designs are the amount and the accuracy of collected data and providing desired information while keeping the number of experiments (Lin *et al*., 2009).

Artificial neural networks (ANN) have been employed to analyze data in poultry experiments (Ahmadi & Golian, 2008; Ahmadi & Golian, 2010a; Ahmadi and Golian, 2010b; Ahmadi & Golian, 2011; Ahmadi *et al*., 2008; Mehri, 2012; Roush *et al*., 2006). Central composite design (CCD) has been successfully used to optimize dietary nutrients using response surface methodology (Mehri *et al*. 2012) and ANN approach (Ahmadi & Golian, 2011; Mehri, 2012). Zhang *et al*. (1998) used UD for calibration ANN and concluded that ANN model based on UD always results in better performance than other experimental designs.

The objective of this study were: 1) to develop ANN models based on UD to analyze the growth response of Japanese quails to dietary ME, dLys, and dMet from 7 to 14 d of age; 2) to rank independent variables in terms of their relative importance in the developed models; and 3) to optimize the ANN model to obtain optimal values of input factors to maximize BWG and minimize FCR in Japanese quail under tropical conditions.

MATERIALS AND METHODS

Bird management

One-day-old Japanese quails were obtained from the hatchery of the Research Center of Special Domestic Animals of the University of Zabol (RCSDA, Zabol, Iran). Quail chicks were fed a starter diet (2900 kcal ME/kg and 26% CP) from d 0 to d 7 of age. At d 7 of age, 700 quail chicks were distributed into 100 floor pens and fed the dietary treatments until 14 d of age. Each pen was equipped with a drinker and a feeder, and wood-shavings litter. House temperature was maintained at 35ºC during the first week of age. On the second week of age the temperature was changed from 32 to 38ºC to mimic tropical condition. Relative humidity was 55% throughout the experiment.

Experimental Diets

Experimental diets containing corn, wheat, soybean meal, and corn gluten meal were formulated based on UD in which dietary ME, dMet, and dLys ranged from 2806 to 3090 kcal/kg, 0.31 to 0.49% of diet, and 0.91 to 1.39% of diet, respectively. To design the experimental diets, 25 levels of each independent variable (i.e., ME, dMet, and dLys) were calculated based on table of U25(25^5) provided in JMP software (JMP, 2007). Experimental levels of input variables and corresponding responses are shown in Table 1.

Table 1 – Dietary concentrations of metabolizable energy (ME), digestible lysine (dLys), and digestible methionine (dMet) in the experimental diets provided according uniform design and corresponding BWG and FCR response values of Japanese quails from 7 to 14d of age

	Input variable			Observed responses	
Treatment no.	ME (kcal/kg)	dLys (%)	dMet (%)	BWG (g/bird)	FCR (g/g)
1	2852	0.95	0.42	37.03	3.05
2	3090	1.27	0.48	36.73	3.07
3	2974	1.37	0.46	40.70	2.75
4	2938	1.17	0.31	41.18	2.87
5	2950	1.29	0.38	37.22	2.79
6	2828	1.15	0.33	34.38	2.96
7	3042	1.13	0.45	34.08	3.11
8	2998	1.21	0.44	40.33	2.49
9	2900	1.11	0.35	33.93	3.09
10	3036	1.39	0.34	33.11	3.11
11	2926	1.23	0.42	39.45	2.77
12	2959	1.03	0.40	33.43	3.11
13	2914	0.93	0.43	39.56	2.78
14	3005	0.91	0.36	37.84	2.58
15	2840	1.25	0.37	38.04	2.72
16	2890	1.33	0.47	37.93	2.54
17	3069	1.19	0.39	33.69	3.13
18	2983	1.07	0.38	36.04	2.64
19	2816	1.35	0.41	37.40	2.57
20	2866	1.01	0.49	41.19	2.59
21	2806	1.05	0.46	40.33	2.46
22	3021	0.97	0.34	35.99	2.77
23	3079	1.00	0.32	28.06	3.75
24	2875	1.31	0.31	30.27	3.37
25	3054	1.09	0.49	33.63	2.86

Model Development and Evaluation

An algorithm of a feed forward multilayer perceptron (MLP) with 3 inputs, 1 output (with linear activation function), and 8 hidden neurons (with hyperbolic tangent activation function) was considered to construct the ANN models. The number of hidden neurons of the MLP was determined using the selection algorithms integrated in the "intelligent problem solver" module of Statistica software (StatSoft, 2008). In order to train the networks for BWG and FCR separately, a quasi-Newtonian algorithm was used in which the 3 input variables were dietary ME (kcal/kg), dLys, and dMet (% of diet). The 100 data lines were randomly divided into 2 sets of training (70 data lines) and testing (30 data lines). All data were imported into the Statistica Neural Network software version 8.0 (StatSoft, 2008) to develop the models and the goodness-of-fit of the ANN models was evaluated using R^2, mean absolute deviation (MAD), mean square error (MSE), mean absolute percentage error (MAPE), and bias (Roush *et al*., 2006).

Sensitivity Analysis

In most cases the weight of inputs in the model may vary and some factors have stronger effects on the response. The sensitivity analysis indicates the relative importance of each variable in the model that could be defined as the ratio between the error with omission and the baseline error (Hunter *et al.*, 2000). More important variables in the have higher variable sensitivity ratio (VSR) and VSR may be used to rank the input variables according to their importance (Ahmadi & Golian, 2010b).

Model Optimization

The final goal of modeling process is to find a condition in which the predictive model yields the optimal response. Several methods may be used to optimize ANN models including genetic algorithm, simulated annealing, particle swam optimization, and gradient-free search. Random search is a family of numerical optimization methods that is relatively easy to implement on complex problems with "black-box" function evaluations (Mehri, 2012). Because the methods typically rely only on function evaluations, rather than gradient and Hessian information, they can be quickly coded and applied to a broad class of global optimization problems (Huang *et al.*, 2006). In this study the random search algorithm was used to optimize the ANN models for BWG and FCR. This method is an iterative optimization algorithm which is provided in Response Optimization for Data Mining Models module of Statistica software (StatSoft, 2008). For each selected set of independent values over the search space, the prediction model was evaluated and compared with the desired response. This process was then repeated until a set of independent values, for which the model yield was equal or as close as possible to the desired response value, were determined (StatSoft, 2008).

RESULTS AND DISCUSSION

Model Evaluation

The plots of actual and predicted values of BWG and FCR are shown in Figures 1 and 2. The relatively high

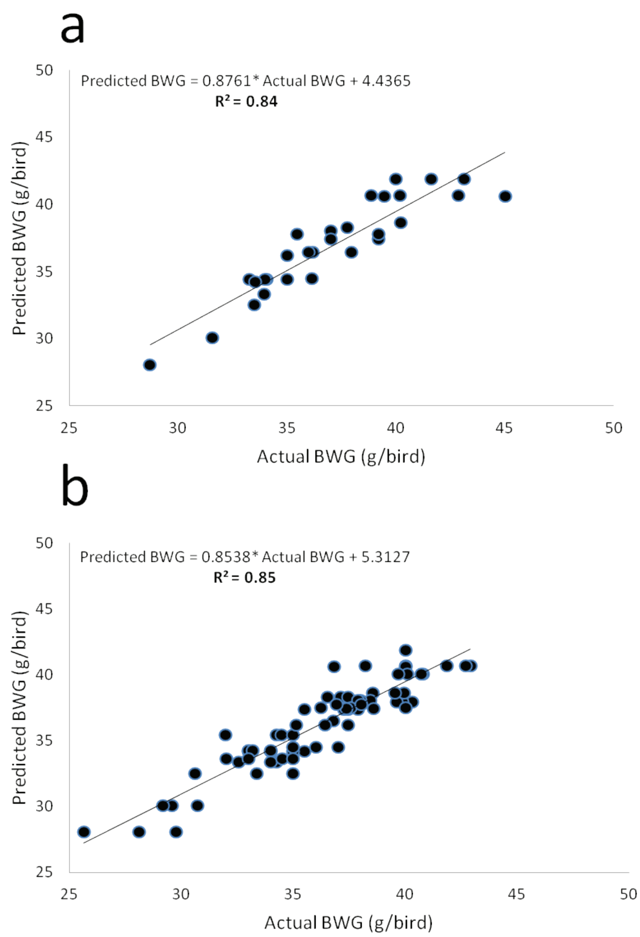

Figure 1. Scatter plot of actual vs. predicted values for BWG (g/bird) of Japanese quails (block dots) and regression line on scatter points (solid line). a) Testing set (n=30); b) training set (n=70).

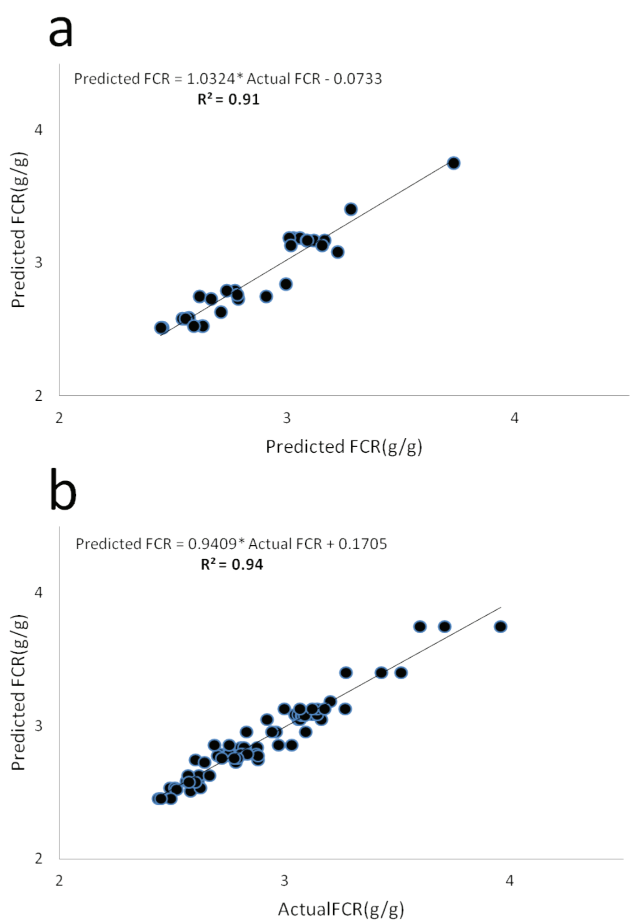

Figure 2. Scatter plot of actual vs. predicted values for FCR (g/g) of Japanese quails (block dots) and regression line on scatter points (solid line). a) Testing set (n=30); b) training set (n=70).

R^2 (84%) is an indicator of the accuracy of the ANN models. A good agreement between actual and ANN model-predicted values of BWG and FCR are shown in 2-dimensional graphs and fitted simple regression lines for both subset data lines (i.e., training and testing). The goodness-of-fit was evaluated using statistics values such as R^2, MAD, MSE, MAPE, and bias (Table 2). The relatively high R^2 values obtained when testing the BWG ($R^2 > 0.80$) and FCR ($R^2 > 0.90$) models showed that the ANN models were capable of describing the growth response of Japanese quails to dietary inputs based on UD. The balanced statistical values for the training and testing models indicated that overlearning had not occurred during the training process and the developed models had good generalizability (StatSoft, 2008). The statistical values showed that the ANN models based on UD efficiently fit the growth response of Japanese quail to dietary inputs (Table 2).

Table 2 – Statistics and information on artificial neural network models for body weight gain (BWG) and feed conversion ratio (FCR) of Japanese quails from 7 to 14 d of age.

	Model			
	BWG		FCR	
Item	Training	Testing	Training	Testing
Statistic				
R^2	0.85	0.84	0.94	0.91
MAD	1.08	1.19	0.056	0.081
MSE	1.87	2.11	0.005	0.009
MAPE	3.02	3.14	1.92	2.83
Bias	-0.02	0.16	0.00	-0.01
Information				
Type of neural network	Three-layer perceptron			
Training algorithm	Quasi-Newtonian			
No. of hidden neuron	8			
Type of activation function in hidden neurons	Hyperbolic tangent			

MAD: mean absolute deviation; MSE: mean square error; MAPE: mean absolute percentage error

The growth response of poultry species to dietary nutrients is not linear (MacLeod, 2000). It is argued that some experimental designs such as UD provide a good experimental framework for nonlinear models (Liang *et al.*, 2001). It has been shown that data obtained from UD presented better performance than Box-Behnken Design (BBD) and CCD to build ANN models in terms of lower prediction error and consequently higher confidence of the estimates (Lin *et al.*, 2009).

Sensitivity Analysis of the ANN Models

The relative importance of input variables was determined using all 100 lines of data (training and testing). The VSR of each input variable for the BWG and FCR models is shown in Table 3. Sensitivity analysis of the BWG model indicated that the growth rate of quail chicks was more sensitive to dietary ME (VSR = 14.53) than to dMet (VSR = 8.77) or dLys (VSR = 7.62). In terms of FCR, the model was more sensitive to dietary ME (VSR = 21.66), followed by dLys (VSR= 19.55) and dMet (VSR = 16.00). It was shown that dietary ME was the most important variable in the performance models of stressed quail chicks.

Table 3 – Sensitivity analysis of input variables in the artificial neural network models for body weight gain (BWG) and feed conversion ratio (FCR) of Japanese quails from 7 to 14 d of age.

	Input variable		
Model	ME (kcal/kg)	dLys (%)	dMet (%)
BWG			
VSR	14.53	7.62	8.77
Rank	1	3	2
FCR			
VSR	21.66	19.55	16.00
Rank	1	2	3

VSR: variable sensitivity ratio

In this study, quail chicks suffered from the heat stress, which may have affected their feed consumption and energy intake (Ferket & Gernat, 2006; Quinteiro-Filho et *al.*, 2010). The integration between feed intake and dietary energy is possibly coordinated by the brain. Heat stress may increase corticosterone serum levels, consequently decreasing food intake (Quinteiro-Filho e*t al.*, 2010). On the other hand, feed intake may be suppressed under high environmental temperatures to balance body energy expenditure (Richards and Proszkowiec-Weglarz, 2007), resulting in higher ME requirements.

Model Optimization

Research has shown the suitability of the random search algorithm for nutrient optimization in poultry (Ahmadi & Golian, 2010b; Mehri, 2012). Random search algorithm was used in the present study to optimize the dietary inputs that maximize BWG and minimize FCR of quail chicks from 7 to 14 d of age (Table 4). The optimization results revealed that BWG model was optimized at 39.9 (g/bird) when the concentrations of dietary ME, dLys, and dMet were 2995 kcal/kg, 1.18%, and 0.45% of diet, respectively. The optimal value obtained with the FCR model was 2.74 (g/g) with 3000 kcal/kg ME, 1.17% dLys, and 0.45% dMet. These estimated values to maximize BWG and minimize FCR may be considered as dietary requirements under tropical conditions. However, from economic point of view, the values estimated as "requirements" may be different from those to obtain profit maximization (Pesti e*t al.*, 2009). The estimated values in this study may not be economical in practice as the most economical feeding level may replace the concept of "requirement" in the poultry industry.

Table 4 – Optimal dietary metabolizable energy (ME), digestible lysine (dLys), and digestible methionine (dMet) levels obtained by the developed artificial neural network models to reach maximal body weight gain (BWG) and minimal feed conversion ratio (FCR) in Japanese quails from 7 to 14 d of age.

	Optimal value of input variable			
Model	ME (kcal/kg)	dLys (%)	dMet (%)	Predicted output factor at optimal point
BWG	2995	1.18	0.45	39.9
FCR	3000	1.17	0.45	2.74

In conclusion, an integration of ANN with UD platform may be a useful and accurate procedure to study several essential nutrients. The average estimated requirement for dietary ME was 2997 kcal/kg and dietary requirements of dLys (1.17% of diet) and dMet (0.45% of diet) were similar for both BWG and FCR in Japanese quails from 7 to 14 d of age. Further studies are needed to explore the ability of the ANN-UD procedure to determine the requirements of essential amino acids in poultry species.

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