Growth analysis of chickens fed diets varying in the percentage of metabolizable energy provided by protein, fat, and carbohydrate through artificial neural network

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ABSTRACT A radial basis function neural network (RBFN) approach was used to develop a multi-input, multi-output model for the effect of diets varying in the percentage of ME provided by protein (% ME_P), fat (% ME_F), and carbohydrate (% ME_C) on live weight gain, protein gain, and fat gain in growing chickens. Thirty-three data lines representing response of the White Leghorn male chickens during 23 to 33 d of age to the diets varying in the % ME_P, % ME_F, and % ME_C were obtained from literature and used to train the RBFN model. The prediction values of the RBFN model were compared with those obtained by multiple regression models to assess the fitness of these 2 methods. The fitness of the models was tested using R^2, MS error, mean absolute deviation, residual SD, and bias. The developed RBFN model was used to evaluate the relative importance of each input parameter on chicken growth using a sensitivity analysis method. The calculated statistical values corresponding to the RBFN model showed a higher accuracy of prediction than multiple regression models. The sensitivity analysis on the model indicated that dietary % ME_P is the most important variable in the growth of chickens, followed by dietary % ME_F and % ME_C. It was found that the RBFN model is an appropriate tool to recognize the patterns of input-output data or to predict chicken growth in terms of live weight gain, protein gain, and fat gain given the proportion of dietary percentage of ME intake supplied through protein, fat, or carbohydrates.

Key words: dietary composition, chicken growth, neural network model

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INTRODUCTION

Dietary protein, fat, and carbohydrate content of isoenergetic diets influences all aspects of growth in chickens (Swennen et al., 2007). Several methods have been used to describe the relationship between these dietary factors and response of chickens (Yoshida et al., 1962; Toyomizu et al., 1982, 1985, 1986). In these works, nonlinear responses of chickens were analyzed by classical methods of multiple regression and response surface analyses. Alternatively, a soft-computing method of artificial neural network (**ANN**) has shown a great ability for solving complex nonlinear system identification and control problems. The ANN is a mathematical model based on biological neural networks. The model is an interconnected group of artificial neurons that process information in a parallel form. Indeed, the ANN is a nonlinear data-mining tool used for modeling complex relationships between inputs and outputs in a database (Dayhoff and DeLeo, 2001). Recently, the ANN has been applied in many fields to model and predict the behaviors of systems, based on given input-output data. Successful applications of ANN have been reported in various poultry subjects (Roush et al., 1996, 2006; Roush and Wideman, 2000; Salle et al., 2003; Ahmadi et al., 2007, 2008). One submodel of ANN is radial basis function network (**RBFN**), which is a 3-layer feed-forward network that uses a nonlinear transfer function of Gaussian form for the hidden layer neurons and a linear transfer function for the output layer. The RBFN may require more neurons than standard feed-forward backpropagation networks, but often they can be designed with lesser time. Most of the inspiration for RBFN came from traditional mathematical and statistical modeling techniques (Haykin, 1999; Bishop, 2006). This method has gained much attention over recent years because of its rapid training and its desirable properties in classification and functional approximation applications. However, the use of such method is not common in poultry science.

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Table 1. The 33 data lines representing the observed and predicted response of chickens fed diets varying in the percentage of ME provided through protein (% ME$_P$), fat (% ME$_F$), and carbohydrate (% ME$_C$)[1]

				Gain (g)								
	Diet composition			Observed			Multiple regression predicted values[2]			RBFN model predicted values[3]		
Diet no.	% ME$_P$	% ME$_C$	% ME$_F$	Live weight	Protein	Fat	Live weight	Protein	Fat	Live weight	Protein	Fat
1	5	89	6	59	1	40	53	0	42	58	0	40
2	5	73	22	64	2	55	56	1	46	66	3	54
3[4]	5[4]	57[4]	38[4]	52[4]	−1	47	55	1	48	60[4]	2[4]	53[4]
4	5	41	54	44	−1	43	50	0	49	48	0	46
5[5]	5[5]	25[5]	70[5]	35[5]	−1[5]	44[5]	40	−1	48	36[5]	0[5]	42[5]
6	5	9	86	29	−1	42	26	−2	45	25	−1	41
7	12	82	6	82	8	35	86	10	36	83	9	36
8[4]	12[4]	66[4]	22[4]	90[4]	11[4]	40[4]	89	10	41	90[4]	10[4]	47[4]
9	12	50	38	100	12	50	89	10	43	88	9	46
10	12	34	54	80	9	39	84	9	44	82	8	43
11	12	18	70	73	8	49	74	8	43	76	8	44
12	12	2	86	63	7	43	60	6	40	66	7	46
13	19	75	6	105	17	28	112	17	31	107	16	30
14	19	59	22	105	16	35	117	17	36	114	17	38
15	19	43	38	120	15	42	116	17	39	115	15	39
16[5]	19[5]	27[5]	54[5]	109[5]	17[5]	41[5]	111	16	40	113[5]	15[5]	40[5]
17	19	11	70	110	14	44	102	15	39	107	15	43
18	26	68	6	136	23	29	133	23	28	128	23	25
19[4]	26[4]	52[4]	22[4]	141[4]	24[4]	29[4]	137	23	32	137[4]	23[4]	32[4]
20	26	36	38	130	20	34	137	23	35	140	22	34
21[5]	26[5]	20[5]	54[5]	133[5]	21[5]	37[5]	133	22	36	136[5]	22[5]	36[5]
22	26	4	70	125	20	38	124	20	36	124	20	38
23	33	61	6	141	27	21	147	27	24	145	27	23
24	33	45	22	156	26	30	152	27	29	157	28	31
25[4]	33[4]	29[4]	38[4]	157[4]	28[4]	31[4]	152	26	33	158[4]	27[4]	33[4]
26	33	13	54	153	27	29	148	25	34	149	25	32
27	40	54	6	156	29	24	156	30	22	156	29	23
28	40	38	22	179	34	31	161	29	27	168	31	31
29	40	22	38	163	30	32	161	29	31	166	30	32
30	40	6	54	143	25	28	157	27	32	147	26	27
31[5]	47[5]	47[5]	6[5]	154[5]	30[5]	21[5]	158	30	21	156[5]	28[5]	23[5]
32	47	31	22	161	29	29	163	30	26	167	30	30
33	47	15	38	163	28	29	164	29	30	159	28	28

[1] All chickens were force-fed 971 to 981 kcal of diet for 10 d on the basis of calculated ME.

[2] Results of multiple regression analysis obtained from Toyomizu et al. (1982).

[3] RBFN = radial basis function neural network.

[4] Data lines used for verification of neural network model (n = 4).

[5] Data lines used for testing neural network model (n = 4).

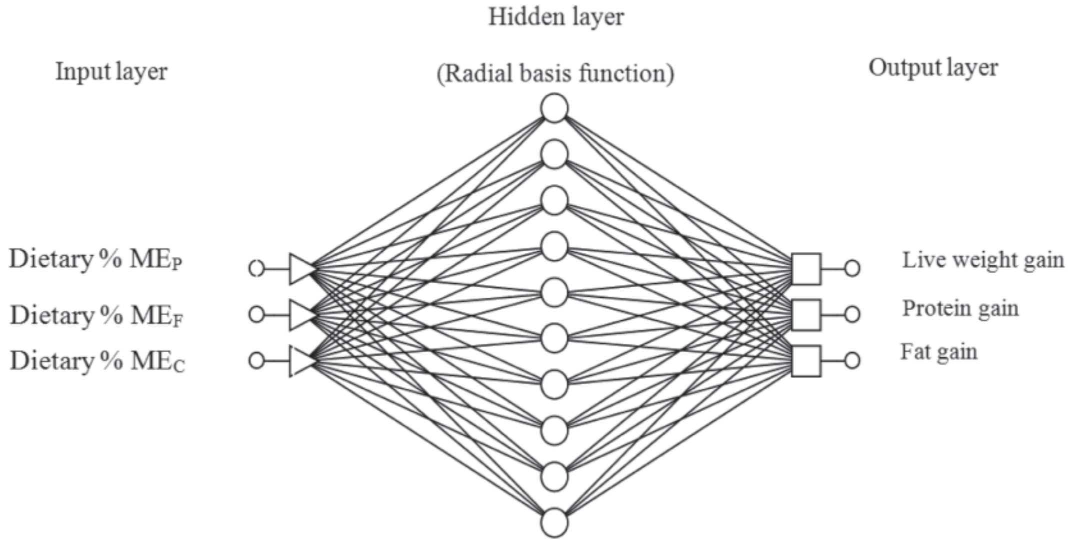

Figure 1. The general scheme of the radial basis function neural network structure used for modeling chicken growth with 3 inputs of dietary ME provided through protein (% ME$_P$), fat (% ME$_F$), and carbohydrate (% ME$_C$) and 3 outputs of live weight gain, protein gain, and fat gain, with 10 hidden neurons.

The objectives of this study were 1) to develop a RBFN-based model to investigate the effects of diets varying in the percentage of ME provided by protein (**% ME$_P$**), fat (**% ME$_F$**), and carbohydrate (**% ME$_C$**) on live weight gain (**LWG**), protein gain, and fat gain in growing chickens; 2) to compare the prediction values of the RBFN model as a new method and multiple regression models as a classical method to assess the capability of these 2 methods; and 3) to apply the developed RBFN model to evaluate the relative importance of % ME$_P$, % ME$_F$, and % ME$_C$ on chicken growth.

MATERIALS AND METHODS

Data Source

The data used in this study were extracted from the study reported by Toyomizu et al. (1982). They investigated the effects of diets varying in % ME$_P$, % ME$_F$, and % ME$_C$ on LWG, protein gain, and fat gain of White Leghorn male chickens during 23 to 33 d of age. Thirty-three groups of 4 chickens were housed individually and force-fed the isocalorically purified diets consisting of 5 to 47% protein, 6 to 86% fat, and 2 to 89% carbohydrate on a ME basis for 10 d. Thus, the produced 33 data lines represented the response of chickens force-fed diets with constant ME content provided through different levels of protein, fat, and carbohydrate (Table 1). More details of diets and chicken growth study experiment are described in the paper reported by Toyomizu et al. (1982).

Model Development

The RBFN is a type of ANN employing a hidden layer of radial units and an output layer of linear units, characterized by fast training and a compact network. This method was introduced by Powell (1987), Broomhead and Lowe (1988), and Moody and Darkin (1989). A detailed description of RBFN model terminology, development, application, and examples of using this approach is reported by several researchers (Haykin, 1999; Bishop, 2006).

The variables of interest in this multi-input, multi-output model were dietary % ME$_P$, % ME$_F$, and % ME$_C$ (as inputs) and chicken LWG, protein gain, and fat gain (as outputs). The 33 data lines were randomly divided into 3 sets of learning, verification, and testing with 25, 4, and 4 data lines, respectively. The data set was imported into the Statistica Neural Networks software version 7.1 (StatSoft, 2005). The architecture of the RBFN (i.e., the number of hidden neurons in the network) was determined using the selection algorithms integrated in the "intelligent problem solver" module of Statistica software. The optimization of the architecture by the intelligent problem solver was performed on the basis of the "balance error against diversity" option.

Table 2. The statistics and information on radial basis function network (RBFN) and multiple regression models for predicting the live weight gain, protein gain, and fat gain of chickens[1]

	RBFN model									Multiple regression model		
	Live weight gain (g)			Protein gain (g)			Fat gain (g)					
Statistics[2]	Training	Verification	Testing	Training	Verification	Testing	Training	Verification	Testing	Live weight gain (g)	Protein gain (g)	Fat gain (g)
R^2	0.9830	0.9946	0.9997	0.9847	0.9908	0.9926	0.9196	0.9846	0.9999	0.977	0.9795	0.8190
MSE	29.32	20.82	7.90	1.69	2.95	1.79	5.67	24.06	2.71	40.67	2.36	12.58
MAD	4.31	3.31	2.61	0.97	1.48	1.20	1.91	4.50	1.57	4.97	1.15	2.88
Bias	0.00	−1.46	−2.61	0.00	−0.02	0.58	0.00	−4.50	0.61	0.24	0.00	0.09
RSD	5.53	4.99	1.20	1.33	1.98	1.39	2.43	2.24	1.76	6.47	1.56	3.60

[1] The statistics on multiple regression models calculated based on results obtained from Toyomizu et al. (1982).

[2] MSE = mean square error; MAD = mean absolute deviation; RSD = residual SD.

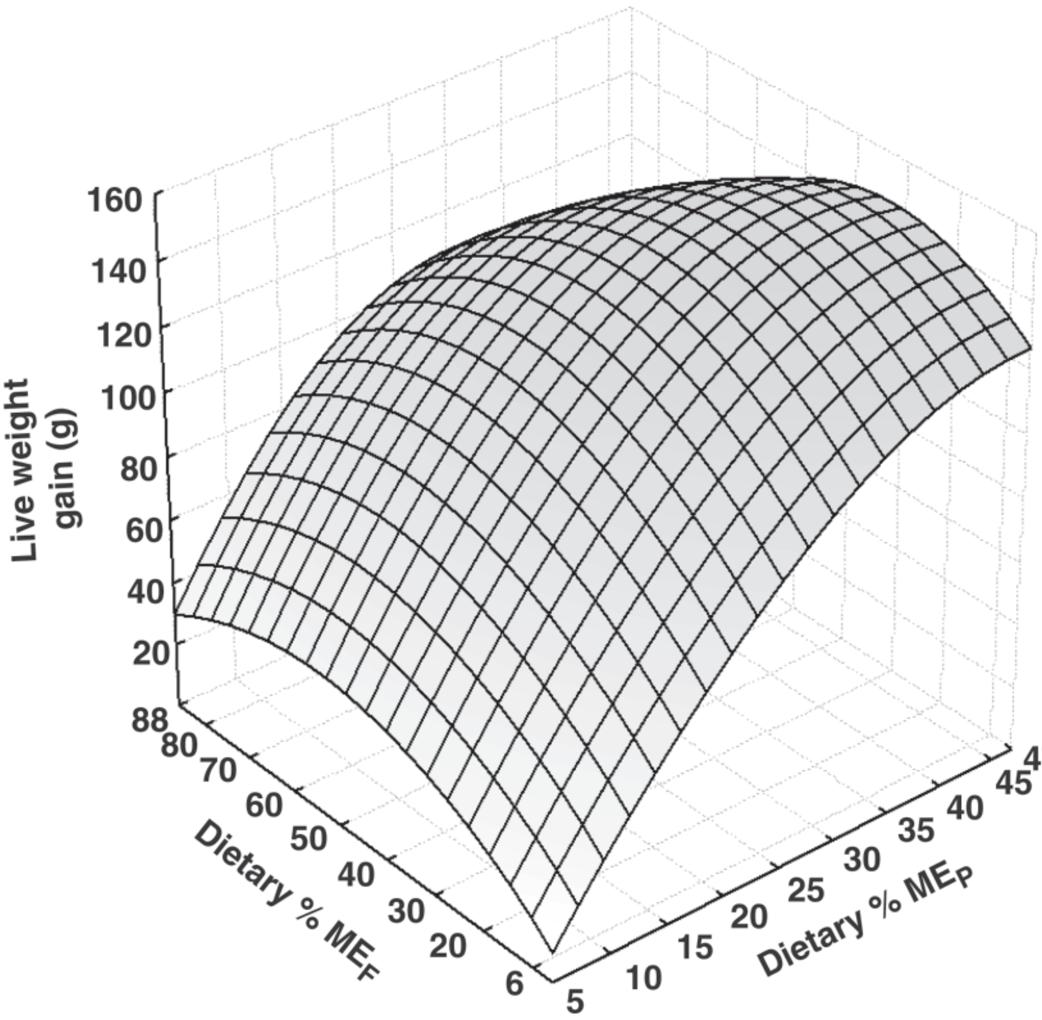

Figure 2. The variation of model predicted values of live weight gain with dietary percentage of ME provided through protein (% ME_P) and fat (% ME_F) at 2% constant dietary percentage of ME provided through carbohydrate.

Sensitivity Analysis

The sensitivity analysis indicates which input variable is considered most important by the RBFN model. The sensitivity is defined as the ratio between the error with omission and the baseline error and ranks the variables in the order of importance (Hunter et al., 2000). The sensitivity of an input variable against the output variable(s) may be determined using following criteria (Lou and Nakai, 2001; StatSoft, 2005):

- The variable sensitivity error (**VSE**) value indicates the performance of the developed RBFN model if that variable is unavailable.
- The variable sensitivity ratio (**VSR**) value is a relative indication of the ratio between the VSE and the error of the RBFN model when all variables are available.
- A more important variable has a higher VSR value. Thus, according to the obtained VSR value, the input variables could be ranked in order of importance.

Model Evaluation

The predicted values obtained with the RBFN model and those obtained with multiple regression models (Toyomizu et al., 1982) were compared using criteria, which are commonly used to evaluate forecasting models. The accuracy of the models was determined using R^2, MS error, mean absolute deviation, residual SD (**RSD**), and bias (Oberstone, 1990).

RESULTS AND DISCUSSION

The optimal structure of the RBFN model that was suggested by intelligent problem solver was found with 3 inputs, 3 outputs, and 10 hidden neurons. The general scheme of such RBFN structure is outlined in Figure 1. The predicted values of LWG, protein gain, and fat gain by the RBFN and multiple regression models are shown in Table 1. The results of multiple regression were adapted from Toyomizu et al. (1982). The evaluation statistic values derived from the RBFN and the

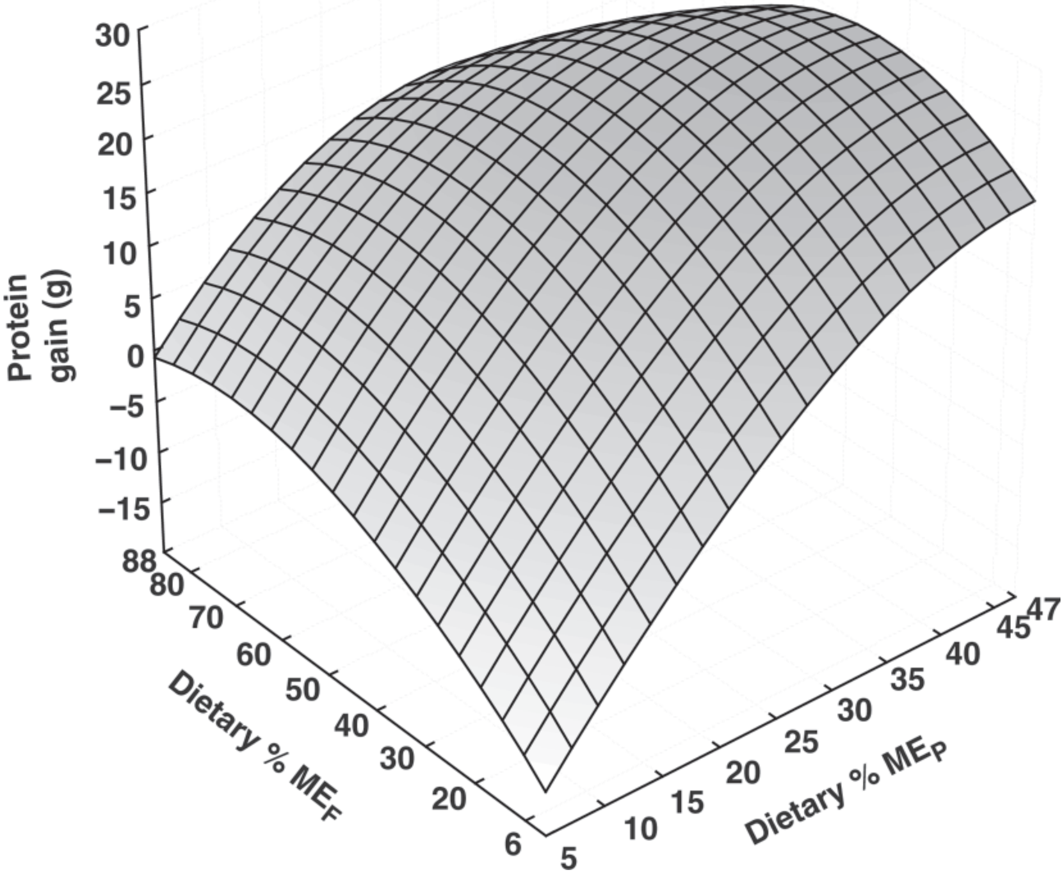

Figure 3. The variation of model predicted values of protein gain with dietary percentage of ME provided through protein (% ME_P) and fat (% ME_F) at 2% constant dietary percentage of ME provided through carbohydrate.

multiple regression models for predicting the chicken growth are given in Table 2. The comparison of observed and predicted outputs describes the behavior of the RBFN model from investigating inputs. The results revealed a good agreement between the observed and the predicted values of chicken growth for training, verification, and testing sets (Table 1). As described earlier, 33 data lines were randomly divided into 3 subsets of learning (n = 25), verification (n = 4), and testing (n = 4). It was found that the calculated statistics on the RBFN model are in close agreement for the 3 subsets in prediction of each output (Table 2). A well-trained ANN model should have close statistical values (the calculated goodness-of-fit criteria) for the 3 subsets. This suggests that overlearning has not occurred during the training process (Lou and Nakai, 2001; StatSoft, 2005).

The RBFN model could accurately predict the chicken growth in the testing data set that was not used during the training processes ($R^2 > 0.99$). The overall statistical tests (in terms of R^2, MS error, mean absolute deviation, RSD, and bias) indicated that there was a slightly better prediction of LWG, protein gain, and fat gain for the network testing as compared with the trained and verification values (Table 2).

Toyomizu et al. (1982) used the 3 polynomial models using the multiple regression method to investigate the biological response of growing chickens based on 3 variables of % ME_P, % ME_F, and % ME_C. They developed 3 polynomial equations with 2 variables of dietary % ME_P and % ME_F (as inputs) for fitting the growth data. The results and statistics of their study are presented in Tables 1 and 2, respectively. We proposed the RBFN model with 3 variables and the same data lines to compare the results of this study with those of Toyomizu et al. (1982). The goodness of fit in terms of R^2 corresponding to training of the RBFN model showed a higher accuracy of prediction than equations reported by Toyomizu et al. (1982) for either LWG (0.983 vs. 0.977), protein gain (0.985 vs. 0.980), and fat gain (0.920 vs. 0.819). In terms of RSD, the RBFN model showed lower residuals distribution than that of multiple regression models (5.5 vs. 6.5 for LWG, 1.3 vs. 1.6 for protein gain, and 2.4 vs. 3.6 for fat gain models).

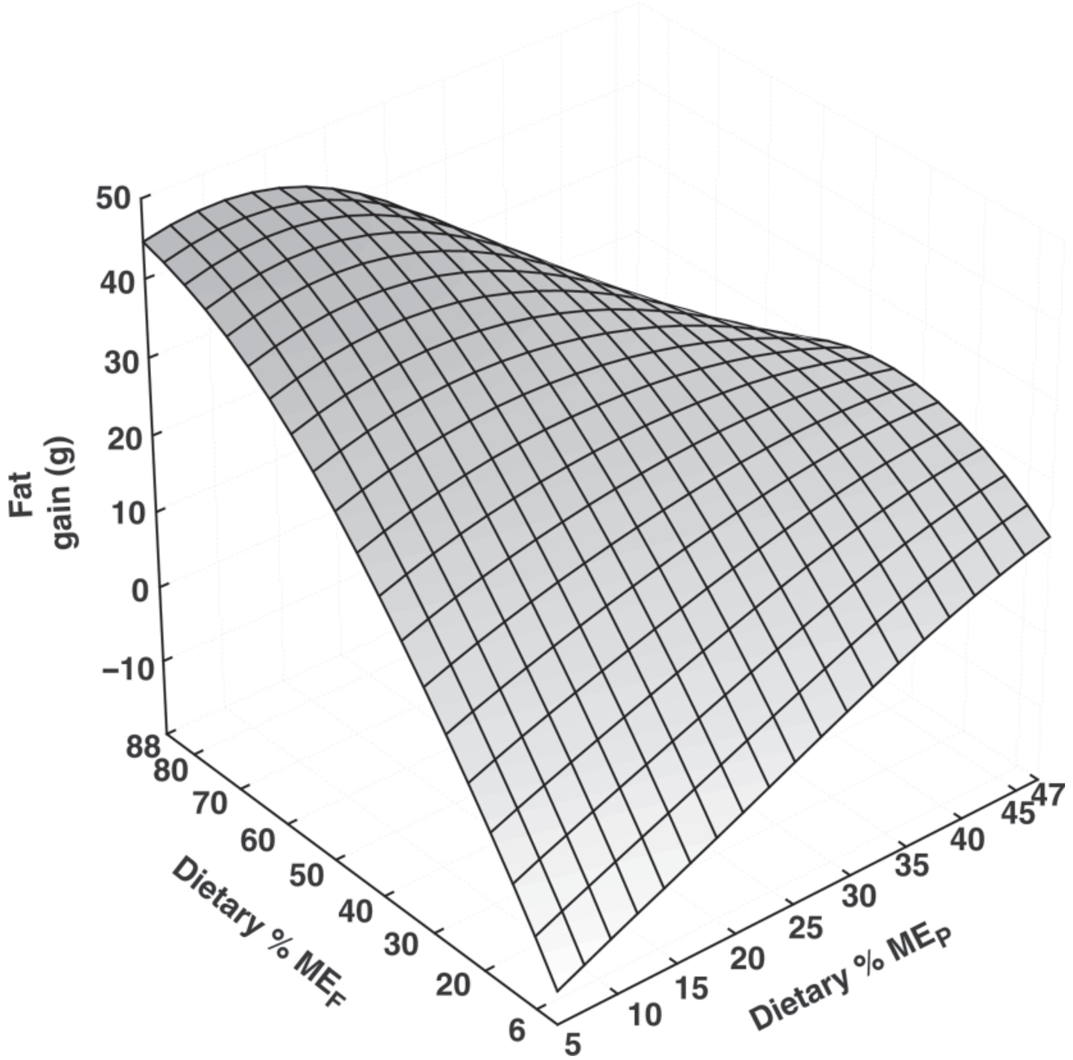

Figure 4. The variation of model predicted values of fat gain with dietary percentage of ME provided by protein (% ME_P) and fat (% ME_F) at 2% constant dietary percentage of ME provided through carbohydrate.

Based on the obtained RBFN model, 3 response surface graphs were generated to represent the variation of LWG, protein gain, and fat gain at various percentages of ME provided by protein and fat (Figures 2, 3, and 4). In each graph, the variation % ME_P and % ME_F is considered as their range in the experimental data set, whereas the % ME_C is chosen as an arbitrary constant at its minimum value. For example, as shown in Figure 2, the variation ranges of dietary % ME_P and % ME_F are 5 to 47 and 6 to 86 on the ME basis, respectively, whereas the dietary % ME_C is constant at 2% on the ME basis. The well-designed 3-dimensional response surface graphs obtained by an accurate model may be useful for understanding the complete nutrient-response relationship and for the evaluation of combined effects of the nutrients (Mercer, 1992). The purpose of this study was not to optimize growth based on dietary nutrients; however, in a nutrition optimization plan, it appeared that the 3-dimensional graphs obtained by the RBFN model may be used to optimize growth based on dietary nutrients.

To determine the relative importance of input variables, the training and verification sets of the entire 29 data sets (another 4 data sets are used for testing) were used to calculate the VSE and VSR. The obtained VSR for the model output variables with respect to dietary % ME_P, % ME_F, and % ME_C are shown in Table 3. Based on VSR values, the percentages of ME provided by nutrients were ranked according to their importance of effect on chicken growth. Among the input variables, dietary % ME_P has the highest values of VSR in training (4.21) and verification sets (2.13). It is followed by the dietary % ME_F (3.45 and 1.10 for training and verification sets, respectively) and % ME_C (2.98 and 0.52 for training and verification sets, respectively). This indicates that the dietary % ME_P is the most important variable in the RBFN model, followed by dietary % ME_F and % ME_C (Table 3).

In this case, it is not surprising that the dietary % ME_P was the most important factor influencing the model outputs. It should be noted that, in the experiment of Toyomizu et al. (1982), the chickens were fed

Table 3. The sensitivity analysis of input variables in the neural network model (training and verification sets) for chicken growth

	Input variables[1]		
Item	% ME_P	% ME_F	% ME_C
Training			
VSR[2]	4.21	3.45	2.98
Rank	1	2	3
Verification			
VSR	2.13	1.10	0.52
Rank	1	2	3

[1] The dietary proportion of ME provided through protein (% ME_P), fat (% ME_F), and carbohydrate (% ME_C).

[2] VSR = variable sensitivity ratio.

the same amount of ME per day, and it can be calculated that the levels of protein in the diets varied between 50 to 550 g/kg and the protein intake between 1.3 to 13.3 g/d. Thus, the experiment is mainly a protein response study. To separate the effects of ME and protein on growth, it is necessary to have diets with different levels of ME and different levels of protein.

In conclusion, the description of the relationship between dietary macronutrients and the response of chickens may help to establish a specific feeding program for an optimal performance. In this way, the use of new methods such as an ANN-based model may help to define a nutrition system. In the present study, we developed the multi-input, multi-output RBFN model to investigate the effects of diets varying in the % ME_P, % ME_F, and % ME_C on LWG, protein gain, and fat gain in growing chickens. The results revealed that the RBFN model may efficiently be used to describe the chicken growth based on investigating inputs. The sensitivity analysis on the model indicated that dietary % ME_P is the most important variable influencing the growth of chicken, followed by dietary % ME_F and % ME_C.

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