Estimation and modeling true metabolizable energy of sorghum grain for poultry

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ABSTRACT Sorghum grain is an important ingredient in poultry diets. The TMEn content of sorghum grain is a measure of its quality. As for the other feed ingredients, the biological procedure used to determine the TMEn value of sorghum grain is costly and time consuming. Therefore, it is necessary to find an alternative method to accurately estimate the TMEn content. In this study, 2 methods of regression and artificial neural network (ANN) were developed to describe the TMEn value of sorghum grain based on chemical composition of ash, crude fiber, CP, ether extract, and total phenols. A total of 144 sorghum samples were used to determine chemical composition and TMEn content using chemical analyses and bioassay technique, respectively. The values were consequently subjected to regression and ANN analysis. The fitness of the models was tested using R^2 values, MS error, and bias. The developed regression and ANN models could accurately predict the TMEn of sorghum samples from their chemical composition. The goodness of fit in terms of R^2 values corresponding to testing and training of the ANN model showed a higher accuracy of prediction than the equation established by regression method. In terms of MS error, the ANN model showed lower residuals distribution than the regression model. The results suggest that the ANN model may be used to accurately estimate the TMEn value of sorghum grain from its corresponding chemical composition.

Key words: metabolizable energy, neural network model, sorghum

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INTRODUCTION

Sorghum (*Sorghum bicolor*) is an important feed ingredient in many parts of the world. Certain agronomic characteristics, such as drought tolerance, allow sorghum to be grown in diverse geographical regions. The feeding value of sorghum is essentially 95% that of corn, although it is priced less than corn in many markets (Dowling et al., 2002). Different cultivars of sorghum have been shown to have different physical and chemical characteristics with large differences in digestibility (Neucere and Sumrell, 1980). Some sorghum varieties contain tannins and polyphenols that adversely affect the utilization of its protein and ME for poultry (Boren and Waniska, 1992). Some studies suggested that sorghum tannins may not always reduce performance (Nyachoti et al., 1997). Therefore, it appears that other factors may be responsible for the poor feeding value of some sorghum cultivars. Understanding what these factors are may help more effectively screen sorghum on the basis of its nutritional value for poultry (Nyachoti et al., 1997). An important measure of the relative usefulness of a feed ingredient is its TMEn value. The biological procedure required to determine the TMEn value of sorghum grain is costly and time consuming. An accurate method of estimating TMEn value from chemical composition would be useful; hence, nutritionists are interested in using a model that can accurately predict the TMEn value of feedstuffs. Predictive models are accepted as mathematical tools that assist in rapid and accurate assessment of animal feed quality based on chemical compositions. Traditionally, multiple linear regression models were used to predict the ME in feedstuffs (Carpenter and Clegg, 1956). A more useful method is to use the artificial neural network (**ANN**) model to estimate TMEn of sorghum grains based on chemical composition. Ahmadi et al. (2008) introduced an ANN model for predicting TMEn of poultry byproducts based on their chemical composition. Perai et al. (2010) reported an accurate prediction of TMEn using ANN for meat and bone meal. The objective of this study was to compare the accuracy of the regression and ANN models in describing the relationship between

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Table 1. Chemical composition (% of DM) and TMEn (kcal/kg) of 36 sorghum varieties

Variety	No. of replicates[1]	CP	Ether extract	Crude fiber	Ash	Total phenols	TMEn
1	6	13.950	3.015	3.231	1.014	0.443	3,312
2	3	13.947	4.375	2.588	1.974	0.391	3,515
3	6	12.083	4.030	2.944	1.500	0.129	3,737
4	6	12.873	3.986	1.854	1.745	0.063	3,761
5	6	11.295	3.977	5.388	2.498	0.681	3,207
6	3	14.464	3.501	3.129	2.002	0.469	3,523
7	3	14.151	4.484	6.677	3.495	1.040	3,003
8	3	11.813	2.792	1.896	2.000	0.095	3,605
9	3	12.264	1.516	1.956	1.495	0.023	3,611
10	3	11.053	4.123	2.039	1.502	0.047	3,703
11	3	12.697	2.643	2.357	1.996	0.184	3,899
12	3	12.353	3.813	1.786	1.503	0.044	3,621
13	6	13.864	3.423	2.116	1.736	0.046	3,638
14	6	13.227	3.742	2.474	1.753	0.072	3,753
15	3	10.418	2.835	2.220	1.495	0.056	3,815
16	3	13.723	3.996	2.347	1.496	0.080	3,753
17	3	12.451	4.300	2.757	1.751	0.144	3,258
18	3	14.139	3.124	2.020	1.501	0.217	3,675
19	3	14.823	1.858	1.504	0.996	0.198	3,354
20	3	13.714	4.253	3.451	1.000	0.208	3,625
21	3	11.908	3.553	1.941	1.469	0.414	3,290
22	3	12.456	4.148	6.485	3.002	0.079	3,095
23	3	10.481	2.505	3.425	2.495	0.649	3,563
24	6	11.550	3.590	7.801	2.958	0.409	3,058
25	6	14.123	4.020	2.452	1.755	0.379	3,509
26	6	12.584	3.621	3.385	2.039	0.556	3,200
27	6	12.439	3.444	2.378	1.502	0.236	3,747
28	6	12.067	3.957	3.921	2.251	0.525	3,228
29	6	12.164	3.438	2.067	1.480	0.662	3,339
30	3	13.656	2.764	2.544	1.498	0.591	3,358
31	3	13.827	3.904	5.943	2.500	0.382	3,603
32	3	12.516	3.407	2.967	2.495	0.158	3,758
33	3	14.880	3.377	2.157	1.503	0.094	3,588
34	3	13.323	6.280	6.839	3.000	1.073	3,153
35	3	11.965	3.510	1.876	1.744	0.502	3,490
36	3	11.278	4.626	1.949	1.498	0.160	3,798
Average		12.792	3.609	3.135	1.879	0.319	3,504
Maximum		14.88	6.28	7.801	3.495	1.073	3,899
Minimum		10.418	1.516	1.504	0.996	0.023	3,003
SD[2]		1.188	0.835	1.661	0.594	0.274	243

[1]A value of 6 indicates that 12 sorghum varieties were grown and examined for chemical composition and TMEn in 2 consecutive years with 6 replicates (3 replicates/yr). A value of 3 indicates that 24 sorghum varieties were grown and examined for chemical composition and TMEn in 1 yr with 3 replicates.

[2]Standard deviation of 36 sorghum varieties.

sorghum TMEn (as model output) and chemical composition (as model inputs).

MATERIALS AND METHODS

Data Collection

Thirty-six varieties of sorghum grain differing in seed characteristics were grown and harvested under similar conditions in Isfahan, Iran. Twelve varieties that had the highest yield were selected, grown, and harvested in the next consecutive year. Three samples from each variety grown in each year were collected and analyzed for ash (method 942.05; AOAC, 2000), crude fiber (**CF**; method 978.10; AOAC, 2000), CP (method 990.03; AOAC, 2000), ether extract (**EE**; method 920.39; AOAC, 2000), and total phenol contents. The total phenols of sorghum samples were assayed by the Folin-Denis method (method 952.03; AOAC, 2000). The 144 sample TMEn values [(36 varieties × 3 samples) + (12 regrown selected varieties × 3 samples); 3 replicates/sample] were obtained by using precision-fed rooster assay (Sirbald, 1976).

Model Development

The obtained experimental values related to total phenols, CP, ash, CF, and EE (inputs) and TMEn (output) were normalized into the range of −1 to +1. A total of 144 data lines were randomly divided into 2 sets, training and testing, with 100 and 44 data lines, respectively. The training set was fitted into a linear regression model using total phenols, CP, ash, CF, and EE as independent variables and TMEn as the dependent variable. The model was fitted to data using PROC REG of SAS (SAS Institute, 2003).

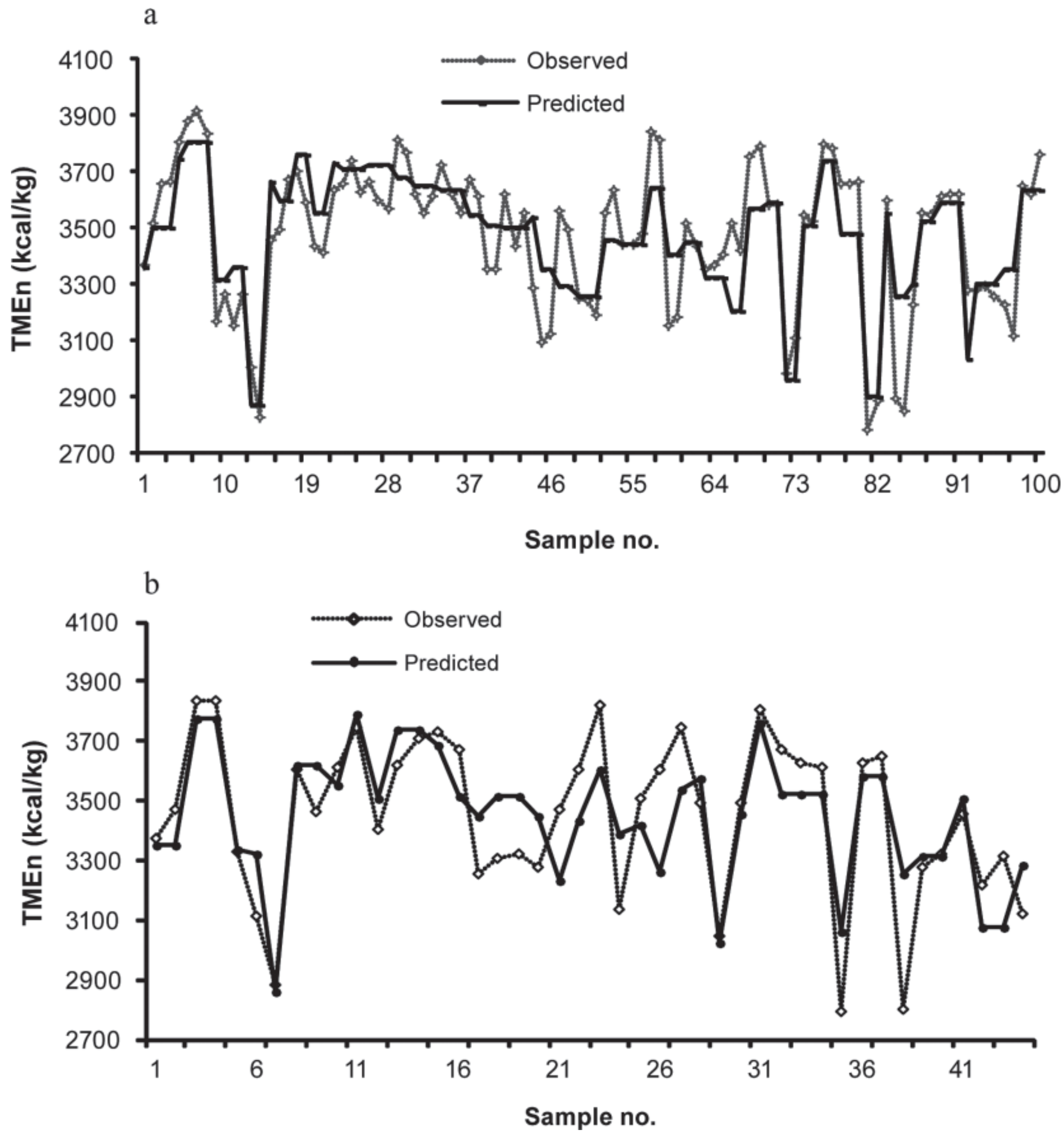

Figure 1. The comparison of observed and model-predicted TME_n values obtained by linear regression model from training (a) and testing (b) data sets that use artificial neural network.

An algorithm of feed-forward multilayer perceptron with 5 inputs, 1 output (with linear activation function), and 4 hidden neurons (with hyperbolic tangent activation function) was considered to construct the ANN model. A training algorithm of quasi-Newton was used to train the network. The ANN processing was conducted using Statistica Neural Networks software (version 8.0; StatSoft, 2009). Evaluation of the models' performance was based on the accuracy of their predictions in the test set. The goodness of fit for regression and ANN models was determined using R^2 values, MS error, and bias (Roush et al., 2006).

RESULTS AND DISCUSSION

Average values ($n = 3$) of chemical composition and TMEn for sorghum samples obtained from chemical analyses are shown in Table 1. The calculated linear regression model on the training data set was obtained as follows:

$$\mathrm{TME_n} = 3{,}960.8\ (\mathrm{SE} = 173) + 15.15\ (\mathrm{SE} = 40) \times \mathrm{ash} + 57.76\ (\mathrm{SE} = 18) \times \mathrm{EE} - 85.3\ (\mathrm{SE} = 12) \times \mathrm{CF} - 23.9\ (\mathrm{SE} = 11) \times \mathrm{CP} - 469\ (\mathrm{SE} = 62) \times \mathrm{total\ phenols}\ (\mathrm{R}^2 = 0.71).$$

The plots of regression model-predicted versus observed values of TMEn from the training and testing sets obtained by the linear regression model are shown in Figures 1 a and b, respectively. There seemed to be a relatively good relationship between TMEn and chemical composition (CP, EE, ash, CF, and total phenols) in both training ($R^2 = 0.71$) and testing ($R^2 = 0.63$) data sets used in the linear regression method.

Table 2. The statistic values derived from regression and artificial network models to estimate the TMEn value of sorghum grain based on ash, ether extract, crude fiber, CP, and total phenols

	Artificial network model		Regression model	
Item	Training set	Testing set	Training set	Testing set
Statistic				
R^2	0.97	0.94	0.71	0.63
MS error	2,192	4,374	18,683	26,819
Bias	−0.285	−1.7	0.0	−0.737
Type of network	3 layers perceptron[1]			
Training algorithm	Quasi-Newton[1]			
Number of hidden neurons	4[1]			
Type of activation function in hidden neurons	Hyperbolic tangent[1]			

[1]Applies to training and testing sets in artificial network model and training set in regression model.

The plots of observed versus predicted values of TMEn from the training and testing sets obtained by ANN model are shown in Figures 2 a and b, respectively. It appeared that the percentage of CP, CF, EE, ash, and total phenols had a strong effect on the TMEn prediction. The results of the ANN model revealed very good agreement between the observed and predicted TMEn values for both training and testing sets.

The prediction efficiency and some statistics of the chosen ANN model and regression method are shown in Table 2. The goodness of fit in terms of R^2 values corresponding to the ANN model showed a higher accuracy of prediction than that of the equation obtained by the regression method (0.97 vs. 0.71 for training and 0.94 vs. 0.63 for testing). In terms of MS error, the ANN model showed lower residuals distribution than the regression model for training (2,192 vs. 18,683) and testing (4,374 vs. 26,819) data. Thus, the ANN model may more accurately predict the TMEn of the testing data set that was not used during the training processes than the regression model. However, the statistical tests (Table 2) indicated that a relatively better prediction of TMEn existed for the testing compared with the training values.

The results of the present study are in agreement with the previous work (Douglas et al., 1990; Boren and Waniska, 1992; Selle et al., 2010) that reported that digestible energy is inversely related to the phenolic content of sorghum cultivars. Elkin et al. (1996) reported that the increase in tannin concentration showed a decrease in amino acid digestibility and energy utilization determined in cockerels. The digestibility of sorghum starch is generally lower than that in other cereals, which may be attributed to differences in protein types and matrix (Selle et al., 2010). Kafirin as a portion of sorghum proteins has been shown to depress energy utilization in poultry. The disulfide cross linkages in sorghum kafirin is greater than that in maize protein (Salinas et al., 2006; Selle et al., 2010). Salinas et al. (2006) showed that the kafirin was negatively correlated with both TMEn ($r = -0.63$; $P < 0.01$) and AME ($r = -0.61$; $P < 0.01$) measured in cecectomized roosters. Both soluble polyphenols and condensed tannins have been shown to increase fecal fat excretion (Bravo, 1998). Dietary polyphenols may influence intestinal microflora and consequently their fermentative capacity of feed components (Bravo, 1998). Although the low molecular weight polyphenols may be absorbed (Jimenez-Ramsey et al., 1994; Bravo, 1998), the high molecular weight phenols as condensed tannins cannot be absorbed from the gastrointestinal tract. This finding confirms that other phenolic compounds beside tannins are partially responsible for the toxic effects associated with the feeding value of high tannin sorghum for poultry. In our study the acid detergent fiber and neutral detergent fiber concentrations of sorghum samples were measured (data not shown). The phenolic components are presented in the testa and pericarp of sorghum grain, which increased with enhancement of acid detergent fiber and neutral detergent fiber to reduce the TMEn of sorghum in this study. It may be suggested that some other components besides tannins and polyphenols are responsible for variations in the availability of nutrients in sorghum.

Several studies have been conducted to evaluate the predictive ability of regression and ANN models in poultry. Bolzan et al. (2008) used ANN and multiple linear regression models to predict eggs hatchability of broiler breeders. Their results showed that ANN was a more accurate prediction tool compared with the regression model.

Roush and Cravener (1997) have applied the ANN and linear regression models to predict amino acid levels of some poultry feed ingredients based on CP or proximate analysis. Ahmadi et al. (2008) proposed an ANN model to predict the TMEn of poultry byproducts using 3 variables of CP, EE, and ash. They reported that the ANN model may be used to accurately estimate the nutritive value of feedstuffs from their corresponding chemical composition, and the ANN model may show a higher efficiency of prediction compared with regression models. Similarly, Perai et al. (2010) examined the relationship between chemical composition of meat and bone meal (EE, ash, and CP) and TMEn values by multiple linear regression, partial least squares, and ANN models. The results showed that the

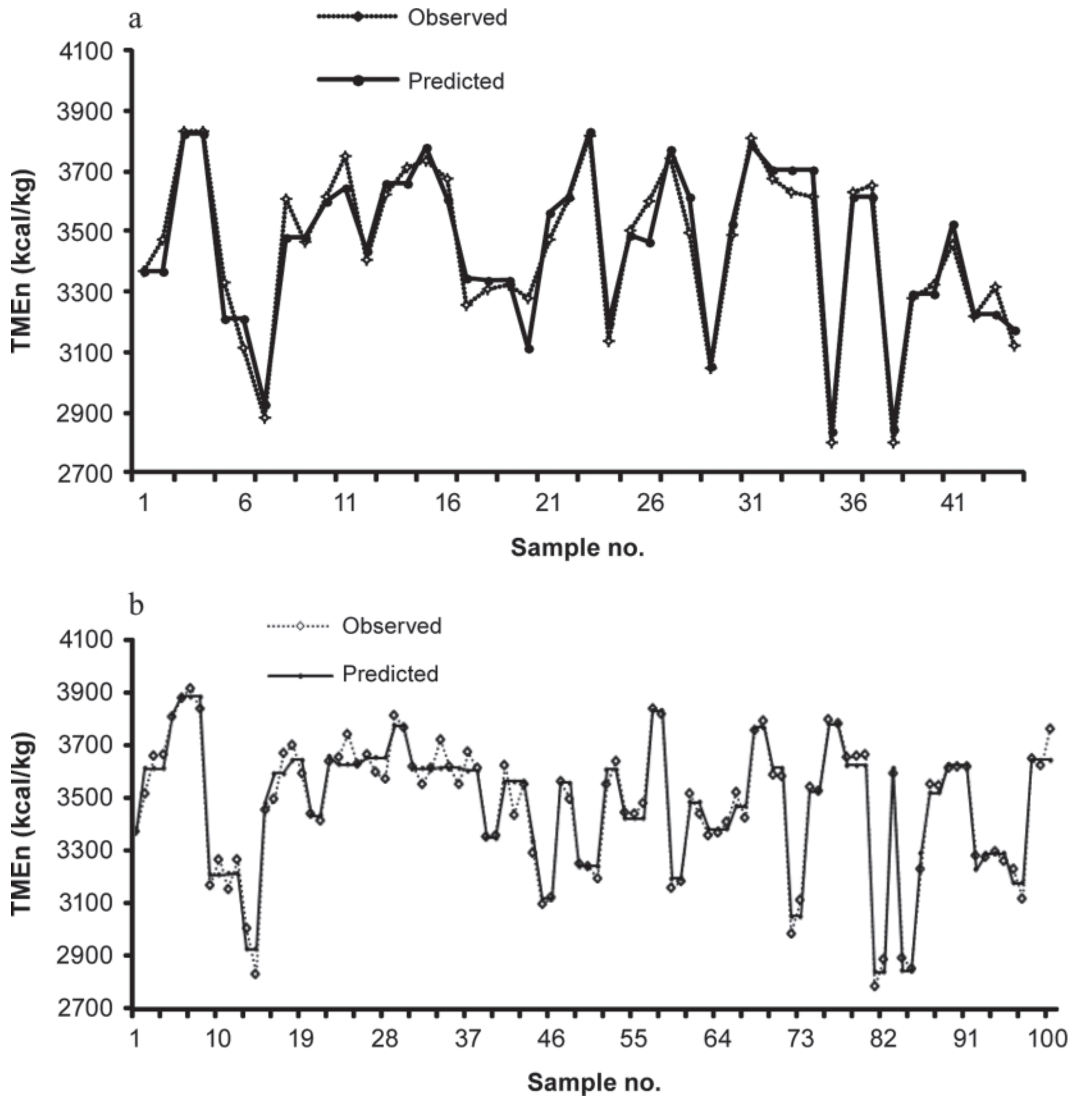

Figure 2. The comparison of observed and model-predicted TME_n values obtained by artificial neural network model from training (a) and testing (b) data sets.

ANN model was a more accurate method for TMEn estimation of meat and bone meal for poultry.

It is concluded that a good relationship exists between TMEn value of sorghum grain and its chemical composition. Statistical evaluation revealed a more accurate prediction of TMEn using the ANN approach compared with the regression model. The ANN model may be efficiently used to predict the TMEn of sorghum grain samples based on CP, EE, CF, ash, and total phenol contents.

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