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Application of Mathematical Models to Estimate Metabolizable Energy Contents of Energetic Concentrate Feedstuffs for Poultry

Research Article

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ABSTRACT

A study using 51 wheat, 56 barley and 34 oat grain samples was conducted to investigate the feasibility of predicting the apparent metabolizable energy (AME) value of these cereals for poultry. Stepwise regression analyses were performed to evaluate the relationship of AME with starch, ether extract (EE), crude fiber (CF), soluble sugar (SS), ash and crude protein (CP) (for wheat and barley grain samples) or dry matter (DM), CF, ash and CP (for oat grain samples) as independent variables. According to the stepwise regression analyses, SS, CF and ash for wheat, CF, EE and starch for barley and CF and CP for oat were found to be useful predictors for AME prediction. Also, multiple linear regression (MLR) and artificial neural network (ANN) methods were developed to find the best models which can estimate the AME content of these cereals. Mean square deviation, Mean square variation and their components were used to evaluate the performance of MLR and ANN models. The results showed that AME of wheat can be predicted by SS, CF and ash. The CF, EE and starch are good independent variables to estimate AME content of barley samples. Also, CF and CP are good predictor parameters for AME prediction in oat samples. In case of model performance, the accuracy of the ANN model was stronger than MLR. Based on these results, it was concluded that the use of chemical composition in combination with the ANN model is a promising method to predict AME of wheat, barley and oat grain samples in poultry nutrition.

KEY WORDS artificial neural network, chemical composition, metabolizable energy, multiple linear regression, stepwise regression.

INTRODUCTION

Cereal grains are important feed ingredients to meet the energy requirement for poultry. Different cultivars of each cereal grains vary widely in metabolizable energy (ME) content as a result of variation in chemical composition according to genotype (Sibbald, 1976; Classen *et al.* 1988), location and environmental conditions under which the grains are grown (Jeroch and Danicke, 1996). In order to enhance energy efficiency and optimize poultry performance it is suggested that the metabolizable energy value of feedstuffs be measured before feed formulation. However AME determination requires elaborate assays, use of test animals, sample collection, and bomb calorimetry which can take several weeks and is costly. Therefore, nutritionists are interested in developing simpler, rapid, inexpensive and accurate methods to estimate the nutritional values of feedstuffs based on chemical composition.

Several chemical factors influence ME of cereals, including starch, crude protein (CP), non-starch polysaccharides (NSP) and ether extract (EE) content (Metayer *et al.* 1993; Zhang *et al.* 1994; Lozano *et al.* 1995; Steenfeldt, 2001; Svihus and Gullord, 2002; Pirgozliev *et al.* 2003; Losada *et al.* 2009). Previous studies demonstrated that there is a negative correlation between protein content and AME of wheat grains (Svihus and Gullord, 2002). Also some studies suggested that the fiber fraction should be considered when the chemical composition is used to establish a regression equation for predicting the ME of feedstuffs (Noblet and Perez, 1993; Fairbairn *et al*. 1999; Nascimento *et al*. 2011). Nascimento *et al.* (2011) predicted AME_n values of energetic feedstuffs using chemical composition by meta-analysis and used the stepwise procedure to study the association among equation variables by their importance. They demonstrated that NDF and ADF variables are influencing the feedstuffs energetic values. Villamide *et al.* (1997) reported that there are significant relations among AME_n values of supplemented barley cultivars and EE, NSP and sugars of them. Metayer *et al.* (1993) found that there is a noticeable correlation between starch, crude fiber (CF) and ME in oat. Losada *et al.* (2009) used regression equations to estimate metabolizable energy of some grains using dry matter (DM), EE, ash, total sugars and CF. Although multiple linear regression (MLR) has been used to predict the ME in several cereals, artificial neural network (ANN) is another candidate that can be successfully used to estimate the AME content of cereals. The ANN is modeling technique that is especially useful to address problems where solutions are not clearly formulated or where the relationships between inputs and outputs are not sufficiently known (Roush *et al.* 1996; Roush and Cravener, 1997). Successful ANN applications have been found in various poultry subjects, such as in the prediction of ME, amino acid and tannin of cereals (Ebadi *et al.* 2011; Sedghi *et al.* 2011; Sedghi *et al.* 2012; Soleimani Roudi *et al.* 2012; Mariano *et al.* 2013).

The primary goal of this study was comparison between ANN and MLR and their performance. Also the performance of the models was compared and the best predictor for AME estimation was selected from their chemical composition of tested cereals.

MATERIALS AND METHODS

Three data groups were collected from Sibbald and Price (1976), Coates *et al.* (1977), and Peltonen Sainio *et al.* (2004) studies to predict the AME value of wheat, barley and oat samples based on their chemical compositions. Sequential multiple linear regression analyses (stepwise procedure) were used to select the effective model's inputs for AME prediction. Starch, EE, CF, soluble sugar (SS), ash and CP were used to select the effective parameters for prediction of AME in wheat and barley grain samples. The DM, CF, ash and CP were the candidates for selection of model's inputs to estimate AME in oat grain samples. Stepwise regression analysis was conducted using SAS (SAS, 2003). Subsequently, independent variables that caused a significant improvement (P<0.05) in stepwise regression, were used for prediction of AME of wheat, barley and oat grain samples by MLR and ANN models (Table 1). The ranges of data patterns (input-output) which selected based on stepwise regression, for wheat, barley and oat grain samples are shown in Tables 2, 3 and 4, respectively.

Table 1 The significant inputs (obtained via stepwise regression) and their contribution for predicting AME of wheat, barley and oat

Samples	Variable entered	R^2	F-value	P > F
Wheat	Soluble sugar	0.261	17.33	< 0.0001
	Soluble sugar + crude fiber	0.482	22.34	< 0.0001
	Soluble sugar + crude fiber + ash	0.594	22.96	< 0.0001
Barley	Crude fiber	0.406	36.98	< 0.0001
	Crude fiber + ether extract	0.486	25.04	< 0.0001
	Crude fiber + ether extract + Starch	0.547	20.90	< 0.0001
Oat	Crude fiber	0.597	47.33	< 0.0001
	Crude fiber + crude protein	0.651	28.94	< 0.0001

The collected data lines (using stepwise regression) were randomly divided into two sets; the 70% of data were selected as training and 30% of the data were used for testing data. In this study a type of ANN as multilayer perceptron (MLP) was employed. Furthermore, feed forward neural network (a special type of artificial neural network) was used to construct the models. We trained neural networks with vary the number of hidden units (4 and 6).

All data processing algorithms were implemented with the STATISTICA networks software (Stat Soft, 2009). Multiple linear regressions were used as a comparison control for the ANN procedures. The MLR model construction obtained using 70% of data which had been used for training in ANN models. The remaining (30%) data were used to test the MLR equations. The PROC REG of the SAS (SAS, 2003) was used for regression analyses. The ANN and MLR models performance tested using mean squared deviation (MSD), squared bias (SB), squared difference between standard deviations (SDSD), lack of correlation weighted by the standard deviations (LCS) and mean squared variation (MSV) as described by Kobayashi and Salam (2000).

RESULTS AND DISCUSSION

By considering result obtained from stepwise regressions, SS, CF and ash are the most important factors that can be used as independent variables to predict AME of wheat samples, while CF, EE and starch are useful inputs for AME estimation in barley. In case of oat, CF and CP have a significant effect on AME value. The MLR equations for

Table 2 The selected parameters obtained via stepwise regression used to predict AME of wheat samples by multiple linear regression and neural networks models

Wheat samples	Inputs (g/kg of DM)			Output (MJ/kg)
	Soluble sugar	Crude fiber	Ash	AME
1	31.40	35.70	14.80	14.92
2	37.00	35.40	17.10	14.46
3	34.40	31.80	16.10	15.13
4	35.30	42.00	19.60	14.30
5	32.00	38.10	15.70	15.13
6	27.20	41.70	15.80	14.71
7	31.70	35.60	16.80	15.34
8	28.00	35.30	15.30	15.22
9	31.20	33.70	18.80	14.71
10	27.10	32.20	17.40	15.47
11	33.60	32.70	17.50	15.17
12	34.30	38.30	13.70	14.96
13	38.40	35.20	21.40	14.13
14	34.60	33.60	20.80	14.67
15	27.90	37.00	16.70	14.63
16	43.10	26.20	30.20	14.76
17	25.60	32.90	18.50	14.84
18	28.80	34.40	19.20	14.09
19	34.50	36.10	19.00	14.17
20	51.50	33.60	26.60	11.70
21	32.70	34.20	15.80	14.55
22	32.70	31.40	20.00	15.22
23	29.40	38.60	18.20	15.22
24	33.40	32.60	24.40	15.05
25	29.90	34.50	13.60	14.84
26	35.20	34.00	21.60	15.55
27	35.10	29.30	22.00	15.42
28	30.40	34.70	18.30	15.05
29	32.80	41.50	20.90	13.84
30	27.10	37.80	20.60	14.34
31	24.10	35.80	21.20	14.13
32	38.00	39.30	19.40	14.04
33	35.70	40.60	20.80	13.59
34	33.90	37.50	22.60	14.13
35	33.50	34.50	22.20	13.84
36	36.30	29.00	15.40	15.93
37	29.10	28.00	16.10	15.34
38	33.70	30.00	30.90	14.59
39	23.50	26.00	18.90	15.68
40	29.60	34.00	18.10	15.38
41	36.70	29.00	33.20	14.42
42	24.00	28.00	21.40	16.05
43	41.80	35.00	15.10	14.84
44	29.10	30.00	19.50	15.05
45	28.90	34.00	19.00	15.13
46	36.90	34.00	20.50	15.17
47	30.00	28.00	19.80	15.72
48	32.10	28.00	24.20	15.68
49	32.90	29.00	20.00	15.76
50	36.80	29.00	18.90	15.55
51	30.60	28.00	15.90	15.63

AME prediction established by training data set is shown in Table 5. Also the statistical values derived from multiple linear regressions and artificial neural network models using

Table 3 The selected parameters obtained via stepwise regression used to predict AME of barley samples by multiple linear regression and neural networks models

Barely samples	Inputs (g/kg of DM)			Output (MJ/kg)
	Starch	Ether extract	Crude fiber	AME
1	700	19.00	55.10	11.70
2	622	18.50	61.10	11.95
3	681	20.40	41.60	14.50
4	676	18.90	50.30	13.96
5	656	19.50	54.90	13.04
6	618	17.60	67.70	13.59
7	685	16.10	58.30	13.33
8	622	14.20	71.00	13.63
9	633	20.30	64.60	12.87
10	649	19.20	61.70	13.67
11	657	16.10	52.00	13.54
12	664	17.50	61.00	13.46
13	668	20.30	53.20	14.25
14	607	15.70	57.80	14.34
15	617	16.40	64.90	12.67
16	629	17.60	56.40	13.17
17	569	13.40	70.00	12.71
18	617	14.00	62.20	12.16
19	584	12.70	79.90	12.04
20	674	26.00	46.40	13.25
21	543	11.70	58.10	14.00
22	623	21.00	56.30	13.54
23	634	18.30	56.40	13.46
24	643	18.40	54.70	12.83
25	624	12.10	66.30	11.24
26	578	17.20	70.20	12.79
27	607	14.10	83.00	9.86
28	546	11.70	80.90	11.54
29	565	14.80	75.50	14.13
30	572	9.80	95.60	11.45
31	607	13.00	74.20	11.16
32	638	16.00	50.60	13.46
33	662	14.30	58.30	10.99
34	540	18.00	57.90	14.34
35	607	9.90	50.90	12.25
36	578	11.70	81.10	10.58
37	538	14.30	93.50	11.75
38	603	14.10	71.30	11.95
39	642	15.00	47.90	13.75
40	597	15.20	73.00	12.96
41	654	22.10	48.30	14.30
42	649	22.40	57.30	13.88
43	639	21.60	53.20	14.17
44	668	24.40	54.70	14.38
45	647	22.70	45.30	14.13
46	652	22.00	50.70	13.50
47	618	24.10	66.20	12.96
48	639	27.00	58.90	13.88
49	648	23.40	53.90	13.79
50	631	31.60	71.70	13.17
51	654	24.30	49.90	13.67
52	648	25.80	49.50	13.71
53	657	26.20	62.90	14.25
54	632	25.50	45.50	13.63
55	631	25.80	62.10	13.54
56	643	19.60	38.90	14.04

testing data set are presented in table 6. These parameters were obtained from a comparison between experimental data with model predicted data using testing data sets. The goodness of fit in terms of R corresponding to testing of the ANN model showed a higher accuracy of prediction than the equation established by the regression method for wheat (0.918 *vs*. 0.618), barley (0.902 *vs*. 0.701) and oat (0.888 *vs*. 0.829).

Table 4 The selected parameters obtained via stepwise regression used to predict AME of oat samples by multiple linear regression and neural networks models

Oat samples	Inputs (g/kg of DM)		Output (MJ/kg)
	Crude fiber	Crude protein	AME
1	91.60	130.59	14.21
2	91.30	119.52	14.25
3	99.50	139.34	13.59
4	144.60	102.03	12.83
5	112.10	107.86	12.54
6	104.30	128.84	13.63
7	135.10	127.09	13.38
8	105.20	133.51	13.04
9	122.90	130.01	13.21
10	126.30	143.42	12.16
11	188.60	113.10	9.74
12	133.00	122.43	12.33
13	117.20	116.60	13.92
14	115.70	177.82	12.33
15	145.00	163.24	10.74
16	105.30	124.76	12.25
17	113.80	107.86	13.71
18	61.50	141.67	15.80
19	30.80	148.67	14.63
20	130.10	125.93	12.96
21	124.60	113.10	11.95
22	140.10	104.94	13.42
23	117.10	134.67	11.16
24	124.00	132.34	13.50
25	126.60	131.18	11.54
26	109.30	135.84	11.16
27	15.40	171.99	15.97
28	28.80	153.33	15.47
29	112.00	114.00	13.88
30	100.00	134.00	13.98
31	116.00	113.00	13.98
32	118.00	160.00	13.58
33	96.00	127.00	14.28
34	108.00	130.00	13.98

In terms of others error parameters, the ANN model generally showed lower error than that of regression model in testing data sets (Table 6). Based on the current results, it is evident that the prediction of AME content of wheat, barley and oat grains as a function of chemical composition through ANN model provides much more accurate values than those with MLR model. There are many prediction equations with use of chemical compositions to determine the energy content of wheat, barley and oat via regression method (Metayer *et al*. 1993; NRC, 1994; Villamide *et al.* 1997). Sibbald and Price (1976) measured the ME values, physical characteristics and chemical compositions of Canadian wheat, barley and oat grain samples to use the data to test published indirect assays for ME. Similar to our result they found that the correlations between observed and predicted ME values were particularly high for oats and poorer for wheat and barley. Villamide *et al.* (1997) expressed that no relationship was found between AME_n of un-supplemented barley cultivars and their chemical composition, while there was a stronger relationship between chemical compositions and AME_n for enzyme-supplemented barley. Metayer *et al.* (1993) measured chemical composition and ME of the cereals grown in France. They reported that prediction of ME of wheat and barley from chemical results is not satisfactory because of the low accuracy. However, they detected that there were good correlations between starch, crude fiber and gross energy with ME of oat grains. They used CF, CP, EE and starch and established four predictive regressions equations for energy estimation of oat grain with r^2=0.82. Similarly we found good correlation between CF and CP with AME of oat grain samples (R^2=0.829). Choct *et al.* (1999) demonstrated that there was no correlation between AME and starch content of wheat. They resulted that this finding is consistent with AME of wheat being influenced more by the anti-nutritive effect of NSPs rather than there being an absolute shortage of energy in the grain. While Mc Cracken and Quintin (2000) and Svihus and Gullord (2002) find the positive correlation between starch content and AME value

Table 5 The multiple linear regressions equation established by training data set to predict AME of grain samples

Grain	Multiple linear regression
Wheat	AME= 20.97-0.03 CF - 0.11 SS- 0.06 ash
Barley	AME= 20.86 - 0.01 starch + 0.09 EE- 0.05 CF
Oat	AME= 18.55 - 0.03 CF - 0.01 CP

AME: apparent metabolizable energy (MJ/kg DM); SS: soluble sugar (g/kg DM); CF: crude fiber (g/kg DM); EE: ether extract (g/kg DM) and CP: crude protein (g/kg DM).

Table 6 The statistic values (derived from testing data sets) obtained by multiple linear regression and artificial neural network models to estimate the AME value of wheat, barley and oat samples based on chemical composition

Statistics	Wheat		Barley		Oat	
	MLR	ANN	MLR	ANN	MLR	ANN
R^2	0.618	0.918	0.701	0.902	0.829	0.888
SB	0.046	0.025	0.000	0.012	0.015	0.090
SDSD	0.160	0.010	0.347	0.249	1.692	0.001
LCS	0.128	0.076	0.288	0.101	0.393	0.336
MSD	0.334	0.111	0.635	0.362	0.558	0.427
MSV	0.288	0.085	0.635	0.350	0.543	0.337

SB: squared bias; SDSD: squared difference between standard deviations; LCS: lack of correlation weighted by the standard deviations; MSD: mean squared deviation and MSV: mean squared variation.
MLR: multiple linear regression and ANN: artificial neural network.

of wheat. Svihus and Gullord (2002) determined that fiber content was negatively correlated to AME. Paris (2000) demonstrated that there is an inverse relationship between fiber concentration and energy per unit of feed, thus high fiber content has been an issue of concern in feeding barley-based diets due to lower ME values. This result corresponds well to finding in the present study. We find a negative correlation between CF and AME of wheat, barley and oat grain samples. Furthermore, we observed that when starch or starch and EE plots to AME for barley samples, there was a positive correlation between them. While when CF added, effect of starch change and be negative. It's maybe due to the strong effect of CF on AME of barley samples. Based on our results and review published studies, it seems that chemical compositions can be used as a rapid method for estimation of metabolizable energy in cereals but not always with strong correlation.

Although estimation of the AME value in feedstuffs has been reported in several studies, these equations aren't used widely in poultry feed formulation because of poorer accuracy and precision. Finding the novel mathematical models with good accuracy and precisely may make these equations acceptable to be used by nutritionists. The ANN models are good candidates that can improve this application. There are some studies that used ANN model for prediction of cereals metabolizable energy (Lozano *et al.* 1995; Sedghi *et al.* 2011; Soleimani Roudi *et al.* 2012). Lozano *et al.* (1995) predicted the AME of barley with 12 easily obtainable analytical parameters by applying neural networks and found correlation coefficient of 0.82. Also, Soleimani Roudi *et al.* (2012) used NSP and / or DM, ash and CP to predict ME of wheat grains and demonstrated that the ANN model was an accurate method for prediction of AME as compared with MLR and partial least square methods. The main goal of previous studies on neural networks was to introduce this method as a powerful tool that can be used in nutrition subject. Based on published article about ANN ability, it seems that this method can be a powerful tool in nutrition area and may terminate nutritionist's concern about the applicability of mathematical model in nutrition science.

CONCLUSION

The results showed that AME can be predicted by chemical compositions. The MLR method is just able to produce a very rough estimate of AME. In comparison the ANN is capable to pursue the fluctuations of AME and could be considered as a promising tool in AME prediction.

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