UDC 636.5 :636.085.1/.55

Original scientific paper

NONLINEAR MODELS FOR PREDICTING METABOLIZABLE ENERGY OF POULTRY DIETS*

Čolović R. Radmilo**[1], Palić V. Dragan[1], Modika Y. Kedibone[2], Barnes Penny[2]

[1]University of Novi Sad, Institute of Food Technology, 21000 Novi Sad, Bulevar cara Lazara 1, Serbia

[2]Agricultural Research Council, Pretoria, Hatfield 0001, Republic of South Africa

**Corresponding author:
Phone: +381214853796
Fax: +38121450725
E-mail address: radmilo.colovic@fins.uns.ac.rs

ABSTRACT: Determination of energy value of the diets is very important in animal feed industry. The amount of available energy of poultry feed is described either by metabolizable energy (ME) or by organic matter digestibility (OMD). Due to expensive and time-consuming process of *in vivo* determination of ME, there has been a considerable interest in developing rapid, low-cost and accurate methods for ME determination. The aim of this study was to develop equations for predicting of ME of poultry diets. Twenty one complete diets for poultry were used in this study. Regression analysis was used to generate mathematical models for prediction of response value of true metabolizable energy (TMEn). Independent variables in models were: *in vitro* digestibility (%, x_1), crude protein (%, x_2), crude fat (%, x_3), crude fibre (%, x_4) and ash content (%, x_5). The six polynomial equations are proposed in this study. Each equation is describing individual and interaction effects of three factors on the TMEn. *In vitro* digestibility was taken into account in all equations. The root mean square of most of equations was lower than 4%, showing that proposed equations had very good prediction of experimental results. Equations with crude protein as one of independent variables have low fit of experimental data ($R^2 < 0,8$), indicating that crude protein did not have strong influence on TMEn. In most of equations *in vitro* digestibility had significant linear, quadratic or interactional effect on TMEn with relatively good fit of data.

Key words: *metabolizable energy, mathematical model, regression analysis, poultry, diets*

* This paper is a result of the research within the project III046012 financed by the Ministry of Science and Technological Development, Republic of Serbia. This study was also supported by the Ministry of Agriculture, Republic of South Africa.

INTRODUCTION

Achieving appropriate nutritional and physical characteristics of animal feed is very important for animal health and growth. Once the nutrient requirements of the animals were established, a correct balanced diet can be formulated if the accurate nutrient composition of feedstuffs is known (Čolović et al., 2010; Dale and Batal, 2002). Energy value of diets is of great importance for animal feed manufacturers and end users. The amount of available energy in feeds is described either by its metabolizable energy (ME) or by organic matter digestibility (OMD), (Palić and Leeuw, 2009; Pojić et al., 2008). ME determination of diets requires the use of live animals, appropriate sample collection, ME assay trial, and determination of energy content of feed ingredients and collected excreta (Elkin, 1987; Mohamed, 1984).

In vivo determination of ME can be expensive in terms of time and resources, thus it is important to develop rapid, inexpensive, and accurate methods for ME prediction which could be helpful to manufacturers and nutritionists in monitoring of animal feed quality. There has been a considerable and continuous interest to develop equations for prediction of ME (Perai et al., 2010; Robbins and Firman, 2005; Zhang et al., 1994).

The aim of this study was to develop equations for rapid prediction of metabolizable energy of diets for poultry.

MATERIAL AND METHODS

Chemical analysis

Twenty one complete diets for broilers were used in this study. Dry matter, crude protein, crude fat, crude fibre and ash of the diets were determined according to AOAC official methods (AOAC, 2000). A modified method of Boisen and Fernandez (1997) for estimating the enzymatic digestibility of organic matter (EDOM) was used. For determination of *in vivo* TME_n, a method of Fisher and McNab (1987) was followed.

Experimental design and statistical analysis

Regression analysis was used to generate mathematical models for prediction of response value of true metabolizable energy (TMEn (MJ/Kg DM)). Independent variables in models were: *in vitro* digestibility (%, x_1), crude protein (%, x_2), crude fat (%, x_3), crude fibre (%, x_4) and ash content (%, x_5). The response was related to selected variables by second-order polynomial model. The generalized model proposed for the response is given in equation below:

$$Y = b_0 + \sum b_i x_i + \sum b_{ii} x_i^2 + \sum \sum b_{ij} x_i x_j$$

where Y represents the experimental response, b_0, b_i, b_{ii}, and b_{ij} are constants and regression coefficients of the model, and x_i and x_j are uncoded values of independent variables. STATISTICA software version 9 (Statsoft, Tulsa, OK, USA) was used for regression analysis of experimental data. The software generated regression coefficients for each of the combinations of the independent variables and their significances were determined using the *p*-values generated through the *t*-tests. Adequacy of predicted model was evaluated by coefficient of determination (R^2) and magnitude of root mean square (RMS):

$$RMS = 100\sqrt{\frac{\sum \left| \frac{Y_{exp} - Y_{pred}}{Y_{pred}} \right|^2}{N}}$$

where Y_{exp} and Y_{pred} are the experimental and predicted values of the response (TMEn (MJ/Kg DM)) and N is the number of experimental values.

RESULTS AND DISCUSSION

The chemical composition of complete diets used in this study is shown in Table 1.

The six polynomial equations are proposed in this study. Each equation is describing individual and interaction effects of three factors on the TMEn. *In vitro* digestibility was taken into account in all equations. Regression equation coefficients are presented in Table 3. Subscript numbers of the coefficients are denoting factors to whom they are related. The significance of the coefficients is evaluated by Student's t-test and p-values. Bold numbers denote values significant at 95% level.

Equation 1 (*in vitro* digestibility, crude protein and crude fat) shows that linear and quadratic effect of *in vitro* digestibility on TMEn is significant ($p \leq 0,05$). Equations 2 (*in vitro* digestibility, crude protein and crude fibre) and 3 (*in vitro* digestibility, crude protein and crude fibre) are not having significant regression coefficients. All three equations are having relatively low coefficient of determination ($R^2 < 0,8$). Equation 4 (*in vitro* digestibility, crude fat and crude fibre) indicated that linear and quadratic influence of crude fat and crude fibre was significant, as well as the interaction of all three factors. Obtained coefficient of determination was relatively higher in comparison with equations 1, 2 and 3. Equation 5 (*in vitro* digestibility, crude fat and ash) is showing significant linear and quadratic influence of *in vitro* digestibility, with high coefficient of determination (R^2 = 0,93). Linear and quadratic influence of *in vitro* digestibility in equation 6 (*in vitro* digestibility, crude fibre and ash), likewise in equations 1 and 5, was significant.

Coefficient of determination of equation 6 was R^2 = 0,87. The EDOM and TMEn values of complete poultry diets are shown in Table 2.

Table 1.
Chemical composition of complete diets

Diet	Dry matter (%)	Crude protein (g/100g DM)	Crude fat (g/100g DM)	Crude fibre (g/100g DM)	Crude ash (g/100g DM)
1	89,85	27,37	11,06	3,58	8,29
2	89,59	21,79	7,50	2,98	7,03
3	88,90	16,63	11,06	4,09	6,43
4	89,84	20,78	14,88	3,68	7,35
5	89,57	17,19	9,74	7,25	11,39
6	89,31	21,88	9,56	8,87	7,02
7	85,30	24,72	9,50	2,73	4,28
8	86,35	25,99	5,72	2,78	3,81
9	88,68	25,01	3,17	2,12	5,86
10	88,31	24,61	6,08	2,65	5,42
11	88,77	25,38	3,56	2,49	6,08
12	87,99	24,65	8,82	2,38	5,21
13	88,50	22,35	5,51	2,11	5,22
14	88,43	19,97	7,50	4,24	5,48
15	88,26	21,40	4,32	2,06	5,94
16	88,25	22,66	7,37	2,16	6,06
17	88,28	26,22	2,91	3,05	6,21
18	88,06	26,39	3,21	1,90	5,32
19	88,21	26,53	3,16	2,69	5,63
20	88,16	25,84	2,89	4,07	5,57
21	88,23	26,77	2,79	2,57	2,25

Table 2.
Enzymatic degistibility of organic matter (EDOM) and true metabolizable energy (TME_n) of poultry diets

Diet	EDOM (%)	TMEn (MJ/kg DM)
1	84,01	14,63
2	84,94	14,59
3	83,31	16,92
4	83,78	16,50
5	71,50	12,60
6	75,27	15,28
7	81,60	17,18
8	86,76	15,81
9	81,94	15,28
10	80,29	16,46
11	81,47	15,21
12	81,83	16,51
13	80,75	16,33
14	78,61	15,67
15	79,20	15,99
16	82,68	16,19
17	77,85	14,71
18	79,65	15,46
19	78,60	15,38
20	78,30	14,92
21	78,57	15,46

DM – dry matter

Table 3.
Regression coefficients for TMEn of complete diets

Eq 1		Eq 2		Eq 3		Eq 4		Eq 5		Eq 6	
b_0	**-348,210**	b_0	-204,868	b_0	-189,923	b_0	297,747	b_0	**-330,648**	b_0	**-645,942**
						Linear					
b_1	**8,848**	b_1	5,453	b_1	5,177	b_1	-6,477	b_1	**8,274**	b_1	**16,183**
b_2	-0,301	b_2	0,473	b_2	-0,349	b_3	**15,586**	b_3	0,467	b_4	-14,945
b_3	2,249	b_4	-4,944	b_3	0,368	b_4	**-39,663**	b_5	3,845	b_5	7,693
						Quadratic					
b_{11}	**-0,058**	b_{11}	-0,036	b_{11}	-0,032	b_{11}	0,037	b_{11}	**-0,049**	b_{11}	**-0,098**
b_{22}	-0,029	b_{22}	-0,019	b_{22}	-0,001	b_{33}	**0,055**	b_{33}	0,004	b_{44}	0,165
b_{33}	-0,039	b_{44}	0,081	b_{55}	0,007	b_{44}	**0,416**	b_{55}	3,845	b_{55}	0,004
						Interaction					
b_{12}	0,027	b_{12}	0,007	b_{12}	0,004	b_{13}	**-0,188**	b_{13}	-0,003	b_{14}	0,165
b_{13}	0,003	b_{14}	0,078	b_{15}	-0,007	b_{14}	**0,478**	b_{15}	-0,052	b_{15}	-0,109
b_{23}	-0,074	b_{24}	-0,082	b_{25}	-0,011	b_{34}	**-0,278**	b_{35}	-0,016	b_{45}	0,240
R^2	0,77	R^2	0,68	R^2	0,79	R^2	0,86	R^2	0,93	R^2	0,87
RMS	2,98	RMS	3,45	RMS	2,80	RMS	2,22	RMS	266,36	RMS	2,10

Eq – equation

The RMS of equations 1, 2, 3, 4 and 6 was lower than 4%, showing that those equations had very good prediction of experimental results. The RMS value of equation 5 was very high due to big discrepancy between experimental and predicted results.

Equations with crude protein as one of independent variables had low fit of experimental data, indicating that crude protein did not have strong influence on TMEn. On the other hand, in most of equations *in vitro* digestibility had significant linear, quadratic or interactional effect on TMEn with relatively good fit of data.

CONCLUSIONS

Each of six proposed equations describe individual and interactional effects of three independent variables, and was evaluated by several quality criteria. This could be helpful in choosing appropriate model depending on chosen variable, or quality criteria. The root mean square of most of equations was very low, showing good prediction of experimental data. The polynomial equations proposed in this study could be successfully used for accurate and rapid prediction of TMEn.

ACKNOWLEDGEMENTS

This paper is a result of the research within the project III046012 "Istraživanje savremenih biotehnoloških postupaka u proizvodnji hrane za životinje u cilju povećanja konkurentnosti, kvaliteta i bezbednosti hrane za životinje (Study of modern biotechnological methods in the production of animal feed in order to increase competitiveness, quality and safety of the feed)", financed by the Ministry of Science and Technological Development, Republic of Serbia. This study was also supported by the Ministry of Agriculture, Republic of South Africa.

REFERENCES

1. AOAC (2000). Official Methods of Analysis, 17th Edition, AOAC INTERNATIONAL, Gaithersburg, MD 20877-2417, USA.
2. Boisen, S., Fernandez, J.A. (1997). Prediction of the total tract digestibility of energy in feedstuffs and feed diets by *in vitro* analyses. *Animal Feed Science and Technology, 68,* 277-286.
3. Čolović, R., Vukmirović, Đ., Matulaitis, R., Bliznikas, S., Uchockis, V., Juškiene, V., Lević, J. (2010). Effect of die channel press way length on physical quality of pelleted cattle feed, *Food and Feed Research*, *37* (1), 1-6.
4. Dale, N., Batal, A. (2002). Feedstuffs Ingredient Analysis Table. *Miller Publishing Co., Minnetonka, MN.*
5. Elkin, R. G. (1987). A review of duck nutrition research, *World's Poult. Sci. J.*, *43*, 84–106.
6. Fisher, C., McNab, J. M. (1987). Techniques for determining the ME content of poultry feeds. In: W. Haresign and D. J. A. Cole (Eds.) *Recent Advances in Animal Nutrition,* Butterworths, London, 3-17.
7. Mohamed, K., Leclercq, B., Anwar, A., El-Alaily, H., Soliman, H. (1984). A comparative study of metabolizable energy in du-

cklings and domestic chicks, *Anim. Feed Sci. Technol. 11*, 199–209.

8. Palić, D., Leeuw, K. J. (2009). Comparison of three in vitro methods for determining and predicting the organic matter digestibility of complete diets for ruminants, *Acta Periodica Technologica*, *40*, 79-86.
9. Perai, A. H., Moghaddam, H. N., Asadpour, S., Bahrampour, J., Mansoori, Gh. (2010). A comparison of artificial neural networks with other statistical approaches for the prediction of true metabolizable energy of meat and bone meal, *Poultry Science*, *89* (7), 1562-1568.
10. Pojić, M., Palić, D., Mastilović, J., Janić-Hajnal, E. (2008). The introduction of a method for determination of organic matter digestibility in feeds into routine laboratory practice, *Food processing, quality and safety*, *35* (3), 151-154.
11. Robbins, D. H., Firman, J. D. (2005). Evaluation of metabolizable energy of meat and bone meal for chickens and turkeys by various methods, *International Journal of Poultry Science*, *4* (9), 633-638.
12. Zhang, W. J., Campbell, L. D., Stothers, S. C. (1994). An investigation of the feasibility of predicting nitrogen-corrected true metabolizable energy (TMEn) content in barley from chemical composition and physical characteristics*, Canadian journal of Animal Science*, *74* (2), 355-360.
13. AOAC (2000). Official Methods of Analysis, 17th Edition, AOAC INTERNATIONAL, Gaithersburg, MD 20877-2417, USA.

НЕЛИНЕАРНИ МОДЕЛИ ЗА ПРЕДВИЂАЊЕ МЕТАБОЛИЧКЕ ЕНЕРГИЈЕ

Чоловић Р. Радмило[1], Палић В. Драган[1], Modika Y. Kedibone[2], Barnes Penny[2]

[1]Универзитет у Новом Саду, Институт за прехрамбене технологије у Новом Саду, 21000 Нови Сад, Булевар цара Лазара бр. 1, Србија

[2]Agricultural Research Council, Pretoria, Hatfield 0001, Republic of South Africa

Сажетак: У индустрији хране за животиње веома је важно да се одреди енергетска вредност смеса за исхрану животиња. Количина искористиве енергије најчешће се описује метаболичком енергијом (МЕ) или сварљивошћу органске материје. Због скупог и временски захтевног поступка *in vivo* одређивања МЕ, јавила се потреба за развијање брзих, јефтиних и прецизних метода за предвиђање МЕ смеса за исхрану животиња. 21 смеса за исхрану бројлера је коришћена у овој студији. За генерисање математичких модела за предвиђање вредности стварне метаболичке енергије (TMEn (MJ/kg)) коришћена је регресиона анализа. Независне промењиве у моделима биле су: *in vitro* сварљивост органске материје (%, x_1), садржај сирових протеина (%, x_2), садржај сирових масти (%, x_3), садржај сирових влакана (%, x_4) и садржај пепела (%, x_5). Шест полиномалних једначина је предложено у овој студији. Свака једначина описује појединачни утицај три фактора, као и утицај међусобне интеракције фактора на вредност TMEn. *In vitro* сварљивост органске материје је фактор који фигурише у свим једначинама. Корен квадратне средње вредности (RMS) одступања између експерименталних и израчунатих података за већину једначина био је мањи од 4%, што указује да су предложене једначине имале добро предвиђање експерименталних вредности TMEn. Једначине у којима фигуришу сирови протеини, као једна од независних промењивих, имале су лоше слагање са експерименталним подацима ($R^2 < 0{,}8$), што показује да је садржај сирових протеина фактор који нема велики утицај на вредност TMEn. У већини једначина *In vitro* сварљивост органске материје је имала значајан линеарни, квадратни и интерактивни утицај на вредност TMEn, уз добро слагање података.

Кључне речи: *метаболичка енергија, математички модел, регресиона анализа, живина, смесе*

Received: 6 September 2011

Accepted: 30 September 2011