Kansas Agricultural Experiment Station Research Reports

Volume 0
Issue 10 *Swine Day (1968-2014)*

Article 257

1983

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PREDICTION FROM CHEMICAL ANALYSES OF ENERGY VALUE AND NITROGEN DIGESTIBILITY OF FEED INGREDIENTS AND DIETS FOR SWINE

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Summary

Nine individual feed ingredients and 12 mixed diets were used in an attempt to select the most suitable regression equation for predicting energy value and nitrogen digestibility from chemical analyses. Samples were analyzed for crude protein (CP), ether extract (EE), crude fiber (CF), ash, moisture and nitrogen-free extract (NFE). Feed ingredients were corn, sorghum grain, wheat (trial 1), alfalfa meal, wheat bran, rice bran (trial 2), soybean meal, meat and bone meal and sunflower meal (trial 3). Levels ranged from 9.9 to 53.9% for CP, from 1.5 to 25.5% for CF, and from 1.7 to 27.3% for ash. A total of 72 pigs with average initial weight of 25 kg (55 lb) were used in three conventional digestion trials to measure the dry matter digestibility (DMD), nitrogen digestibility (ND), digestible energy (DE) and metabolizable energy (ME) of diets and feed ingredients. Feed ingredients were substituted for the basal diets at 50, 30 and 20% in trial 1, 2 and 3, respectively. The DMD, ND, DE and ME were measured by difference between determined values for the test ingredient and the basal diet. Fiber was the major factor depressing DMD, ND, DE and ME in both diets and feed ingredients. Levels of crude fiber and protein affected the ratio of ME to DE in feed ingredients as in the following equation: ME/DE, % = 100.4 - .12 CP - .15 CF ($r = .94$, $P<.01$). High correlations were found between ME and DE and DMD in diets and feed ingredients. The DE and ME in feed ingredients could be predicated from only CF and ash by the following equations: DE, kcal/g DM = 4.360 - .0652 CF - .0489 ash ($r = .93$, $P<.01$); and ME, kcal/g DM = 4.277 - .0676 CF - .0516 ash ($r = .95$, $P<.001$).

These results suggest that nitrogen digestibility and digestible energy of feed ingredients and complete diets for swine can be estimated from chemical analyses.

Introduction

An accurate estimate of the nutritive value of feed ingredients is essential for effective least-cost formulation of diets. The feeding value of feed ingredients for swine is largely determined by the digestible energy (DE) or metabolizable energy (ME). There is substantial variation in the energy values determined for the same feed ingredient. Conventional digestion and balance trials are very time consuming and expensive. Thus, the direct estimation of the

nutritive value of feedstuffs is a difficult routine procedure. Chemical composition of the feed consumed has a direct influence on digestibility. Fiber is the major factor that depresses the digestibilities of organic matter, protein and energy. The DE and ME also are affected by gross energy, crude protein, ether extract and nitrogen-free extract, calcium and phosphorus, sugars, starch and soluble carbohydrate.

The objectives of this study was to predict the nitrogen digestibility, digestible energy and metabolizable energy from conventional proximate analyses with regression equations.

Experimental Procedures

Three trials involving 72 barrows with an average initial weight of 25 kg (55 lb) were employed to determine the DE and ME values of 12 diets and nine feed ingredients. Pigs were selected initially at 17 to 19 kg (37 to 42 lb) and performance monitored to aid in allotment of pigs to treatments. Feed ingredients evaluated were corn, sorghum grain and wheat in trial 1; dehydrated alfalfa, wheat bran and rice bran in trial 2 and soybean meal, meat and bone meal, and sunflower meal in trial 3. The test feed ingredient was substituted for the basal diet (table 1) at the rate of 50, 30 and 20% in trial 1, 2 and 3 respectively.

In each trial, 2 groups of pigs (12 per group) were housed in an environmentally controlled room. Pigs received the diet during a 10-day preliminary period followed by a 5-day period during which total feces and urine were collected. Pigs were fed 550 g (1.21 lb) per meal twice daily at 0900 and 1700 and water was given with the meal at a ratio of 2.5 to 1.

A marker-to-marker technique was used for collection of feces. Ferric oxide at 1% of diet was added to the afternoon feed on day 10 and day 15. Feces were dried daily in a forced air oven. The total dry feces of each pig were weighed and ground in a Wiley mill equiped with a 1 mm screen.

Urine was filtered through glasswool and collected daily in plastic vessels contain 40 ml of 6 N HCl and 5 ml of toluene. The total amount of urine excreted was recorded by weight and an aliquot of 800 ml per pig was stored in a freezer until analyzed. Each sample was analyzed for nitrogen. For energy determinations a 100-150 ml sample of urine from each pig was adjusted to 3.9 to 4.1 pH with 5 N NaOH and mixed with one g of cellulose to facilitate ignition of samples. The mixture was freeze-dried to determine the GE of dry sample with oxygen bomb calorimeter.

Samples of the feed ingredients, complete diets and feces were subjected to proximate analyses and gross energy determinations. The value used for

converting nitrogen to crude protein was 6.25 for all samples, with the exception of wheat and wheat bran for which 5.70 was used. The DE and ME values were calculated for each pig. The apparent nitrogen digestibility (ND) and dry matter digestibility (DMD) also were determined.

Six replicate values were obtained for each basal diet and diets with the test ingredient. Values of DMD, ND, energy digestibility (DE/GE) and ME as percentage of GE (ME/GE) of the test feed ingredients were calculated by the difference between the basal diet with the added test ingredient and the basal diet. The relationship between DE, ME or ND and the chemical analyses as variable parameters, for 12 diets or nine feed ingredients were computed with multiple linear regression equations by stepwise regression procedures. The most suitable regression equation for prediction of DMD, ND, DE, ME and ME/DE was searched for among chemical analyses. Crude protein (CP), ether extract (EE), crude fiber (CF), ash and nitrogen free extract (NFE) were used to estimate in vivo value by regression equation with the highest multiple correlation coefficient (r^2) and minimal residual standard deviation (RSD).

Results and Discussions

Among the 12 diets the range of CP was 16.8 to 25.9%, CF was 2.6 to 10.4%, and GE was 4.28 to 4.62 kcal per g (dry matter basis). The chemical compositions of the nine feed ingredients and the three basal diets are shown in table 2. Among selected feed ingredients, the CP, CF and ash ranged from 9.9 to 53.8%, 1.5 to 25.5% and 1.66 to 27.31%, respectively. The energy value of grains was higher than other feed ingredients (table 3). The ME averaged 96.07% of DE for all feed ingredients, with 98.4% for cereal grains. Crude fiber was the major factor depressing the digestibilities of dry matter, nitrogen and energy and metabolizable energy in diet (table 4) and feed ingredients (table 5). The amount of ash also decreased ($P<.08$) the dry matter digestibility in some of the feed ingredients (table 5) but not in complete diets. This may be because the range of ash content was greater in feed ingredients than in complete diets.

A high correlation was found between ME and DE for diets and feed ingredients. The relationships were:

Diets:
ME (kcal/g DM) = -.183 + 1.027 DE ($r = .998$, $P<.001$)
ME (kcal/g DM) = -.125 + 1.025 DE - .002 CP ($r = .999$, $P<.0001$)
Feed ingredients:
ME (kcal/g DM) = -.173 + 1.014 DE ($r = .994$, $P<.0001$)
ME (kcal/g DM) = -.016 + .999 DE - .044 CP ($r = .998$, $P<.0001$)

The correlation coefficient between ME/DE and crude protein was higher in feed ingredients ($r = -.81$, $P<.01$) than in complete diets ($r = -.52$, $P<.08$). This

might be due to the range of protein level in feed ingredients (9.9 to 53.8%), which was greater than in the complete diets (16.8 to 25.9%). A negative correlation between ratio ME and DE and crude protein level has been reported previously. It was shown that when normal protein levels were fed in balanced rations, the DE could be converted to ME simply by multiplying DE by .98. The disadvantage of this approach is that the ME/DE ratio of a diet may vary according to its composition. For feed ingredients, the test prediction of ME to DE was the equation with crude protein and crude fiber as independent variables (table 7) as follows: ME/DE, % = 100.4 - .122 CP - .148 CF, (r = .94, RSD = .99). This indicates that the ratio of ME to DE is affected not only by the crude protein level but also by crude fiber content. The content of crude fiber decreased the DE and ME utilization and an increase in crude fiber reduced the ME/GE ratio.

The multiple regressions that resulted in the most suitable estimation for energy and nitrogen digestibility in the complete diets and in feed ingredients are shown in table 6 and 7, respectively. The coefficient of variation (CV), expressed RSD as percentage of mean, was 4.56% for DE (kcal/g DM) and 4.83% for ME (kcal/g DM) in 12 diets. No suitable equation for predicting the gross energy for diets was found in this study. To predict the DE more accurately for diets, it was necessary to include the GE value (kcal/g DM) as a component of the equation as DE, kcal/g DM = GE x (95.21 - 1.249 Ee - 1.723 CF), (r = .91, P < .001) (table 6). When measures of chemical composition were used in the regression for prediction of DE and ME as kcal/g DM for a diet, only crude fiber had a significant partial regression coefficient as shown by the following equation: DE, kcal/g DM = 4.017 - .0731 CF (r = .71, P<.05, RSD = .169); ME, kcal/g DM = 3.942 - .0747 CF (r = .71, P<.05), RSD = .175). The most accurate predictions of DE/GE and ME/GE in diets included ether extract and crude fiber as the independent variables for diets are: DE/GE, % = 95.208 - 1.249 EE - 1.723 CF (r = .91, P<.001, RSD = 2.22, CV = 2.68%); ME/GE, % = 93.27 - 1.171 EE - 1.760 CF (r = .90, P<.001, RSD = 2.41, CV = 2.97%). Nitrogen digestibility could be predicted from crude protein, ether extract and crude fiber as follows: ND, % = 83.55 + .414 CP - 1.007 EE - 1.243 CF (r = .92, P<.01, RSD = 1.91).

For feed ingredients, the crude fiber and ash were the major variables in the most accurate predictions of energy value and nitrogen digestibility (table 7). This indicates that crude fiber and ash were the major factors affecting the nutritive value of feed ingredients. The multiple regression equations for predicting nitrogen digestibility and energy values from chemical compositions, percentage of dry matter basis are as follows: ND, % = 73.68 + .617 CP - .701 CF - .886 ash (r = .91, P<.05, RSD = 5.83); DMD, % = 88.22 + .348 CP - 1.181 CF - 1.869 ash (r = .97, P<.001, RSD = 5.02); GE, kcal/g DM = 4.356 .010 CP + .054 EE + .004 CF - .039 ash (r = .97, P<.001, RSD = .03); DE, kcal/g DM = 5.944 - .080 CF - .106 ash - .019 NFE, (r = .97, P<.001, RSD = .219); ME, kcal/g DM = 4.277 - .068 CF - .052 ash (r = .95, P<.001, RSD = 2.67).

These results suggest that nitrogen digestibility, digestible energy and metabolizable energy of feed ingredients and diets for swine can be predicted from chemical analyses.

Table 1. Composition of Basal Diets

Ingredient	Trial 1 A	Trial 2 B	Trial 3 C
Yellow corn, ground (IFN 4-02-935)	57.6	73.15	78.25
Soybean meal (IFN 5-04-612)	36.0	22.10	18.20
Dicalcium phosphate (IFN 6-01-080)	2.2	2.00	1.00
Calcium carbonate (IFN 6-02-632)	2.0	1.40	1.20
Salt (IFN 6-04-151)	0.5	0.50	0.50
Premix[a]			
Trace mineral premix	0.2	0.10	0.10
Antibiotic premix	0.5	0.25	0.25
Vitamin premix	1.0	0.50	0.50

[a] Provided the following contents per kg of basal diet B and C but twice the level for diet A:
Trace mineral premix, Mn, 100 mg; Zn, 100 mg; Fe, 100 mg, Cu, 10 mg; I, 3 mg and Co 1 mg.
Antibiotic premix: chlortetracycline 110 mg; sulfamethazine 110 mg and penicillin 55 mg.
Vitamin premix: vitamin A, 4410 IU; vitamin D_3, 330 IU; vitamin E, 22 IU; riboflavin, 5 mg; d-pantothenic acid, 13.2 mg; niacin, 27.5 mg; vitamin B_{12}, 24.3 µg; and choline chloride, 508 mg.

Table 2. Chemical Composition of Test Feed Ingredients and Basal Diet

Feedstuff	Crude protein	Ether extract	Crude fiber	Ash	NFE	GE
	%					Kcal/g DM
Corn	9.89	4.93	1.66	1.66	81.86	4.66
Sorghum	11.96	3.94	1.55	1.76	80.90	4.63
Wheat	11.45	2.84	2.54	1.94	74.24	4.62
Alfalfa meal	18.54	4.13	25.48	10.23	41.62	4.44
Wheat bran	18.28	5.26	10.03	6.85	57.82	4.60
Rice bran	15.84	18.65	9.51	12.10	43.90	5.08
Soybean meal	51.66	2.23	6.16	7.55	32.39	4.68
Meat & bone meal	53.81	14.56	1.52	27.31	2.80	4.61
Sunflower meal	40.60	1.85	17.67	7.97	31.91	4.66
Basal diet 1	25.88	3.53	3.29	10.07	57.23	4.45
Basal diet 2	18.49	4.15	3.22	6.88	67.26	4.40
Basal diet 3	17.64	3.25	3.05	6.21	69.85	4.28

[a] All analyses are on a dry matter basis.

[b] The value used for converting to crude protein was 6.25 for all samples with the exception of wheat and wheat bran (5.70).

Table 3. Digestibilities of Dry Matter, Nitrogen, Energy and Metabolizable Energy of Test Feed Ingredients

Feed ingredient	Dry matter digestibility	Protein digestibility	Energy value: DE	DE/GE	ME	ME/GE	ME/DE
	%	%	kcal per gm DM	%	kcal per gm DM	%	%
Corn	88.99	77.66	4.12	88.46	4.05	86.89	98.23
Sorghum	88.08	70.90	4.07	88.03	4.02	86.91	98.73
Wheat	88.95	89.54	4.12	89.20	4.04	87.52	98.12
Alfalfa meal	49.50	55.16	2.08	46.87	1.98	44.70	95.37
Wheat bran	60.42	72.60	2.85	62.00	2.75	59.84	96.52
Rice bran	61.12	67.16	3.30	64.93	3.25	63.91	98.43
Soybean meal	87.05	90.05	4.03	86.12	3.79	81.00	94.05
Meat & bone meal	54.20	81.95	2.85	61.74	2.68	58.19	94.25
Sunflower meal	64.26	83.67	3.06	65.71	2.78	59.75	90.93

Table 4. Simple Correlation Coefficients Between Chemical Composition and Nutritive Value of Diets

Item	Chemical composition, %		
	Crude fiber	Crude protein	Nitrogen free extract
DMD, %	-.79**	--	.56+
ND, %	-.73**	--	---
DE, kcal/g DM	-.71**	--	.53+
ME, kcal/g DM	-.71**	--	.55+
DE/GE, %	-.82***	--	.53+
ME/GE, %	-.82***	--	.55+
ME/DE, %	--	-.52+	--

[a] With 12 observations

+ P < .08.

* P < .05.

** P < .01.

***P < .001.

Table 5. Simple Correlation Coefficients Between Chemical Composition and Nutritive Value of Test Ingredient

Item[a]	Chemical composition, %				
	CP	EE[b]	CF	Ash	NFE
DMD, %	--	--	-.65+	-.70+	.66+
ND, %	--	--	--	--	--
GE, kcal/g DM	--	.67*	--	--	--
DE, kcal/g DM	--	--	-.77*	--	--
ME, kcal/g DM	--	--	-.78*	--	.63+
DE/GE, %	--	--	-.76*	--	--
ME/GE, %	--	--	-.77*	-.61+	--
ME/DE, %	-.81**	--	--	--	.79*

[a]With 9 observations.

[b]Ether extract, other abbreviations as in table 4.

+* ** As in table 4.

Table 6. Prediction of Dry Matter and Nitrogen Digestibilities and Energy Value From Chemical Composition of Diets

		Regression coefficients of chemical composition							
Item[a]	Intercept	Crude protein	Ether extract	Crude fiber	Ash	NFE	r^2	RSD[b]	CV[c] %
DMD, %	96.02	---	-1.533**	-1.625***	---	---	.86***	1.99	2.40
ND, %	83.55	.414*	-1.007*	-1.243**	---	---	.85**	1.91	2.31
DE, kcal/g DM	4.017	---	-----	-0.0731**	---	---	.51*	.169	4.56
ME, kcal/g DM	3.942	--	-0.0747**	---	---	.50*	.175	4.83	
DE/GE, %	95.21	---	-1.249*	-1.723***	---	---	.83**	2.22	2.68
ME/GE, %	93.22	---	-1.171*	-1.760***	---	---	.81***	2.41	2.97
ME/DE, %	99.85	-.080*	-----	-.102[+]			.51*	.364	.37

[a]With 12 observations.

[b]Residual standard deviation = MSE.

[c]Coefficient of variation, % = (RSD/mean) x 100.

+ * ** *** As in table 4.

Table 7. Prediction of Dry Matter and Nitrogen Digestibilities and Energy Value From Chemical Composition of Feed Ingredients

Item[a]	Intercept	Regression coefficient[c]					r^2	RSD[b]
		CP	EE	CF	Ash	NFE		
DMD, %	88.22	.348*	---	-1.181*	-1.869*	---	.94***	5.02
ND, %	73.68	.617*	---	-.701*	-.886*	---	.83*	5.83
GE, kcal/g DM	4.356	.010**	.053***	.004*	-.039***	---	.98***	.03
DE, kcal/g DM	5.944	---	---	-.080***	-1.06**	-.019*	.94**	.219
DE, kcal/g DM	4.360	---	---	-.065**	-.049*		.87**	.31
ME, kcal/g DM	4.277	---	---	-.069***	-.052**	---	.91***	.27
DE/GE, %	88.45	.319*	---	-1.329***	-1.526**	---	.96***	4.18
ME/GE, %	91.60	---	---	-1.414***	-1.138**	---	.93***	5.00
ME/DE, %	100.4	-.122***	---	-.148*	---	---	.89**	.99

[a]With 9 observations.

[b]As in table 6.

[c]Abbreviations as in table 6.

* ** *** As in table 4.