Metabolizable Energy Values of Some Poultry Feeds Determined by Various Methods and Their Estimation Using Metabolizability of the Dry Matter

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ABSTRACT Metabolizable energy (M.E.) values of 12 U.S. feedstuffs and 10 Korean feed ingredients for poultry were determined both by the total collection method and by the chromic oxide indicator method. It was found that M.E. values of most poultry feedstuffs can be measured accurately by either method. Limitation of feed intake to almost maintenance level (approximately 60% of *ad libitum*) did not increase or decrease the M.E. value of the feeds.

An attempt was made to establish a prediction equation to estimate the M.E. values based on the apparent metabolizability of dry matter (D.M.) in the feedstuffs. The results indicated that linear relationships do exist between D.M. metabolizability and M.E. values of carbohydrate-rich feedstuffs (grains and their by-products) or protein-rich feed ingredients (oil seed meals and animal protein feeds) or lipid-rich feeds (fats and oils) as follows: The prediction equation for carbohydrate-rich feedstuffs was $Y = 0.0947x - 3.498$ ($r^2 = 0.99$, Sy.x = 0.015); for protein-rich feed ingredients, it was $Y = 0.1294x - 4.898$ ($r^2 = 0.99$, Sy.x = 0.027); and for lipid-rich feedstuffs it was $Y = 0.0844x + 0.774$ ($r^2 = 0.99$, Sy.x = 0.032), where x = metabolizability of dry matter of feeds in %, and Y = metabolizable energy values in kcal./g. The errors attached to these estimations were relatively small. Thus these prediction equations may be very useful for estimation of the M.E. values from D.M. apparent metabolizability of feeds, especially in areas of the world where calorimetry is not possible.

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INTRODUCTION

METABOLIZABLE energy values of poultry feeds are computed as the difference between gross energy content of the feed and the energy lost through the excreta. Metabolizable energy (M.E.) is the most widely used energy term for expressing calorific concentration of poultry feeds, and is a more precise measure than productive energy (Hill and Anderson, 1958). The methods usually used for the determination of M.E. of poultry diets are based on the studies developed by Hill and his associates, and on the use of chromic oxide as an index substance (Hill and Anderson, 1958; Hill *et al.*, 1960). The latter method avoids the necessity for total collection and weighing of feed intake and excreta. Methods employing index substances are more commonly used in measuring M.E. values for poultry, while the total collection method is the predominant technique employed with swine and ruminants (Carew, 1973).

The reliability of M.E. values and the reproducibility of analytical data for chromic oxide have been questioned by many scientists (Lee and Han, 1974; Carew, 1973; Kohler and Kuzmicky, 1970; Halloran, 1972). The amount of intestinal absorption of chromic oxide in poultry may be open to question (Vohra and Kratzer, 1967). However, Sibbald *et al.* (1960) suggested that the use of chromic oxide may lead to greater precision than the

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use of the total measurements of feeds and feces. Errors inherent in the total collection methods have been stated to lead to M.E. values biased in a direction higher than that obtained with index substances (Sibbald *et al.*, 1960; Halloran, 1972). Advantages of chromic oxide as a good index material for use in experiments on nutrient digestibility and balance have been reported by Schürch *et al.* (1950), Dansky and Hill (1952) and Yoshida and Morimoto (1957). Bolin *et al.* (1952) and Czarnocki *et al.* (1961) discussed the chemical methods for the determination of chromic oxide. Although chromic oxide is the most widely accepted index substance, crude fiber also can be used as a tracer in M.E. determination (Almquist and Halloran, 1971).

In addition to direct methods for the determination of M.E., a number of indirect methods have been proposed. Metabolizable energy values of feeds have been estimated indirectly from either chemical composition of ingredients (Carpenter and Clegg, 1956; Sibbald *et al.*, 1963; Begin, 1961; Watts and Davenport, 1971) or animal growth data (Gordon *et al.*, 1961; Young and Artman, 1961; Squibb, 1971).

Metabolizable energy values of oil seed meals (Zablan *et al.*, 1963; Lohdi *et al.*, 1969; Hill and Renner, 1960; Olson *et al.*, 1961; Lee *et al.*, 1973), of grains and their by-products (Leong *et al.*, 1962; Lee and Kim, 1974; Hill *et al.*, 1960; Bayley *et al.*, 1968; Schumaier and McGinnis, 1967), of fats and fatty substances (Young, 1961; Young and Artman, 1961; Sibbald *et al.*, 1962; Hill and Renner, 1959; Renner and Hill, 1960; Cullen *et al.*, 1962; Kalmbach and Potter, 1959) and of miscellaneous feedstuffs (Halloran and Almquist, 1970; Maust *et al.*, 1972; Potter and Matterson, 1960; Anderson *et al.*, 1958; Stutz and Matterson, 1964) have appeared in the literature. The overall aspects of M.E. are well reviewed by Sibbald and Slinger (1961), Vohra (1966, 1972) and Anderson (1955).

In view of the need for further information concerning the M.E. values of certain feedstuffs, and also a need to simplify the M.E. determination as much as possible, a series of experiments was conducted (1) to determine M.E. values of 22 commonly used poultry feed ingredients of both U.S. and Korean origin; (2) to compare the M.E. values obtained by either total collection method or chromic oxide indicator method; (3) to study the effect of level of feed intake on the M.E. values; and (4) to establish prediction equations for estimation of M.E. values from apparent metabolizability of dry matter of the test ingredients.

MATERIALS AND METHODS

Experimental Chicks and Design. Male crossbred chicks of Vantress × White Ply-

TABLE 1.—*Reference diet*[1]

Components	Proportion
	%
Glucose monohydrate (Cerelose)	52.8
Soybean meal (50% protein)	16.0
Casein, crude	11.0
Gelatin	2.5
Corn oil	2.5
Fish meal (menhaden)	4.0
Fish solubles	1.0
Yeast, brewers dried	2.5
Whey, whole dried	2.0
Limestone, ground	2.0
Dicalcium phosphate	1.0
Salt, iodized	0.6
Vitamin mixture[2]	0.7
Mineral mixture[3]	0.4
Chromic oxide "bread"[4]	1.0

[1] From Hill *et al.* (1960).

[2] Supplies (in I.U. or mg./100g. diet): 1.5 thiamin, 1.5 riboflavin, 5.0 niacin, 0.6 folic acid, 0.6 pyridoxine, 0.06 biotin, 0.02 vitamin B_{12}, 200 choline chloride, 2.0 calcium pantothenate, 0.15 menadione Na-bisulfite, 5 I.U. vitamin E, 450 I.U. vitamin D_3, 450 I.U. vitamin A, 10 antioxidant.

[3] Supplies (in mg./100 g. diet): 220 KH_2PO_4, 120 $MgSO_4$, 30 $MnSO_4$, 30 $FeSO_4 \cdot 7H_2O$, 0.8 $CuSO_4 \cdot 5H_2O$, 0.3 NaI, 6.3 ZnO, 0.8 $NaMoO_4 \cdot 2H_2O$, 0.17 $CoCl_2 \cdot 6H_2O$, 0.022 Na_2SeO_3.

[4] Chromic oxide bread prepared and used in each diet at level of 1.0% (0.3% CR_2O_3) as an external index substance (Dansky and Hill, 1952).

mouth Rock were fed the reference diet (Table 1) in electrically-heated thermostatically-controlled Petersime batteries to 2 weeks of age. They were then allotted to groups of 8 chicks each on the basis of body weight, equalizing both mean body weight and body weight distribution among groups. Each experimental diet containing the test ingredient was fed to duplicate lots of chicks from 2 to 4 weeks of age. Feed and water were supplied *ad libitum* to all groups except the restricted groups, in which feed intake was controlled to 60% of that consumed by the corresponding *ad libitum* groups.

Experimental Feed Ingredients. Test ingredients used in the experiments were No. 2 yellow corn, opaque-2 corn, high sugar corn, rice, barley, wheat, milo, meat and bone meal, fish meal (herring), soybean meal and alfalfa meal produced in the United States, and broken rice, barley, fish meal, perilla oil meal, rapeseed oil meal, sesame oil meal, corn gluten meal, wheat shorts, rice bran (defatted) and wheat bran produced in Korea. The nutrient composition of the experimental feedstuffs is listed in Table 2. These feedstuffs were substituted for glucose monohydrate (cerelose) in the reference diet at a level of 40%.

Total Collection and Preparation of Excreta. After the chicks had received the experimental diet containing a specific feed ingredient for 10 days, excreta were collected at 24 hour intervals on four consecutive days. During the collection period, the amount of feed consumed also was quantitatively recorded. Special attention was given to eliminate the contamination of excreta with feed,

TABLE 2.—*Nutrient composition of reference diet and test ingredients*

Nutrient / Feedstuffs	Moisture	Crude protein	Crude fat	Crude fiber	Crude ash	Nitrogen-free extract
	%	%	%	%	%	%
Reference diet	11.0	25.6	3.8	0.7	4.9	54.0
Yellow corn (U.S.#2, Sample A)	11.7	9.6	3.7	2.0	1.1	71.9
Opaque-2 corn (U.S.)	9.7	9.3	4.1	2.3	1.2	73.4
Yellow corn (U.S.#2, Sample B)	9.4	8.6	3.8	2.2	1.4	74.6
High sugar corn (U.S.)	9.2	10.8	5.6	2.6	1.5	70.3
Rice (U.S.)	9.1	7.9	0.2	0.4	0.5	81.9
Broken rice (Korea)	9.0	8.3	5.0	1.0	3.0	73.7
Barley (Korea)	9.8	13.4	1.5	4.1	3.1	68.1
Barley (U.S.)	7.6	10.1	2.0	6.3	2.2	71.8
Wheat (U.S.)	7.4	12.3	1.7	2.6	1.9	74.1
Milo (U.S.)	7.4	10.8	3.4	6.0	1.3	71.2
Meat and bone meal (U.S.)	7.5	45.4	6.3	2.5	23.6	14.3
Fish meal (Korea)	7.1	59.0	6.2	0.6	27.1	0
Fish meal (herring, U.S.)	8.1	70.5	13.0	0.4	9.1	0
Perilla oil meal (Korea)	7.0	44.4	1.9	20.3	9.5	16.9
Rapeseed oil meal (Korea)	8.3	38.7	2.0	10.8	7.0	33.2
Soybean meal (U.S.)	9.5	51.4	0.4	2.6	5.8	30.3
Sesame oil meal (Korea)	7.3	46.5	2.1	14.1	11.6	18.4
Corn gluten meal (Korea)	7.0	43.2	1.7	1.4	1.4	45.3
Wheat shorts (Korea)	8.9	15.7	3.8	7.8	3.6	60.2
Rice bran, defatted (Korea)	7.8	20.3	1.2	9.8	13.7	47.2
Wheat bran (Korea)	8.2	15.4	3.2	8.4	4.7	60.1
Alfalfa (U.S.)	8.4	15.9	2.8	25.2	7.8	39.9

feathers and scales. Immediately after each day's collection, the excreta were placed in a pan and dried in an oven at 70° C. for 24 hours. The successive dried excreta samples were added together to make a total sample. The composite sample then was ground and stored for proximate analysis, chromic oxide and heat of combustion determinations.

Chemical Analyses. All feeds and excreta were analyzed for proximate composition by the methods described in A.O.A.C. (1970), and heat of combustion values by an adiabatic

TABLE 3.—*Metabolizable energy values of some poultry feedstuffs determined by total collection method and chromic oxide indicator method*

Feedstuffs	M.E.$_n$ values: Total collection method	M.E.$_n$ values: Indicator method
	kcal./g.	kcal./g.
Yellow corn (Sample A)	3.31 ± 0.11	3.01 ± 0.13
Opaque-2 corn (U.S.)	3.23 ± 0.01	3.26 ± 0.06
Yellow corn (Sample B)	3.21 ± 0.06	3.29 ± 0.07
High sugar corn (U.S.)	3.22 ± 0.02	3.17 ± 0.06
Rice (U.S.)	3.60 ± 0.04	3.60 ± 0.05
Broken rice (Korea)	3.48 ± 0.05	3.50 ± 0.05
Barley (Korea)	2.39 ± 0.06	2.49 ± 0.10
Barley (U.S.)	2.50 ± 0.01	2.66 ± 0.04
Wheat (U.S.)	3.06 ± 0.02	3.08 ± 0.11
Milo (U.S.)	3.30 ± 0.07	3.38 ± 0.06
Meat and bone meal (U.S.)	2.06 ± 0.03	2.02 ± 0.14
Fish meal (Korea)	2.16 ± 0.06	2.13 ± 0.10
Fish meal (herring, U.S.)	3.37 ± 0.17	3.44 ± 0.05
Rapeseed oil meal (Korea)	1.40 ± 0.05	1.75 ± 0.42
Soybean meal (U.S.)	2.19 ± 0.11	2.15 ± 0.19
Corn gluten meal (Korea)	3.54 ± 0.07	3.42 ± 0.05
Wheat shorts (Korea)	1.97 ± 0.05	1.41 ± 0.23
Rice bran, defatted (Korea)	1.41 ± 0.12	1.18 ± 0.18
Wheat bran (Korea)	1.68 ± 0.09	1.50 ± 0.18
Mean	2.68 ± 0.06	2.65 ± 0.12

TABLE 4.—*Metabolizable energy values obtained at different levels of feed intake*

Feedstuffs	Level of feed intake: *Ad libitum*	Level of feed intake: Limited[1]
	kcal./g.	kcal./g.
Yellow corn (U.S.#2)	3.39 ± 0.03	3.24 ± 0.06
Barley (Korea)	2.43 ± 0.05	2.36 ± 0.03
Rice (U.S.)	3.61 ± 0.05	3.59 ± 0.01
Broken rice (Korea)	3.45 ± 0.04	3.55 ± 0.03
Wheat (U.S.)	3.05 ± 0.01	3.08 ± 0.01
Fish meal (U.S.)	3.51 ± 0.07	3.24 ± 0.02
Fish meal (Korea)	2.17 ± 0.03	2.15 ± 0.07
Meat and bone meal (U.S.)	2.06 ± 0.03	2.06 ± 0.01
Soybean meal (U.S.)	2.27 ± 0.08	2.11 ± 0.01
Corn gluten meal (Korea)	3.48 ± 0.01	3.59 ± 0.01
Rice bran, defatted (Korea)	1.52 ± 0.02	1.31 ± 0.01
Wheat bran (Korea)	1.71 ± 0.06	1.65 ± 0.08
Mean	2.72 ± 0.04	2.66 ± 0.03

[1] Approximately 60% of *ad libitum*.

oxygen bomb calorimeter. Chromic oxide concentration was determined on both feed and excreta by the method described by Hill and Anderson (1958). Details of the calculation of metabolizable energy content have been described previously (Hill and Anderson, 1958; Hill *et al.*, 1960). These M.E. values represent the averages of the data obtained from the duplicate lots, or from four to six replicated lots for some ingredients.

The apparent dry matter metabolizability of each *diet* [I] was calculated according to the following formula:

D.M. apparent metabolizability (%) of diet

$$= \frac{\text{D.M. intake (g.)} - \text{D.M. excreted in feces and urine (g.)}}{\text{D.M. intake (g.)}} \times 100 \quad [I]$$

The apparent dry matter metabolizability of each *test ingredient* [II] was calculated according to the following formula:

TABLE 5.—*Comparison of apparent metabolizability of dry matter with biologically-determined metabolizable energy values of feedstuffs*

Item & Feedstuff	Apparent dry matter metaboliz- ability	M.E. value
	%	kcal./g.
1. *High carbohydrate feedstuffs*		
Yellow corn (U.S. Sample A)	75.2	3.73
	76.1	3.80
	73.1	3.53
	74.9	3.67
Opaque-2 corn (U.S.)	74.6	3.61
	74.4	3.58
Yellow corn (U.S. Sample B)	75.1	3.63
	74.8	3.61
High sugar corn (U.S.)	73.3	3.60
	72.0	3.56
Rice (U.S.)	80.7	4.07
	79.5	3.91
	79.9	3.99
	80.4	3.99
Barley (U.S.)	67.7	2.79
	68.7	2.76
Wheat (U.S.)	72.6	3.40
	73.0	3.38
	71.7	3.41
	73.4	3.42
Milo (U.S.)	76.5	3.74
	75.0	3.59
Alfalfa (U.S.)	49.1	1.04
	48.7	1.10
Broken rice (Korea)	77.0	3.88
	76.3	3.78
	77.5	3.91
	79.2	3.98
Barley (Korea)	65.3	2.65
	66.6	2.75
	64.6	2.58
	65.8	2.65
Wheat shorts (Korea)	59.5	2.26
	58.6	2.15
Rice bran, defatted (Korea)	54.9	1.67
	55.1	1.70
	52.0	1.47
	51.8	1.44
Wheat bran (Korea)	57.4	1.97
	56.1	1.84
	56.8	1.92
	54.8	1.74
2. *High protein feedstuffs*		
Meat and bone meal (U.S.)	56.6	2.25
	56.6	2.31
	55.4	2.29
	55.6	2.29
Fish meal (herring, U.S.)	65.3	3.97
Soybean meal (U.S.)	57.6	2.61
	56.0	2.43
	54.3	2.36
	56.4	2.33
Rapeseed oil meal (Korea)	49.4	1.50
	49.6	1.61
Fish meal (Korea)	55.8	2.44
	54.8	2.38
	56.3	2.46
	54.3	2.31
Perilla oil meal (Korea)	45.6	0.94
	45.1	0.65
	42.3	0.55
	42.2	0.62
Sesame oil meal (Korea)	47.5	1.19
	45.8	0.98
	46.1	0.94
Corn gluten meal (Korea)	68.6	3.87
	68.7	3.86
	69.3	4.00
	70.7	3.98
3. *High lipid feedstuffs*[1]		
Corn oil	97.0	8.89
	92.0	8.36
Lard	91.0	8.69
	90.0	8.55
Tallow	65.0	6.18
	74.0	6.97
Choice white grease	95.0	8.67
Bleachable fancy tallow	86.0	7.94
All beef tallow	79.0	7.62

[1] Data of Renner and Hill (1960) and Cullen *et al.* (1962).

$$\text{D.M. apparent metabolizability of test ingredient} = \text{Reference diet D.M. metabolizability (\%)} - \left(\frac{\text{Reference diet D.M. metabolizability} - \text{Test diet D.M. metabolizability}}{\text{Proportion of test ingredient substituted into reference diet}}\right) \quad \text{[II]}$$

RESULTS AND DISCUSSION

1. Total Collection Method vs. *Indicator Method.* Metabolizable energy values of 19 experimental feed ingredients were determined by total collection and chromic oxide indicator methods (Table 3). These values are expressed on a 90% air-dry-matter basis and are corrected for nitrogen retention. The M.E. values were generally similar to those

TABLE 6.—*Relationship between D.M. metabolizability and metabolizable energy*

Feedstuffs	Prediction equation	r^2	Sy.x	n
Carbohydrate-rich feeds	Y = 0.0949x − 3.498	0.99	0.015	44
Protein-rich feeds	Y = 0.1294x − 4.898	0.99	0.027	26
Lipid-rich feeds	Y = 0.0844x + 0.774	0.99	0.032	9[1]

[1]Data adapted from Renner and Hill (1960) and Cullen *et al.* (1962).

reported in the existing literature. Metabolizable energy values of corn, barley, wheat, soybean meal and rice bran (defatted) were slightly lower than the figures listed in the National Research Council bulletin on Nutrient Requirements of Poultry (1971). However, M.E. values of milo, meat and bone meal, and fish meal (herring) were slightly higher than the N.R.C. (1971) values. Metabolizable energy values were lower for Korean fish meal, rapeseed oil meal (Lee and Kim, 1973) and wheat bran (Lee and Han, 1974) and M.E. value of local corn gluten meal was higher than values found for this material in Korea (Lee *et al.*, 1973).

As compared to published values, these variations in M.E. are not great and probably represent the normal variability to be expected from sample to sample.

It may be concluded from these results that the total collection method can be used in accurately determining M.E. values of poultry feeds, since the mean values of M.E. of the 19 ingredients determined by this method was found to be 2.68 kcal./g., and that by the chromic oxide indicator method, 2.65 kcal./g.

2. *Restriction of Feed Intake.* The effect of level of feed intake (*ad libitum vs.* limited) on the M.E. values of 12 feedstuffs is summarized in Table 4. No increases or decreases in the M.E. values of experimental ingredients were observed between two levels of feed intake. Although the average M.E. values of the ingredients tested were slightly lower (2.66 kcal./g.) when the level of feed intake was limited to the almost maintenance level (approximately 60% of *ad libitum*) as compared with the results obtained with *ad libitum* feeding (2.72 kcal./g.), these results were not statistically significant. The present data support the observations of Yoshida *et al.* (1964) that level of feed intake has no effect on M.E. values. Similar results also were obtained by Anderson *et al.* (1958). It is apparent from the present results that the level of feed intake did not exert any effect on the M.E. values of feed ingredients.

3. *Prediction Equation of Metabolizable Energy.* Many scientists have tried in the past to establish an indirect method to estimate the M.E. values of poultry feeds from either

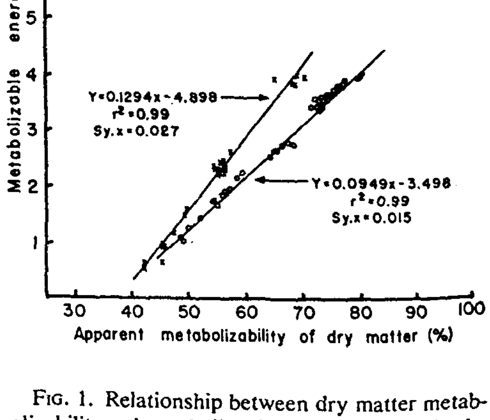

FIG. 1. Relationship between dry matter metabolizability and metabolizable energy values of feeds.

chemical composition of test ingredients or animal growth data. Unfortunately, no satisfactory method of prediction has thus far been established. An attempt was made, therefore, to formulate a prediction equation of M.E. values of feeds based on the metabolizability of dry matter in the feed ingredients. The M.E. values of test ingredients were largely proportional to the apparent metabolizability of the dry matter content of test feeds (Table 5). These data indicate that the determination of M.E. values of ingredients may be inaccurate when the apparent metabolizability of D.M. of a specific feed is less than 50%. Linear relationships between D.M. metabolizability and M.E. values of feeds were found. Three different relationships appeared to exist, depending upon whether the ingredient was carbohydrate-rich, protein-rich, or lipid-rich. These relationships are shown in Table 6 and Figure 1, where X = dry matter metabolizability (%) and Y = M.E. values (kcal./g., dry matter basis).

The M.E. values of various feedstuffs apparently can be computed from the availability of dry matter, since the errors of the estimates are relatively small. For the computation of M.E. values by these equations, only determinations of metabolizability of D.M. in the test ingredients are needed. This should be a useful method of estimating feeding values in areas where a calorimeter is not available.

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