Apparent and True Metabolizable Energy Values of Feedstuffs for Ducks[1]

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ABSTRACT Two experiments were conducted, each with 24 White Pekin ducks, to determine the AME and TME content of five feedstuffs for ducks. In each experiment, fasting losses were obtained from six ducks and six ducks were used for each feedstuff. Each experiment lasted 102 h with an initial 48-h period and a 54-h excreta collection period. During the first 48-h period, all birds were tube-fed dextrose (30 g/100 mL of water) at 8 and 32 h after feed was withdrawn. Thirty grams of each feedstuff were tube-fed (30 g/100 mL of water) at 48 and 54 h after feed was withdrawn. The birds from which fasting losses were obtained were intubated with 30 g dextrose (30 g/100 mL of water) at 48 and 54 h after feed was withdrawn. Excreta were collected during the last 54 h into bags screwed onto lids sutured around the vent of each bird. In the first experiment, the feedstuffs evaluated were corn, dehulled oats, and wheat. The fasting energy and nitrogen losses per bird in the 54-h collection period were 12.1 kcal and 0.29 g, respectively. The AME_n values for the birds fed corn, dehulled oats, and wheat were 3.10, 3.48, and 3.14 kcal/g, respectively. The TME_n values for the respective feedstuffs were 3.27, 3.64, and 3.30 kcal/g. In the second experiment, the feedstuffs evaluated were corn, parboiled rice, and rye. The fasting energy and nitrogen losses per bird in the 54-h collection period were 18.9 kcal and 1.09 g, respectively. The AME_n values for the birds fed corn, parboiled rice, and rye were 3.24, 3.45, and 2.69 kcal/g, respectively. The TME_n values for the respective feedstuffs were 3.40, 3.61, and 2.85 kcal/g. The data provide new information on AME_n and TME_n values of corn, wheat, parboiled rice, dehulled oats, and rye for ducks.

(*Key words*: metabolizable energy, feedstuffs, rice, oats, rye, duck)

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INTRODUCTION

Ducks and chickens exhibit differences in growth rate and body composition (Siregar and Farrell, 1980a). Bioavailable energy studies have shown significant differences in the dietary requirements and energy utilization of ducks and chickens (Muztar *et al.*, 1977; Siregar and Farrell, 1980b; Ostrowski-Meissner, 1983). However, duck diets are usually formulated by using ME values taken from tables of chicken bioassay data because there are limited data on determinations of the available energy content of feedstuffs for ducks. Therefore research to determine the ME content of a wide range of feedstuffs for ducks is warranted.

The primary dietary energy sources in commercial poultry diets have traditionally been corn and wheat. In an effort to ease the competition for these cereal grains between humans and monogastric food animals, alternative cereal grains have been used in formulating poultry feeds. Some of the cereal grains used for this purpose are rice, oats, and rye. Oats and rye, which contain higher levels of growth-depressing factors than corn, wheat, and rice, have received limited use in poultry diets. One of the growth-depressing factors limiting the bioavailable energy content of these alternative grains is their high crude fiber content. A study by Schubert *et al.* (1982) suggested that Muscovy and White Pekin ducks were better able to digest organic matter and crude fiber than laying hens. If this is true, then the ME content of oats and rye should be higher for ducks than for chickens because of the high fiber content of these cereal grains. Consequently, oats and rye could be used in duck rations when economic conditions allow. The current study was undertaken to determine the AME and TME contents of corn, wheat, parboiled rice, dehulled oats, and rye, with the aim of providing new information for improved duck diet formulations.

MATERIALS AND METHODS

Experimental Design and Feeding of Birds

Twenty-four male White Pekin ducks, age 9 and 10 wk, of similar weight (3.7 and 3.8 kg) were used in each of two

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TABLE 1. Gross energy, crude protein, and dry matter of corn, dehulled oat, wheat, parboiled rice, and rye[1,2]

Variable	Corn	Oats	Wheat	Rice	Rye
Gross energy, kcal/g	3.99	4.09	3.89	3.86	3.92
Crude protein, %	6.83	10.95	13.10	10.09	10.70
Dry matter, %	88.50	87.75	87.22	90.32	89.16

[1] Samples were analyzed in duplicates.

[2] Values are means of the samples analyzed for each feedstuff.

experiments. The ducks used in Experiment 1 were not re-used in Experiment 2. Birds were housed in a three-tier stainless-steel battery cage with 12 compartments. Two birds were randomly assigned to each of the compartments (66 × 66 cm), which were equipped with a feeder and a waterer. When not under experimental conditions, the birds had unrestricted access to water and a basal diet. The environmental temperature of the room was maintained between 21 and 25 C under continuous light. In each experiment, there were four treatments comprised of three dietary groups and one feed-restricted group. Each bird served as an experimental unit and there were six birds per treatment. During the experimental period, approximately 500 mL of distilled water was provided daily to each compartment.

The feedstuffs were ground through a 0.5-mm screen to ensure a fine particle size. Each feedstuff was mixed with water in 125-mL plastic beakers to ensure a homogeneous wet mash. The wet mash was force-fed to the birds through a 35-cm-long, 8-mm diameter tygon tube connected to a 60-mL syringe. Several feedstuff to water ratios were evaluated and a mixture of 30 g feedstuff to 80 mL of water was found to facilitate easy flow through the tygon tube. The tygon tube was inserted into the esophagus of each duck. After 30 g of a feedstuff was mixed with 80 mL of distilled water in the plastic beaker, the contents were poured into the syringe. The syringe plunger was used to gently force the mash through the syringe into the esophagi of the ducks. Approximately 20 mL of distilled water were used to wash particles of feedstuff that adhered to the tube and syringe into the birds' esophagi. The analyzed gross energy, crude protein, and dry matter percentages of the feedstuffs are given in Table 1.

Excreta Collection Equipment and Methodology

Birds were fitted with individual excreta collection vessels as described previously by Adeola *et al.* (1997). In summary, approximately 60 h before the start of an experiment, each duck was surgically fitted with a Playtex™[3] bottle retainer lid. The ducks were placed head first supine into a restrainer box, and their feet were secured with cotton string tied to two bolts on the surface of the box. The feathers around the vent of the ducks were plucked by hand. Four milliliters of the local anesthetic lidocaine hydrochloride were injected around the vent (1 mL in each of four regions). A continuous suture was applied to secure the lid snug against the skin of the bird. The Playtex™ bottles were cut 3 cm below the threads and Whirl-Pak™[4] bags inserted into the tops of the bottles so that the edges of the bags hung over the threads of the bottle. Duct tape was used to cover the bags to prevent punctures. The procedure was reviewed and approved by the Purdue University Animal Care and Use Committee.

Experimental Procedures

During the first 48 h of each experiment all the birds were intubated with dextrose solution (30 g/100 mL of water) at 8 and 32 h after feed was removed (McNab and Blair, 1988). Thirty grams (30 g/100 mL of water) of each feedstuff were tube-fed to each bird at 48 and 54 h after food was withdrawn. The remaining six ducks that served as controls for the measurement of fasting energy and nitrogen losses were given 30 g dextrose (30 g/100 mL of water) at 48 and 54 h after feed was withdrawn. The Playtex™ bottles with attached Whirl-pak™ bags were screwed on to the affixed lids after the first feeding. Total excreta samples were collected the following 54 h from each bird, labeled, and frozen. The experimental protocol is summarized in Table 2.

Analysis of Excreta and Treatment of Results

The frozen excreta samples were allowed to come to equilibrium with room temperature, dried at 55 C, weighed, and then ground through a 0.5-mm screen. The gross energy contents of the feedstuffs and excreta samples were determined by bomb calorimetry with benzoic acid as a standard. Nitrogen determination was by combustion analysis, using the FP-2000 nitrogen analyzer.[5] Dry matter was determined by oven drying at 105 C for 24 h. The AME values of the feedstuffs were calculated by the method described by Sibbald (1976). The AME, AME_n, TME, and TME_n were calculated as follows:

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[3] Playtex Products Inc., Dover, DE 19901.

[4] Nasco, Fort Atkinson, WI 53538.

[5] LECO Corp., St. Joseph, MI 49085.

TABLE 2. Experimental protocol

Time (h)	Operation
0	Feed withdrawn.
8	Each bird fed dextrose solution (30 g/100 mL water).
32	Each bird fed dextrose solution (30 g/100 mL water).
48	Birds fed (30 g/100 mL of water) appropriate feedstuff. Birds used for FEL[1] and FNL[2] calculations were fed dextrose solution (30 g/100 mL water). Collection bags screwed into affixed lids.
54	Birds fed (30 g/100 mL water) appropriate feedstuff. Birds used for FEL and FNL calculations fed dextrose solution (30 g/100 mL water).
60	Excreta collected and frozen. New collection bags screwed into lids.
72	Excreta collected and frozen. New collection bags screwed into lids.
84	Excreta collected and frozen. New collection bags screwed into lids.
96	Excreta collected and frozen. New collection bags screwed into lids.
102	Excreta collected and frozen. Lids removed from birds.

[1] FEL = fasting energy loss.

[2] FNL = fasting nitrogen loss.

$$\begin{aligned} \text{AME} &= (\text{EI} - \text{EO})/\text{FI} \\ \text{AME}_n &= \text{AME} - (8.22 \times \text{ANR}/\text{FI}) \\ \text{TME} &= \text{AME} + (\text{FEL}/\text{FI}) \\ \text{TME}_n &= \text{TME} - (8.22 \times \text{ANR}/\text{FI}) - (8.22 \times \text{FNL}/\text{FI}) \end{aligned}$$

where EI is gross energy intake of the feedstuff, EO is gross energy voided of the feedstuff, FI is the feed intake of the feedstuff fed to each bird (60 g), ANR is the apparent nitrogen retained, FEL is the fasting energy loss, and FNL is the fasting nitrogen loss in the group of feed-deprived ducks. Nitrogen retained in tissue can be catabolized to yield energy-containing excretory products that contribute to fasting energy loss. Therefore, the gross energy excreted was corrected to zero nitrogen balance using a factor of 8.22 kcal/g nitrogen (Hill and Anderson, 1958).

Analysis of variance using the General Linear Models (GLM) procedure for SAS® (SAS Institute, 1990) was performed. Treatment mean differences were separated for statistical significance ($P < 0.05$) by the Newmans-Keuls multiple range test (Steel and Torrie, 1980).

RESULTS

Experiment 1

The weight losses of the birds during the 102-h experimental period were 543, 654, 479, and 533 g for the feed-deprived birds and the birds fed corn, dehulled oats, and wheat, respectively. Fasting losses of nitrogen and energy for the 54-h collection period were 0.29 ± 0.11 g and 12.1 ± 3.63 kcal, respectively. Feed-deprived birds voided 3.9 ± 0.45 g of dry excreta during the 54-h collection period. The dry excreta voided were 13.27 ± 2.07, 8.17 ± 0.32, and 9.20 ± 0.20 g for the birds that were tube-fed corn, oats, and wheat, respectively. The dry matter digestibilities, nitrogen balances, and energy

TABLE 3. Percentage of dry matter digestibilities, nitrogen, and energy balances of fed ducks[1]

Variable	Corn	Oats	Wheat	SE
Experiment 1				
DMD[2]	77.49	86.21	84.28	2.08
Nitrogen intake, g	0.68^c	1.05^b	1.32^a	. . .
Energy intake, kcal	239.20^b	245.6^a	233.2^c	. . .
Nitrogen output, g	0.62	0.47	0.45	0.08
Energy output, kcal	52.50^a	32.10^b	37.50^b	5.05
ANR,[3] g	0.06^c	0.58^b	0.87^a	0.08
TNR,[4] g	0.35^c	0.87^b	1.16^a	0.08
	Corn	Rice	Rye	SE
Experiment 2				
DMD	78.80	86.64	67.30	1.07
Nitrogen intake, g	0.66	0.97	1.08	. . .
Energy intake, kcal	236.10	231.80	235.20	. . .
Nitrogen output, g	1.21	1.16	1.41	0.15
Energy output, kcal	46.40^b	26.50^c	77.20^a	2.33
ANR, g	–0.56	–0.19	–0.39	0.15
TNR, g	0.53	0.89	0.70	0.08

[a–c] Means in each row with no common superscript differ significantly ($P \leq 0.05$).

[1] Mean of six ducks.

[2] DMD = dry matter digestibilities.

[3] ANR = apparent nitrogen retained.

[4] TNR = true nitrogen retained.

balances of the tube-fed ducks are given in Table 3. The total dry matter digestibilities were highest for oats and lowest for corn ($P < 0.05$). The birds fed corn excreted approximately 20% of the energy intake. The true nitrogen retained was highest in wheat and lowest in corn ($P < 0.05$). The AME, AME_n, TME, and TME_n values are presented in Table 4. Nitrogen correction resulted in a 2 to 5% reduction in the TME values off all the feedstuffs. The TME_n content of dehulled oats was higher ($P < 0.05$) than those of corn and wheat and were 3.64, 3.27, and 3.30 kcal/g, respectively.

Experiment 2

The weight losses of the birds during the 102-h experimental period were 439, 457, 431, and 463 g for the feed-deprived birds and the birds fed corn, rice, and rye, respectively. Fasting losses of nitrogen and energy for the 54-h collection period were 1.09 ± 0.40 g and 18.90 ± 5.10 kcal, respectively. Feed-deprived birds voided 6.48 ± 0.63 g of dry excreta during 54-h collection period. The dry excreta voided were 12.36 ± 0.57, 7.90 ± 0.40, and 18.78 ± 0.68 g for the birds that were tube-fed corn, rice, and rye, respectively. The dry matter digestibilities, nitrogen balances, and energy balances of the tube-fed ducks are given in Table 3. The total dry matter digestibilities were highest for rice and lowest for rye ($P < 0.05$). The birds fed corn excreted approximately 20% of the energy intake compared to 11 and 33% for the birds fed rice and rye, respectively. The true retained nitrogen did not differ significantly between the three feedstuffs ($P > 0.05$). The AME, AME_n, TME, and TME_n values are presented in Table 4. The TME_n content was highest ($P < 0.05$) for rice, intermediate for corn, and lowest for rye and were 3.61, 3.40, and 2.85 kcal/g, respectively.

DISCUSSION

The ducks used in this study were 9 and 10 wk of age and weighed 3.7 and 3.8 kg, respectively. Ducks at these ages and weights can be intubated with 30 g of feedstuff mixed with 100 mL water without undue discomfort to the birds and are easier to handle than mature birds. Furthermore, previous work done with chickens (Sibbald, 1978; Ten Doeschate *et al*, 1993) has indicated that TME values were independent of the age of the birds.

TABLE 4. The AME, AME_n, TME, and TME_n values of corn, oats, wheat, rice, and rye[1]

Variable	Corn	Oats	Wheat	SE
	(kcal/g)			
Experiment 1				
AME	3.11^b	3.56^a	3.26^b	0.084
AME_n	3.10^b	3.48^a	3.14^b	0.075
TME	3.31^b	3.76^a	3.46^b	0.084
TME_n	3.27^b	3.64^a	3.30^b	0.075
	Corn	Rice	Rye	SE
Experiment 2				
AME	3.16^b	3.42^a	2.63^c	0.038
AME_n	3.24^b	3.45^a	2.69^c	0.039
TME	3.48^b	3.74^a	2.95^c	0.038
TME_n	3.40^b	3.61^a	2.85^c	0.039

[a–c]Means in the same row with no common superscript differ significantly ($P < 0.05$).

[1] Mean of six ducks.

To reduce variation in fasting energy losses, ducks were given an energy source that is completely absorbed and not excreted in the urine. From preliminary experiments ducks under similar experimental conditions regained the weight lost during the 102-h experimental period within 7 d (data not shown). This was much shorter than the 3 wk reported by McNab and Blair (1988) and the 17 d reported by Yalcin and Onol (1994) for chickens. This ability of ducks to regain weight faster than cockerels may be attributable to the fact that ducks have a higher body content of fat than chickens and hence do not have to mobilize their labile protein reserves during a short-term period without feed. It was therefore possible to carry out assays on the same group of birds every 2 wk with no apparent effect on their well-being. During the experiments, ducks showed no signs of discomfort, and there were no significant weight loss ($P > 0.05$) differences between the feed-deprived birds and the fed birds.

Yalcin and Onol (1994) reported that feed-deprived 2.5 kg-cockerels excreted 5.0 ± 0.31 g during 48 h without feed. For the present study, feed-deprived ducks weighing 3.7 and 3.8 kg-ducks voided on average 3.90 ± 0.45 and 6.48 ± 0.63 g of dry excreta during the 54-h collection periods of the first and second experiments, respectively. As both Experiments 1 and 2 were performed under similar conditions, it appears that this variation in voided excreta was due to individual differences among ducks. Therefore, for any TME assay, fasting losses for that assay should be established.

One of the disadvantages of bioavailable assays, based on force feeding, is the limited amounts of feed that can be fed to birds at one feeding. In preliminary experiments, attempts to intubate 50 g of feedstuff mixed with 120 mL of water following the procedure of McNab and Blair (1988) led to about 50% of the birds in each experiment regurgitating portions of the mixture. To achieve the accuracy of bioavailable assay data obtained with high feed intakes, assay birds were fed 30 g of each feedstuff twice with a 6-h interval between feeding, extending the total time of the experiments from 96 to 102 h.

The two ME estimates of practical importance for birds are AME and TME. The AME and TME energy assays rely on total excreta collection from individual birds and usually involve the use of trays placed under birds housed in wire cages as collection vessels. Because of the watery nature of duck excreta and the tendency of duck excreta to be voided far and wide, collecting duck excreta on trays placed below wire cages can lead to excreta being ejected beyond the perimeter of the tray, which can result in significant errors in establishing total excreta outputs. Furthermore, with open trays, errors frequently occur in excreta energy output due to contamination with scales, blood, and feathers from the birds. To avoid these contaminants, Sibbald and Wolynetz (1986) used human colostomy bags affixed to cockerels with a bond of supplementary adhesive for excreta collection; however, they experienced high losses of bags due to premature separation of the bags from the birds. A cup and harness excreta collection technique was reported to give comparable results as those obtained with tray collection (Revington *et al.*, 1991). This technique involved the use of rigid plastic specimen containers held in place with tied cotton tape. Numerous problems were encountered when attempts to collect total duck excreta according to this method were made. Over 50% of the specimen container slipped away from the vent of the birds during the experiment; hence, total excreta collection was not possible with this method. To overcome this problem, Playtex™ bottle retainer lids were sutured around the vents of the birds. Surgical procedures to fasten collection devices around the vents of avian species for total excreta collection are not new. Various modifications of this procedure have been used previously with turkeys and chickens (Blakely, 1963; Calvin *et al.*, 1966). The main problem encountered with this technique was the rigidity of the sutured plastic cups. There was a tendency for the cups to tilt when the birds assumed a squatting position, resulting in the spillage of the liquid portion of the collected excreta. These losses were pronounced in preliminary experiments because of the watery nature of duck excreta compared to chicken excreta. With the present procedure, no loss of bags or spillage of excreta occurred. In addition, collection bags were changed, and collected samples were immediately frozen five times during the 54 h to limit microbial activity in the excreta.

With the present technique, the low feed intakes relative to maintenance needs may modify the physiological state of the birds and the small amount of excreta voided changes drastically the proportion of endogenous losses to total excreta losses. These variations have profound effects on the accuracy of AME, AME_n, and TME as estimates of bioavailable energy (Wolynetz and Sibbald, 1984). The TME_n is not affected as much, and therefore, is the most useful estimate of bioavailable energy under low feed intake conditions. The TME_n values obtained were higher than the corresponding AME_n values—the result of high endogenous excretory losses. A study by Mohamed *et al.* (1984) reported a TME_n of corn for chicken as 3.09 ± 0.33 kcal/g. Work done with adult cockerels reported mean TME_n values of ground wheat to be 2.99 kcal/g (Salah Uddin *et al.*, 1996). These values are lower than those obtained for ducks in the present study. Castanon and Marquardt (1991) reported that high fiber fababeans fed to cockerels caused a reduction in the rate of passage of semipurified starches in the gastrointestinal tract and that this allows more complete digestion of the feed. This suggests that the increased ME values of some high fiber feedstuffs for ducks compared to chickens may be due to more efficient starch digestion because of the reduction in transit time caused by feeding ducks high fiber diets. The TME_n of 3.18 kcal/g for naked oats as determined by multiple level assay in broiler chickens (Maurice *et al.*, 1985) and between 2.5 and 2.6 kcal/g for whole oats (Scott *et al.*, 1982) have been reported previously. The dehulled oats TME_n values reported in this study are appreciably higher than these reported values. A major disadvantage of oats is the presence of hulls, which reduces its feeding value for nonruminants. Consequently, the low ME content of whole oats has excluded it from poultry diets (Scott *et al*, 1982). Naked oat cultivars have been used commercially in poultry diets in an effort to decrease the fiber level and thereby increase the bioavailable energy level of this grain. Dehulled oats have been evaluated for chickens and have supported growth comparable to that of a chicken starter diet (Maruyama *et al.*, 1975).

Rye is particularly attractive as an alternative grain because of its superior winter hardiness. This cereal grain offers producers significant advantages over its spring-grown counterparts, including more effective use of water resources. However, problems exist when rye-based diets are fed to chickens. It produces a sticky wet litter (Lee and Campbell, 1983), which can cause severe management difficulties for chickens raised on litter, and it has growth depressing properties when fed to chickens (Campbell *et al.*, 1983). Furthermore, when 10% total pentosans (arabinose and xylose) were incorporated into wheat-based diets fed to chickens, at levels found in similar rye-based diets, the result was severe growth depression (Antoniou *et al.*, 1981). Campbell and Campbell (1989) reported that substitution of rye for wheat did not significantly affect egg production, feed consumption, egg weight, shell elasticity, or tibia ash at dietary levels of rye below 46.7% for laying hen diets.

The NRC (1994) nutrient requirements for poultry lists TME_n values for rice grain and rye grain as 3.54 and 2.93 kcal/g, respectively. The former value is lower than that obtained in the present study. The latter value for rye, when compared to the TME_n value in the present study, suggests that ducks are just as susceptible to the energy-limiting effects of pentosans as chickens.

The ideal technique for determining ME should combine the simplicity, convenience, and precision of the Sibbald assay (Sibbald, 1976) with higher feed intakes. The excreta collection technique used in this study allows total excreta collection with minimal contamination. Microbial activity in the excreta should also be further reduced by increasing the frequency of excreta collection. The addition of a dilute HCl solution to each collection bag prior to it being attached to the birds, which was not done in the present study, should further reduce nitrogen losses as ammonia. With these slight modifications, this technique should be suitable for bioavailable amino acid assays in ducks.

The least-cost formulation of commercial duck rations should rely upon accurate information regarding the bioavailable energy content of a wide range of available feedstuffs. The data from this study provide some evidence that dehulled oats can be a good alternative grain source to supply the energy requirements for duck diets. The present data also suggest that ME values taken from chicken bioassay cannot be extrapolated to ducks; however, additional confirmation work is required. The TME_n data presented in this paper provide new information for duck diet formulations.

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