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Energy Required for Maintenance of Broiler Chickens and the Change Due to Body Fat Content

[1]J.D.Latshaw and [2]B. L. Bishop
[1]Department of Animal Sciences,The Ohio State University,Columbus, Ohio 43210
[2]Computing and Statistical Services, Ohio Agricultural Research and Development Center, Wooster, OH 44691 Metabolism and Nutrition

Abstract: An experiment was designed to determine the amount of energy that was used for maintenance each day by broiler chickens. They were reared on litter and had free access to a nutritionally adequate diet until the average weight was about 1.34 kg. Nineteen males of intermediate weight were selected. Twelve were randomly allotted to individual cages, and the remainder were assigned to an initial group. The same procedure was followed for females. All of the chickens in cages were fed the same complete feed as pellets. Each chicken was fed an amount of feed that provided between 100 and 320 kcal ME/d/kg$^{0.75}$. Two males and two females fed either the smallest amount of feed or the largest amount of feed continued on experiment for 10d. The remaining chickens were fed for 14 d. A total excreta collection from a 48h period was completed for each chicken. Amount of feed eaten each day did not affect digestibility (ME/g = 2.974 kcal/g). Chickens in the initial groups were killed at day 0 and the others after completing the experiment. The whole body of each chicken was ground, and a portion was dried and used to determine fat and energy content. Multiple linear regression of the data provided the following model: Energy balance (kcal/d/ kg$^{0.75}$) = −188.2 + 7.398 (avg % body fat) + 0.777 (ME/d/kg$^{0.75}$) A chicken with 13% body fat requires 118 kcal ME/d/kg$^{0.75}$ for maintenance.

Key words: Body fat, energy, maintenance

Introduction

Two different approaches have been used to estimate the amount of energy needed to maintain energy balance. The first is to estimate the energy expenditure when there is minimal metabolic activity then to add, stepwise, increases in energy expenditure due to normal activities such as eating and movement. The second approach is to determine energy balance when normal activities are included and refer to this energy expenditure as maintenance.

Efforts to precisely quantify minimal energy expenditure have continued for more than a century. Managing an animal so that it is at the point of minimal metabolic activity, or basal metabolism, is not easy. For sheep, basal metabolism was measured after 5 days without feed (Graham, 1967). In human studies, the condition of basal metabolism is not exactly met after 10-12 hours of fasting; instead, energy expenditure is called resting metabolic rate (McArdle *et al.*, 1996). The thermic effect of feeding and thermic effect of physical activity are then added to arrive at a daily energy expenditure.

The best way to estimate basal metabolism or resting metabolism is still being debated. An animal's heat production is approximately proportional to its surface area and its weight to an exponential power (Kleiber, 1932). Basal metabolism was estimated at 70 kcal per kg of metabolic weight (kg $^{0.75}$). However, for pigs, a better fit of the data results when metabolic weight is expressed as kg $^{0.60}$ (van Milgen *et al.*, 1998). For humans it has been suggested that the resting metabolic rate can be estimated more precisely if factors are included for the sex of the individual and ethnic origin (Schofield, 1985). Other research indicates these factors are not needed if energy expenditure is calculated per kg of fat-free mass (Cunningham, 1982). The basal metabolic rate (kcal/d) was 21.2 x fat-free mass (kg) + 410 (Soares *et al.*, 1998).

For food animals, energy required for maintenance, rather than for basal metabolic rate, has generally been estimated. Maintenance is the amount of energy needed for energy balance in conditions approaching day-to-day life. Energy expenditure resulting from feed intake and minimal physical activity are included in maintenance estimates. Varied amounts of energy intake and carcass analysis were used to estimate the maintenance requirements of beef cattle (Lofgreen, 1964; Lofgreen and Garrett, 1968). The estimate was 132 kcal ME/d/kg$^{0.75}$. Research with dairy cattle used indirect calorimetry and varied amounts of energy intake (Moe *et al.*, 1972). Maintenance energy was estimated at 134 kcal ME /d/kg$^{0.75}$.

Estimates of the energy required for maintenance of chickens are variable. De Groote (1974) summarized results of eight experiments with growing or mature chickens. The method used was regression of ME intake and energy retention in the body to find zero energy retention. Estimates ranged from 67 to 124 kcal ME/d/kg$^{0.75}$. In the same report, estimates of energy maintenance requirements ranged from 99 to 133 kcal ME/d/kg$^{0.75}$ for hens in egg production. Indirect calorimetry was used in a different study with hens (Rising *et al.*, 1989) and a range of 102 to 124 kcal ME/d/kg$^{0.75}$ was reported for the maintenance energy. An estimate (MacLeod, 1997) of the energy required for maintenance of broiler chickens, in terms of TME, was 176 kcal ME/d/kg$^{0.75}$. Research with broiler breeder pullets determined maintenance at 147, 131, and 119 kcal ME/d/kg$^{0.75}$ when temperatures were 15, 22, and 30° C, respectively (Sakomura *et al.*, 2003).

The purpose of the present study was to determine the energy required for maintenance of broiler chickens. They were fed amounts of feed that provided a range of daily energy. The effect on energy retention, as measured by whole body analysis, was used to estimate maintenance. From whole body analysis it was also possible to determine how body fat content affected the maintenance requirement.

Materials and Methods

Collection of Data from Animals: The protocol for this research was reviewed and approved by the institutional animal care committee. One hundred male broiler chickens of the Hubbard White Mountain strain were obtained. They were reared on litter with free access to a nutritionally adequate diet until the average weight of males was about 1.34 kg. At that time, chickens with any obvious defects were removed. Prior to weighing, food was withheld for 16 h and water was withheld for 4 h. All of the males were leg-banded and weighed. Those with weights at both extremes were discarded, and 19 were retained for the experiment. Each chicken was randomly assigned to a cage (42.7 cm x 61.0 cm) in a room with an ambient temperature of 24 ± 1 C. Every third chicken was assigned to the initial group. After completion, 12 were in cages and 7 comprised the initial group. Three days later, the same procedure was followed for females. All of the chickens were housed in the same room.

All of the chickens were fed a nutritionally adequate diet that was pelleted. Males were fed amounts of feed that provided from approximately 120 to 320 kcal ME/d/kg$^{0.75}$, in 40 kcal increments. Two males were fed each amount of feed. Females were fed amounts of feed that ranged from approximately 100 to 300 kcal ME/d/kg$^{0.75}$, also in 40 kcal increments. Two females were also fed each amount of feed. Amounts of feed were recalculated every fourth day as body weights changed. The two males fed the smallest amount of feed and the two males fed the largest amount of feed continued on experiment for 10 days. Other males remained on experiment 14 days. The identical procedure was followed with females. Beginning on day 6, a total excreta collection was made by suspending plastic under the cages of the males. The excreta collection was for 48 hours. Samples were dried in a forced air oven at 52 C before weighing and freezing in sealed plastic bags. An identical procedure was followed with females.

All of the chickens were killed by cervical dislocation. The initial chickens were killed on day 0, four of each sex were killed on day 10 (after 16 h without feed and 4 h without water), and 8 were killed on day 14. Chickens were stored in polyethylene bags at -20°C.

Preparation of Samples for Energy Determination. Homogeneous samples were prepared from each chicken, as described previously (Latshaw and Bishop, 2001). Each frozen chicken was partially thawed and cut into appropriately-sized pieces, which were then ground in a meat grinder with a plate that had 1.27 cm holes. The resulting material was reground through a plate with 0.3175 cm holes, and this was minced in turn by a meat chopper. An aluminum pan was weighed, a sample of approximately 100 g of minced chicken was added to the pan, and contents were re-weighed and stored at -20°C.

To dry the samples, pan and contents were placed in a forced air oven at 65°C for 3 h and then 52°C for 60 h. Final drying was completed in desiccators for 48 h. The pan and contents were weighed, and the contents were stored in a polyethylene bag at -20°C. While still cold, the sample was shredded with a kitchen blender. The sample was again placed in the polyethylene bag and stored at -20°C.

Fat content of the dry material was determined by extracting a 2 g sample with diethyl ether in a Soxhlet apparatus for 16 h. The energy content was determined by using a 0.5 g sample in a bomb calorimeter. The energy content of feed and excreta samples was determined using the bomb calorimeter.

Calculations and Statistical Analysis

The ME of the feed given to each chicken was calculated as follows:

$$\text{kcal ME / g} = \frac{(\text{g\_feed/48h})\ (\text{KJ/g}) - (\text{g\_excreta/48h})\ (\text{KJ/g})}{\text{g\_feed /48h}}$$

An average daily energy intake was calculated for each chicken. Total feed intake for each chicken was divided by days on experiment. Average daily feed intake for each chicken was multiplied by the determined ME of the feed for that particular chicken to determine the average daily energy intake. ANOVA was used to test if the amount of feed eaten each day affected the ME of the feed.

Energy balance was estimated for each chicken. The energy content of each chicken at the end of the experiment was calculated from its body weight and energy per g of body weight. The energy content of each chicken at the beginning of the experiment was estimated using the average energy per g of the 7 initial chickens of that sex, multiplied by the weight of each experimental chicken. Final body energy minus beginning body energy divided by days resulted in energy loss or gain each day.

An average percentage body fat was calculated for each chicken during the time it was on experiment. The final body fat was determined. The body fat at the beginning of the experiments was predicted from the average percentage body fat of the 7 initial chickens. Percentage body fat used for statistical analysis was the average of the final and beginning body fat. Fat was determined on dry material but was expressed as it related to the live chicken.

Data from the experiment were analyzed using multiple linear regression techniques (Draper and Smith, 1981). The independent variables were daily energy intake and average percentage body fat, and the dependent variable was daily energy balance. To determine the optimum fit of the data, daily energy intake was transformed to kcal ME/day and expressed as powers of weight that were $kg^{0.66}$ or $kg^{0.75}$. Daily energy balance was transformed to kcal body gain or loss/d and also expressed as powers of weight as above.

Results and Discussion

There was no evidence that the amount of feed a chicken ate each day or its sex had an effect on digestibility, as measured by the ME of the feed. The range of determined ME values was from 2.900 to 3.073 kcal/g with a mean of 2.974 kcal/g . Other statistics from the ANOVA were a mean square error of 0.046 kcal and $p = 0.13$ for amount of feed and $p = 0.57$ for sex

Animals with different kinds of digestive systems apparently respond differently to increasing amounts of feed. The chickens in the present study, with an energy intake of 0.9 to 2.5X maintenance, responded similarly to other birds (Karasov, 1996). Evidence from those studies suggests that birds adjust to increased food intake by enlarging the intestine. As a result, efficiency of digestion is not affected. Evidence from ruminant animals, however, indicates that digestive efficiency decreases as feed consumption increases (National Research Council, 2001). If diets contain 62, 67, 72 and 77% TDN at maintenance, data indicate that digestibility is decreased by 0.9, 1.8, 2.7, and 3.6%, respectively, for each increase in feed intake that is equal to a multiple of maintenance.

Ranges of the data collected in this experiment are shown in Table 2. Results of the linear regression are in Table 3, with a plot of the data in Fig. 1. The resulting model was:

Energy balance = intercept + body fat variable + energy intake variable

Where energy balance = $kcal/d/kg^{0.75}$

intercept = −188.2

body fat variable = 7.398 (average % body fat)

energy intake variable = 0.777 ($ME/d/kg^{0.75}$)

There is precedent for expressing metabolic body weight as $kg^{0.66}$ in birds (Norberg, 1996). When $kg^{0.66}$ was used in the data calculations in the present experiment, the R^2 resulting from linear regression of the variables body fat and energy intake was 0.98, the same R^2 as when $kg^{0.75}$ was used. This experiment indicates that the historical standard for metabolic body weight, $kg^{0.75}$, is also appropriate for broiler chickens.

Table 1: Composition of the diet

Ingredient	%
Corn	49.78
Wheat	20.00
Dehulled soybean meal	25.85
Soybean oil	1.00
Dicalcium phosphate	1.10
Limestone	1.45
Iodized salt	0.50
Vitamin and trace mineral mix[1]	0.25
D, L - methionine	0.07
Calculated composition (%)	
Crude protein	19.0
Calcium	0.88
Non phytate phosphorus	0.32
Methionine and cystine	0.76
Lysine	0.90

[1]Provided per kg of diet: retinyl palmitate, 6000 IU; cholecalciferol, 800 IU; D, L - α - tocopherol acetate, 10 IU; menadione sodium bisulfite, 1 mg; thiamin, 1.8 mg; riboflavin, 3.6 mg; niacin, 25.0 mg; pantothenic acid, 10.0 mg; pyridoxine, 3.5 mg; folacin, 0.5 mg; biotin, 0.15 mg, B12, 0.01 mg; choline, 500 mg; ethoxyquin, 50 mg; manganese, 60 mg; zinc, 40 mg, selenium, 0.1 mg; copper, 8 mg; and iron, 80 mg.

Table 2: The range and mean of parameters that were measured to determine the energy balance of broiler chickens

Parameter	Average	Range
Initial weight (kg)	1.338	1.200 - 1.466
Final weight (kg)	1.832	1.264 - 2.348
Feed energy (kcal ME/chicken/d)	298	140 - 472
Final body energy (kcal/g·)	2.126	1.780 - 2.660
Final body fat (%)	12.20	9.53 - 15.80
Energy balance (kcal/chicken/d)	75	-32 - 275

Table 3: Relating daily energy intake[1] and percentage body fat to daily energy balance[2] by using multiple linear regression

Variables	Parameter Estimate	Standard error	Probability > p +
Intercept	-188.231	13.469	< 0.0001
Average Fat	7.398	1.191	< 0.0001
Daily energy intake[1]	0.777	0.030	< 0.0001

[1] kcal ME/d/kg $^{0.75}$
[2] kcal/d/kg $^{0.75}$

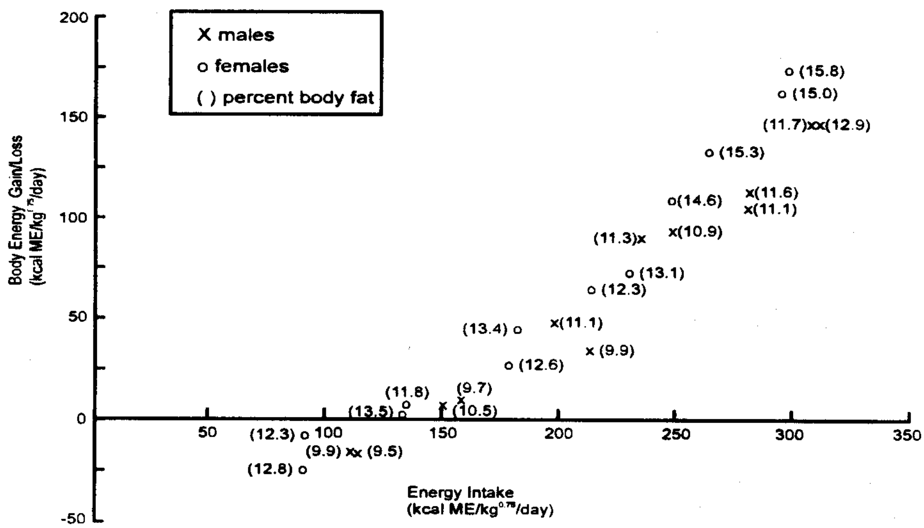

Fig. 1: Body energy retention of broilers as affected by energy intake. The percent body fat is an average of the fat content of an initial group and the final fat content of each chicken

To determine if the effect attributed to body fat was better described as an effect due to sex, that model was tested. When sex replaced average % body fat, the resulting R^2 was 0.97. As a result, average % body fat was retained in the model. The body fat content has a large effect on the energy need for maintenance. This observation may provide an explanation for the range of numbers determined as maintenance energy. One explanation for the effect of fat is related to the hierarchy of tissues for energy expenditure. Tissues such as the liver and brain have a high rate of energy utilization, muscle is intermediate, and fat is relatively inert (Passmore and Draper, 1970 and van Milgen *et al.*, 1998). If two animals are the same weight, the fatter animal has more energetically inert material per kg of weight and has a lower requirement for energy per kg of weight. Changes in body composition brought about by level of feed intake tend to counteract each other, as related to energy expenditure (Burrin *et al.*, 1990). An animal that is fed a limited amount of feed has smaller viscera and less fat. Smaller viscera decrease energy expenditure and more lean (less fat) increases energy expenditure. An animal fed unlimited amounts of feed will have larger viscera and more fat, body composition changes that also tend to cancel each other.

The observation that increasing body fat decreases maintenance energy does not appear to be fully explained by changes in viscera size. Over the range of body fat in this experiment (9.5 to 15.8%), the effect was large, 7.4 kcal for each % fat. Other possible explanations might relate to the insulative effect of fat, a change in level of activity, or a decrease in metabolic rate related to fat content; however, none of these possible explanations was explored in this research.

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