Research Note: Estimation of individual feed intake of broiler chickens in group-housing systems

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ABSTRACT In most experiments, broiler chickens are group-housed and share the same feeder in a given cage or pen. Correction of feed intake in a given pen is sometimes required in the event of mortality or identification of birds within a pen as outliers. For this reason, an accurate estimation of individual feed intake (**IFI**) is important. The objective of this study was to compare 3 different methods of estimating the IFI of broiler chickens in group-housing systems. The methods utilized in the current study consisted of an averaging method, a ratio method, and a partitioning method. The assumption of the averaging method is that birds in a cage consume an equal amount of feed, whereas feed intake of a given bird is proportional to its BW gain in the ratio method. The partitioning method bifurcates IFI into IFI for maintenance and growth. To validate these methods, 32 male broiler chickens (initial BW = 161 ± 19 g) at d 7 post hatching were individually housed in cages. Birds were fed a corn-soybean meal-based diet for 28 d, and body weight and feed disappearance were recorded on d 14, 21, 28, and 35. Excreta were collected over the last 3 d of each week. As age of broiler chickens increased, body weight gain, feed intake, and dietary metabolizable energy both linearly and quadratically increased, whereas gain-to-feed ratio both linearly and quadratically decreased ($P < 0.05$). The partitioning method estimated IFI more accurately compared with the averaging method and the ratio method ($P < 0.05$). The current result implies that the partitioning method would accurately estimate IFI of broiler chickens in group-housing systems.

Key words: broiler, energy for maintenance, feed intake estimation, growth, metabolizable energy

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INTRODUCTION

Generally, multiple broiler chickens are reared in group-housing systems such as cages or pens in experimental situations. During the course of the experiment, mortality of broiler chickens sometimes occurs. Furthermore, some birds may be identified as outliers during the statistical analysis. In these cases, researchers should consider losses of birds in pens and adjust pen feed intake for individual feed intake (**IFI**) of birds in interest. With advances in technology, computerized systems can accurately record the IFI of animals, but they are not widely utilized in research because of their high cost (Lindemann and Kim, 2007).

Averaging method ("Bird-day") may be used to estimate IFI of birds, which predicts IFI as total cage feed intake × number of days in experimental period ÷ sum of the number of alive birds in each day. The method assumes that birds in a cage consume an equal amount of feed regardless of their BW. Alternative methods include a ratio or a partitioning method. The assumption of the ratio method is that feed intake of a given bird is proportional to its BW gain, while the partitioning method divides IFI into IFI for maintenance and growth.

In previous swine studies, the partitioning method estimated IFI of group-housed pigs more accurately when compared with the averaging and ratio methods (Lindemann and Kim, 2007; Lee et al., 2016). However, based on the literature, the 3 different methods have not been tested in broiler chickens. For this reason, the objective of this study was to investigate the use of the averaging, ratio, and partitioning methods in estimating IFI of group-housed broiler chickens.

MATERIALS AND METHODS

All protocols used in the study were approved by the Purdue University Animal Care and Use Committee (West Lafayette, IN).

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Birds, Experimental Diets, and Sample Collection

Thirty-two 7-d-old Cobb 500 male broiler chickens (initial BW = 161 ± 19 g) were individually housed in battery cages (model SB 4 T, Alternative Design Manufacturing, Siloam Springs, AR). Birds had free access to water and a corn-soybean meal-based diet containing 590 g/kg corn, 290 g/kg soybean meal, 50 g/kg soybean oil, and 5 g/kg chromic oxide for 28 d. Body weight of birds and feed disappearance were recorded on d 14, 21, 28, and 35 post hatching. Excreta were collected over the last 3 d of each week.

Methods Used to Estimate Individual Feed Intake

The averaging, ratio, and partitioning methods were used for estimating IFI of birds (Lee et al., 2016).

For the averaging method, all birds in a cage were assumed to consume an equal amount of feed.

$$\text{IFI, kg} = \text{cage feed intake (kg)} \div \text{the number of birds in a cage}$$

In the ratio method, IFI of bird was assumed to be proportional to its BW gain.

$$\text{IFI, kg} = [\text{BW gain of individual bird (kg)} \div \text{total BW gain in cage (kg)}] \times \text{cage feed intake (kg)}$$

For the partitioning method, metabolizable energy for maintenance (**ME_m**) for broiler chickens was estimated as follows (Noblet et al., 2015):

$$ME_m\text{, kcal/d} = 136 \times \text{mean BW}^{0.70}$$

where mean BW is the mean BW (kg) for the period of interest.

Feed intake for maintenance (FI_m) within a period was calculated as follows:

$$FI_m \text{ for individual bird, kg} = \left(136 \times \text{mean BW}^{0.70} \times \text{number of days}\right) \div \text{ME in diet (kcal/kg)}$$

$$FI_m \text{ for cage, kg} = \sum (FI_m \text{ of each bird in a cage})$$

As feed intake can be divided into FI_m and feed intake for growth (FI_g), FI_g for cage was calculated as follows:

$$FI_g \text{ for cage, kg} = \text{FI for cage (kg)} - FI_m \text{ for cage (kg)}$$

Then, FI_g for individual bird was assumed to be proportional to its BW gain

$$FI_g \text{ for individual bird, kg} = FI_g \text{ for cage (kg)} \times [\text{Individual BW gain (kg)} \div \text{cage BW gain (kg)}]$$

$$\text{Estimated IFI, kg} = FI_m \text{ (kg)} + FI_g \text{ (kg)}$$

Simulations

To test the accuracy of the 3 individual models, simulations were conducted using growth performance data from the 32 birds. In each simulation, 8 artificial cages with 4 birds were created using a program provided by Lindemann and Kim (2007) based on either completely randomized design or randomized complete block design. A total of 160 artificial cages were created based on 20 simulations in each period (d 7 to 14, 14 to 21, 21 to 28, 28 to 35, and 7 to 35). Estimated IFI was calculated by 3 different methods with the actual IFI and BW gain of 4 birds within cages, and the difference (%) between actual and estimated IFI was calculated for all birds. Overall, the number of created individual bird observations were 640 in each period for each 2 experimental designs. Artificial cages with 8 birds were also created, resulting in a total of 80 artificial cages (640 observations) in each period for each 2 experimental designs. However, for d 28 to 35, one bird was excluded in simulations due to BW loss (306 g) and low feed intake (27 g). For this reason, artificial cages with 4 or 7 birds were created, resulting in 6 or 4 artificial cages in each simulation, and subsequently, 480 or 560 observations, respectively. Cage data with 4 and 7 or 8 birds were pooled for statistical analysis.

Chemical Analysis

Excreta samples were placed in a forced-air drying oven at 55°C until constant weight. The experimental diet and excreta were ground (<0.75 mm) using a centrifugal grinder (ZM 200; Retsch GmbH, Haan, Germany). Ground samples were analyzed for gross energy by an isoperibol bomb calorimeter (Parr 6200; Parr Instrument Co., Moline, IL) and chromium concentration (Fenton and Fenton, 1979). The experimental diet was also analyzed for dry matter by drying at 105°C overnight in a forced-air drying oven (Precision Scientific Co., Chicago, IL) and nitrogen using the combustion method (TruMac N; LECO Corp., St. Joseph, MI) based on the procedure provided by Adeola et al. (2018).

Calculations and Statistical Analysis

Metabolizable energy in the experimental diet was calculated using the index method (Kong and Adeola, 2014). Difference between actual and estimated IFI was calculated as follows (Lee et al., 2016):

$$\text{Difference, \%} = |\text{Actual IFI} - \text{estimated IFI}| \div \text{Actual IFI} \times 100$$

Data were analyzed using the MIXED procedure of SAS (SAS Inst. Inc., Cary, NC). Repeated measures analysis was used to determine changes of growth performance and dietary ME. The model included age as an

Table 1. Growth performance and metabolizable energy (ME) in the experimental diet (as-fed basis)[1].

Item	Initial BW, g	Final BW, g	BW gain, g	Feed intake, g	G:F[2], g/kg	ME, kcal/kg
D 7 to 14	161	369	209	245	840	3,102
D 14 to 21	369	809	439	613	708	3,319
D 21 to 28	809	1,352	543	842	636	3,364
D 28 to 35	1,362	1,966	603	935	625	3,430
SEM	26	42	22	24	24	33
P-value						
Linear	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001
Quadratic	< 0.001	0.042	< 0.001	< 0.001	0.012	0.023

[1]Each least squares mean represents 32 observations except for d 28 to 35 (n = 31 for growth performance and n = 30 for ME).
[2]G:F, gain-to-feed ratio.

independent variable, and least squares mean for each period was calculated. Orthogonal polynomial contrasts were conducted to determine linear and quadratic effects of increasing age. For differences between actual and estimated IFI, independent variable was the method, and least squares mean was calculated for each method. Multiple comparisons of least squares means for the differences between actual and estimated IFI were conducted using the PDIFF option with Tukey's adjustment. The experimental unit was a bird, and statistical significance was determined at α level of 0.05.

RESULTS AND DISCUSSION

An accurate estimation of IFI of birds is required for correcting feed intake in a given cage in the event of mortality or identification of birds within a cage as outliers. Three different methods to estimate IFI utilized in the current study were the averaging, ratio, and partitioning methods. The averaging method assumes that every bird in a cage consumes the same amount of feed. However, lack of uniformity in growth rate among birds within cage results in variation that questions the fundamental assumption of the averaging method. In the ratio method, IFI of a bird is assumed proportional to its BW gain. The main drawback with this method is that if BW gain of a bird is zero, IFI of the bird is estimated as zero. Though BW gain is zero, feed consumption is required to support maintenance of birds. The partitioning method is more biologically reasonable compared with the averaging and ratio methods. Animals utilize dietary energy for maintenance and growth. The partitioning method originates from this principle and it considers IFI as the sum of IFI for maintenance and growth. The current study is the first attempt to test 3 methods of estimating IFI in broiler chickens.

Analyzed gross energy and crude protein concentration in the experimental diet was 4,182 kcal/kg and 199 g/kg (as-fed basis), respectively. As age of broiler chickens increased, BW gain and feed intake both linearly and quadratically increased, whereas gain-to-feed ratio both linearly and quadratically decreased ($P < 0.05$; Table 1). Discrepancies between gain-to-feed least squares means presented in Table 1 and those calculated based on the division of least squares means of BW gain by feed intake are a case of average of ratios and ratio of averages. For example, gain-to-feed value in d 28 to 35 was 625 g/kg, whereas a calculated value using BW gain (603 g) and feed intake (935 g) would have been 645 g/kg. The reason for these discrepancies is mainly attributed to variability in growth performance among experimental units. Generally, multiple birds are reared in each cage in experimental situations. Because cage is an experimental unit for growth performance, variability among cages within each treatment is alleviated by averaging data of birds within each cage. However, only one bird was assigned to each cage in the current study, which induced a high variability among simulated group-housing cages.

Dietary ME both linearly and quadratically increased ($P < 0.05$) with the age of birds (Table 1). Increasing ME value of the corn-soybean meal-based diet in broiler chickens with age has been consistently reported in the current and previous studies (Stefanello et al., 2016; Adeola et al., 2018; Yang et al., 2020). The reason for increase in ME can be primarily attributed to the improvement in utilization of nutrients with age, particularly in dietary fiber. Dietary fiber increases passage rate of digesta, which reduces the opportunity for other nutrients to be digested and absorbed (Nguyen et al., 2021). Furthermore, dietary fiber itself is less utilized in chickens compared with other nutrients. As birds age, the gastrointestinal tract matures, and subsequently, capacity for digestion as well as endogenous enzyme activity, absorption, and hindgut fermentation of fiber and other nutrients are improved (Bautil et al., 2019).

In all periods, difference between actual and estimated IFI was the smallest ($P < 0.05$) for the partitioning method (Table 2). Complete randomization or randomization within blocks by BW was employed to represent respective completely randomized design and randomized complete block design when creating artificial cages in the current study. Except for d 7 to 14, differences between actual and estimated IFI were smaller in the ratio method compared with the averaging method. The reason for this is not clear, and information on the effect of age on the proportion of energy used for maintenance in broiler chickens is limited. As the difference between actual and estimated IFI was the smallest in the partitioning method, this method is regarded as the most accurate to estimate IFI among the 3 methods. In the current study, ME_m value (136 × mean $BW^{0.70}$)

Table 2. Difference (%) between actual and estimated individual feed intake (IFI) using different methods for estimating IFI in group-housing systems[1,2].

Item	Method			SEM	P-value
	Averaging[3]	Ratio[4]	Partitioning[5]		
Complete randomization					
D 7 to 14	13.4[b]	16.6[a]	8.8[c]	0.4	< 0.001
D 14 to 21	12.9[a]	9.4[b]	6.5[c]	0.4	< 0.001
D 21 to 28	13.4[a]	9.2[b]	5.7[c]	0.3	< 0.001
D 28 to 35	11.5[a]	8.4[b]	3.1[c]	0.2	< 0.001
D 7 to 35	14.9[a]	7.1[b]	4.5[c]	0.5	< 0.001
Randomization within blocks by body weight					
D 7 to 14	12.8[b]	17.0[a]	9.2[c]	0.4	< 0.001
D 14 to 21	11.0[a]	9.0[b]	6.1[c]	0.4	< 0.001
D 21 to 28	12.1[a]	9.3[b]	5.6[c]	0.3	< 0.001
D 28 to 35	10.7[a]	8.3[b]	3.0[c]	0.2	< 0.001
D 7 to 35	14.1[a]	7.2[b]	4.5[c]	0.5	< 0.001

[a–c]Least squares means within a row without a common superscript differ ($P < 0.05$).

[1]Each least squares mean represents 1,280 observations except for d 28 to 35, where n = 1,040.

[2]Difference between actual and estimated IFI, % = | Actual IFI − estimated IFI | ÷ Actual IFI × 100.

[3]All birds in a cage were assumed to consume an equal amount of feed. IFI, kg = cage feed intake (kg) ÷ the number of birds in a cage.

[4]Feed intake of each bird was assumed to be proportional to its BW gain. IFI, kg = [BW gain of individual bird ÷ total BW gain in cage] × cage feed intake (kg).

[5]Feed intake was bifurcated into IFI for maintenance (FI_m) and growth (FI_g). FI_m for individual bird, kg = (136 kcal × kg mean $BW^{0.70}$ × number of days) ÷ ME in diet (kcal/kg). FI_m for cage, kg = $\sum$ (FI_m of each bird in a cage). FI_g for cage, kg = FI for cage (kg) − FI_m for cage (kg). FI_g for the individual bird, kg = FI_g for cage (kg) × [Individual BW gain (kg) ÷ cage BW gain (kg)]. Estimated IFI, kg = FI_m (kg) + FI_g (kg).

suggested by Noblet et al. (2015) was used because the 0.70 exponent represents maintenance energy in modern fast-growing broiler chickens.

One of limitations of the partitioning method is an inaccuracy of estimating IFI of birds with BW loss (Lindemann and Kim, 2007). If BW loss occurs in a bird, the bird might have not eaten, but IFI of the bird should be regarded as same as IFI of maintenance. However, this approach may not be reasonable because metabolism of birds with BW loss is different from that of healthy birds. Furthermore, the partitioning method may not be applicable to broiler breeder hens, where consumed energy is divided into energy for maintenance, growth of hens, and egg production. Using the partitioning method to estimate IFI of broiler breeder hens requires consideration of energy for egg production, which remains to be tested.

In summary, the partitioning method is the most accurate of the 3 methods for estimating IFI of broiler chickens in group-housing systems. If a bird dies in a cage or pen during experiments, researchers are recommended to take following steps:

1. Immediately weigh the feed and all birds including the dead bird in the cage.
2. Calculate ME for maintenance of each bird during an experiment using the average value of initial and the most recent BW. Calculate feed intake for maintenance for each bird using the ME required for maintenance and the dietary ME. The sum of feed intake for maintenance of each bird in the cage is feed intake for maintenance in the cage.
3. Subtract cage feed intake for maintenance from the total feed consumption in the cage to obtain cage feed intake for growth.
4. Calculate individual feed intake for growth as the product of cage feed intake for growth and proportion of individual BW gain in cage BW gain.
5. Individual feed intake of each bird is the sum of feed intake for maintenance and growth. Feed intake of the dead bird in the cage should be used to correct cage feed intake and hence feed efficiency during the final data analysis.

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DISCLOSURES

The authors declare no conflict of interests.

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