Different Coefficients and Exponents for Metabolic Body Weight in a Model to Estimate Individual Feed Intake for Growing-finishing Pigs

S. A. Lee, C. Kong, O. Adeola[1], and B. G. Kim*

Department of Animal Science and Technology, Konkuk University, Seoul 05029, Korea

ABSTRACT: Estimation of feed intake (FI) for individual animals within a pen is needed in situations where more than one animal share a feeder during feeding trials. A partitioning method (PM) was previously published as a model to estimate the individual FI (IFI). Briefly, the IFI of a pig within the pen was calculated by partitioning IFI into IFI for maintenance (IFI_m) and IFI for growth. In the PM, IFI_m is determined based on the metabolic body weight (BW), which is calculated using the coefficient of 106 and exponent of 0.75. Two simulation studies were conducted to test the hypothesis that the use of different coefficients and exponents for metabolic BW to calculate IFI_m improves the accuracy of the estimates of IFI for pigs, and that PM is applied to pigs fed in group-housing systems. The accuracy of prediction represented by difference between actual and estimated IFI was compared using PM, ratio (RM), or averaging method (AM). In simulation studies 1 and 2, the PM estimated IFI better than the AM and RM during most of the periods ($p<0.05$). The use of 0.60 as the exponent and the coefficient of 197 to calculate metabolic BW did not improve the accuracy of the IFI estimates in both simulation studies 1 and 2. The results imply that the use of 197 kcal×kg $BW^{0.60}$ as metabolizable energy for maintenance in PM does not improve the accuracy of IFI estimations compared with the use of 106 kcal×kg $BW^{0.75}$ and that the PM estimates the IFI of pigs with greater accuracy compared with the averaging or ratio methods in group-housing systems. (**Key Words:** Feed Consumption, Group-housing, Growth Performance, Maintenance Energy, Swine)

INTRODUCTION

Estimation of feed intake (FI) for individual animals in a group-housed pen is often required due to mortality or abnormal weight gain of animals (Lindemann and Kim, 2007). Moreover, when a response of animals is related to total intake of a specific nutrient or energy rather than the concentration of the nutrient or energy (Baker, 1986), it is crucial to knowledge the FI of individual animals in a group-housed pen. A partitioning method (PM) was previously proposed as a procedure to estimate individual FI (IFI) for pigs group-housed in a pen (Lindemann and Kim, 2007). This method partitions the IFI of animals within the pen into IFI for maintenance (IFI_m) and IFI for growth (IFI_g). The IFI_m is calculated based on the

metabolizable energy (ME) of a diet and the mean body weight (BW) of an individual animal during the feeding period using an equation suggested by NRC (1998).

The ME for maintenance (ME_m) has been estimated from various coefficients and exponents for metabolic BW (Kil et al., 2013). In NRC (1998), the use of ME_m values calculated based on the metabolic BW using an exponent of 0.75 and a mean estimate of 106 as the coefficient for growing-finishing pigs: ME_m, kcal/d = 106 kcal×kg $BW^{0.75}$. However, Noblet et al. (1999) suggested that the exponent of metabolic BW be expressed as 0.60 rather than 0.75 for growing-finishing pigs. In NRC (2012), the ME_m of growing-finishing pigs is described using the exponent of 0.60 and the mean coefficient of 197: ME_m, kcal/d = 197 kcal×kg $BW^{0.60}$. To our knowledge, the use of the coefficient and metabolic BW exponent for calculating ME_m suggested in NRC (2012) has not been tested for the estimation of IFI.

Lindemann and Kim (2007) proposed a model for IFI estimation and compared the model with 2 other methods

* Corresponding Author: B. G. Kim. Tel: +82-2-2049-6255, Fax: +82-2-455-1044, E-mail: bgkim@konkuk.ac.kr
[1] Department of Animal Sciences, Purdue University, West Lafayette, IN 47907, USA.

using simulation studies. These simulation studies used data from pigs fed individually. The application of PM to group-housed pigs has not been documented. Therefore, the objective was to test the hypotheses that the use of the coefficient and metabolic BW exponent suggested by NRC (2012) for ME_m to calculate IFI_m improves the accuracy of the estimates of IFI for pigs and that the PM estimates IFI of pigs fed in group-housing systems with greater accuracy compared with other methods.

MATERIALS AND METHODS

Simulation study 1

In simulation study 1, twenty-four barrows and 24 gilts with initial BW of 33.9 kg (standard deviation, SD = 2.1) were used and the animals were fed individually. Pigs were allowed *ad libitum* access to the diet (2,945 kcal of ME/kg) and water. Body weight of individual pigs and IFI were recorded weekly. Growth data on a bi-weekly basis were used to compare the actual and estimated IFI. The final BW of the pigs was 57.7 kg (SD = 3.7).

Within pens, the growth data of each pig were pooled, calculated, and compared according to the procedures described by Lindemann and Kim (2007). Two hundred and forty-four artificial pens were created by grouping 4 or 6 pigs in a pen. Complete randomization, randomization within blocks by BW without regard to sex, randomization within blocks by BW with balanced sex, and randomization within blocks by BW and sex were used to regroup the pigs. The experimental animal allotment program of Kim and Lindemann (2007) was used for the simulation. Lastly, the IFI estimated based on the new pens were compared with the actual IFI.

Simulation study 2

Twenty gilts with initial BW of 67.1 kg (SD = 6.1) were used in simulation study 2. Pigs had *ad libitum* access to the diet of 3,312 kcal of ME/kg and to water. Pigs were fed in group pens of practical farms, and individual BW of pigs and IFI records were kept daily using FIRE System (Osborne Industries Inc., Osborne, KS, USA) and Acema-128 (Acemo, Pontivy, France). The growth data on a bi-weekly basis were used to compare the actual and estimated IFI. The final BW of the pigs was 101.8 kg (SD = 7.4).

The growth data were pooled, calculated, and analyzed as described in simulation study 1. Thirty-two artificial pens were created by grouping 4, 5, or 6 pigs in a pen. Complete randomization was used for 5, 4, or 3 pens, which yielded the aforementioned grouping, respectively. The pigs were also blocked by BW and allotted to each pen to make 2, 3, 4, or 5 replications using the animal allotment program (Kim and Lindemann, 2007). Lastly, the IFI estimated based on

the new pens were compared with the actual IFI.

Partitioning method to estimate individual feed intake

The model proposed by Lindemann and Kim (2007) partitions IFI into IFI_m and IFI_g. Based on the ME in feed (kcal/kg), IFI_m can be calculated as:

$$IFI_m, kg = (106\ kcal \times kg\ BW^{0.75} \times d)/ME_f$$

where BW is the mean BW for the period of interest; d is the number of days in the period of interest; and ME_f is the ME concentration in the feed (kcal/kg). The coefficient of 197 and exponent of 0.60 for metabolic BW is also used according to NRC (2012):

$$IFI_m, kg = (197\ kcal \times kg\ BW^{0.60} \times d)/ME_f$$

Sum of IFI_m for all pigs within the pen represented as the pen FI (PFI) for maintenance (PFI_m) is then subtracted from total PFI (kg), and the remainder is PFI for growth (PFI_g) as:

$$PFI_g, kg = total\ PFI - PFI_m$$

where PFI_m is the sum of IFI_m for all pigs in the pen, in kilograms.

Next step is to calculate the IFI_g by apportioning PFI_g equally to each kg of BW gain during the period of interest within the pen:

$$IFI_g, kg = PFI_g \times (IBWG/PBWG)$$

where IBWG is the individual BW gain (kg); and PBWG is the pen BW gain whose value is the sum of IBWG for all pigs in the pen (kg).

Lastly, the sum of IFI_m and IFI_g is IFI for the pig in the pen as:

$$IFI, kg = IFI_m + IFI_g$$

The PM calculated based on the metabolic BW using the coefficient of 197 and exponent of 0.60 (NRC, 2012) was referred to as PM 1, and the PM calculated based on the coefficient of 106 and exponent of 0.75 (NRC, 1998) was referred to as PM 2.

Ratio method to estimate individual feed intake

The ratio method (RM) does not consider the IFI_m of pigs, but focuses of IBWG. This method only apportions the PFI equally to each kg of IBWG:

$$IFI, kg = total\ PFI \times (IBWG/PBWG)$$

Averaging method to estimate individual feed intake

The averaging method (AM) does not reflect the individual's biological aspects to the FI of pigs. All pigs in a pen are believed to have the same FI during the feeding trials as:

IFI, kg = total PFI/the number of pigs

Comparison among methods to estimate individual feed intake

To describe the accuracy of estimation, we measured the difference using percentages. The difference between the actual and estimated IFI were calculated as:

Difference, % = 100×|actual IFI – estimated IFI| /actual IFI

In this study, a smaller value of the difference (%) was considered to be more accurate when there was a significant difference.

Statistical analysis

Analysis of variance and mean separation tests were performed using PROC general linear model of SAS (SAS Inst. Inc., Cary, NC, USA) with PDIFF option and Tukey's adjustment. The model included method as a fixed variable. The experimental unit was each difference between the actual and estimated IFI from a pig, and the significance level was set at p-value less than 0.05.

RESULTS

Metabolizable energy for maintenance

The absolute values of difference between the estimated ME_m (kcal/d) based on the different coefficients and exponents for metabolic BW ranged from 0 to 459.9 kcal/d
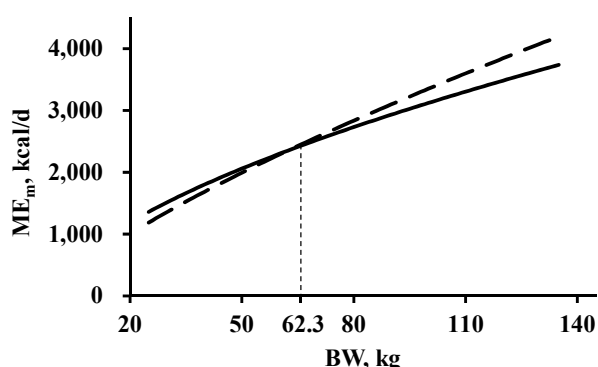

Figure 1. Metabolizable energy for maintenance (ME_m, kcal/d) calculated using different coefficients and exponents for metabolic body weight (BW). Metabolizable energy for maintenance was estimated based on the equations: 106 kcal×kg $BW^{0.75}$ (NRC, 1998) represented by dashed line, and 197 kcal×kg $BW^{0.60}$ (NRC, 2012) represented by solid line.

Table 1. Difference (%) between actual and estimated individual feed intake (IFI) using different methods for IFI estimation in simulation study 1 (n = 1,104)

Item	Method				Statistical parameter	
	PM 1	PM 2	AM	RM	SEM	p-value
d 0 to 14	9.26[b]	9.33[b]	10.7[a]	11.5[a]	0.27	<0.001
d 14 to 28	8.45[b]	8.43[b]	9.74[a]	9.79[a]	0.25	<0.001
d 0 to 28	8.23[b]	8.25[b]	9.74[a]	8.90[a,b]	0.24	<0.001

PM 1, partitioning method which estimates IFI based on the model proposed by Lindemann and Kim (2007), but calculated IFI for maintenance using the metabolic BW with a coefficient of 197 and an exponent of 0.60 (NRC, 2012); PM 2, partitioning method which estimates IFI based on the model proposed by Lindemann and Kim (2007); AM, averaging method; RM, ratio method; SEM, standard error of the mean.

[a,b] Within a row, means without a common superscript differ (p<0.05).

for growing-finishing pigs (Figure 1). Point of intersection where the difference in values of ME_m equaled 0 was approximately 62.3 kg of BW.

Simulation study 1

In simulation study 1, the PM 1 and 2 were able to estimate IFI better than AM during any period of interest (p<0.05; Table 1). The greater accuracy of PM 1 and 2 for IFI estimation was observed than RM during d 0 to 14 and d 14 and 28, but the accuracy did not differ between PM and RM during d 0 to 28. The accuracy did not differ between AM and RM during any period of interest. Lastly, the criterion also did not differ between PM 1 and 2 during all periods.

Simulation study 2

In simulation study 2, the PM 1 and 2 were able to estimate IFI better than AM during d 0 to 14, d 14 to 28, and d 0 to 42 (p<0.05; Table 2), but the criterion did not differ between PM 1 or 2 and AM during d 28 to 42. The

Table 2. Difference (%) between actual and estimated individual feed intake (IFI) using different methods for IFI estimation in group-housing systems (simulation study 2; n = 152)

Item	Method				Statistical parameter	
	PM 1	PM 2	AM	RM	SEM	p-value
d 0 to 14	4.89[b]	4.86[b]	6.90[a]	7.61[a]	0.41	<0.001
d 14 to 28	6.00[b]	6.07[b]	8.23[a]	8.33[a]	0.45	<0.001
d 28 to 42	8.39[b]	8.14[b]	8.10[b]	11.3[a]	0.58	<0.001
d 0 to 42	4.42[b]	4.39[b]	5.96[a]	6.05[a]	0.32	<0.001

PM 1, partitioning method which estimates IFI based on the model proposed by Lindemann and Kim (2007), but calculated IFI for maintenance using the metabolic BW with a coefficient of 197 and an exponent of 0.60 (NRC, 2012); PM 2, partitioning method which estimates IFI based on the model proposed by Lindemann and Kim (2007); AM, averaging method; RM, ratio method; SEM, standard error of the mean.

[a,b] Within a row, means without a common superscript differ (p<0.05).

PM 1 and 2 estimated IFI better than the RM during all periods (p<0.05). The RM showed less accuracy (p<0.05) in estimation of IFI than AM during d 28 to 42, but the accuracy did not differ between AM and RM during d 0 to 14, d 14 to 28, and d 0 to 42. Again, the accuracy of PM 1 and 2 for IFI estimation did not differ during any period.

DISCUSSION

The PM 1 and 2 consistently showed greater accuracy in estimation of IFI than AM and RM in both simulation studies 1 and 2. Lindemann and Kim (2007) validated the PM as a model to estimate IFI that is represented by PM 2 in the present study and found greater accuracy of PM than AM and RM in individual-housing system. This result was consistent with the present study. Feed intake for maintenance is an important factor to estimate IFI because PM 1 and 2 showed greater accuracy in most of the periods in simulation studies 1 and 2 than RM which calculates IFI based on only IBWG of pigs. Additionally, the results from the simulation study 2 showed that the PM may be applied to estimate IFI with fairly good accuracy in the group-housing systems. Turner et al. (2003) reviewed the previous studies of different group size (3<pigs/pen<100) and found no correlation between the average daily FI of growing-finishing pigs and the group size.

The IFI estimated based on AM may be attained with reliable values when the actual IFI are homogenous among the pigs within a pen. In the simulation study 2, however, the variation in FI among pigs during d 28 to 42 was similar to that of other periods (coefficient of variation = 10.1%, 11.1%, and 11.4%, respectively for d 0 to 14, d 14 to 28, and d 28 to 42). The different responses among the periods may be partly explained by the different physiological states such as a digestive physiology of pigs. Digestibility of the nutrients is one of the major factors affecting the accretion of proteins and lipids (Harris et al., 2012), but Kim et al. (2007) failed to find the effects of BW on the dry matter digestibility within the weanling, growing, and finishing stages. In this study, the growing and finishing pigs were used and whether the digestibility was affected by the different stage was not clear.

On the other hand, pigs showed greater variation in gain to feed ratio during d 28 to 42 than other periods in simulation study 2 (coefficient of variation = 10.7%, 11.7%, and 17.8%, respectively for d 0 to 14, d 14 to 28, and d 28 to 42). When the gain to feed ratio showed large variation among the pigs, accurate IFI may not be attained by PM because gain to feed ratio represents performance traits of animals such as BW gain and FI and because PM calculates the IFI based on the IBWG and FI of pigs. Indeed, greater difference between estimated and actual FI was observed during d 28 to 42 than other periods (Table 2).

The accuracy of PM 1 and 2 for IFI estimation did not differ for IFI of pigs during any period tested in the simulation studies 1 and 2. The ME_m estimated using the equation suggested by NRC (1998) becomes greater than ME_m estimated using the equation suggested by NRC (2012) as the BW of pigs exceeds 62.3 kg (Figure 1). The mean BW of pigs for the total period of simulation studies 1 and 2 were 48.6 and 84.4 kg, respectively. The absolute difference between the respective ME_m values of pigs with BW of 48.6 and 84.4 kg calculated based on the equations suggested by NRC (1998) and NRC (2012) were 74.0 and 132 kcal/d, which accounts for small portion of the daily FI when the ME_m was divided by ME in the diets.

CONCLUSION

The results from this study demonstrate that the use of 197 kcal×kg $BW^{0.60}$ as ME_m in PM does not improve the accuracy of IFI estimates compared with the use of 106 kcal×kg $BW^{0.75}$, and that partitioning the IFI into IFI_m and IFI_g provided the IFI of the pigs with greater accuracy compared with an AM or RM in group-housing systems.

CONFLICT OF INTEREST

We certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript.

ACKNOWLEDGMENTS

REFERENCES

Baker, D. H. 1986. Problems and pitfalls in animal experiments designed to establish dietary requirements for essential nutrients. J. Nutr. 116:2339-2349.

Harris, A. J., J. F. Patience, S. M. Lonergan, C. J. M. Dekkers, and N. K. Gabler. 2012. Improved nutrient digestibility and retention partially explains feed efficiency gains in pigs selected for low residual feed intake. J. Anim. Sci. 90:164-166.

Kil, D. Y., B. G. Kim, and H. H. Stein. 2013. Invited review: Feed energy evaluation for growing pigs. Asian Australas. J. Anim. Sci. 26:1205-1217.

Kim, B. G. and M. D. Lindemann. 2007. A new spreadsheet method for experimental animal allotment. J. Anim. Sci. 85(Suppl. 2):112.

Kim, B. G., M. D. Lindemann, G. L. Cromwell, A. Balfagon, and J. H. Agudelo. 2007. The correlation between passage rate of digesta and dry matter digestibility in various stages of swine. Livest. Sci. 109:81-84.

Lindemann, M. D. and B. G. Kim. 2007. Technical note: A model to estimate individual feed intake of swine in group feeding. J. Anim. Sci. 85:972-975.

Noblet, J., C. Karege, S. Dubois, and J. van Milgen. 1999. Metabolic utilization of energy and maintenance requirements in growing pigs: effects of sex and genotype. J. Anim. Sci. 77:1208-1216.

NRC (National Research Council). 1998. Nutrient Requirements of Swine, 10th rev. edn. Natl. Acad. Press. Washington, DC, USA.

NRC (National Research Council). 2012. Nutrient Requirements of Swine, 11th rev. edn. Natl. Acad. Press. Washington, DC, USA.

Turner, S. P., D. J. Allcroft, and S. A. Edwards. 2003. Housing pigs in large social groups: a review of implications for performance and other economic traits. Livest. Prod. Sci. 82:39-51.