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ScienceDirect
Animal Feed Science and Technology
132 (2007) 94–102
ANIMAL FEED SCIENCE AND TECHNOLOGY
www.elsevier.com/locate/anifeedsci

Effect of feeding schedule on apparent energy and amino acid digestibility by growing pigs☆

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Received 30 August 2005; received in revised form 25 January 2006; accepted 13 March 2006

Abstract

An experiment was conducted to investigate the effects of feeding schedule on dry matter (DM), gross energy (GE), crude protein (CP), and amino acid (AA) digestibility by growing pigs. Six growing castrates (initial body weight: 40.5 ± 2.25 kg) were equipped with a T-cannula in the distal ileum and allotted to a repeated 3 × 3 Latin square design with three animals and three periods in each square. A maize–soybean meal based diet (181 g CP/kg) was formulated and fed to the pigs in three different feeding schedules; *i.e.*, one meal per day, two meals per day, or free access to feed. Pigs fed one or two meals per day were allotted a daily amount of feed equivalent to three times the maintenance energy requirement. Fecal and ileal samples were collected from all pigs in each period. The coefficients of ileal apparent digestibility (CIAD) for DM, GE, CP, and AA were calculated as were the coefficients of total tract apparent digestibility (CTTAD) of DM and GE. Results of the experiment showed that there were no differences in the CIAD for DM, GE, or for any of the AA among the three feeding schedules. In contrast, pigs given free access to the diet had lower (P<0.002) CTTAD for DM and GE compared with pigs fed a restricted amount of feed either once or twice daily. Therefore, the concentration of digestible energy in the diet was lower if calculated from pigs given free access to the diet compared with pigs fed the diet once or twice daily (14.38 MJ/kg *versus* 14.83 MJ/kg and 15.13 MJ/kg). It is concluded that the feeding schedule does not influence the CIAD for DM, GE, CP, or AA by pigs. Therefore, any of the three feeding schedules that were used in the current experiment

Abbreviations: AA, amino acids; CIAD, coefficient of ileal apparent digestibility; CP, crude protein; CTTAD, coefficient of total tract apparent digestibility; DM, dry matter; GE, gross energy

☆ Publication No. 3519 from the South Dakota Agric. Exp. Stn. Journal Series.

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doi:10.1016/j.anifeedsci.2006.03.012

may be used in experiments aimed at measuring CIAD in pigs. However, if the CTTAD of DM and GE are measured, it is recommended that pigs are given free access to feed.

Keywords: Amino acids; Digestibility; Energy; Feeding schedule; Pigs; T-cannula

1. Introduction

Under commercial conditions, most growing pigs are allowed to consume their diets on an *ad libitum* basis. In contrast, pigs that are used in experiments aimed at measuring energy and nutrient digestibility coefficients are usually fed a restricted amount of feed in one or two daily meals. Previous research has documented that the level of feed intake influences the coefficients of ileal apparent digestibility (CIAD) of amino acids (AA) by growing pigs (Moter and Stein, 2004). The CIAD of most AA increases as feed intake is increased from a level equal to the maintenance energy requirement of the pigs to a level that equals two or three times this amount. As a consequence, it is recommended that pigs that are used to measure AA digestibility are fed at a level of three times the maintenance energy requirement (Moter and Stein, 2004). However, it is not known if the feeding schedule (*i.e.*, one or two daily feedings) influences AA digestibility. Likewise, it is not known if the digestibility values that are obtained in pigs fed a limited amount of feed are representative of pigs that are allowed to consume their feed on an *ad libitum* basis. The current experiment was conducted to test the hypothesis that the CIAD for dry matter (DM), gross energy (GE), crude protein (CP), and AA are not influenced by the feeding schedule. A second objective was to determine the effect of feeding schedule on the coefficients of total tract apparent digestibility (CTTAD) of DM and GE.

2. Materials and methods

2.1. Animals, housing, and experimental design

Six growing castrates (initial body weight: 40.5 ± 2.25 kg) originating from the matings of Line 13 sows to SP-1 boars (Ausgene Intl. Inc., Gridley IL) were used in this experiment. All pigs were surgically fitted with a T-cannula in the distal ileum using procedures adapted from Stein et al. (1998). Pigs were housed individually in $1.2\,m \times 1.8\,m$ pens in an environmentally controlled building. Room temperature was maintained at $20\,^{\circ}C$. A feeder and a nipple drinker were installed in each pen. Pigs were allowed to recuperate for 2 weeks following the surgery; they were then randomly allotted to a repeated 3×3 Latin square design with three periods and three pigs in each square. Individual pig weights were recorded at the beginning of each experimental period. The experiment was reviewed and approved by the Institutional Animal Care and Use Committee at South Dakota State University (#04-A007).

2.2. Diet and feeding schedule

A maize–soybean meal based diet was formulated (Table 1). The diet was fortified with vitamins and minerals to meet current nutrient requirement estimates for growing pigs (NRC, 1998). Because the diet had a low concentration of crude fibre, it was assumed that chromic oxide was an appropriate marker that could be used to calculate digestibility coefficients. Chromic oxide was, therefore, included in the diet (4 g/kg). The diet was fed to all pigs during each period of the experiment. The only difference between the three treatments was the feeding schedule. Pigs received the diet either in one or two meals per day or on an *ad libitum* basis. Both groups of meal-fed pigs received feed in an amount equal to three times the estimated daily requirement for maintenance energy (*i.e.*, 444 kJ ME per $kg^{0.75}$; NRC, 1998). The pigs that were fed only once daily received their feed every morning at 8:00 a.m. Pigs that were fed twice daily had their daily allotment of feed divided into two equal meals that were supplied at 8:00 a.m. and 5:00 p.m. Pigs that were given free access to the diet were allowed to eat on an *ad libitum* basis from a one-hole feeder. Feed was supplied to the feeder at 8:00 a.m. and at 5:00 p.m. as needed to make sure that the pigs had access to feed at all times. Regardless of the dietary treatment, water was available to the pigs at all times.

2.3. Sample collection and chemical analysis

Each experimental period lasted 7 days. The initial 4 days were considered an adaptation period to the diet. On day 5, fecal samples were collected from the pigs and stored at −20 °C. Ileal digesta were collected from the cannula on day 6 and on day 7 as previously described (Stein et al., 1999). Briefly, the cap was removed from the cannula and a 225 mL plastic bag was attached to the cannula using an auto locking cable tie. Bags were removed as soon as they were filled with digesta, or at least once every 30 min, and the digesta were immediately stored at −20 °C to prevent microbial degradation of the AA in the digesta.

All ileal samples were lyophilized and finely ground prior to chemical analysis. Fecal samples were dried in a forced air oven at 60 °C and ground. All samples were analyzed for their concentration of DM (Procedure 4.1.06; AOAC, 1998) and chromium (Fenton and Fenton, 1979). The concentration of GE was also determined in all samples using bomb calorimetry (Parr Instruments, Moline IL). Crude protein was analyzed in the diet and ileal samples according to the procedure by Thiex et al. (2002). The concentrations of AA were analyzed in the diet and in ileal digesta samples on a Chrom-tech HPLC as previously described (Petersen et al., 2005). The concentration of Trp in the samples was not determined.

2.4. Calculations and statistical analysis

The CIAD for AA were calculated for each feeding schedule according to Eq. (1) (Stein et al., 1999):

$$\text{CIAD} = 1 - [(\text{AAd}/\text{AAf}) \times (\text{Crf}/\text{Crd})] \qquad (1)$$

Table 1
Composition of the experimental diet (as-fed basis)

	Inclusion (g/kg)
Ingredient	
Maize	666.5
Soybean meal (44%)	280.0
Soybean oil	30.0
Limestone	9.0
Dicalcium phosphate	4.5
Salt	4.0
Chromic oxide	4.0
Vitamin premix[a]	0.5
Micromineral premix[b]	1.5
Energy and nutrient concentrations[c]	
Gross energy (MJ/kg)	17.25
Metabolizable energy (MJ/kg)	14.32
Crude protein (g/kg)	181.5
Calcium (g/kg)	5.5
Phosphorus (g/kg)	4.2
Neutral detergent fibre (g/kg)	101.1
Acid detergent fibre (g/kg)	45.0
Indispensable amino acids (g/kg)	
Arginine	11.7
Histidine	4.7
Isoleucine	7.7
Leucine	16.0
Lysine	9.8
Methionine	3.5
Phenylalanine	9.0
Threonine	6.1
Valine	8.4
Dispensable amino acids (g/kg)	
Alanine	9.1
Aspartic acid	17.9
Cysteine	2.4
Glutamic acid	32.3
Glycine	7.4
Proline	10.1
Serine	10.1
Tyrosine	6.8

[a] Provided the following quantities of vitamins per kg of complete diet: Vitamin A, 10,990 IU as Vitamin A acetate; Vitamin D_3, 1648 IU as D-activated animal sterol; Vitamin E, 55 IU as alpha tocopherol acetate; Vitamin K_3, 4.4 mg as menadione dimethylpyrimidinol bisulphite; thiamin, 3.3 mg as thiamine mononitrate; riboflavin, 9.9 mg; pyridoxine, 3.3 mg as pyridoxine hydrochloride; Vitamin B_{12}, 0.044 mg; D-pantothenic acid, 33 mg as calcium pantothenate; niacin, 55 mg; folic acid, 1.1 mg; biotin, 0.17 mg.

[b] Provided the following quantities of minerals per kg of complete diet: Cu, 26 mg as copper sulfate; Fe, 125 mg as iron sulfate; I, 0.31 mg as potassium iodate; Mn, 26 mg as manganese sulfate; Se, 0.3 mg as sodium selenite; Zn, 130 mg as zinc oxide.

[c] Values for metabolizable energy, calcium, neutral detergent fibre, and acid detergent fibre were calculated (NRC, 1998), but all other values were analyzed. All values on an as-fed basis.

where CIAD is the coefficient of ileal apparent digestibility of an AA, AAd the AA concentration in the ileal digesta DM (g/kg DM), AAf the AA concentration in the feed DM (g/kg DM), Crf the chromium concentration in the feed DM (g/kg DM), and Crd is the chromium concentration in the ileal digesta DM (g/kg DM). The CIAD for DM, CP, and GE were calculated using the same equation. The CTTAD for DM and GE were also calculated using Eq. (1) with the exception that the concentration of DM and GE in the fecal samples was used rather than the concentration in the ileal digesta.

Data were analyzed statistically using the PROC MIXED procedure of SAS (Littell et al., 1996). An analysis of variance was conducted with feeding schedule as the fixed effect and pigs and periods as random effects. Treatment means were separated using the LSMeans statement and the PDIFF option of PROC MIXED. The pig was the experimental unit and an alpha level of 0.05 was used to assess differences among treatment means.

3. Results

All pigs stayed healthy throughout the experiment. There were no differences (1664 g per day *versus* 1632 g per day) in the amount of feed that was consumed by the pigs fed once or twice daily (Table 2). However, the pigs allowed to consume the diet on an *ad libitum* basis consumed much more feed (2730 g per day) than did the pigs on the other two treatment groups. The CIAD for DM, GE, and CP were not different among the treatment groups. Likewise, no differences among treatment groups were observed for any of the AA or for the average of indispensable, dispensable, or all AA.

The effect of feeding schedule on the CTTAD of DM and GE are presented in Table 3. Pigs given free access to the diet had a lower ($P<0.002$) CTTAD for DM and GE compared with pigs fed once or twice daily (0.85 *versus* 0.87 and 0.89 and 0.83 *versus* 0.86 and 0.88 for DM and GE, respectively). By multiplying the total GE in the diet by the CTTAD for GE, the DE of the diet was calculated for each feeding schedule. The pigs given free access to the diet found less ($P<0.001$) DE in the diet than did the pigs fed once or twice daily (14.38 MJ/kg *versus* 14.83 MJ/kg and 15.13 MJ/kg, respectively).

4. Discussion

It was expected that the pigs fed once or twice daily had a similar feed intake because both groups were fed at a level calculated to be equal to three times the energy requirement for maintenance. However, it was unexpected that the pigs given free access to feed had a much higher feed intake than the pigs on the other two treatments. This observation indicates that growing pigs fed a maize–soybean meal based diet will consume feed in excess of three times the maintenance energy requirement if allowed to do so. The results obtained for the pigs that were fed on an *ad libitum* basis are, therefore, not only reflective of a different feeding schedule, but also of a different level of feed intake.

The CIAD for CP and AA that were obtained in this experiment are in agreement with the values recently reported for similar diets (Bohlke et al., 2005; Stein et al., 2005). These results indicate that growing pigs are able to digest energy and nutrients prior to the distal

Table 2
Effect of feeding schedule on coefficients of ileal apparent digestibility (CIAD) for energy, DM, CP, and AA by growing pigs

Item	Feeding schedule			S.E.M.	P-value
	Once daily	Twice daily	*Ad libitum*		
Average daily feed intake (g)	1664	1632	2730	–	–
Dry matter	0.71	0.70	0.68	0.013	0.511
Gross energy	0.72	0.71	0.70	0.013	0.568
Crude protein	0.73	0.74	0.75	0.013	0.630
Indispensable AA					
Arginine	0.87	0.88	0.88	0.006	0.244
Histidine	0.81	0.81	0.81	0.009	0.876
Isoleucine	0.79	0.79	0.79	0.008	0.293
Leucine	0.82	0.82	0.82	0.008	0.463
Lysine	0.82	0.82	0.82	0.012	0.881
Methionine	0.84	0.84	0.84	0.008	0.329
Phenylalanine	0.81	0.82	0.82	0.009	0.390
Threonine	0.78	0.78	0.78	0.009	0.311
Valine	0.76	0.76	0.76	0.012	0.500
Mean, indispensable AA	0.81	0.81	0.81	0.009	0.467
Dispensable AA					
Alanine	0.78	0.78	0.77	0.012	0.616
Aspartic acid	0.76	0.77	0.78	0.009	0.323
Cysteine	0.68	0.71	0.69	0.014	0.169
Glutamic acid	0.81	0.82	0.84	0.014	0.208
Glycine	0.56	0.55	0.57	0.023	0.332
Proline	0.77	0.78	0.78	0.012	0.631
Serine	0.70	0.70	0.69	0.014	0.532
Tyrosine	0.79	0.81	0.81	0.014	0.665
Mean, dispensable AA	0.76	0.76	0.78	0.012	0.468
Mean, all AA	0.78	0.78	0.79	0.010	0.496

Data are means of six observations per treatment.

Table 3
Effect of feeding schedule on coefficients of total tract apparent digestibility (CTTAD) for energy and DM by growing pigs and digestible energy concentration in the diet

Item	Feeding schedule			S.E.M.	P-value
	Once daily	Twice daily	*Ad libitum*		
Average daily feed intake (g)	1664	1632	2730	–	–
CTTAD, dry matter	0.87 x	0.89 x	0.85 y	0.005	0.002
CTTAD, energy	0.86 x	0.88 x	0.83 y	0.007	0.001
Digestible energy (MJ/kg)	14.83 x	15.13 x	14.38 y	0.112	0.001

Data are means of six observations per treatment. Means within a row lacking a common superscript letter differ ($P<0.05$).

ileum at a similar rate regardless of the feeding schedule that is being used. Ruckebusch and Bueno (1976) reported reduced motility of the stomach and small intestine of pigs fed once or twice daily compared with pigs allowed to consume their feed on an *ad libitum* basis. However, the results from the current experiment indicate that this does not negatively influence the digestibility of AA and CP. The results also are in agreement with data published by Mroz et al. (1994) who fed pigs once, twice, or seven times per day. In that experiment, no effects of feeding schedule on the CIAD for any AA except for Arg, Cys, Ile, and Phe were observed.

The lack of an effect of feed intake on the CIAD of AA is in contrast to previous results showing that the CIAD for all AA are significantly influenced by the level of feed intake (Moter and Stein, 2004). However, the levels of feed intake used by Moter and Stein (2004) were one, two, or three times the energy requirement for maintenance. The differences in CIAD of AA were observed only between pigs fed one and two times the maintenance energy requirement, but not between pigs fed two and three times the maintenance energy requirement. In the current experiment, all pigs were fed three times the maintenance energy requirement or a greater amount of feed. This is likely the reason for the discrepancy between the results from the current experiment and the data reported by Moter and Stein (2004). Other experiments also have reported that there is no influence of feed intake on CIAD of AA in meal-fed pigs, if the feed intake is at or above two times the energy requirement for maintenance (Sauer et al., 1982; Haydon et al., 1984; Albin et al., 2001). It also has been reported that the proportion of dietary AA that are retained in the body of weanling pigs (5–22 kg) is similar between pigs given *ad libitum* access to the diet and pigs fed only 900 g/kg of *ad libitum* intake (Waltz and Pallauf, 1997). The results from the current experiment are in agreement with these reports and confirm that at relatively high levels of feed intake, no differences in CIAD are observed among different levels of feed intake. Likewise, the CIAD for AA, CP, and GE remain constant regardless of how often feed is supplied to the pigs. To our knowledge, this is the first time that it has been demonstrated that the CIAD of pigs fed once a day is equal to pigs given free access to feed. As a consequence, digestibility experiments that are conducted to measure the CIAD of AA, CP, DM, or GE may be conducted with pigs that are fed a restricted amount of feed in one or two daily meals or with pigs that are given free access to their diet. If feed intake is restricted, the daily feed intake should be close to or above three times the energy requirement for maintenance.

The CTTAD for GE was reduced in pigs given free access to feed compared with pigs fed a restricted amount of feed every day. Because the CIAD for the GE was not different among the feeding schedules, this observation indicates that the digestibility of DM and energy in the large intestine was lower in pigs given free access to the diet compared with pigs fed once or twice daily. While the majority of the prececal digestion is enzymatic, the digestion in the large intestine is almost exclusively microbial. The larger quantities of feed consumed by the pigs on the *ad libitum* schedule may have overwhelmed the microbes in the large intestine that in turn resulted in the reduction in the CTTAD for DM and GE. Previously, Haydon et al. (1984) reported that pigs given free access to feed have lower CTTAD of DM and GE than pigs that are provided feed in quantities equal to 30 or 45 g/kg BW. The results of the current experiment are in close agreement with the work by Haydon et al. (1984). Because it is mainly the fibre portion of the diet that is fermented by the microbes in the large intestine, results may be different in pigs fed diets with a different level of fibre than used in the present experiment. The present results were obtained using fecal spot collection from animals that had T-cannulas installed in the distal ileum and the CTTAD for DM and GE were calculated assuming full marker recovery in the feces. It was assumed that this procedure yields results that are comparable to results obtained under commercial conditions.

For CIAD and for CTTAD, the values obtained for the digestibility of DM and GE were very similar. This observation indicates that DM digestibility is a good predictor of GE digestibility. The differences between CIAD and CTTAD for GE (0.72 *versus* 0.86, 0.71 *versus* 0.88, and 0.70 *versus* 0.83 for pigs fed once daily, twice daily, or given free access to feed, respectively) were expected. The CIAD represent the disappearance of energy in the small intestine of the pigs as a result of enzymatic digestion of dietary starch and other energy yielding components that are digestible by enzymes. As the digesta moves into the large intestine, the microbes will ferment any carbohydrates, including the nonstarch polysaccharides, and produce volatile fatty acids that may be absorbed from the large intestine and contribute to the energy status of the pig. The differences between CIAD and CTTAD, therefore, represent the quantities of energy present in the volatile fatty acids that were absorbed in the large intestine. The CIAD for GE obtained in the present experiment are lower than the value of 0.80 reported by Herkelman et al. (1990). However, the diets used in the experiment by Herkelman et al. (1990) contained not only maize and soybean meal, but also 510 g/kg of maizestarch which is likely the reason why a higher CIAD was obtained in that study. Nevertheless, the CTTAD for GE of 0.88 reported by Herkelman et al. (1990) is close to the values obtained in the present experiment.

5. Conclusions

The results of the present experiment confirmed that pigs used to measure the CIAD of AA, CP, DM, and GE may be given free access to their diet or fed a restricted amount of feed in one or two daily meals. This is true if the feeding level for the restricted fed pigs is at least three times the maintenance energy requirement. However, if the total tract digestibility of DM and GE is measured, results may depend on the feeding strategy with lower digestibility values obtained for pigs given free access to feed than pigs fed a restricted amount of feed.

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