Effects of Dietary Crude Fiber Level and Feeding Time on Intestinal Chyme Transit Rate in Growing Pigs (Postprint)

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Abstract

This experiment was conducted to investigate the effects of dietary crude fiber level and feeding time on digesta passage rate in various intestinal segments of growing pigs, and to provide a physiological basis for the establishment of in vitro simulated digestion processes. A 2 × 2 completely randomized design was employed, with dietary crude fiber levels of 3.39% and 5.56%, and feeding times at 08:00 and 16:00. Twenty-four Duroc × Landrace crossbred castrated male pigs with a body weight of (21.90±1.62) kg were selected and randomly allocated to 4 groups, with 6 replicates per group and 1 pig per replicate. Two groups were randomly chosen for surgical installation of T-cannulas in the duodenum, while the other two groups were fitted with T-cannulas at the terminal ileum. The appearance and disappearance times of ferric oxide (the marker) in the diet were measured in the duodenum, terminal ileum, and whole digestive tract. The results showed that: 1) When the appearance of marker color in digesta was used as the timing criterion for passage rate, dietary crude fiber level significantly affected digesta passage rate in the duodenum, terminal ileum, and whole digestive tract ($P<0.05$); feeding time significantly affected digesta passage rate in the duodenum and terminal ileum ($P<0.05$), but had no significant effect on digesta passage rate in the whole digestive tract ($P>0.05$); and there was a significant interaction between the two factors on digesta passage rate in the duodenum ($P<0.05$). Compared with the 3.39% dietary crude fiber level, the 5.56% dietary crude fiber level significantly accelerated digesta passage rate ($P<0.05$), and the digesta passage rate for pigs fed at 08:00 was significantly faster than that for pigs fed at 16:00 (except for the whole digestive tract) ($P<0.05$). 2) When the disappearance of marker color in digesta or the average time of marker color appearance and disappearance was used as the timing criterion for passage rate, both dietary crude fiber level and feeding time had significant effects on digesta passage rate in the duodenum, terminal ileum, and whole digestive tract ($P<0.05$), but there was no significant interaction effect

between the two factors on digesta passage rate in the duodenum and terminal ileum (P>0.05), while there was a significant interaction effect on passage rate in the whole digestive tract (P<0.05). Compared with the 3.39% dietary crude fiber level, the 5.56% dietary crude fiber level significantly accelerated digesta passage rate (P<0.05), and the digesta passage rate for pigs fed at 08:00 was significantly faster than that for pigs fed at 16:00 (P<0.05). In conclusion, the 5.56% dietary crude fiber level can increase digesta passage rate in various segments of the pig digestive tract; the digesta passage rate for pigs fed at 08:00 is higher than that for pigs fed at 16:00.

Full Text

Effects of Dietary Crude Fiber Level and Feeding Time on Passage Rate of Digesta in the Intestinal Tract of Growing Pigs

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Abstract

This study investigated the effects of dietary crude fiber level and feeding time on the passage rate of digesta through various segments of the intestinal tract in growing pigs to provide a physiological basis for designing in vitro digestion simulations. A 2 × 2 factorial completely randomized design was employed, with dietary crude fiber levels of 3.39% and 5.56% and feeding times of 08:00 and 16:00. Twenty-four crossbred (Duroc × Large White) barrows weighing (21.90 ± 1.62) kg were randomly allocated to 4 groups with 6 replicates per group and 1 pig per replicate. Two groups were fitted with T-cannulas in the duodenum, while the remaining two groups were fitted with T-cannulas at the terminal ileum. The appearance and disappearance times of ferric oxide marker in digesta were recorded for the duodenum, terminal ileum, and total digestive tract. The results showed: (1) When passage rate was measured by marker color appearance, dietary crude fiber level significantly affected digesta passage rate in the duodenum, terminal ileum, and total digestive tract ($P < 0.05$). Feeding time significantly affected passage rate in the duodenum and terminal ileum ($P < 0.05$) but not in the total digestive tract ($P > 0.05$). A significant interaction between dietary crude fiber level and feeding time was observed for duodenal passage rate ($P < 0.05$). Compared with the 3.39% crude fiber diet, the 5.56% crude fiber diet significantly accelerated digesta passage rate ($P < 0.05$). Digesta passage rate at 08:00 was significantly faster than at 16:00 (except for the total digestive tract) ($P < 0.05$). (2) When passage rate was measured by marker color disappearance or the mean time of appearance and disappearance, both dietary crude fiber level and feeding time significantly affected passage

rate in the duodenum, terminal ileum, and total digestive tract ($P < 0.05$). No significant interaction was found for duodenal or ileal passage rate ($P > 0.05$), but a significant interaction existed for total digestive tract passage rate ($P < 0.05$). The 5.56% crude fiber diet significantly accelerated digesta passage rate compared with the 3.39% diet ($P < 0.05$), and passage rate at 08:00 was significantly faster than at 16:00 ($P < 0.05$). These results indicate that a dietary crude fiber level of 5.56% increases digesta passage rate throughout the intestinal tract of growing pigs, and passage rate is faster when pigs are fed at 08:00 compared with 16:00.

Key words: crude fiber level; feeding time; passage rate of digesta; growing pigs

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Introduction

The passage rate of digesta through the gastrointestinal tract influences the duration of exposure to digestive enzymes and microbial fermentation, thereby potentially affecting the extent of digestion. Consequently, investigating factors that affect digesta passage rate is of considerable importance. Generally, longer retention time of digesta in the digestive tract corresponds to higher nutrient digestibility. Kim et al. [**?**] reported that dry matter digestibility in pigs increased with longer digesta retention time in the gastrointestinal tract. Hughes et al. [**?**] found that apparent metabolizable energy values in broiler diets increased linearly with prolonged digesta retention time. Digesta passage rate in animals is influenced by multiple factors, among which dietary fiber level is a primary determinant [**?**, **?**]. Le Goff et al. [**?**] demonstrated that high-fiber diets tended to have faster passage rates in pigs. Keys et al. [**?**] observed that different fiber contents in feed ingredients resulted in varying passage rates through the duodenum, jejunum, and ileum of growing pigs. Additionally, porcine digestive physiology exhibits clear circadian rhythms, with gastrointestinal motility and pancreatic secretion showing substantial differences between day and night [**?**]. Therefore, digesta retention time may differ between morning and afternoon feeding, consequently affecting passage rate. However, few studies have reported on this aspect. This experiment was designed to measure digesta passage rates through the duodenum, terminal ileum, and total digestive tract of growing pigs using two dietary crude fiber levels and two feeding times as starting points, thereby providing a physiological basis for establishing digestion times for the stomach, small intestine, and large intestine in simulated porcine digestion methods.

Materials and Methods

1.1 Experimental Animals and Diets Twenty-four crossbred (Duroc × Large White) barrows weighing (21.90 ± 1.62) kg were selected and randomly divided into 4 groups of 6 pigs each, housed individually in metabolism cages.

After a 1-week adaptation period, two groups were surgically fitted with T-cannulas in the duodenum approximately 50 cm from the pylorus, while the remaining two groups were fitted with T-cannulas at the terminal ileum 10–15 cm from the ileocecal valve. The T-cannulas were manufactured by the State Key Laboratory of Animal Nutrition, Institute of Animal Science, Chinese Academy of Agricultural Sciences (Patent No.: ZL201520207381.0). Following surgery, pigs were returned to metabolism cages after regaining consciousness and mobility, received postoperative care for 2 weeks, and then underwent a 1-week adaptation period before the experiment commenced. Metabolic room sanitation management followed standard procedures of the State Key Laboratory of Animal Nutrition.

Based on the nutrient requirements for growing pigs (NRC, 2012), a corn-soybean meal diet (Diet 1) was formulated. To minimize substantial changes in ingredient composition due to increased dietary fiber, 15% wheat bran was added to Diet 1 to create a high-fiber diet (Diet 2). The composition and nutrient levels of the experimental diets are presented in Table 1 . The experiment consisted of a 5-day preliminary period and a 13-day formal trial period, totaling 18 days. Daily feed intake was set at 4% of body weight and divided into two meals fed as wet mash at 08:00 and 16:00, with free access to water.

1.2 Experimental Design A 2 × 2 completely randomized factorial design was employed, with two dietary crude fiber levels (3.39% and 5.56%) and two feeding times (08:00 and 16:00) as the starting points for measurement. During days 1–10 of the experimental period, two groups of duodenal-cannulated pigs were fed the 3.39% and 5.56% crude fiber diets at 08:00 (0 time point) to measure digesta passage rate through the duodenum and total digestive tract. Simultaneously, two groups of ileal-cannulated pigs were fed the same diets at 16:00 (0 time point) to measure passage rate through the ileum and total digestive tract. During days 11–13, the duodenal-cannulated pigs were fed at 16:00 to measure duodenal passage rate, while the ileal-cannulated pigs were fed at 08:00 to measure ileal passage rate. At each measurement starting time, 0.03% ferric oxide was added to the meal as a color indicator, after which marker-free diets were fed. The next experimental batch commenced after the indicator color completely disappeared from feces, with each pig in each group measured for 3 replicate batches.

1.3 Measurement of Digesta Passage Rate Ferric oxide was selected as the indicator due to its high color visibility and was mixed with diets at 0.3 g/kg [**?**]. The measurement method followed Imbeah et al. [**?**], where a single meal containing the marker was fed at the start of the experimental period, followed by marker-free experimental diets. Passage rate was expressed using the method of Kim et al. [**?**], recording the first appearance and disappearance times of marker color in digesta or feces through visual observation, with the mean of these times representing average passage rate.

Duodenal passage rate was measured by collecting small digesta samples 20 minutes after feeding the marked diet to observe marker appearance; if absent, samples were checked every 5 minutes. After marker appearance, digesta was collected hourly for 4 hours until marker color disappeared. Ileal passage rate was measured by collecting digesta samples 2 hours after feeding the marked diet to check for marker appearance, then hourly for 6 hours after appearance until disappearance. Total digestive tract passage rate was measured by checking feces every 3 hours starting 12 hours after feeding the marked diet, recording marker appearance and disappearance times.

1.4 Data Processing and Statistical Analysis The MEANS procedure in SAS 9.0 was used for basic statistical analysis of digesta passage rates in the duodenum, terminal ileum, and total digestive tract. The GLM procedure was used for two-way ANOVA to analyze the effects of dietary crude fiber level and feeding time on passage rates in each digestive segment, with Duncan' s multiple range test used for post-hoc comparisons. Differences were considered significant at $P < 0.05$.

Results

2.1 Effects of Dietary Crude Fiber Level and Feeding Time on Duodenal Passage Rate in Growing Pigs As shown in Table 2 , when passage rate was measured by marker color appearance, both dietary crude fiber level and feeding time significantly affected digesta passage rate ($P < 0.05$), with a significant interaction between the two factors ($P < 0.05$). The 5.56% crude fiber diet significantly accelerated passage rate compared with the 3.39% diet ($P < 0.05$), and passage rate at 08:00 was significantly faster than at 16:00 ($P < 0.05$). The effect of feeding time was more pronounced for the 3.39% crude fiber diet (0.13 h difference) than for the 5.56% diet (0.07 h difference).

When passage rate was measured by marker color disappearance or the mean time of appearance and disappearance, dietary crude fiber level and feeding time both significantly affected passage rate ($P < 0.05$), but no significant interaction was observed ($P > 0.05$). The 5.56% crude fiber diet significantly accelerated passage rate compared with the 3.39% diet ($P < 0.05$), and passage rate at 08:00 was significantly faster than at 16:00 ($P < 0.05$).

2.2 Effects of Dietary Crude Fiber Level and Feeding Time on Ileal Passage Rate in Growing Pigs As shown in Table 3 , when passage rate was measured by marker color appearance, disappearance, or their mean time, both dietary crude fiber level and feeding time significantly affected digesta passage rate ($P < 0.05$), with no significant interaction between the two factors ($P > 0.05$). The 5.56% crude fiber diet significantly accelerated passage rate compared with the 3.39% diet ($P < 0.05$), and passage rate at 08:00 was significantly faster than at 16:00 ($P < 0.05$).

2.3 Effects of Dietary Crude Fiber Level and Feeding Time on Total Digestive Tract Passage Rate in Growing Pigs As shown in Table 4 , when passage rate was measured by marker color appearance in feces, dietary crude fiber level significantly affected digesta passage rate ($P < 0.05$), with the 5.56% diet significantly accelerating passage rate compared with the 3.39% diet ($P < 0.05$). However, feeding time had no significant effect ($P > 0.05$), and no significant interaction was observed ($P > 0.05$).

When passage rate was measured by marker color disappearance or the mean time of appearance and disappearance, both dietary crude fiber level and feeding time significantly affected passage rate ($P < 0.05$), with a significant interaction between the two factors ($P < 0.05$). The 5.56% crude fiber diet significantly accelerated passage rate compared with the 3.39% diet ($P < 0.05$), and passage rate at 08:00 was significantly faster than at 16:00 ($P < 0.05$). The effect of feeding time was greater for the 3.39% crude fiber diet than for the 5.56% diet.

Discussion

3.1 Expression of Digesta Passage Rate in Animals Digesta passage rate in animals is commonly estimated using either visual indicator color observation or exogenous marker cumulative excretion curves [**?**, **?**, **?**, **?**, **?**]. The indicator color observation method is widely used in pigs and poultry due to its simplicity, minimal analytical workload, and intuitive nature. In the United States, this method serves as the basis for determining when to begin fecal collection in pig digestion trials [**?**]. In terms of expression, marker color appearance indicates the arrival of the marked meal at the monitored intestinal site, while disappearance indicates complete passage of the marked meal. Therefore, the time difference between appearance and disappearance represents the duration required for that meal to pass the monitored site. Based on this principle, expressing passage rate by appearance time versus disappearance time yields substantially different results. Kim et al. [**?**] reported that appearance and disappearance times of a color marker in growing pig feces were 27 and 102 hours, respectively. Similar differences were reported by Stanogias et al. [**?**] (22 and 85 hours for appearance and disappearance, respectively). In the present study, large differences between appearance and disappearance times were also observed for duodenal digesta, ileal digesta, and feces under both dietary fiber levels, consistent with previous literature. Based on the biological meaning of marker appearance and disappearance, feeding the 3.39% crude fiber diet at 16:00 further delayed duodenal arrival time and increased both total passage time and mean time for complete transit through the total digestive tract, but showed no interactive effect on ileal passage time. This suggests that feeding the low-fiber diet at 16:00 further reduced passage rate through the cecum and colon. This indicates an additive effect of dietary crude fiber level and feeding time on digesta passage rate in the cecum and colon of growing pigs, likely because the cecum and colon have the longest retention time (>30 h), and both low fiber level and afternoon feeding increase retention time, making their combined

effect evident in this segment.

3.2 Passage Rate of Digesta in Pigs and Influencing Factors Digesta passage rate affects the extent of diet digestion. Adeola et al. [**?**] demonstrated that different basal diets (semi-purified vs. corn-soybean meal) yielded different metabolizable energy values for corn distillers dried grains with solubles in chickens due to differences in basal diet passage rate, indicating that dietary chemical composition influences passage rate. Le Goff et al. [**?**] added various fiber sources to basal diets and accelerated digesta passage rate in pigs. Mateos et al. [**?**] reported that increasing dietary fat content decreased digesta passage rate in chickens. In the current study, adding 15% wheat bran significantly accelerated digesta passage rate in all segments of the growing pig digestive tract, likely because indigestible fiber enhanced intestinal propulsive motility. Additionally, animals fed at fixed times daily exhibit circadian variation in digesta flow rate, which increases postprandially then decreases and stabilizes, with overall daytime flow exceeding nighttime flow [**?**]. Even under ad libitum conditions, pigs and poultry rarely feed during dark periods [**?**, **?**], maintaining higher daytime flow rates. This occurs because gastrointestinal motility is lower at night, particularly during rest, significantly reducing organ activity and slowing passage rate. In this study, digesta passage rate at 08:00 was significantly faster than at 16:00 because feeding at 08:00 was only 8 hours from the next meal, whereas feeding at 16:00 was 16 hours from the next meal. Postprandial arrival of new digesta promotes forward movement of marked digesta, causing differences in marker appearance times. These physiological phenomena demonstrate that digesta passage rate is dependent on feeding time when measured in animal digestive tracts.

Conclusion

Both dietary crude fiber level and feeding time affect digesta passage rate through the duodenum, terminal ileum, and total digestive tract of growing pigs. Compared with the 3.39% crude fiber diet, the 5.56% crude fiber diet accelerates digesta passage rate, and passage rate is significantly faster when pigs are fed at 08:00 versus 16:00.

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Note: Figure translations are in progress. See original paper for figures.