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Glucose, starch, and dextrin utilization in the small intestine of steers

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GLUCOSE, STARCH, AND DEXTRIN UTILIZATION IN THE SMALL INTESTINE OF STEERS

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Summary

Holstein steers (775 lbs) were surgically fitted with abomasal and ileal cannulae, portal and mesenteric venous catheters, and an elevated carotid artery. These steers were used to study starch digestion in the small intestine. Glucose, corn starch, and corn dextrin were infused into the abomasum at various levels and ileal digesta samples were collected. Disappearance of carbohydrate (CHO) in the small intestine was determined using Cr:EDTA as an indigestible marker. Blood samples were collected from the portal vein and carotid artery during carbohydrate infusion. Blood flow was determined, and net glucose absorption across the small intestine was calculated. Glucose infusions resulted in higher arterial glucose concentrations and increased net glucose absorption than either starch or dextrin infusions. Increasing infusion rates above 20 g/h for both starch and dextrin resulted in no further increases in net glucose absorption. Even though the enzymatic processes for starch and dextrin hydrolysis became saturated at a low infusion rate, the amount of starch and dextrin disappearing in the small intestine increased with higher infusion rates. This was accompanied by an increased volatile fatty acid (VFA) concentration in the ileal fluid with starch and dextrin infusions, but not when glucose was infused. Data from these experiments support two concepts: (1) microbial fermentation is involved in small-intestinal starch appearance and (2) starch and dextrin hydrolysis in the small intestine of steers is more rate limiting than glucose absorptive capacity.

Introduction

Feed grains are composed of about 70% starch, and because of the amount of grain fed, starch is the primary energy source in the diet of lactating dairy cows. Digestion of starch can occur either by microbial fermentation in the rumen and hindgut, or by enzymatic hydrolysis in the small intestine. Total tract starch digestion in dairy cows ranges from 80-95% and is affected by grain type, as well as processing method. Overprocessing of grain will increase its digestibility, but may result in reduced fiber digestion, lower milk fat, and increased potential for acidosis. Underprocessing, however, results in decreased starch digestion and poor feed efficiency. Starch hydrolysis in the small intestine of dairy cows may be beneficial. Increased glucose absorption (versus VFA production) may promote milk production as well as lowering the incidence of ketosis in dairy cows. However, as the amount of starch escaping ruminal fermentation increases, so does fecal starch excretion. This indicates that small-intestinal starch digestion becomes limiting in ruminant animals. Therefore, a series of experiments was conducted to evaluate small-intestinal starch digestion and to determine factors that may be limiting.

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Procedures

Two groups of four Holstein steers (group 1, 660 lbs; group 2, 890 lbs) were surgically fitted with abomasal and ileal cannulae, portal and mesenteric catheters, and an elevated carotid. A temporary catheter was placed in the carotid artery during sampling periods. Glucose, corn starch, and corn dextrin were infused abomasally at 0, 20, 40, and 60 g/h. Ileal digesta samples were collected, and disappearance of CHO within the small intestine was determined with Cr:EDTA as an indigestible marker. Simultaneous blood samples were collected from the portal vein and carotid artery, and glucose absorption across the small intestine was calculated. Portal blood flow was determined by a primed continuous infusion of para-amino-hippuric acid (PAH) into a small mesenteric vein.

Two experiments were conducted with the first group of steers. Glucose (exp 1) and corn starch (exp 2) were continuously infused into the abomasum at 0, 20, 40, and 60 g/h for 10 h. Steers were infused with 250 ml of solution per hour, consisting of tap water, CHO, and Cr:EDTA. Steers were fed chopped alfalfa hay at 1.5% of body weight (dry matter basis). Animals and treatments were randomized to an 8-period crossover design for each experiment. During the infusion period, 7 ileal digesta samples and 5 sets of blood samples were collected from each steer. Ileal digesta was analyzed for VFA concentration, dry matter, starch, glucose, and chromium. Plasma samples were analyzed for glucose and PAH.

The second group of steers was infused with glucose (exp 3), corn starch (exp 4), and corn dextrin (exp 5). Infusions, digesta and blood collections, lab analysis, and animal care were identical to those in experiments 1 and 2. Animals and treatments were randomized to a 4 x 4 Latin square design for experiments 3 and 4, whereas experiment 5 was an 8-period crossover design.

Results and Discussion

Exp. 1. Steers consumed 9 lbs of alfalfa hay daily (dry matter basis) during the glucose infusions (table 1). Increasing levels of abomasal glucose infusion resulted in glucose passing the ileum into the large intestine, yet there was no change in ileal fluid VFA concentration. This indicated that there was little microbial fermentation of glucose in the small intestine. Arterial glucose concentration as well as net glucose absorption continued to increase with higher glucose infusions. The amount of glucose absorbed was approximately equal to the amount of glucose disappearing in the small intestine.

Exp. 2. Steers consumed 7.25 lbs. of alfalfa daily (table 2). Even though corn starch was infused, both free glucose and starch passed the ileum. The amount of starch that escaped small intestinal digestion increased with increasing amounts of starch infusion. In addition to starch passing the ileum, there was a continual increase in ileal fluid VFA concentration. This indicates that small-intestinal starch digestion included microbial fermentation. Arterial glucose and net glucose absorption increased as the infusion rate was raised from 0 to 20 g/h, with no additional change with increased levels of infusion. It appears that the process for small-intestinal starch hydrolysis became saturated at the 20 g/h infusion level.

The results of experiments 3 and 4 (tables 3 and 4) conducted with group 2 steers are similar to trends observed in the first 2 experiments. The final experiment (table 5) was the infusion of corn dextrin. Dextrin is partially hydrolyzed starch, consisting of straight chain glucose polymers with an average chain length of 17 glucose units. By infusing dextrin, we eliminated any granular characteristics as well as branch points that are found in starch. These characteristics may limit enzymatic hydrolysis of the starch granule. When corn dextrin was infused, steers consumed 11.5 lbs of alfalfa hay daily. At higher levels of infusion, free glucose as well as dextrin flowed past the ileum to the large intestine. There was an increase in ileal fluid VFA concentration, whereas arterial glucose levels and net glucose absorption both plateaued at the 20 g/h infusion rate.

Regardless of the type of CHO infused, increased infusion rates resulted in increased amounts of small intestinal disappearance. When glucose was infused, most of the disappearance could be accounted for by glucose absorption. With starch and dextrin infusions, arterial glucose and glucose absorption plateaued at 20 g/h infusion rate. This was accompanied by a continual increase in ileal fluid VFA concentration. Therefore, it is probable that a large amount of starch digestion in the small intestine is by microbial fermentation. It also appears that enzymatic processes responsible for starch and dextrin hydrolysis are more rate limiting than the glucose absorptive capacity of the small intestine.

Table 1. Effect of abomasal glucose infusions on small intestinal disappearance and net portal glucose absorption (Exp. 1)

Item	Infusion rate, g/h				SE
	0	20	40	60	
Daily feed, lbs	9.2	9.7	9.2	8.6	0.4
Glucose flowing past ileum, g/h ^{ab}	0	0.8	8.0	20.6	1.5
VFA in ileal fluid, mM	20.8	21.3	22.0	21.3	1.5
Arterial glucose, mM ^a	4.1	4.5	4.6	5.0	0.1
Net portal glucose absorption, g/h ^a	-2.5	13.4	18.2	34.2	5.5

^aLinear effect $P < .01$, ^bQuadratic effect $P < .01$.

Table 2. Effect of abomasal starch infusions on small intestinal disappearance and net portal glucose absorption (Exp. 2)

Item	Infusion rate, g/h				SE
	0	20	40	60	
Daily feed, lbs	7.5	7.5	6.6	7.5	0.4
Glucose flowing past ileum, g/h ^a	0	0.5	0.9	1.1	0.1
Starch flowing past ileum, g/h ^{a,b}	0	1.3	13.3	26.2	1.8
VFA in ileal fluid, mM ^a	23.3	26.2	28.9	30.2	1.9
Arterial glucose, mM ^a	4.1	4.3	4.4	4.3	0.1
Net portal glucose absorption, g/h ^a	-5.7	5.0	2.1	6.3	3.2

^aLinear effect $P < .05$, ^bQuadratic effect $P < .05$.

Table 3. Effect of abomasal glucose infusions on small intestinal disappearance and net portal glucose absorption (Exp. 3)

Item	Infusion rate, g/h				SE
	0	20	40	60	
Daily feed, lbs	12.5	13.0	10.4	12.3	1.3
Glucose flowing past ileum, g/h ^a	0	0	4.90	13.8	2.8
VFA in ileal fluid, mM ^a	23.9	25.8	27.9	20.5	2.8
Arterial glucose, mM ^a	4.4	4.9	5.1	5.1	0.1
Net portal glucose absorption, g/h ^a	-7.3	19.8	20.0	36.6	7.9

^aLinear effect $P < .01$.

Table 4. Effect of abomasal starch infusions on small intestinal disappearance and net portal glucose absorption (Exp. 4)

Item	Infusion rate, g/h				SE
	0	20	40	60	
Daily feed, lbs	11.9	13.2	13.2	13.0	0.9
Glucose flowing past ileum, g/h ^a	0	0.7	2.3	2.7	0.5
Starch flowing past ileum, g/h ^a	0	5.5	10.9	26.1	4.1
VFA in ileal fluid, mM	26.9	30.9	29.8	29.6	2.3
Arterial glucose, mM ^a	4.1	4.2	4.3	4.4	0.1
Net portal glucose absorption, g/h ^{ab}	-6.7	8.5	12.0	12.1	1.9

^aLinear effect $P < .01$, ^bQuadratic effect $P < .01$.

Table 5. Effect of abomasal glucose infusions on small intestinal disappearance and net portal glucose absorption (Exp. 5)

Item	Infusion rate, g/h				SE
	0	20	40	60	
Daily feed, lbs	11.0	13.2	9.9	16.6	1.4
Glucose flowing past ileum, g/h ^{ab}	0	0	0.4	1.0	1.3
VFA in ileal fluid, mM ^a	22.3	24.7	22.4	30.7	3.2
Arterial glucose, mM ^{ab}	4.3	4.6	4.7	4.6	0.1
Net portal glucose absorption, g/h ^{ab}	-7.3	14.4	14.3	9.4	4.6

^aLinear effect $P < .05$, ^bQuadratic effect $P < .05$.