

# Digestion of Starch in the Small or Large Intestine of the Equine

G. D. Potter, F. F. Arnold, D. D. Householder, D. H. Hansen, and K. M. Brown

Department of Animal Science  
Texas A & M University  
College Station, Texas, USA

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The incidence of digestive dysfunction in the stalled, meal-fed horse seems greater than that in pastured horses. Some variations of the colic syndrome and most diet-related laminitis cases are apparently due to an overloading of the capacity for starch digestion in the equine small intestine. If such overloading of the small intestine occurs, it is likely that normal fermentive digestion in the equine large intestine would be compromised. Thus, it has been a long-term objective of research in this laboratory to quantify the extent of starch digestion in the small and large intestines when equines are meal-fed varying amounts and sources of starch. Also, the effects of processing starches has been studied. Some of the data from these studies have been reported abstractly (Householder et al., 1976; Arnold et al., 1981; Hinkle et al., 1983; Massey et al., 1985). This paper presents remaining data and a summary of this long-term research project.

## Experimental Procedures

The basic technique used in these studies was that of sequential sampling of feed, ingesta and feces from horses and ponies fitted with permanent posterior ileal cannulas. The animals were meal-fed varying amounts, sources and forms of cereal grain in conventional hay and grain diets. Procedures for installing the ileal cannulas were described by Householder (1978). Chromic oxide was fed as an external indicator in all experiments. The basic approach was to feed the animals assigned diets in Latin square or switchback arrangements such that all animals received all experimental diets. Experimental periods were composed of adjustment periods of 10 – 14 days and sampling periods of 4 – 7 days. In the sampling periods, fecal grab samples were obtained at each 2 hours during the interfeeding intervals. Ileal samples were generally collected at each 30-min interval for 2 – 3 hours following feeding then each 2-hour

## Summary

A series of experiments was conducted to determine the site and extent of starch digestion in the equine and whether the source of starch, method of processing and intake of starch were factors that influence these phenomenon. Clearly, any starch that escaped digestion in the small intestine was fermented in the large intestine in these experiments. However, the digestion of starch in the small intestine was variable.

It appears that the method of grain processing may be a significant factor in whether starch is digested in the small or large intestine of the equine. Those sources of starch that are relatively insoluble may be gelatinized by sophisticated grain processing to an extent that enhances the small intestinal digestion of that starch, particularly at moderate or high intake of starch. It appears that at low intake of starch, almost any source of starch will be digested primarily in the small intestine. Perhaps the most significant finding in these experiments is a quantitative estimate of the capacity for starch digestion in the small intestine of the meal-fed equine. It appears from these data that in order to prevent digestion dysfunction resulting from a starch overload to the small intestine, starch intake in the equine fed 2 – 3 meals per day should be limited to approximately 0.4 % of body weight per feeding.

## Verdauung von Stärke im Dün- oder Dickdarm des Pferdes

Eine Reihe von Untersuchungen diente zur Bestimmung des Ortes und der Höhe der Stärkeverdaulichkeit beim Pferd, in Abhängigkeit von Stärkeart, -zubereitung und -aufnahme.

Jede Stärkeart, die den Dünndarm passiert, wird im Dickdarm fermentiert. Es scheint, daß die Zubereitungsart einen signifikanten Einfluß auf den Ort der Verdauung, d. h. im Dün- bzw. Dickdarm, besitzt. Stärkearten, die relativ unlöslich sind, scheinen nach technischer Aufbereitung aufzuquellen, mit der Folge einer höheren Stärkeverdaulichkeit im Dünndarm, besonders bei mittlerer oder hoher Stärkeaufnahme. Bei niedriger Stärkeaufnahme wird anscheinend jede Stärkeart vorrangig im Dünndarm verdaut. Die meisten signifikanten Ergebnisse dieser Untersuchung führen zu einer Abschätzung der Kapazität der Stärkeverdauung im Dünndarm nach Aufnahme von gemahlenem Pferdefutter. Ausgehend von diesen Ergebnissen sollte, um eine Verdauungsstörung durch Stärkeüberladung zu vermeiden, die Stärkeaufnahme bei einer 2- bis 3maligen täglichen Fütterung auf annähernd 0,4 % der Körpermasse begrenzt werden.

interval during the remainder of the interfeeding interval. Samples were composited to provide one sample of ileal contents and one sample of feces for each animal on each diet treatment. Starch concentrations in feed, ileal contents and feces were determined from glucose analyses following chemical or enzymatic hydrolysis using procedures similar to those reported by Dalquist (1964), and chromium concentrations in those samples were determined colorimetrically following acid oxidation. Digestion of starch in different segments of the digestive tract was determined from changes in starch: chromium ratios. Data were analyzed by analyses of variance appropriate for the Latin square design, and when treatment effects were significant, differences between means were identified by Duncan's multiple range test. Least squares regression analyses were also used to determine relationships between starch intake and digestion.

**Table 1:** Digestion of Various Sources of Starch in the Equine Small and Large Intestines – Low Intake

	Primary Source of Starch					
	Corn	Oats	Barley	Sorghum	Mean	SE
Starch intake <sup>a</sup>	134.8	121.3	150.3	118.9	131.3	10.3
Digested						
Total tract <sup>a</sup>	133.3	120.0	148.6	116.0	129.5	10.5
% of intake	98.9	98.9	98.9	97.6	98.6	0.6
Prececal <sup>a</sup>	109.1	98.2	144.1	95.5	111.7	14.8
% of intake	80.9	81.0	95.9	80.3	85.1	5.9
% of digested	81.8	81.8	97.0	82.3	86.3	19.6
Postileal <sup>a</sup>	24.2	21.8	4.5	20.5	17.8	8.6
% of ileal	94.2	94.4	72.6	87.6	90.8	14.6
% of digested	18.2	18.2	3.0	17.7	13.7	7.6

<sup>a</sup> g/100 kg body weight/feeding  
From Arnold (1982)

## Results and Discussion

### Sources of Starch

Four ileal cannulated ponies weighing an average of 120 kg were fed mixed diets based on chopped bermudagrass hay and rolled corn, oats, barley and sorghum grain in a 4 x 4 Latin square arrangement. The proportions of hay and grain were varied such that the neutral detergent fiber and starch concentrations in each diet were similar (approximately 60 % and 30 %, respectively). Feed was offered at 12-hour intervals, and the ponies were allowed 1.5 hours to eat each meal. Feed consumption averaged approximately 0.4 % of body weight at each meal.

Digestion of different sources of starch is shown in tab. 1. As seen in many other reports, starch digestion over the whole digestive tract was almost complete, and there was no difference in digestion of different sources of starch. Similarly, digestion of starch in the small intestine was very high (average 85 %) and was not different between sources

**Table 2:** Digestion of Oats and Sorghum Starch in the Equine Small and Large Intestines – Moderate Intake

	Primary Source of Starch			
	Oats	Sorghum	Mean	SE
Starch intake <sup>a</sup>	250.8	288.8	269.8	16.0
Digested				
Total tract <sup>a</sup>	236.1	271.9	253.9	14.8
% of intake	94.1	94.3	94.2	0.3
Prececal <sup>a</sup>	136.1	134.4	135.2	11.8
% of intake	55.2	47.5	51.4	4.0
% of digested	58.6	50.3	54.3	4.2
Postileal	100.0	137.5	118.7	14.4
% of ileal	86.5	88.3	87.4	1.0
% of digested	41.4	49.7	45.6	4.2

<sup>a</sup> g/100 kg body weight/feeding  
From Householder (1978)

**Table 3:** The Influence of Processing Grains on Starch Digestion in the Equine Small and Large Intestines – Moderate Intake

	Processing Method			
	Crimping	Micronizing <sup>a</sup>	Mean	SE
Starch intake <sup>b</sup>	279.7	260.0	269.8	16.0
Digested				
Total tract <sup>b</sup>	263.3	244.6	253.9	14.8
% of intake	94.2	94.2	94.2	0.3
Prececal <sup>b</sup>	115.6	154.9	135.2	11.8
% of intake	42.0	60.7	51.3	4.0
% of digested	44.5	64.3	54.4	4.2
Postileal <sup>b</sup>	147.7	89.8	118.7	14.0
% of ileal	89.8	85.0	87.4	1.0
% of digested	55.5	35.7	45.6	4.2

<sup>a</sup> dry-heat treated, rolled; <sup>b</sup> g/100 kg body weight/feeding  
From Householder (1978)

of starch. The apparently high value for digestion of barley starch is an artifact due to one pony. From a slaughter experiment, Hintz *et al.* (1971) reported carbohydrate digestion in the small intestine in the range of 55 %. The higher small intestinal starch digestibility in this experiment can be attributed to the low intake of starch, which may have masked any differences in digestion of various sources of starch that might occur at higher intakes.

### Oats vs. Sorghum Starch and Effects of Processing

Four ileal cannulated horses weighing an average of 370 kg were fed diets containing 50 % bermudagrass hay and 50 % concentrate in a 4 x 4 Latin square design. The concentrates were based on oats or sorghum grain that was dry-crimped or „micronized“ (dry-heated and crimped). Concentrates were formulated to contain similar amounts of protein (12 – 13 %), crude fiber (7 – 9 %) and starch (50 – 55 %). The total diets were fed at 12-hour intervals at approximately 1 % of body weight per feeding.

**Table 4:** The Interaction Between Source of Starch and Grain Processing on Starch Digestion in the Equine Small and Large Intestines – Moderate Intake

	Treatment					
	CO <sup>a</sup>	MO <sup>b</sup>	CS <sup>c</sup>	MS <sup>d</sup>	Mean	SE
Starch intake <sup>e</sup>	264.2	237.4	295.0	282.6	269.8	16.0
Digested						
Total tract <sup>e</sup>	249.4	222.7	277.2	266.5	253.9	14.8
% of intake	94.4	93.8	94.0	94.5	94.1	0.3
Prececal <sup>e</sup>	123.8 <sup>gh</sup>	148.4 <sup>hi</sup>	107.4 <sup>i</sup>	161.4 <sup>i</sup>	135.2	11.8
% of intake	48.0 <sup>fg</sup>	62.3 <sup>g</sup>	36.0 <sup>f</sup>	59.0 <sup>g</sup>	51.3	4.0
% of digested	50.7 <sup>fg</sup>	66.4 <sup>g</sup>	38.3 <sup>f</sup>	62.2 <sup>g</sup>	54.4	4.2
Postileal <sup>e</sup>	125.6 <sup>fg</sup>	74.3 <sup>f</sup>	169.7 <sup>g</sup>	105.2 <sup>f</sup>	118.7	14.4
% of ileal	89.5 <sup>g</sup>	83.5 <sup>f</sup>	90.0 <sup>g</sup>	86.5 <sup>fg</sup>	87.4	1.0
% of digested	49.3 <sup>fg</sup>	33.6 <sup>g</sup>	61.7 <sup>f</sup>	37.8 <sup>g</sup>	45.6	4.2

<sup>a</sup> Crimped oats; <sup>b</sup> micronized oats; <sup>c</sup> crimped sorghum; <sup>d</sup> micronized sorghum; <sup>e</sup> g/100 kg body weight/feeding; <sup>ghi</sup> means in the same row not sharing same superscript differ (P < .1)  
From Householder (1978)

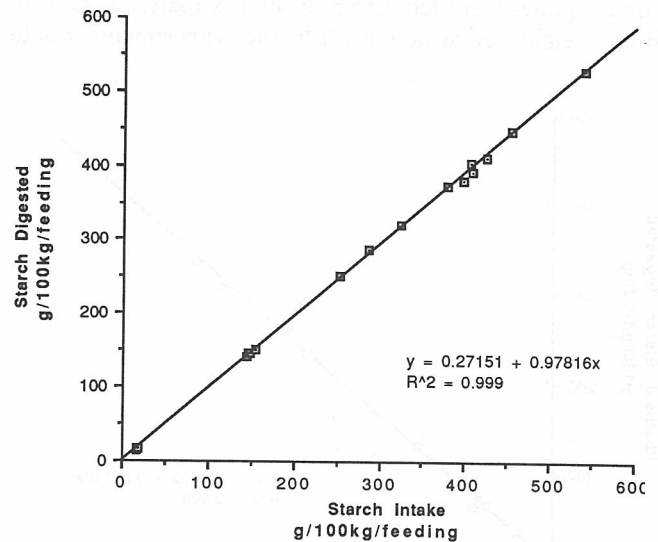
**Table 5:** Influence of Frequency of Feeding on Starch Digestion in the Equine Small and Large Intestines – Moderate Intake

	Meals Per Day			Daily Mean
	2	3	4	
Starch intake	265.4 <sup>a</sup>	177.5 <sup>a</sup>	133.2 <sup>a</sup>	531.9 <sup>b</sup>
Digested				
Total tract	261.7 <sup>a</sup>	173.2 <sup>a</sup>	131.4 <sup>a</sup>	522.9 <sup>b</sup>
% of intake	98.6	97.6	98.7	98.3
Prececal	194.8 <sup>a</sup>	132.8 <sup>a</sup>	93.5 <sup>a</sup>	387.3 <sup>b</sup>
% of intake	73.4	74.8	70.2	72.8
% of digested	74.4	76.6	71.1	74.0
Postileal	66.9 <sup>a</sup>	40.5 <sup>a</sup>	38.0 <sup>a</sup>	135.6 <sup>b</sup>
% of ileal	94.9	90.6	95.7	93.7
% of digested	25.6	23.4	28.9	26.0

<sup>a</sup> g/100 kg body weight/feeding; <sup>b</sup> g/100 kg body weight/day  
From Brown (1987)

Total, prececal and postileal digestion of starch is shown in tab. 2 – 4. A comparison of the digestion of oats vs. sorghum starch is shown in tab. 2. As before, digestion of starch over the total tract was almost complete and did not differ between sources of starch. There was a trend for prececal starch digestion to be higher when the horses were fed oats than when they were fed sorghum with a corresponding increase in postileal starch digestion when the horses were fed sorghum. However, the effect of processing, seen in tab. 3, masked some of the differences between sources of starch. Micronized starch was apparently more highly digestible in the small intestine than crimped starch, but again the entire effect of processing was masked by the source of starch. Thus, the interaction between the source of starch and the method of processing on digestion of starch in the small and large intestines is shown in tab. 4. Prececal starch digestion was highest when the horses were fed micronized oats and lowest when the horses were fed crimped sorghum. Conversely, the major site of starch

digestion when the horses were fed crimped sorghum was the large intestine. While micronizing the grains tended to improve prececal digestion of both oats and sorghum, the improvement was much greater for sorghum than oats. Thus, it appears that some form of processing that will gelatinize starch may improve small intestinal starch digestion in the equine, particularly for those starches that may have lower solubility in the raw state. McNeill et al. (1975) reported that sophisticated grain processing altered

**Fig. 1:** Total starch digested at varying intakes.

the solubility of sorghum starch which improved starch digestibility. It should be noted that there was a virtually complete compensating effect of the large intestine on digestion of starch that escaped digestion in the small intestine. Acute consequences of excessive carbohydrate fermentation in the equine large intestine may include excessive gas production, colic and laminitis, and more chronic effects on fiber fermentation may be important.

**Table 6:** Starch Digestion in the Small and Large Intestines of Ponies Fed Varying Amounts of Corn

	Percent Corn in Diet					SE
	20	40	60	80	Mean	
Starch intake <sup>a</sup>	113.2 <sup>b</sup>	223.7 <sup>c</sup>	315.8 <sup>d</sup>	343.2 <sup>d</sup>	249.0	15.7
Starch digested						
Total tract <sup>a</sup>	110.5 <sup>b</sup>	221.3 <sup>c</sup>	313.7 <sup>d</sup>	341.8 <sup>d</sup>	246.8	29.2
% of intake	97.7	98.9	99.3	99.6	98.9	0.2
Prececal <sup>a</sup>	73.0 <sup>b</sup>	129.7 <sup>bc</sup>	172.9 <sup>cd</sup>	223.6 <sup>d</sup>	149.8	14.7
% of intake	64.5	59.6	54.3	65.8	60.2	2.8
% of digested	65.0	60.3	54.7	66.0	61.5	2.9
Postileal <sup>a</sup>	37.5 <sup>b</sup>	91.6 <sup>c</sup>	140.9 <sup>d</sup>	118.2 <sup>cd</sup>	97.1	6.0
% of ileal	92.9	97.1 <sup>c</sup>	98.3	98.9	96.8	0.9
% of digested	35.0	39.7	45.3	34.0	38.5	2.9

<sup>a</sup> g/100 kg body weight/feeding; <sup>bcd</sup> means not sharing same superscript differ ( $P < .05$ )

From Hinkle et al. (1983)

#### Starch Intake – Frequency of Feeding and Meal Size

Results of the previous experiments led to the speculation that there may be an upper limit to the capacity for starch digestion in the small intestine of the meal-fed equine that was not reached previously. Thus, three experiments were conducted to quantify small and large intestinal starch digestion in ponies and horses fed varying sizes of meals. In the first of these experiments, three ileal cannulated ponies weighing an average of 144 kg were fed a 70 % commercial, oats and corn based concentrate: 30 % alfalfa diet in a 3 x 3 Latin square arrangement. The daily ration was fed in 2, 3 or 4 meals at 12-, 8-, and 6-hour intervals, respectively. In a pre-experimental period, it was determined that maximal voluntary intake of the diet in 2-hour meal periods was 1.5 % of body weight daily. Thus, that level of feed was provided in the experimental periods. As seen in tab. 5, total starch digestion was about 98 % regardless of the frequency of feeding, and of the total starch digested, about

74 % was digested in the small intestine. Clearly, the amount of starch consumed in the twice-daily feeding schedule in this experiment was not sufficient to overwhelm the capacity of the small intestine for starch digestion. Thus, at the same daily intake, the more frequent feeding schedules and smaller meal sizes would not be expected to increase small intestinal starch digestion beyond that observed during the twice-daily feeding schedule. From these and previous data, it was concluded that (1) the capacity for small intestinal digestion of starch was not reached when these equines were fed starch at approximately 0.25 % of body weight per meal and (2) further experiments would

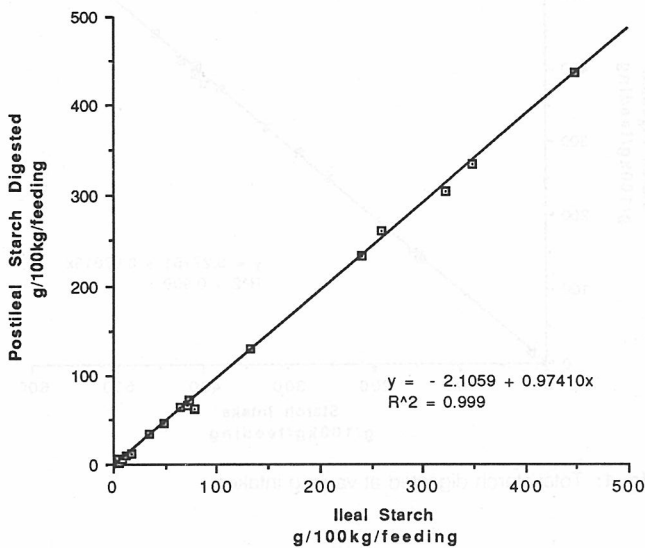


Fig. 2: Postileal starch digested at varying amounts of ileal starch.

be necessary to determine the upper limits to small intestinal starch digestion in the equine. In the next experiment, 4 ileal cannulated ponies weighing an average of 150 kg were fed complete mixed diets containing chopped alfalfa and ground corn, with corn comprising 20, 40, 60 or 80 % of the diet. The diets were fed at 12-hour interval in a 4 x 4 Latin square arrangement. Feed was offered at approximately 0.75 % of body weight per feeding and the ponies were given 2 hours to consume their meals. An objective in this experiment was to have the ponies consume starch in amounts approximating 0.5 % of body weight per feeding. However, when the ponies were fed the 60 % and 80 % corn diets, they did not consume the entire meals, and consequently, the highest starch intake achieved was approximately 0.35 % of body weight per meal (tab. 6). As in earlier experiments, total starch digestion was near complete, and similar to some earlier experiments approximately 60 % of the starch digestion occurred in the small intestine regardless of starch intake. These data further indicated that at moderate feed intake, starch digestion occurred principally in the small intestine in these ponies even though sizeable amounts of starch were digested in the large intestine when the ponies were fed the highest amounts of corn.

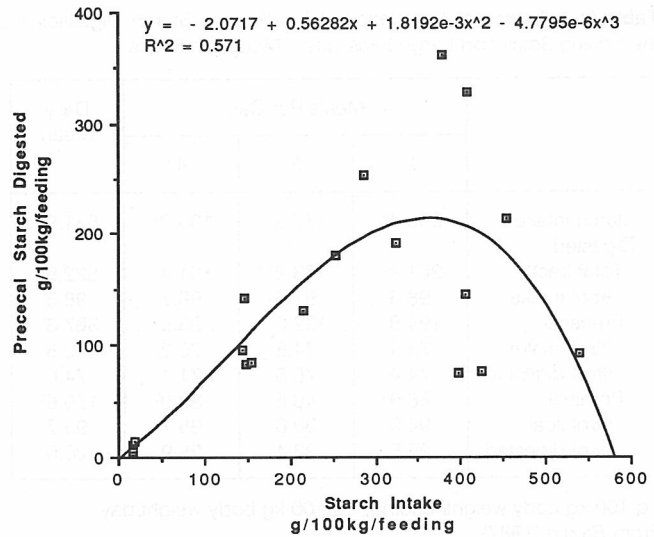


Fig. 3: Prececal starch digested at varying starch intake.

In the final experiment, two 500-kg mature geldings with aggressive eating behavior and good appetites were fitted with posterior ileal cannulas. The horses were fed 1.4 kg of alfalfa and varying amounts of chopped corn at 12-hour intervals. Hay intake remained constant, and the horses were offered the corn in each 2-week experimental period beginning at 0.1 kg and increasing up to 5.2 kg per feeding, then in decreasing amounts back to the lowest intake. This regimen provided two observations on each horse at each of 5 amounts of corn offered and resulted in starch intakes ranging from .02 to 0.55 % of body weight per feeding. The data were plotted and subjected to least squares regression analyses to determine relationships between starch intake and various measures of starch digestion. Total starch digestion is shown in fig. 1. As in all other experiments, total digestion of starch was very near complete at all levels of starch intake. Similarly, starch digestion in the large intestine was over 97 % at all levels of starch intake (fig. 2)

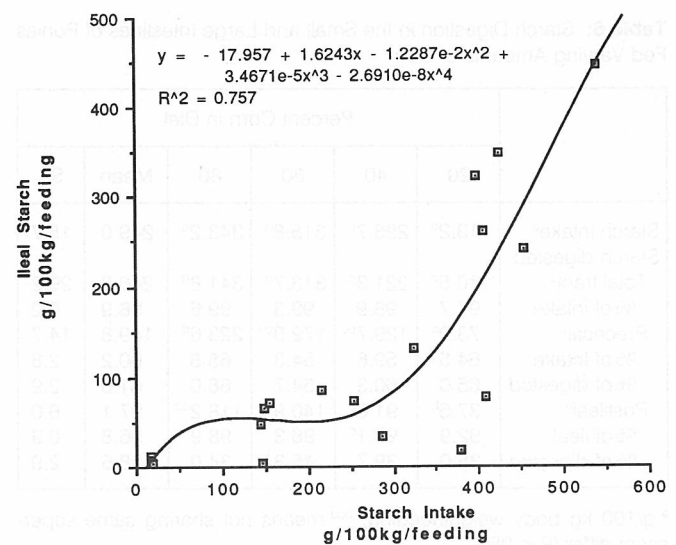


Fig. 4: Ileal starch at varying starch intake.



which reinforces the concept that the large intestine has a highly compensatory effect on the digestion of any starch that escapes digestion in the equine small intestine. The consequences of this phenomenon on potential lower intestinal dysfunction at high starch intakes seem obvious. Digestion of starch in the small intestine is shown in fig. 3. While the relationship between starch intake and the amount of starch digested in the small intestine was much more variable than that observed for large intestinal digestion, it appears that there was no further increase in small intestinal starch digestion when starch intake exceeded approximately 0.4 % of body weight per feeding. This relationship can be seen more clearly in fig. 4. When starch intake exceeded approximately 0.4 % of body weight per feeding, there was a dramatic increase in the amount of starch that reached the posterior ileum. Thus, it is suggested from these data that perhaps the upper limit to starch digestion in the small intestine of the meal-fed equine may be an amount in the range of 0.35 - 0.4 % of body weight per feeding.

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*Gary D. Potter*  
*Equine Science*  
*249 Kleberg Center*  
*College Station*  
*Texas 77843-2471*  
*USA*