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THE GLYCEMIC AND INSULINEMIC INDEX IN HORSES

INGRID VERVUERT AND MANFRED COENEN
Institute of Animal Nutrition, School of Veterinary Medicine, Hannover, Germany

Introduction

In horses, the total tract apparent digestibility of starch for various types of grain is usually very high. Arnold et al. (1981) reported values of 97.0, 96.7, and 97.0% respectively for corn, oats, and sorghum starch. On the other hand, considerable differences in prececal starch digestibility were observed between the different starch sources. In general, the prececal digestibility of oat starch exceeds that of corn starch or of barley starch (Kienzle et al., 1992; Potter et al., 1992; Meyer et al., 1995). Prececal starch digestibility of grains is improved by different processing techniques. The granular structure of starch might be destroyed mechanically (e.g, rolling, crushing, or grinding) or by heat and pressure in combination with moisture (Kienzle et al., 1992; Potter et al., 1992; Meyer et al., 1995). The effect of thermal processing such as micronizing, steam-flaking, or popping is an irreversible swelling and destruction of the internal crystalline structures of the starch granules; this transformation is termed gelatinization (Holm et al., 1988; Selmi et al., 2000). Thus, the extent of prececal digestion influences the proportion of cereal carbohydrates absorbed as glucose in the small intestine and that are fermented and absorbed as volatile fatty acids or lactic acids in the large intestine.

Consequently, an increase in availability of starch for enzymatic digestion in the small intestine might alter the metabolic response as more substrate will be absorbed. In humans, the measurement of blood glucose and insulin response is known as a suitable tool for assessing the effects of food processing on starch digestion (Jenkins et al., 1981; Brand et al., 1985; Granfeldt et al., 1994). In human subjects, starchy foods have been classified over the entire range from restrained, or low glycemic and insulin response, to rapid with respect to effects on blood glucose and insulin responses after a meal (Jenkins et al., 1988; Granfeldt et al., 1994). The resulting glycemic or insulinemic index utilized white bread as the standard source and all foods were ranked accordingly (Jenkins et al., 1981).

Influence of Grain Source and Processing Techniques on the Glycemic and Insulinemic Responses in Horses: Recent Work

Information is available regarding the influence of various grain sources on glucose and insulin response in horses, but no such glycemic or insulinemic index has yet been formulated for horses.

Stull and Rodiek (1988) noticed a significant increase in plasma glucose concentration after corn feeding as well as after a combined diet of corn and alfalfa (50% corn and 50% alfalfa) in two-year-old Quarter Horse geldings. Insulin concentrations closely followed the glucose curves. However, postprandial response area for glucose did not differ between alfalfa feeding (100%), corn feeding (100%), and combined corn and alfalfa feeding (50% corn and 50% alfalfa).

In ponies (age 3 to 18 years), oat feeding caused higher blood glucose concentrations in comparison to whole corn or barley. The addition of roughage to the diet blunted the postprandial rise in blood glucose, while the increase in starch intake (2 g starch/kg BW per meal and 4 g starch/kg BW per meal, respectively) did not influence blood glucose response (Radicke et al., 1994). The higher glycemic response to oat feeding was accompanied by a higher prececal starch digestibility rate of oats. However, in the study by Radicke et al. (1994), mean peak plasma glucose concentrations after oat feeding were lower (<5.55 mmol/L) when compared to the mean peak plasma glucose concentrations following corn feeding (7.85 ± 1.03 mmol/L) measured by Stull and Rodiek (1988), although starch intake was comparable between these two studies. No differences in mean postprandial peak plasma glucose concentrations were observed for sweet feed (45% cracked corn, 45% whole oats, and 10% molasses), whole oats, and cracked corn by Pagan et al. (2001) in six Thoroughbred geldings. Furthermore, area under the postprandial glucose curve did not differ for whole oats and cracked corn, but mean glucose concentrations were higher for whole oats (5.51 mmol/L) when compared to cracked corn (5.4 mmol/L).

The effect of corn processing on glycemic response was investigated by Hoekstra et al. (1999) in 6 horses (four Arabians, two Thoroughbreds; age 6 to 10 years). This experiment was conducted to evaluate how cracking, grinding, or steam processing affects starch digestibility of corn using glycemic response as an indirect measure of prececal starch digestibility. The glycemic response of each grain was compared using a glycemic index in which each feed´s glucose area under the curve (AUC) was expressed relative to cracked corn. The highest glycemic index was noticed for the steam-flaked corn (2 g starch/kg BW in a single meal; Figure 1). It is speculated that the high glycemic response reflects changes in prececal starch digestibility by thermal corn processing.

In a recent study by our own research group, mechanical or thermal processing of oats, barley, or corn did not clearly influence glycemic or insulinemic response in horses (Bothe 2001; Vervuert et al., 2002; Coenen et al., 2002). In a crossover design, six Standardbred horses (age 4 to 15 years, mean body weight 450 ± 37

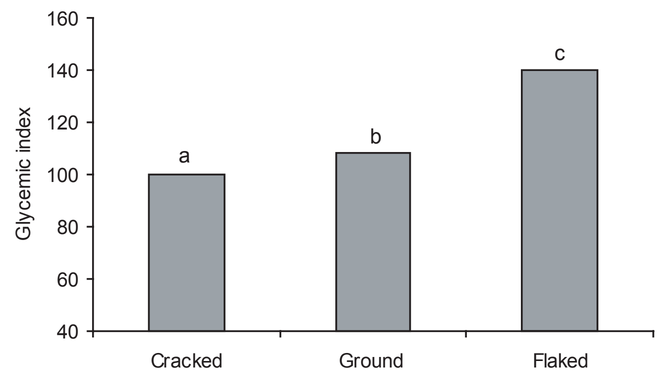

Figure 1. Glycemic index for processed corn (starch intake is 2 g/kg BW in a single meal) (Hoekstra et al., 1999).

kg) were fed in random order: untreated, finely ground, steam-flaked, and popped grain. All diets were adjusted to a starch content of 630 g starch per day from oats, barley, or corn (1.2-1.5 g starch/kg BW in a single meal). Grain feeding resulted in a significant increase in plasma glucose and insulin concentrations, but glucose and insulin peaks as well as AUC were not clearly influenced by grain processing of oats, barley, and corn (Table 1).

Table 1. Peak glucose (mmol/L), peak insulin (μU/ml), and area under the curve (AUC) for all diets.

Dietary treatment	*Horses (N)*	*Glucose peak (mmol/L)*	*Glucose AUC*	*Insulin peak (μU/ml)*	*Insulin AUC*
oats, untreated	6	6.7 ± 1.3	1659 ± 254	31.9 ± 22.9	6052 ± 4623
finely ground	6	6.6 ± 0.9	1697 ± 318	49.3 ± 54.1	9946 ± 11415
steam-flaked	6	6.1 ± 0.2	1549 ± 67	22.9 ± 6.7	4662 ± 1351
popped	3	6.0 ± 1.2	1577 ± 187	27.2 ± 21.6	4998 ± 3166
barley, untreated	6	6.1 ± 0.5	1564 ± 160^{a}	19.1 ± 6.5^{ab}	3792 ± 1713^{a}
finely ground	6	5.7 ± 0.7	1494 ± 144^{bc}	19.9 ± 8.2^{a}	3766 ± 1565^{ac}
steam-flaked	6	6.5 ± 0.6	1541 ± 116^{ac}	29.4 ± 11.9^{a}	5135 ± 2012^{bc}
popped	3	6.1 ± 0.4	1563 ± 132^{ac}	21.5 ± 8.1^{b}	3840 ± 2164^{a}
corn, untreated	6	6.6 ± 0.8	1630 ± 170	23.6 ± 12.9	4333 ± 2129
finely ground	6	6.2 ± 1.2	1527 ± 175	30.4 ± 22.9	4539 ± 2455
steam-flaked	4	5.9 ± 0.3	1513 ± 48	24.6 ± 10.6	4674 ± 1889
popped	3	6.3 ± 1.2	1691 ± 283	18.8 ± 10.8	3511 ± 1929

Treatments lacking a common superscript differ ($P<0.05$) within a column.

Insulin concentrations followed the glucose curves, but the correlation of mean plasma glucose and plasma insulin concentrations was not as close as expected and best described by the following equation: y = 12.6 x – 49.24, where y = mean plasma insulin and x = mean plasma glucose ($r^2 = 0.47$, $p<0.001$).

The glycemic index where each feed´s glucose area under the curve was expressed relative to untreated oats varied between 90.44 ± 13.55% (steam-flaked corn) and 112.02 ± 18.71% (popped corn, P< 0.05.). The insulin index where each feed´s insulin area under the curve was expressed relative to untreated oats ranged between 78.06 ± 33.75% (untreated barley) and 114.76 ± 34.06% (popped corn, n.s.). The glycemic and insulinemic indexes of oat, barley, and corn processing are shown in Figure 2.

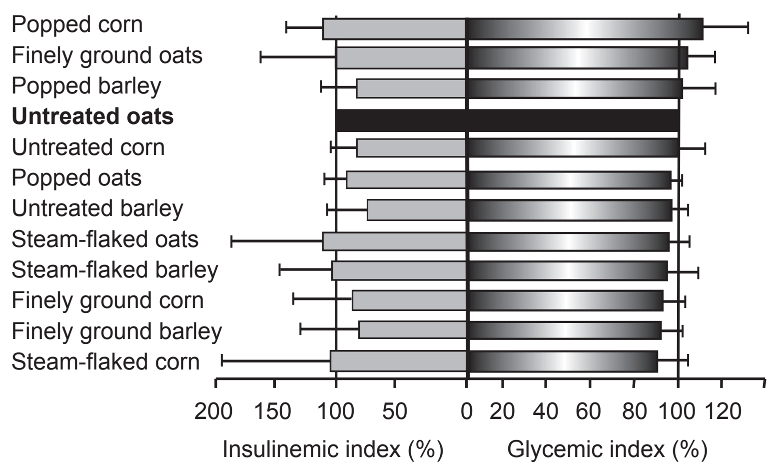

Figure 2. Glycemic and insulinemic indexes for processed oats, barley, and corn (starch intake is 1.2 1.5 g/ kg BW in a single meal).

In our study one striking feature was the high variation in plasma glucose and insulin response between the horses (e.g., peak plasma insulin concentrations for oat treatment; Figure 3). The reasons for the great individual variation are not fully understood. Ralston (1992) noticed a similar individual reaction in horses after feeding pelleted concentrates with a high or low level of soluble carbohydrates. In accordance, a high variation in glycemic response was monitored by Venner and Ohnesorge (2001) after an oral glucose load in healthy horses. A great variation in behavioral response to grain feeding is monitored by several horse owners and might be related to the variable glycemic and insulinemic responses to starch feeding.

In contrast to the investigation by Hoekstra et al. (1999), the effects of mechanical or thermal grain processing seemed to be of minor importance for the metabolic reaction and were not reflected in a raised glycemic or insulinemic response. However, untreated barley or corn was known to have a low prececal starch digestibility, and thermal treatment enhanced starch digestibility in the small intestine about threefold (Kienzle et al., 1992; Potter et al., 1992; Meyer et al., 1995). On the other hand, the improvement in prececal starch digestibility by grain processing and the increase in substrate availability might have been masked by other factors. Some of these factors include the chemical nature of the grain (amylose-amylopectin ratio), interactions with proteins and fat, the presence of dietary fiber, the rate of gastric emptying, and amylase availability in the small intestine (Rooney and Pflugfelder, 1986; Granfeldt et al., 1994).

Several studies have been conducted in humans to compare the amylose-amylopectin content of starch and its effect on glycemic and insulinemic response. The glucose and insulin response to high-amylose starch is significantly lower when compared to starch with moderate levels of amylose (Byrners et al., 1995; Kabir et al., 1998). More research is necessary to compare the digestibility of and metabolic reaction to different varieties of oats, barley, and corn.

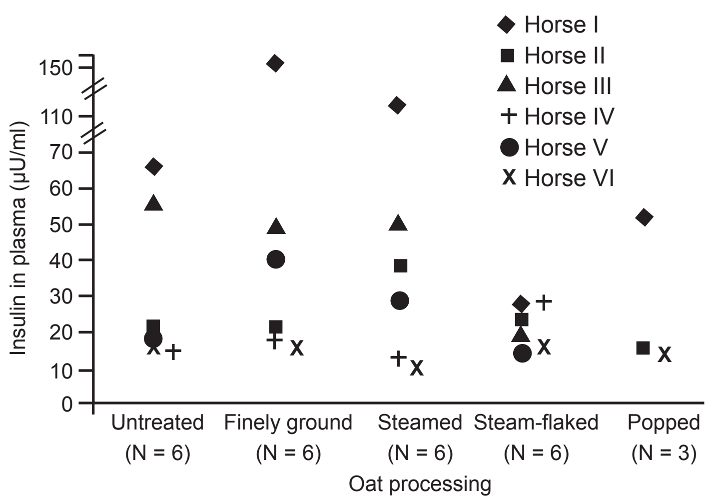

Figure 3. Peak plasma insulin concentrations for oat processing (Vervuert et al., in print).

Clinical Application of the Glycemic and Insulinemic Index in Horses

The nutritional importance of postprandial glucose and insulin response with regard to different sources of cereals and processing techniques is gaining greater awareness. On one hand, a high prececal starch digestibility is important to minimize starch flow into the large intestine, which might lead to considerable alterations in the microbial fermentation. On the other hand, exaggerated plasma glucose and insulin responses after carbohydrate intake have been associated with noninsulin-dependent diabetes and cardiovascular diseases in humans. Foods that elicit low postprandial glycemic responses are considered beneficial in subjects with metabolic diseases as well as in healthy human subjects. In horses, glucose and insulin control may be impaired in a number of life stages and/or conditions such as diabetes, obesity, gestation, pituitary dysfunction, laminitis, and aging. In horses with impaired glucose metabolism, plasma glucose concentration remains higher for longer periods of time, and horses were less sensitive to insulin than control individuals.

Table 2. Plasma glucose (mmol/L) in OCD-negative (OCD -) and OCD-positive (OCD +) horses after feeding meals of sweet grain mix plus hay (Ralston, 1996).

	Time after feeding (hours)						
	0	*1*	*2*	*3*	*4*	*5*	*6*
OCD -	6.89 ± 0.13	9.12 ± 0.20	8.85 ± 0.26	8.29 ± 0.18	7.78 ± 0.12	7.29 ± 0.11	7.04 ± 0.11
OCD +	6.22 ± 0.17	10.3 ± 0.52	11.4 ± 0.06	10.2 ± 0.69	8.59 ± 0.50	7.01 ± 0.36	6.36 ± 0.27

These results by Ralston (1996) were supported in a field study with 218 Thoroughbred weanlings where a high glucose and insulin response to a concentrate meal was associated with an increased incidence of OCD (Pagan et al., 2001). At Rutgers University a patented glucose challenge test has been developed to identify foals with a high risk of developing OCD by their glycemic and insulinemic response (Ralston, 2001). Based on these results it would be beneficial to feed young growing horses feedstuffs that are known to elicit a moderate or low glycemic and insulinemic response.

METABOLIC DYSFUNCTIONS AND THE GLYCEMIC AND INSULINEMIC INDEX

Ponies that were fat or had previously suffered laminitis were found to be more intolerant to oral glucose loads than healthy ponies or Standardbred horses (Jeffcott et al., 1986). These ponies exhibited a far greater response in plasma glucose and insulin levels after glucose loading (1 g glucose/kg BW). Furthermore, aged horses often exhibit a relative glucose intolerance characterized by hyperglycemia and hyperinsulinemia following a glucose challenge (Ralston et al., 1988).The glucose intolerance in old horses is caused by a high incidence of pituitary adenomas. The pituitary adenomas cause excess corticosteroid secretion and impaired glucose metabolism.

The dietary management of glucose intolerance in horses is not well defined. However, there are two different ways of influencing dietary glycemic load:

reducing carbohydrate intake or using feedstuffs with a low glycemic index. However, in humans there is good evidence that a high-carbohydrate intake with a low glycemic index improved pancreatic b -cell function in subjects with impaired glucose tolerance in comparison to a low-carbohydrate and high monounsaturated fat diet (Wolever et al., 2002). In consequence, diets with a low glycemic index might be preferable in dietary prevention and management of glucose intolerance in horses.

GLYCEMIC AND INSULINEMIC RESPONSE PRIOR TO EXERCISE AND TRAINING

Dietary management prior to exercise may affect performance by altering energy metabolism during exercise in horses. In several investigations, corn feeding one, two, three, or four hours prior to exercise resulted in a marked drop in plasma glucose and insulin concentration below pre-feeding levels during exercise (Rodiek et al., 1991; Lawrence et al., 1995; Stull and Rodiek 1995; Pagan and Harris,1999). In general, horses that began exercise with high blood glucose and insulin levels (e.g., after corn feeding) showed a transient hypoglycemia during exercise, but the size of the meal (1, 2, or 3 kg) did not affect the response, although higher pre-exercise glucose levels were observed when the horses received 3 kg of corn (Lawrence et al., 1993). In contrast, horses with lower pre-exercise blood glucose and insulin concentrations (e.g., after alfalfa feeding) maintained steady glucose and insulin levels throughout exercise.

A drop in blood glucose concentration may indicate a lack of glucose availability for the muscle or brain and might have a deleterious effect on performance. In addition, FFA concentrations during exercise as a major substrate for energy metabolism were very low when horses received a pre-exercise meal of corn (Lawrence et al., 1993; Pagan and Harris 1999). In the performance horse, it might be useful to develop feeding strategies that include feedstuffs with a high carbohydrate content and low glycemic index.

Conclusion

In humans, starchy foods have been classified over the entire range from restrained to rapid with respect to effects on blood glucose and insulin responses after a meal. The resulting glycemic or insulinemic index utilized white bread as the standard source, and all foods were ranked accordingly. In horses, the classification of starchy foods with respect to their effects on blood glucose and insulin responses after a meal might prove useful in developing appropriate feeding strategies for horses with impaired glucose control or for performance horses. The glycemic or insulinemic index for horses should use untreated oats as the standard source. Nutritional factors like amylose-amylopectin ratio, interactions with proteins, or the presence of dietary fiber that might influence the glycemic and insulinemic index should be developed, and the great individual differences in response to starch feeding need further investigation. Furthermore, research is necessary to investigate the relationship between precedal starch digestibility and the glycemic and insulinemic index as an indirect measurement of precedal starch digestibility in horses.

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