Glycaemic index of feeds for horses

Ingrid Vervuert and Manfred Coenen

Institute for Animal Nutrition, University of Veterinary Medicine Hannover Foundation, Hannover, Germany

Introduction

The glycaemic response to foods has been of concern in humans for many years, especially in the management of obesity, diabetes mellitus and cardiovascular diseases. The glycaemic index (GI) is a ranking of foods based on the postprandial blood glucose response compared with the response to a 50-g glucose test load (*Jenkins* et al. 1981). The GI was originally introduced to classify different sources of carbohydrate-rich foods, usually those with an energy content of > 80% from the available carbohydrates, as to their effect on post-meal glycaemia. Thus, low-GI carbohydrates were classified as those that are digested and absorbed slowly and lead to a low glycaemic response, while high-GI carbohydrates are digested and absorbed rapidly and lead to a high glycaemic response (*Foster-Powell* and *Brand Miller* 1995). There are convenient international tables of glycaemic indexes for more than 700 foods containing all published data on the GIs of individual foods (*Foster-Powell* and *Brand Miller* 1995, *Foster-Powell* et al. 2002).

There is interest in the glycaemic response in horses for conditions such as exercise performance, obesity, insulin resistance, laminitis and osteochondrosis (*Kronfeld* et al. 2005). There is information available on the influence of different grain sources on glucose and insulin responses in the horse, but little is known about the influence of different grain processing techniques and the effect of mixed meals (compound feeds or grain-roughage mixtures) on glucose and insulin control. Furthermore, no standardised glycaemic or insulinaemic index has yet been formulated for horses such as that for humans.

Starch digestibility

In horses, the total tract apparent digestibility of starch is usually very high for the different types of grains. *Arnold* et al. (1981) reported values of 97.0%, 96.7% and 97.0% for corn, oats and sorghum starch, respectively. However, considerable differences in precaecal starch digestibility were found between the different starch sources. In general, the precaecal 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). In general, precaecal starch digestibility of cereals is increased by improving the accessibility of the starch to enzyme degradation in the small intestine in both humans and animals (*Brand* et al. 1985, *Holm* et al. 1988, *Kienzle* et al. 1992, *Potter* et al. 1992, *Meyer* et al. 1995). The granular structure of starch can be destroyed mechanically (*Kienzle* et al. 1997) or by heat and pressure in combination with moisture (*Ross* et al. 1987, *Granfeldt* et al. 1994). The effect of thermal processing is the irreversible swelling and destruction of the internal crystalline structure of the starch granules; this transformation is termed gelatinisation (*Holm* et al. 1988, *Selmi* et al. 2000). Consequently, an increase in the availability of starch for enzymatic digestion might alter the metabolic response, as more substrate will be absorbed in the small intestine.

Importance of grain source and starch intake on glucose and insulin responses

In ponies (aged 3 to 18 years), oat feeding led to higher blood glucose levels than feeding whole corn or barley. However, increasing starch intake (by 2 or 4 g starch/kg BW per meal) did not influence blood glucose responses (*Radicke* et al. 1994). The higher glycaemic response to oat feeding was accompanied by a higher praececal starch digestibility of oats. On the other hand, *Jose-Cunilleras* et al. (2004) found no differences in the glycaemic response of Thoroughbred horses to cracked corn, oat groats and rolled barley when fed 2 g of available carbohydrates/kg BW per meal.

Pagan et al. (1999) found no differences in mean postprandial peak plasma glucose concentrations in six Thoroughbred geldings fed whole oats and cracked corn. Furthermore, there was no difference in the area under the postprandial glucose curve between whole oats and cracked corn (0.75, 1.5, or 2.5 g/BW).

Our research group found no differences between whole oats, barley or corn in the response of healthy Standardbred horses with a moderate starch intake (between 1.2 and 1.5 g starch/kg BW, Vervuert et al. 2003, 2004), whereas increasing amounts of oat starch (1.2-1.5, 2 or 4 g starch/kg BW) resulted in higher glycaemic responses (Figure 1).

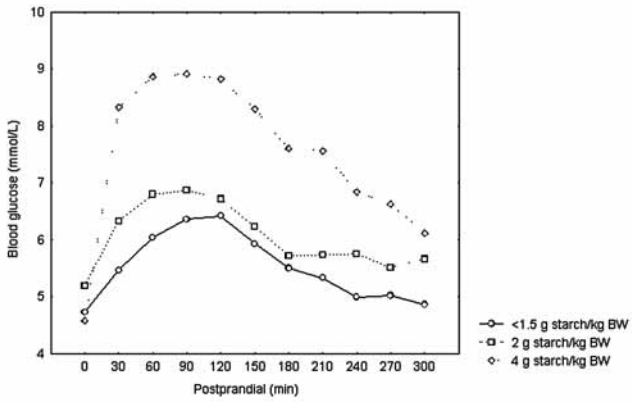

Fig 1 Glycaemic response to different levels of starch intake per meal from oats (*Vervuert* et al. 2003, current project).

Rodiek and *Stull* (2005) created a glycaemic index for common horse feeds assuming that the starch intake comprises 25% of equines' daily digestible energy requirement. In general, concentrate feeds (rich in starch) were found to have the highest GI, while those of forages and by-products were relatively lower. The

GI of oats was used as the reference (GI: oats=100%, corn=117%, barley=101%, oats + oil=86%, wheat=71%, carrots=51%, timothy hay=32% and beet pulp=1%).

Conclusion

Grain source seemed to be of minor importance while starch intake per meal influences GI.

Importance of grain processing on glucose and insulin responses

Hoekstra et al. (2001) investigated the effect of corn processing on glycaemic responses in six horses (four Arabians and two Thoroughbreds aged 6 to 10 years). That experiment was conducted to evaluate the effect of cracking, grinding or steam processing on starch digestibility of corn. The glycaemic response was used as an indirect measure of precaecal starch digestibility. The glycaemic response to each grain was compared using a glycaemic index, so that the glucose area of each feed under the curve was expressed relative to that of cracked corn. The highest glycaemic index was found for steam-flaked corn (2 g starch/kg BW in a single meal). Those authors speculated that the high glycaemic response reflects changes in precaecal starch digestibility due to thermal corn processing.

Our own research group recently found that mechanical or thermal processing of oats, barley or corn had no clear influence on glycaemic or insulinaemic responses in horses when starch intake was moderate (between 1.2 and 1.5 starch/kg BW; *Vervuert* et al. 2003, *Vervuert* et al. 2004), but increasing the starch intake (to 2 g starch/kg BW) resulted in a clear distinction between rolled, steam-flaked and extruded barley (Figure 2).

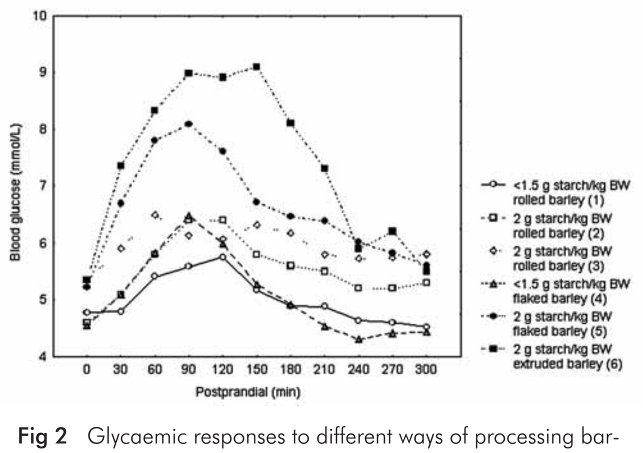

Fig 2 Glycaemic responses to different ways of processing barley (starch intake per meal; 1, 4: *Vervuert* et al., publication in preparation, 2: *Jose-Cunilleras* et al. 2004, 3, 5, 6: actual project).

Effects of grain processing on GI depend on dosage of starch intake.

Complex diets

Generally, foods are not eaten in isolation but in combination in mixed meals; furthermore, single foods are consumed as components of complex diets. It is therefore important to ensure that the GI concept is also applied in the context of mixed meals (*Flint* et al. 2004). Similarly to humans, horses consume compound feeds as well as grains enriched with roughage. This leads to two questions: Does a feed have the same GI when eaten alone and when combined with other feeds? Can we predict the GI of a meal by the GIs of the different feeds consumed within the meal? The results of pertinent studies in humans are equivocal: while some studies support the predictability of the GI in mixed meals, others indicate that several factors (gastric emptying, consumption rate and nutrient composition) will interact with the carbohydrates, reducing the predictability of the GI (*Flint* et al. 2004, *Brouns* et al. 2005).

The matrix structure per se seemed to influence the GI in horses, as a pelleted meal and a sweet feed meal was found to produce different glycaemic responses, despite the fact that the starch content of the two diets was similar (*Harbour* et al. 2003).

Stull and *Rodiek* (1988) found a significant increase in the plasma glucose concentration in two-year-old quarter horse geldings both after corn feeding as well as after a combined diet of 50% corn and alfalfa. Insulin concentrations closely followed the glucose curves. However, there was no difference in the postprandial response area for glucose between alfalfa feeding (100%), corn feeding (100%), and combined corn and alfalfa feeding (50% each). Similar results were obtained by Harris et al. (2005), who recently reported that the addition of 35% short Lucerne chaff did not influence the glycaemic response to oats.

In contrast, *Radicke* et al. (1994) observed a blunted glycaemic response after the addition of roughage to the oat diet. Similarly, *Pagan* and *Harris* (1999) found that the glycaemic response was significantly reduced by feeding hay either before or with a sweet feed (42% oats, 31% corn, 8% molasses and 19% supplement pellet).

Conclusion

The modifying effect of dietary fibre on GI seemed to be overestimated in horses, however results are equivocal. Complex diets and GI needs further clarification.

Relationship between glucose and insulin responses

A major rationale for using the GI is the assumption that there is a close correlation between the postprandial blood glucose response and insulin regulation, and for that reason glycaemic response is used to control insulin resistance in horses (*Kronfeld* et al. 2005). However, only limited information is available in the horse, as there are only a few studies on the relationship between GI and insulinaemic index (II). *Zeyner* et al. (2005) found a close relationship between GI and II in adult Quarter horses fed mixed diets with sugar beet pulp, rice bran, grass meal and soybean oil.

In three other studies no correlation was found between GI and II, which indicates that more information is necessary on both GI and II in order to formulate dietary recommendations (*Jose-Cunilleras* et al. 2004, *Vervuert* et al. 2003, 2004).

Other factors affecting glycaemic and insulinaemic responses

It is interesting to note that the same feedstuff (e.g. flaked barley) was found to induce different glycaemic responses in different studies (Figure 2). These differences appear to be related to the consumption rate, gastric emptying rate, the digestibility of the starch, and the factors determining digestibility, including the interaction of starch with fibre, protein, fat and antinutrients (e.g. phytate) in the food, together with the nature of the starch itself and its physical form (*Thorne* et al. 1983, Table 1). For example, larger meal size and higher starch content were found to be associated with slower gastric emptying in horses (*Métayer* et al. 2004). Furthermore, dietary fat is known to slow down the rate of gastric emptying and absorption of nutrients from the gut, which in turn slows the release of glucose to the blood. Increased amounts of fat and protein in the gut also induce increased secretion of certain gut hormones; this in turn increases the insulin response and glucose clearance. Much attention has been focused on dietary fibre in the equine diet. High fibre meals have been shown to produce lower blood glucose responses in healthy and diabetic humans by altering the rate of nutrient absorption (*Thorne* et al. 1983), but the results of comparable studies in horses were equivocal (see the chapter on complex diets). The rate and extent of starch digestion is further influenced by the botanical origin of the feed, as this determines the amylase:amylopectin ratio and the structural type of the starch granule (*Kienzle* et al. 1997, *Kienzle* et al. 1998). Another important factor is food processing, which determines the extent of starch gelatinisation, particle size and the integrity of the plant cell wall (*Granfeldt* et al. 1994, *Granfeldt* et al. 2000).

Table 1 Factors affecting the GI of foods and meals in humans (adapted from *Thorne* et al. 1983, *Rooney* and *Pflugfelder* 1986, *Brouns* et al. 2005).

Food factor	Influencing factor	Effect on GI
Gross matrix structure	Grinding	Homogenised: GI ↑
Cell-wall and starch structure	Degree of ripening	Ripe: GI ↑
Granular starch structure	Mechanical and thermal treatment	High degree of gelatinization: GI ↑
Amylose & amylopectin	Digestibility: amylopectin > amylose	Amylopectin ↑: GI ↑
Dietary fibre	Adding fibre	Fibre ↑: GI ↓
Dietary protein	Adding protein	Protein ↑: GI ↓
Dietary fat	Adding fat	Fat ↑: GI ↓
Organic acids	Adding organic acids	Organic acids ↑: GI ↓
Molecular composition of carbohydrates	Type of carbohydrates	Increased number of bonds other than $\alpha 1-4$ and $\alpha 1-6$: GI ↓
Resistant starch, retrogradation	Heating – cooling cycles	Resistant starch ↑: GI ↓
Antinutrients	Amylase inhibitors, phythate	Antinutrients ↑: GI ↓

Furthermore, a standardised methodology is required for both the nutrient composition of foods and their classification according to their impact on blood glucose and insulin. Differences in results obtained for horses might be due to differences in experimental protocols. One important question is what the reference food should be, and a variety of feedstuffs like corn, oats or glucose have been used as the reference for GI measurement in horses. Nor have other parameters been standardised for horses, such as consumption time, amount of carbohydrates, mixed meals, blood sampling times, adaptation to the diets and calculation of the area under the curve, which greatly limits the possibility to compare data from different research groups.

Conclusion

A simple index is needed that could help in the development of nutritional recommendations for horses for specific issues, such as insulin resistance, laminitis or exercise performance. However, it appears that the GI cannot serve as the only such criterion, as it is considerably influenced by several factors: consumption rate, nutrient composition and gastric emptying, especially in the case of mixed feeds. Furthermore, a standardised methodology should be developed for the estimation of GI and II in feedstuffs for horses to make it possible to compare the results of different research groups.

References

Arnold F. F., Potter G. D., Kreider J. L. and *Schelling G. T.* (1981): Carbohydrate digestion in the small or large interstine of the equine. Proc 7th Equine Nutr Phys Symp 19-22

Brand J. C., Nickolson P. L., Thorburn A. W. and *Truswell A. S.* (1985): Food processing and the glycemic index. Am J Clin Nutr 42, 1192-1196

Brouns F. , Bjorck I. , Frayn K. N., Gibbs A. L., Lang V., Slama G. and *Wolever T. M. S.* (2005): Glycaemic index methodology. Nutr Res Rev, 145-171

Flint A., Moller B. K., Raben A., Pedersen D., Tetens I., Holst J. J. and *Astrup A.* (1995): The use of glycaemic index tables to predict glycaemic index of composite breakfast meals. British J Nutr 91, 979-989

Foster-Powell K. and *Brand Miller J. C.* (1995): International table of glycaemic index. Am J Clin Nutr 62, 871-893

Foster-Powell K., Holt S. H. A and *Brand Miller J. C.* (2002): International table of glycaemic index and glycaemic load values. Am J Clin Nutr 76, 5-56

Granfeldt Y., Eliasson A. C. and *Björck I.* (2000): An examination of the possibility of lowering the glycaemic index of oat and barley flakes by minimal processing. J Nutr 130, 2207-2214

Granfeldt Y., Liljeberg H., Drews A., Newman R. and Björck I. (1994): Glucose and insulin responses to barley products: influence of food structure and amylose-amylopectin ratio. Am J Clin Nutr 59, 10751082

Harbour L. E, Lawrence L. M., Hayes S. H., Stine C. J. and *Powell D. M.* (2003): Concentrate composition, form, and glycemic response in horses. Proc 18 Equine Nutr Phys Symp 2003, 329-330

Harris P. A., Sillence M., Inglis R., Siever-Kelly C., Friend M., Munn K. and *Davidson H.* (2005): Effect of Lucerne chaff on the rate of intake and glycaemic response to an oat meal. Proc 19 Equine Nutr Phys Symp 2005, 151-152

Hoekstra K. E., Newman K., Kennedy M. A. P. and *Pagan J. D.* (1999): Effect of corn processing on glycemic responses in horses. Proc 16 Equine Nutr Phys Symp 1999, 144-148

Holm J., Lundquist I., Björck I., Eliasson A. C. and *Asp N. G.* (1988): Degree of starch gelatinization, digestion rate of starch in vitro, and metabolic response in rats. Am J Clin Nutr 47, 1010-1016

Jenkins D. J., Wolever A., Taylor T. M. S., Barker R. H., Fielden H., Baldwin H., Bowling J. M., Newmann A. C., Jenkins H. C. and *Goff A. L.* (1981): Glycemic index of foods: a physiological basis for carbohydrate exchange. Am J Clin Nutr 34, 362-366

Jose-Cunilleras E., Taylor L. E. and *Hinchcliff K. W.* (2004): Glycemic index of cracked corn, oat groats and rolled barley in horses. J Anim Sci 82, 2623-2629.

Kienzle E., Pohlenz J. and *Radicke S.* (1998): Microscopy of starch digestion in the horse. J Anim Physiol Anim Nutr 80, 213-216

Kienzle E., Pohlenz J. and *Radicke S.* (1997): Morphology of starch digestion in the horse. J Vet Med A 44, 207-221

Kienzle E., Radicke S., Wilke S., Landes E. and *Meyer H.* (1992): Praeileale Stärkeverdauung in Abhängigkeit von Stärkeart und –zubereitung. 1. Europ Conf Horse Nutr, Pferdeheilkunde 1992, 103-106

Kronfeld D. S., Treiber K. H., Hess T. M. and *Boston R. C.* (2005): Insulin resistance in the horse: Definition, detection, and dietetics. J Anim Sci 83, 1-10

Metayer N., Lhöte M., Bahr A., Cohen N. D., Kim I., Roussel A.J. and *Julliand V.* (2004): Meal size and starch content affect gastric emptying in horses. Equine Vet J 35, 436-440

Meyer H., Radicke S., Kienzle E., Wilke S., Kleffken D. and *Illenseer M.* (1995): Investigations on preileal digestion of starch grain, potato and manioc in horses. J Vet Med A 42, 371-381

Pagan J. D. and *Harris P. A.* (1999): The effects of timing and amount of forage and grain on exercise response in Thoroughbred horses. Equine Vet J Suppl 30, 451-457

Pagan J. D., Harris P. A., Kennedy M. A. P., Davidson N. and *Hoekstra K. E.* (1999): Feed type and intake affects glycaemic response in Thoroughbred horses. Proc 16th Equine Nutr Phys Symp, 149-150

Potter G. D., Arnold F. F., Householder D. D., Hansen D. H. and *Brown K. M.* (1992) Digestion of starch in the small or large intestine of the equine. 1. Europ Conf Horse Nutr, Pferdeheilkunde, 107-111

Radicke S., Meyer H. and *Kienzle E.* (1994): Über den Einfluß von Futterart und Fütterungszeitpunkt auf den Blutglucosespiegel bei Pferden. Pferdeheilkunde 10, 187-190

Rodiek A. V. and *Stull C. L.* (2005): Glycemic index of common horse feeds. Proc 19 Equine Nutr Phys Symp, 153

Rooney L. W. and Pflugfelder R. L. (1986): Factors affecting starch digestibility with special emphasis on sorghum and corn. J Anim Sci 63, 1607-1623

Ross S. W., Brand B. S., Thorburn A. W. and *Truswell A. S.* (1987): Gylcemic index of processed wheat products. Am J Clin Nutr 46, 631-635

Selmi B., Marion D., Perrier Cornet J. M., Douzals J. P and *Gervais P.* (2000): Amylogluosidase hydrolysis of high-pressure and thermally gelatinized corn and wheat starches. J Agric Food Chem 48, 2629-2633

Stull C. L. and *Rodiek A. V.* (1988): Responses of blood glucose, insulin and cortisol concentrations to common equine diets. J Nutr 206-213

Thorne M. J., Thompson L. U. and Jenkins J. A. (1983): Factors affecting starch digestibility and the glycaemic response with special reference to legumes. Am J Clin Nutr 38, 481-488

Vervuert I., Coenen M. and *Bothe C.* (2003): Effects of oat processing on the glycaemic and insulin responses in horses. J Anim Physiol 87, 96-104

Vervuert I., Coenen M. and *Bothe C.* (2004): Effects of corn processing on the glycaemic and insulinaemic responses in horses. J Anim Physiol 88, 348-355

Zeyner A., Hoffmeister C., Einspanier A. and *Lengwenat O.* (2005): Glycemic and insulinaemic responses of Quarter horses to concentrates high in fat and low in soluble carbohydrates. Proc 19 Equine Nutr Phys Symp, 312-313

I. Vervuert
Institute for Animal Nutrition
University of Veterinary Medicine Hannover, Foundation
Bischofsholer Damm 15
30173 Hannover
Germany
Ingrid.Vervuert@tiho-hannover.de