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Glucose and insulin responses to delayed rate of intake of concentrate meals by horses

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ABSTRACT
Pronounced changes in postprandial blood glucose and insulin concentrations in horses may be problematic for horses with metabolic disorders. Research has identified specific grains and processing methods for attenuating glycemic response to concentrate meals, and other methods of manipulating concentrate meals are needed when these are not available to horse caretakers. Controlling rate of intake of a concentrate meal through portioning may be one method that could attenuate glycemic response. In 2 experiments, a serial blood draw was performed in conjunction with offering of a concentrate meal to follow postprandial changes in plasma glucose and insulin. Meals were portioned into smaller allotments and offered at 15-min increments. In Exp. 1, 8 horses received 4 Mcal of DE from oats or sweet feed divided into 1, 2, 3, or 4 portions. Glucose and insulin area-under-the-curve concentrations and peak concentration values were not different between feed types or among portioning treatments (P > 0.05). In Exp. 2, the equivalent of 8 Mcal of DE divided into 1, 3, or 5 portions was offered to 6 horses fed a conventional sweet feed or a sweet feed with grains processed to minimize glycemic response. Horses consuming conventional sweet feed had greater glucose and insulin area-under-the-curve concentrations (P < 0.05) that may have been due to differences in total nonstructural carbohydrate content of the 2 feedstuffs. Portioning of the concentrate meal had no effect (P > 0.05) on postprandial glucose and insulin responses in Exp. 2. Delaying the rate of intake of a concentrate meal under these conditions did not alter glycemic response.

Key words: glucose, insulin, concentrate, horse, rate of intake

INTRODUCTION
The high soluble carbohydrate content of cereal grains makes them ideal feedstuffs for inclusion in diets of horses with increased energy demands. Most horses can tolerate pronounced changes in postprandial blood glucose concentration following consumption of cereal grains, although it can be a problem for horses with reduced insulin sensitivity and related metabolic disorders. Fats and readily digestible fiber have been introduced into horse diets as a way to reduce dependence on grain-source soluble carbohydrates while providing additional energy, but cereal grains rarely can be completely replaced in horse diets. As a result, research has been directed toward classifying the suitability of various feedstuffs based on blood glucose response to feeding trials.

Several researchers have constructed glycemic response indices comparing common horse feedstuffs and individual grains subjected to different processing techniques (Hoekstra et al., 1999; Pagan et al., 1999; Rodiek and Stull, 2005; Vernuert et al., 2005). This information has been useful in designing new concentrate formulations for horses sensitive to pronounced changes in blood glucose.

Factors other than feed ingredients may also influence the postprandial response of a horse to a concentrate. Meal size and frequency (Steelman et al., 2006), the addition of oil to sweet feed that may slow gastric emptying rate (Pagan et al., 1999), and differences in voluntary rate of intake of grains (Jose-Cunilleras et al., 2004) have been shown to alter glycemic response. It is not known if slowing the time to consume a given meal can have a similar effect on glycemic index, though it appears plausible that if starch is presented to the small intestine slowly, the rate at which glucose enters the blood may also be controlled.

Many horses continue to be fed traditional high-soluble carbohydrate concentrates for several reasons, so finding other ways to attenuate blood
Glucose response to a meal can serve as either an alternative or a complementary strategy in feeding management for these horses. The objective of this research was to evaluate whether controlling the rate of intake of a concentrate by horses could affect postprandial plasma glucose and insulin responses. We hypothesized that slowing rate of intake of concentrate by as much as 45 min would delay peak concentration, minimize the concentration peak, and reduce area-under-the-curve (AUC) concentration for plasma glucose and insulin.

MATERIALS AND METHODS

Animal Work, Exp. 1

For all experiments, all animal procedures were approved by the Auburn University Institutional Animal Care and Use Committee. Eight horses were used in a study consisting of 8 periods each lasting 7 d. The mean age of the horses was 7 ± 3.4 yr. Horses had a mean weight of 500 ± 89 kg at the onset of the project. Five mares and 3 geldings were used, with 1 Arabian, 1 Arabian–Appaloosa cross, 1 Appaloosa, and 5 Quarter Horses being represented. Horses were maintained as a single group on bermudagrass pasture and were not exercised during the study.

The experimental design was a 2 × 4 factorial arrangement of 2 different concentrate feeds and 4 different feeding treatments in a Latin square design. Horses were randomly assigned to 1 of 8 treatment combinations for the first period and then rotated sequentially through all treatment combinations such that each horse served as its own control. Horses were individually fed whole oats or a conventional sweet feed (CSF; Triumph 12%, Cargill-Nutrena, Minneapolis, MN) beginning at 0600 and 1800 h. The amount of oats and CSF offered was calculated to provide 4 Mcal of DE at each feeding, equivalent to 1.37 kg of oats and 1.36 kg of CSF. This caloric quantity is a standard measure in many equine glycemic response studies. The feeding strategies consisted of dividing the allotted concentrate into 1, 2, 3, or 4 equal portions and offering the portions at 15-min intervals to slow the rate of intake of the concentrate. In this manner, the horse receiving the 1-portion treatment received its entire concentrate allotment at 0600 h for the morning feeding, whereas the horse on the 4-portion treatment received one-fourth of its allotment at 0600, 0615, 0630, and 0645 h.

Following 6-d adaptation to treatments for experimental period, horses were placed in stalls at 1200 h on d 7 in preparation for a serial blood draw in conjunction with the evening feeding. During this time horses were fasted but allowed access to water. Indwelling jugular catheters were inserted at least 3 h before feeding to facilitate blood sampling. Horses were fed as usual at 1800 h and had access to water but were not offered hay during the serial blood draw. A fasting blood sample was collected 30 min before feeding and at 30-min intervals beginning at 1830 h and continuing through 2400 h. At each sampling time, 5 mL of blood was collected to clear the catheter, followed by approximately 20 mL of blood for laboratory analysis. Blood was immediately transferred from a collection syringe to 2 Vacutainer (BD, Franklin Lakes, NJ) tubes containing sodium heparin and to 2 treated with sodium fluoride. After each blood collection catheters were flushed with 7 mL of heparinized saline solution (0.9% NaCl) to prevent clotting. Catheters were removed after completion of the serial blood draw, and horses were returned to pasture.

Exp. 2

Six geldings were used in a study consisting of 6 periods each lasting 7 d. Mean weight of the horses at the start of the project was 580 ± 67 kg. The horses were 14 ± 5 yr old and included 3 Quarter Horses, 1 Thoroughbred, and 2 warmbloods. Horses were maintained as a single group on bermudagrass pasture and were not exercised during the study.

The experimental design was a 2 × 3 factorial arrangement of 2 different concentrates and 3 feeding treatments in a Latin square design. Horses were fed either CSF (Triumph 12%) or a sweet feed with grains that had been processed to minimize glycemic response.

| Table 1. Mean ± SE ADF, calculated DE, and total nonstructural carbohydrate (TNC) concentrations of test feeds in Exp. 1 and 2 (DM basis) |
|-----------------|------------------|-----------------|-----------------|
| Item            | % ADF            | Calculated1 Mcal of DE/kg | % TNC          |
| Exp. 1          |                  |                  |                |
| Whole oats      | 13.67 ± 0.44     | 3.32 ± 0.02      | 56.50 ± 1.00   |
| Sweet feed2     | 5.38 ± 0.10      | 3.77 ± 0.01      | 71.85 ± 0.86   |
| Exp. 2          |                  |                  |                |
| Conventional sweet feed2 | 5.28 ± 0.15     | 3.78 ± 0.01      | 73.40 ± 1.56   |
| Specially processed sweet feed3 | 6.80 ± 0.21     | 3.70 ± 0.01      | 53.71 ± 1.97   |

1DE (Mcal/kg) = 4.07 − 0.055 × (%ADF) (NRC, 2007).
2Triumph 12%, Cargill-Nutrena, Minneapolis, MN.
3Vitality 12%, Cargill-Nutrena.
response (Vitality 12%, Cargill-Nutrena). Horses were individually fed CSF or the specially processed sweet feed (PSF) once daily at 1600 h and received 2.27 kg of their respective treatment concentrate as a single portion during the 6-d diet adaptation in each period.

Horses were placed in stalls at 1000 h on d 7 in preparation for a serial blood draw in conjunction with the concentrate feeding. During this time horses were fasted but allowed access to water. Indwelling jugular catheters were inserted at least 3 h before feeding to facilitate blood sampling. Horses were fed at 1600 h and received either 2.64 kg of CSF or 2.58 kg of PSF, which were amounts calculated to provide 8 Mcal of DE based on manufacturer’s information. The concentrate was divided into 1, 3, or 5 equal portions, and portions were offered at 15-min intervals to slow the rate of intake. In this manner, the horse receiving the 1-portion treatment received its entire allotment at 1600 h, whereas the horse on the 5-portion treatment received one-fifth of the concentrate allotment at 1600, 1615, 1630, 1645, and 1700 h. Horses had access to water but were not offered hay during the serial blood draw. A fasting blood sample was collected 30 min before feeding and at 30-min intervals beginning at 1630 h and continuing through 2400 h. At each sampling time, 5 mL of blood was collected to clear the catheter, followed by approximately 20 mL of blood for laboratory analysis. Blood was immediately transferred from a collection syringe to 2 Vacutainer tubes containing sodium heparin and to 2 treated with sodium fluoride. After each blood sampling, catheters were flushed with 7 mL of heparinized saline solution (0.9% NaCl) to prevent clotting. Catheters were removed after completion of the serial blood draw, and horses were returned to pasture.

**Laboratory Analyses**

Blood samples were cooled in ice water for 15 min before centrifugation for 10 min at 1,560 × g at ambient temperature. Plasma was harvested, placed in microcentrifuge tubes, and frozen at −20°C for subsequent analysis. Plasma from sodium fluoride–treated blood tubes was thawed at room temperature, and duplicate samples were analyzed for glucose concentration using an automated glucose–lactate analyzer (YSI 2300 Stat Plus Analyzer, YSI, Yellow Springs, OH). Plasma from sodium heparin–treated tubes was sent to the Department of Anatomy, Physiology and Pharmacology in the College of Veterinary Medicine at Auburn University for determination of insulin concentration by radioimmunoassay (Coat-a-Count).

### Table 2. Mean ± SE glucose area under the curve (mg/dL per hour) for horses consuming 4 Mcal of DE oats or sweet feed, with the meal divided into 1, 2, 3, or 4 equal portions

<table>
<thead>
<tr>
<th>Item</th>
<th>Whole oats</th>
<th>Conventional sweet feed</th>
<th>Overall portion¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>598.48 ± 32.49</td>
<td>576.49 ± 18.61</td>
<td>587.49 ± 18.31</td>
</tr>
<tr>
<td>2</td>
<td>575.15 ± 20.83</td>
<td>557.77 ± 13.86</td>
<td>566.46 ± 12.29</td>
</tr>
<tr>
<td>3</td>
<td>579.44 ± 25.91</td>
<td>558.58 ± 25.27</td>
<td>569.01 ± 17.69</td>
</tr>
<tr>
<td>4</td>
<td>585.72 ± 28.56</td>
<td>580.45 ± 23.37</td>
<td>583.08 ± 17.84</td>
</tr>
<tr>
<td>Overall feed²</td>
<td>584.70 ± 13.06</td>
<td>568.32 ± 10.03</td>
<td></td>
</tr>
</tbody>
</table>

¹Mean values for respective portion treatments.
²Mean values for respective feed treatments.

### Table 3. Mean ± SE insulin area under the curve (μU/mL per hour) for horses consuming 4 Mcal of DE oats or sweet feed, with the meal divided into 1, 2, 3, or 4 equal portions

<table>
<thead>
<tr>
<th>Item</th>
<th>Whole oats</th>
<th>Conventional sweet feed</th>
<th>Overall portion¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>220.10 ± 42.33</td>
<td>165.24 ± 34.31</td>
<td>192.67 ± 27.26</td>
</tr>
<tr>
<td>2</td>
<td>195.51 ± 41.80</td>
<td>149.50 ± 35.18</td>
<td>172.51 ± 27.05</td>
</tr>
<tr>
<td>3</td>
<td>195.22 ± 39.27</td>
<td>176.87 ± 55.70</td>
<td>186.05 ± 33.00</td>
</tr>
<tr>
<td>4</td>
<td>227.28 ± 71.07</td>
<td>229.12 ± 59.43</td>
<td>228.20 ± 44.75</td>
</tr>
<tr>
<td>Overall feed²</td>
<td>209.53 ± 24.06</td>
<td>180.81 ± 23.23</td>
<td></td>
</tr>
</tbody>
</table>

¹Mean values for respective portion treatments.
²Mean values for respective feed treatments.
Insulin, Diagnostic Products Corporation, Los Angeles, CA). When plasma insulin concentrations fell below the threshold of sensitivity of the assay (<2.7 μU/mL), values were replaced with 2.5 μU/mL for data analyses. Samples of test concentrates were collected on the day of the serial blood draws, dried at 65°C for 72 h for determination of DM, and ground through a 1-mm screen in a Wiley Mill. Concentration of ADF was determined by sequential fractionation using a heat-stable amylase (Van Soest et al., 1991). The DE content for each concentrate sample was calculated using the formula DE (Mcal/kg) = 4.07 − 0.055 × (%ADF) (NRC, 2007). Total nonstructural carbohydrate (TNC) content of the concentrates was analyzed by the Department of Agronomy in the College of Agriculture at Auburn University using a modification of an established procedure to determine total available carbohydrates (Mullenix et al., 2012).

Statistical Analyses

Area under the curve, peak concentration, and time to peak concentration for plasma glucose and insulin were calculated using the pharmacokinetic functions of STATA (StataCorp, 2007). The program uses the trapezoidal rule for calculating AUC. Resulting values were analyzed using the ANOVA functions in STATA, with horse, period, feed, portion, and feed × portion interaction as the variables. Significance was set at \( P < 0.05 \).

RESULTS AND DISCUSSION

Exp. 1

One horse refused to consume its concentrate the first week of the study and was detained an additional week at the end of the study to receive its assigned treatment. Data for this horse were grouped with other period-1 data to preserve the integrity of the experimental design for statistical analysis. All other horses readily consumed their treatment concentrates, with no refusals recorded during the serial blood draw.

Laboratory analyses and calculated DE concentration in oats and CSF are presented in Table 1. Total nonstructural carbohydrate concentration was significantly greater \( (P < 0.05) \) for CSF than for oats. Horses were offered 1.37 kg of oats and 1.36 kg of CSF at each feeding, resulting in consumption of 4.1 and 4.5 Mcal of DE from oats and CSF, respectively, at each feeding. Even though DE intakes were significantly different \( (P < 0.05) \) between oats and CSF treatments, they differed from the overall mean DE intake by less than 5%.

Figure 1. Mean glucose response curves for horses fed 4 Mcal of (a) conventional sweet feed or (b) oats, with concentrate meals divided in 1, 2, 3, or 4 portions. Initial offering of feed occurred at 1800 h, as represented by the black arrow; blood was not sampled at 1800 h. No significant differences were found among peak plasma glucose concentration or time to peak concentration between feed or among portion treatments.
Plasma glucose and insulin AUC values are presented in Tables 2 and 3, respectively. Values for AUC were not significantly different between feeds, among portions, or for the feed × portion interaction. There was a trend \((P = 0.05)\) toward difference among periods in glucose AUC but not insulin AUC.

Figures 1 and 2 illustrate mean glucose and insulin response curves, respectively, for horses in Exp. 1. Horse was a significant main effect in the statistical models for peak plasma glucose and insulin concentrations but not for time to peak plasma glucose and insulin concentrations. Period was a significant main effect for peak plasma glucose concentration and time to peak glucose concentration but not for either measure of plasma insulin. Horses receiving CSF reached peak insulin concentration sooner \((P = 0.05)\) after the initial offering of feed \((1.58 ± 0.12\) h) than did those consuming oats \((2.03 ± 0.16\) h). There were no differences due to feed for peak glucose and insulin concentrations or time to peak glucose concentration.

Number of portions did not affect peak glucose and insulin concentrations or time to reach maximum concentration. Interactions among feed and portions were not significant for these variables.

Feed had an influence on time to peak insulin concentration but not on other parameters evaluated in Exp. 1. The CSF had a lower ADF concentration, and therefore greater calculated DE content, than did oats. The CSF also had a significantly greater TNC concentration, which is a measure of starch and other hydrolyzable carbohydrates that are absorbed as glucose and other simple sugars. These compositional differences may explain why horses receiving CSF achieved peak insulin concentration sooner than did horses receiving oats. However, a similar response was not observed for plasma glucose concentrations. One possible explanation is that sampling blood every 30 min may not have been sufficiently frequent to enable detection of a similar response in peak plasma glucose concentration, provided it occurred just before the peak in insulin concentration. Another possibility is that the wide variation in individual horse responses and relatively small sample size confounded some observations, even though each horse rotated through all treatments and served as its own control.

The number of portions in which each concentrate meal was offered did not alter AUC, peak, or time to peak concentrations for plasma glucose or insulin. Variation among individual horses, responsible in part

![Figure 2](image)

**Figure 2.** Mean insulin response curves for horses fed 4 Mcal of (a) conventional sweet feed or (b) oats, with concentrate meals divided in 1, 2, 3, or 4 portions. Initial offering of feed occurred at 1800 h, as represented by the black arrow; blood was not sampled at 1800 h. Time to peak insulin concentration was greater \((P < 0.05)\) for the sweet-feed treatment. No significant differences were found for peak insulin concentration between feed or among portion treatments, or time to peak insulin concentration for portion.
for the large SE values in Tables 2 and 3, prevents overt rejection of the hypothesis that slowing rate of intake of a concentrate might delay peak concentration, minimize the concentration peak, and reduce AUC concentration for plasma glucose and insulin. The use of mares for experimental subjects could have been a contributing factor to the variation. Mares have been shown to have differences in insulin sensitivity between the luteal and follicular phases of the estrous cycle (Cubitt et al., 2007). It is possible that the lack of observed differences among portion treatments could be related to the amount fed and the time interval between successive portions. Increasing the amount of concentrate offered would increase the amount of soluble carbohydrates consumed and presented to the small intestine. Combined with a lengthened period of concentrate intake, the increased soluble carbohydrate intake would discern whether slowing the rate of intake could alter measures of glycemic response to a concentrate meal. Exp. 2 was designed with this concept in mind.

**Exp. 2**

One horse experienced complications with its catheter during the serial blood draw in period 2, and sampling was terminated before the end of the serial draw. Whether plasma glucose and insulin concentrations had peaked by the time at which sampling was terminated for this horse could not be determined. All data collected before the catheter problem were excluded from statistical analysis; therefore, the treatment combination of PSF and 5 portions had 5 observations, whereas all other treatments had 6 observations. There were no other complications with that horse or any other horse during the study. All horses readily consumed their treatment concentrates with no refusals recorded during the serial blood draw.

Laboratory analyses and calculated DE content for the concentrates are presented in Table 1. Feed CSF had a greater \((P < 0.05)\) TNC concentration than did PSF. On the day of the serial blood draw, horses were offered 2.64 kg of CSF and 2.58 kg of PSF resulting in consumption of 8.44 and 8.20 Mcal of DE from CSF and PSF, respectively, during the blood sampling period. As in Exp. 1, the DE intakes were different between CSF and PSF, but each differed from the overall mean DE intake by less than 5%.

Tables 4 and 5 report the values for plasma glucose and insulin AUC in Exp. 2. Horses consuming CSF had greater \((P < 0.05)\) AUC values than did those consuming PSF for both plasma glucose and insulin concentra-

### Table 4. Mean ± SE glucose area under the curve (mg/dL per hour) for horses consuming 8 Mcal of DE conventional or specially processed sweet feed, with the meal divided into 1, 3, or 5 equal portions

| Item               | Conventional sweet feed | Specially processed sweet feed | Overall portion
<table>
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<tbody>
<tr>
<td>Portions</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>1</td>
<td>774.71 ± 42.84</td>
<td>710.66 ± 44.17</td>
<td>742.69 ± 30.88</td>
</tr>
<tr>
<td>3</td>
<td>736.95 ± 51.16</td>
<td>703.52 ± 44.23</td>
<td>720.24 ± 32.63</td>
</tr>
<tr>
<td>5</td>
<td>767.87 ± 55.49</td>
<td>772.12 ± 21.65</td>
<td>769.80 ± 30.42</td>
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<tr>
<td>Overall feed</td>
<td>759.84a ± 27.47</td>
<td>726.22b ± 22.82</td>
<td></td>
</tr>
</tbody>
</table>

\(^{a,b}\)Means within a row with different superscripts differ \((P < 0.05)\).

\(^1\)Mean values for respective portion treatments.

\(^2\)Mean values for respective feed treatments.

### Table 5. Mean ± SE insulin area under the curve (μU/mL per hour) for horses consuming 8 Mcal of DE conventional or specially processed sweet feed, with the meal divided into 1, 3, or 5 equal portions

| Feed               | Conventional sweet feed | Specially processed sweet feed | Overall portion
<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Portions</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>404.49 ± 101.04</td>
<td>202.16 ± 38.72</td>
<td>303.32 ± 59.93</td>
</tr>
<tr>
<td>3</td>
<td>293.58 ± 92.92</td>
<td>220.21 ± 60.49</td>
<td>256.89 ± 54.00</td>
</tr>
<tr>
<td>5</td>
<td>437.04 ± 112.85</td>
<td>232.51 ± 75.08</td>
<td>334.08 ± 74.40</td>
</tr>
<tr>
<td>Overall feed</td>
<td>378.37(^a) ± 57.60</td>
<td>217.46(^b) ± 31.51</td>
<td></td>
</tr>
</tbody>
</table>

\(^{a,b}\)Means within a row with different superscripts differ \((P < 0.05)\).

\(^1\)Mean values for respective portion treatments.

\(^2\)Mean values for respective feed treatments.
tions. No differences were observed for portion or feed × portion interaction.

Glucose and insulin responses to the concentrate meal are illustrated in Figures 3 and 4. Horse was a significant ($P < 0.05$) main effect for peak glucose and insulin concentrations but not for time to peak glucose concentration. Peak glucose and insulin concentrations were greater ($P < 0.05$) for horses receiving CSF versus PSF. Feed was not a significant main effect for time to peak plasma glucose concentration, but horses receiving PSF reached peak insulin concentration significantly sooner than did horses offered CSF (1.88 ± 0.55 h vs. 2.36 ± 0.56 h, respectively). Peak and time to peak glucose and insulin concentrations were not affected by portion, and there were no feed × portion interactions. Period was a significant ($P < 0.05$) main effect for time to peak insulin concentration, and there was a trend ($P = 0.06$) toward a period effect on peak glucose concentration.

Feed type influenced several variables of interest. The feeds used were similar in guaranteed analysis, ingredients, and physical form, though processing methods of individual feedstuffs were different. Consumption of CSF produced greater glucose and insulin AUC values and greater peak concentration values than did consumption of PSF. Also, DE intake by horses consuming CSF was greater, which could have contributed to the observed differences. However, given the magnitude of difference in mean TNC values between the concentrates, the greater concentration of starch and other hydrolyzable carbohydrates in CSF is more likely to have been the cause of the observed differences in glucose and insulin values, in agreement with other studies comparing glycemic responses to different processing methods of individual feedstuffs (Hoekstra et al., 1999; Pagan et al., 1999; Vernuert et al., 2005). As in Exp. 1, time to peak glucose concentration was not different between diets despite differences in TNC concentrations. Horses consuming PSF, which had lower concentrations of DE and TNC than did CSF, reached peak insulin concentrations sooner, which is contrary to what was expected and of what was observed in Exp. 1, especially because peak concentrations of glucose and insulin were greater for horses that consumed CSF.

In both experiments, dividing the concentrate into portions and delaying time to consume the total allotment of feed did not influence AUC, peak concentration, or time to peak concentration for glucose or insulin. Even

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**Figure 3.** Mean glucose response curves for horses fed 8 Mcal of (a) conventional sweet feed or (b) specially processed sweet feed, with concentrate meals divided in 1, 3, or 5 portions. Initial offering of feed occurred at 1600 h, as represented by the black arrow; blood was not sampled at 1600 h. Peak glucose concentration was different by feed ($P < 0.05$) but not by portion. Time to peak concentration was not different between feed or among portion treatments.
though feed was a significant factor, portion \times feed interactions were not significant for the parameters evaluated in either experiment. The lack of response to portioning and restriction of rate of intake observed in this study was unexpected given the findings of previous research. When horses voluntarily took a longer period of time to consume various grains that were offered on an isocaloric basis, differences in glycemic response measures were observed (Jose-Cunilleras et al., 2004). However, given the differences in TNC concentration between feeds despite similar caloric intakes, factors other than rate of intake may have contributed to the differences in glycemic response in the present study. Differences in gastric emptying rates have been proposed by other researchers as a potential factor in altering glycemic response to concentrates (Pagan et al., 1999). The present study was expected to reveal similar findings based on the assumption that changing the rate of introduction of grain to the stomach would alter gastric emptying rate. Portion treatments described herein resulted in some horses consuming their entire meal within 15 min, whereas others took more than 1 h, yet no differences in AUC and peak concentrations of glucose and insulin were observed.

Changes to feeding protocols between Exp. 1 and 2 yielded mixed results. Variability among individual horses was significant despite the use of geldings for research subjects. Given the differences in age, weight, and breed among the 6 horses, it is not possible to determine the extent that these factors may have influenced the observed responses. Increasing the amount of concentrate offered may have facilitated differential responses to feed type. In both Exp. 1 and 2, DE intakes were significantly different within experiment, and there were significant differences in TNC concentrations of the feeds used within the respective studies. However, in Exp. 2, in which megacalories of DE offered was twice the amount offered in Exp. 1, feed was a significant factor in glucose and insulin AUC and peak concentrations. Rate of concentrate intake did not affect glucose and insulin values in spite of the increased caloric intake in Exp. 2.

Numerous researchers have conducted studies that quantified the glycemic response of a horse to various feedstuffs. The present study was designed to examine whether changing how concentrates were offered would alter glycemic response. Glycemic response studies are performed using

![Figure 4](image)

**Figure 4.** Mean insulin response curves for horses fed 8 Mcal of (a) conventional sweet feed or (b) specially processed sweet feed, with concentrate meals divided in 1, 3, or 5 portions. Initial offering of feed occurred at 1600 h, as represented by the black arrow; blood was not sampled at 1600 h. Time to peak insulin concentration was different between feeds ($P < 0.05$) but not among portions. Peak insulin concentration was not different between feed or among portion treatments.
horses that have been fasted for several hours or overnight, but this does not reflect how the typical horse consumes its diet. It may be more beneficial for future research to focus on the interactions of concentrate feeding with hay, pasture, and management practices to begin quantifying whether postprandial responses are different under real-world conditions.

**IMPLICATIONS**

Under these experimental conditions, delaying the rate of intake of a concentrate meal did not alter AUC glucose and insulin concentrations, peak glucose and insulin concentrations, and the amount of time to reach peak glucose concentration. Changing the methods used to process and manufacture feeds, though they are similar in energy density, can alter postprandial glycemic response.

**LITERATURE CITED**


StataCorp. 2007. Stata Statistical Software: Release 10. StataCorp, College Station, TX.

