The effect of different feed delivery methods on time to consume feed and the resulting changes in postprandial metabolite concentrations in horses


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ABSTRACT: Management techniques that reduce the insulin response to feeding in horses have application in preventing insulin resistance (IR) and potential associations (e.g., laminitis). Eight mature idle horses of BCS between 5 and 6.5 and with no previous indication of IR were fed a meal of concentrate under 4 feed delivery treatments in a repeated Latin Square design. Treatments were all based on a bucket of equal dimensions. The treatments included a control (CON) and 3 treatments hypothesized to increase time to consume feed (TCF): mobile obstacles above the feed (BALL), stationary obstacles below the feed (WAFF), and feed with water added (WTR). Jugular venous blood samples were taken at feed delivery, every 10 min for the first hour, and then every 30 min until 300 min after feed delivery. The TCF was different across treatment and was greater (P < 0.05) for BALL and WAFF when compared with CON and WTR. Glucose and insulin concentrations increased after feeding (P < 0.05) and tended to differ among treatments (P < 0.10). Peak insulin and glucose concentrations were affected by treatment as were the time to peak insulin and the area under the curve of insulin (P < 0.05). Therefore, feed delivery methods that include obstacles effectively increase TCF and attenuate postprandial glucose and insulin concentrations. A second experiment was designed to determine if the TCF changes associated with BALL and WAFF in Exp. 1 remain effective over a 4-d period. Four horses with no recent or regular history of consuming concentrates were fed concentrate meals for 4 consecutive d using the same treatments described in Exp. 1 and a Latin square design. Horses were subject to a 4-d adaptation period and were randomly assigned to 4-d treatment periods using the 4 previously described treatments. During adaptation, TCF decreased over time (P = 0.02). After adaptation, WAFF had greater TCF when compared with CON and WTR (P < 0.05) whereas WTR had the lowest TCF overall. Using obstacles to increase TCF on a daily basis may be an effective method to reduce postprandial glucose and insulin concentrations, thereby decreasing the risk of IR development in horses.

Key words: feed management, horse, insulin resistance, meal, time to consume feed

INTRODUCTION

Daily inclusion of concentrate meals is a regular management practice for equines (USDA, 1998; Richards et al., 2006; Hoffman et al., 2009). Concentrated feeds can be high in nonstructural carbohydrates (NSC), and diets with greater than 50% NSC content have been attributed to reduced insulin sensitivity in horses (Pratt et al., 2006, Quinn et al., 2008) and increased postprandial insulin responses to feeding (Stull and Rodiek, 1987). Repeated exposure to increased insulin concentrations reduces tissue sensitivity to insulin (Kopp, 2003). This increases the risk of developing insulin resistance (IR), defined as a decrease in liver, skeletal, and adipose tissue sensitivity to insulin and a decrease in the effectiveness of insulin directed uptake of glucose into these tissues (Kronfeld et al., 2005). Also, IR is a risk factor for development of laminitis and is, therefore, of concern for horse owners (Treiber et al., 2006).

Concentrate intake is often a necessary component of the equine diet for horses; therefore, it is of interest to investigate methods that reduce the risks associated with feeding daily concentrate meals. Diet and
management changes have been proposed to reduce postprandial insulin concentrations, including use of feeds high in structural carbohydrate (fiber), replacing NSC with fats as the primary energy source, and feeding more frequent, smaller meals (Kronfeld et al., 2005).

This study aimed to investigate the effects of novel feed delivery methods on the glucose and insulin response to feeding without diet or extensive management changes. It was hypothesized that feed delivery methods that force equines to take longer to consume a concentrate meal would attenuate the glucose and insulin response to feeding when compared with uninhibited concentrate feed consumption. It was further hypothesized that such feed delivery methods to prolong consumption time would continue to be effective when implemented over several days.

**MATERIALS AND METHODS**

All research techniques were approved by the North Carolina State University Institutional Animal Care and Use Committee.

Experiment 1 was designed to determine if different feed delivery methods could increase time to consume concentrate feed (TCF) and subsequently decrease postprandial glucose and insulin responses to feeding. Experiment 2 was designed to determine if the different feed delivery methods to increase TCF in Exp. 1 would continue to be effective in increasing TCF if the feed delivery methods were offered for a longer (4 d) period.

**Experiment 1**

Eight mature idle Quarter Horse, Thoroughbred, and Arabian horses (6 geldings and 2 mares from 6 to 12 yr old) were used in this trial. The horses had a mean BW of $544 \pm 53$ kg and BCS ranging from 5 to 6.5 out of 9 (Henneke et al., 1983), and no horse used had any history or indication of IR. Once per week, each horse was fed a single concentrate meal in 1 of 4 feed delivery methods as part of a $4 \times 4$ repeated Latin square arrangement of treatments. Thus, the trial lasted 4 wk with 2 sampling d per week. Horses were randomly assigned to a sampling day group (Tuesday or Thursday) before being randomly assigned to treatments, and each horse had 6 d without concentrate meal intake between sampling days when they were maintained solely on grass hay mix of Bermudagrass, fescue, and alfalfa hay.

Each delivery method was based in a commercially available 43 cm diameter by 20 cm deep rubber bucket, which was hung by 3 points at approximately 1 m off the ground. The control delivery (CON) involved an unaltered bucket and unaltered feed. The ball delivery method (BALL) involved an unaltered bucket and unaltered feed with 4 balls placed in the bucket. The balls used were bocce style (Bocce Standards Association of the United States, http://www.boccesstandardassociation.org/), chosen for their smoothness, uniform size (10.7 cm diameter), and heavy weight (0.92 kg each). The waffle delivery method (WAFF) also involved unaltered feed but had an insert attached to the bucket base constructed from 1.25-cm plywood and 2.5- and 5-cm polyvinyl chloride pipes. These pipes were transversely cut and attached to the plywood at intersecting angles, forming crossed raised bars that were 1.25 and 2.5 cm tall and creating dips that were approximately 2.5 by 5 cm into which the feed would settle. The water delivery method (WTR) consisted of an unaltered bucket containing the weighed feed plus an equal weight portion of water. The feed was soaked for approximately 20 min before feeding.

Before the start of the trial, all horses were housed in a mixed grass and white clover pasture with unlimited access to water. Seven days before the trial began, the horses were contained individually in partially covered 5 by 15 m runs without access to pasture, and horses were offered approximately 7 kg of Bermudagrass and fescue hay mix and 3 kg of alfalfa hay per day, given to each horse in 2 meals at 0800 and 1600 h. Additionally, all horses had free access to a trace mineral salt block and water.

On treatment days, horses were weighed and fitted with a jugular catheter (14 gauge, 12 cm) and extension line to facilitate blood sampling approximately 1 h before treatments were administered. Blood samples of 24 ml were collected and placed into evacuated tubes containing either no additive for the collection of serum or EDTA for the collection of plasma (BD Diagnostics, Franklin Lakes, NJ). After collection, blood samples were cooled in a refrigerator and samples containing no additive were allowed to clot at room temperature for approximately 1 h. All samples were centrifuged at approximately 1,500 $\times$ g for 15 min at 5°C. The serum and plasma were then harvested and frozen at –20°C until subsequent analyses.

The horses were given 2 g/kg of BW of commercially available pelleted feed (minimum guaranteed analysis: 14% CP, 6.5% crude fat, 12.5% crude fiber, and 26% NSC on an as-fed basis) via 1 of 4 delivery methods on sample collection days. The average amount of concentrate offered was 1.08 ± 0.10 kg. The horses consumed only the pelleted feed on the morning of sample collections (24 ml) and were not allowed access to any other feed, water, or trace mineral block throughout sample collections, as horses remained tied individually in runs during concentrate feeding and the duration of sample collections. As feed was poured into feed buckets, a blood sample was collected and this sample was considered time 0. The TCF started with the first bite of food and ended when all loose pellets were consumed and only feed fines remained. Additional blood samples were initially collected every 10 min after feed introduction up to 60 min after feed introduction. This
frequency of sampling was chosen so that early changes in metabolites after consumption of a concentrate meal could be noted. Samples were then collected every 30 min up to 300 min after feed introduction. Samples were handled as previously described.

Plasma was analyzed for glucose concentrations in triplicate using a commercially available kit (Autokit Glucose C2; Wako Chemicals USA Inc., Richmond, VA) and spectrophotometry (Pratt et al., 2007; Nielsen et al., 2010). Serum was analyzed for insulin concentrations in duplicate using a RIA kit (Coat-A-Count; Siemens Healthcare Diagnostics Inc., Terrytown, NY) previously validated for use in horses (McGowan et al., 2008). For glucose and insulin, the number of assays needed to analyze all samples was \( n = 16 \) and 5, respectively, the mean intra-assay CV was 5.99 and 4.93%, respectively, the interassay CV was 6.06 and 8.54%, respectively, and the minimum detectable concentration was 0.07 mg/dL and 1.2 \( \mu \)U/ml, respectively.

Area under the curve (AUC) of glucose (AUCG) and insulin (AUCI) were calculated using the trapezoidal method. The peak concentration and the time to reach the peak concentration of glucose and insulin were determined and noted as the peak (PEAK) in glucose (PEAKG) and insulin (PEAKI) and time to reach the peak ( TP) in glucose (TPG) and insulin (TPI). Because they were not normally distributed, insulin and the AUCG and AUCI were log transformed before statistical analyses.

Data were analyzed using ANOVA (SAS Inst. Inc., Cary, NC) with the MIXED procedure. Metabolite concentrations after feeding (glucose and log insulin) were analyzed with a repeated measures mixed model of SAS with horse within day \( \times \) week as the experimental unit. The model included treatment, time after feeding, and treatment \( \times \) time after feeding, with horse, sample day, and week considered as random effects. The TCF and the logAUC, PEAK, and TPG and TPI were analyzed using ANOVA with SAS. For these analyses, horse within day \( \times \) week was the experimental unit. The model included treatment, with horse, sample day, and week considered as random effects. Statistical significance was accepted at \( P < 0.05 \) and trends accepted at \( P < 0.10 \). If an effect of treatment was identified, the least squares means (LSM) of the data were compared using LSD. The TCF, PEAK, TP, and glucose data are reported as means ± the SE. Data that had been log transformed before analysis (insulin, AUCG, and AUCI) are presented as back-transformed geometric means ± 95% confidence intervals.

**Experiment 2**

As a result of the findings from Exp. 1, Exp. 2 was designed to assess if the feed delivery methods used in Exp. 1 could continue to be effective after 4 d of use and to determine if changes in TCF occurred over 4 d as horses got accustomed to the feed delivery methods. Experiment 2 took place approximately 1 yr after Exp. 1. Four mature idle geldings between 6 and 12 yr of age, of Quarter Horse and Thoroughbred lines, and with an average BW of 610 ± 32 kg were used in this trial. Horses used were considered of average temperament and had no history of regular or recent concentrate meal feeding, as the horses had been kept on pasture for the 6 mo before the trial.

A 4-d adaptation period (ADT) was implemented in Exp. 2 to accustom all horses to concentrate meal feeding from an unaltered feed bucket (CON from Exp. 1) before the administration of the treatment delivery methods. The ADT was also implemented to determine whether TCF changed over the first 4 d of offering concentrate meals in a daily feeding schedule. After the adaptation period, 4 feed delivery methods (as described for Exp. 1) were given to the horses in a Latin square arrangement of treatments, with each treatment being administered for 4 consecutive days. After the completion of each 4-d treatment period, horses were switched to a new treatment, with no washout period. When ADT is included in the timeline, the horses consumed concentrate meals for a total of 20 d, and TCF was recorded daily for each horse.

During the trial, the horses grazed ad libitum on mixed grass and white clover pastures from 0800 to 1600 h and were contained individually in 5 \( \times \) 15 m runs without access to pasture for the remainder of the day. The horses had ad libitum access to water at all times. Treatments were administered each day at 1700 h, and after completion of data collection, the horses received approximately 8 kg of rescue and Bermudagrass mix hay.

The first day of each period, the horses were weighed after coming in from pasture and the amount of feed to be given for the 4-d period was calculated. The administered feed was commercially available pelleted feed (as described for Exp. 1) offered at a rate of 2 g/kg BW. At 1700 h, after stall confinement for an hour, the treatment buckets and feed were placed in the stalls. The TCF started with the first bite of food and ended when all loose pellets were consumed and only feed fines remained.

Experiment 2 data were analyzed using ANOVA with the mixed procedure of SAS. For the ADT period, 1-way ANOVA was used to analyze TCF during the 4 d of ADT to determine if TCF changed over time. After ADT, the TCF over the 4 d of each treatment period was analyzed as a repeated measures ANOVA using mixed model of SAS with horse within period as the experimental unit. The model included treatment, day on treatment (DOT), and treatment \( \times \) DOT, with horse and period considered as random effects. Statistical significance was accepted at \( P < 0.05 \) and trends accepted at \( P < 0.10 \). If an effect of
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RESULTS

Experiment 1

Time to Consume Feed. The overall average TCF in Exp. 1 was 694 ± 324 s. There was an effect of treatment on TCF (P = 0.01; Fig. 1). Feed consumption time for BALL and WAFF was greater than CON and WTR (P < 0.05), but there was no difference between WAFF and BALL or between CON and WTR. Specifically, 7 out of 8 horses had the shortest TCF under the CON or WTR treatments and 6 out of 8 horses had the longest TCF under BALL or WAFF treatments (data not shown).

Plasma Glucose. Glucose concentrations increased over time after feeding (P < 0.001) and there was a trend for the effect of treatment (P = 0.06), but there was no effect of time × treatment (Fig. 1A and 1B). The PEAKG of BALL and WAFF was less than control (P = 0.05; Table 1). There was no effect of treatment on TPG or logAUCG.

Serum Insulin. The log of insulin increased after feeding (P < 0.01), and there was a trend for the effect of treatment (P = 0.09), but no time × treatment effect was found (Fig. 2C and 2D). There was an effect of treatment on PEAKI (P = 0.03; Table 1), with PEAKI for BALL being lower than CON and WAFF. There was an effect of treatment on TPI (P = 0.03), with BALL taking longer to reach TPI than WAFF and WTR taking longer to reach TPI than WAFF. There was a trend for the effect of treatment on logAUCI (P = 0.05), with AUCI of BALL being smaller than CON and WTR.

Experiment 2

Results of Exp. 2 are shown in Fig. 3. During ADT, there was an effect of days of adaptation (Fig. 3A) on TCF (P = 0.02) with TCF of d 1 being greater than TCF of d 4 of ADT (P = 0.03). Day 2 and d 3 were not different from any other days of ADT. During the treatment periods, there was an effect of DOT on TCF (P = 0.006; Fig. 3B) and an effect of treatment on TCF (P < 0.001; Fig. 3C), but no effect of treatment × DOT

Table 1. The effects of 4 feed delivery methods on glucose and insulin concentrations postfeeding

<table>
<thead>
<tr>
<th>Item</th>
<th>Control</th>
<th>Ball</th>
<th>Waffle</th>
<th>Water</th>
<th>SE</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Glucose</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PEAKG, mg/dL</td>
<td>144.5</td>
<td>123.6</td>
<td>129.7</td>
<td>131.9</td>
<td>7.4</td>
<td>0.05</td>
</tr>
<tr>
<td>TPG, min</td>
<td>153.8</td>
<td>141.5</td>
<td>157.5</td>
<td>123.8</td>
<td>26.1</td>
<td>0.75</td>
</tr>
<tr>
<td>AUCG, (mg/dL)</td>
<td>2.5 (1.1 and 5.7)</td>
<td>1.0 (0.5 and 2.3)</td>
<td>1.1 (0.5 and 2.5)</td>
<td>1.3 (0.6 and 2.9)</td>
<td>–</td>
<td>0.39</td>
</tr>
<tr>
<td>Insulin</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PEAKI, μU/mL</td>
<td>112.0</td>
<td>62.9</td>
<td>116.6</td>
<td>98.2</td>
<td>34.8</td>
<td>0.03</td>
</tr>
<tr>
<td>TPI, min</td>
<td>157.5</td>
<td>195.0</td>
<td>130.0</td>
<td>210.0</td>
<td>31.1</td>
<td>0.03</td>
</tr>
<tr>
<td>AUCI, (μU/mL)</td>
<td>6.0 (0.9 and 38)</td>
<td>1.9 (0.3 and 12)</td>
<td>4.7 (0.7 and 30)</td>
<td>6.5 (1 and 41)</td>
<td>–</td>
<td>0.05</td>
</tr>
</tbody>
</table>

a,b Within a row, means without a common superscript letter differ (P < 0.05).

1All feed delivery methods were based on the same commercially available bucket with a depth of 20 cm and diameter of 43 cm.
2Control treatment was an unaltered bucket with unaltered feed.
3Ball treatment had 4 bocce style balls (10.7 cm diameter, 0.92 kg) placed above the feed to act as mobile obstacles.
4Waffle treatment had an insert attached to the base to act as stationary obstacles under the feed as the feed was poured on top of the insert.
5Water treatment had an unaltered bucket and an equal weight water portion added to feed.
6The greatest concentration measured of glucose (PEAKG) or insulin (PEAKI) within 300 min after feeding.
7Time until the greatest concentration of glucose (TPG) or insulin (TPI) was measured.
8Area under the curve of glucose (AUCG) and insulin (AUCI) concentrations up to 300 min after feeding as determined by the trapezoidal method. These values are the back-logged mean (lower and upper 95% confidence interval).
was found. The TCF of d 1 and 3 was greater than d 2 and 4, but there was no difference between d 1 and 3 or between d 2 and 4. The TCF of WAFF was greater than the TCF of BALL, CON, and WTR. The TCF of BALL tended to be greater than CON ($P = 0.06$), and the TCF of BALL was greater than WTR. The TCF of CON was greater than WTR, and, therefore, WTR had the shortest TCF of all treatments ($P < 0.05$).

**DISCUSSION**

The major findings of these studies are that feed delivery methods that include obstacles, such as mobile balls or inserts that create dips in the bucket base, can successfully increase TCF, even after 4 d of acclimation to the obstacles, and this can decrease postprandial glucose and insulin concentrations. Although other research has indicated offering different sources of energy (namely fat and fiber) in effort to reduce the risk of IR (Kronfeld et al., 2005), the present findings indicate that simple managerial changes to feeding protocols may be an effective way to reduce some risk factors for development of IR in horses.

Both obstacles in BALL and WAFF prolonged the time horses needed to consume concentrate but worked in very different ways. Compared with CON and WTR, the BALL and WAFF treatment prolonged feed consumption time by approximately 4 min, an increase of almost 50%. The WAFF design allowed food to settle between grooves, making feed retrieval difficult and extending the time until all feed particles were consumed. The BALL treatment required the horses to continuously maneuver the balls to access the food, forcing the horses to eat more slowly. The bocce balls were chosen to mimic rocks...

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**Figure 2.** Mean (±SE) plasma glucose (A and B) and the backlogged geometric mean (±95% confidence intervals) of serum insulin (C and D) concentrations over time and among treatments in Exp. 1. Eight horses were fed a concentrated feed containing 26% nonstructural carbohydrate in 4 different feed delivery methods, including 2 methods, that contained obstacles (balls and waffle) and 2 methods that did not contain obstacles (control and water), and postprandial plasma glucose and serum insulin concentrations were determined. Plasma glucose concentration: after feeding (A), $P < 0.001$; and treatment (B), $P = 0.06$. Serum insulin concentration: after feeding (C), $P < 0.001$; and treatment (D), $P = 0.09$. 

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often used by horse owners to slow feed intake but were considered a safer, more ideal choice with a uniform size and weight. It is notable that 1 horse in each experiment was able to remove 1 ball from the bucket, indicating a limitation and potential negative aspect of this method. Although the removed ball was quickly returned during the experiments, falling bocce balls pose a risk for physical harm to the legs of the horses, and once even a single ball is removed, this feed delivery method may become less effective in increasing TCF.

In Exp. 1, TCF was increased by both BALL and WAFF, but the largest number of beneficial effects on postprandial glucose and insulin concentrations was observed with the BALL treatment. The PEAKG of BALL and WAFF were decreased compared with other treatments, but under the BALL treatment, PEAKI and logAUCI were also reduced and TPI was increased. The fact that these findings were not associated with WAFF may be a function of how effective these 2 treatments could be in altering the specific rate of feed intake (such as grams of feed consumed per minute) as opposed to their respective effectiveness of simply increasing the total TCF.

The nature of the BALL treatment, with obstacles above the feed, may be more successful in forcing the horses to consume feed at a slower rate throughout the entire meal. The WAFF treatment involved fixed obstacles that were a maximum of 2.5 cm in height; thus, when the pelleted feed was poured on the insert, the bottom layer of feed settled into the dips but the top layer of feed was unobstructed by the insert. Because feed settled into the dips of the waffle insert, the WAFF treatment likely only slowed feed consumption towards the end of the meal and, therefore, had little impact on how quickly the horses consumed feed at the beginning of the meal. The low peak insulin concentration and AUC of the BALL treatment supports this theory. It is possible that the actual rate of feed consumption is the key factor in producing the greatest extent of desirable changes in insulin concentrations. However, actual bite rates and feed consumption rates were not determined in either study. Further investigation of the effect of rate of feed intake on metabolic responses to feeding could be determined by combining the feed delivery methods of this research and methods to determine chewing activity, such as those described by Brøkner et al. (2008).

Treatments that included obstacles increased TCF, and both of these treatments tended to decrease peak glucose feeding. Treatments with obstacles above feed decreased peak insulin and total insulin response and prolonged time to peak insulin. These findings have considerable implications on horses at risk of developing metabolic diseases related to insulin resistance, as the amount and duration of tissue exposure to insulin is a factor in reducing tissue sensitivity to insulin (Kopp,

Figure 3. Time to consume feed (TCF) during the adaptation (Adapt) phase (A), the treatment phase (B), and among treatments in the treatment phase (C) in Exp. 2. Four horses were fed a concentrate meal once per day for 20 d, with the first 4 d representing an adaptation phase (A) and the remaining 16 d representing the mean of 4 treatment periods of 4 d each (B). Each period, horses received 1 of 4 feed delivery methods, including 2 methods that contained obstacles (balls and waffle) and 2 methods that did not contain obstacles (control and water), and TCF was recorded for each horse every day. TCF: day on adaptation (A), \( P = 0.02 \); day on treatment (B), \( P = 0.01 \); treatment (C), \( P < 0.001 \). Means with different lowercase letters differ, \( P < 0.05 \).
the actual rate of feed intake, as this may be an even more effective means of beneficially altering glucose and insulin concentrations after concentrate meals.

The postprandial glucose and insulin concentrations reported herein are similar to those reported elsewhere. The mean postprandial concentrations of glucose in Exp. 1 ranged from 101.1 to 111.2 mg/dL across treatments. These are similar to findings reported by Stull and Rodiek (1987) when feeding 1.33 kg of a 50:50 mixture of pelleted alfalfa and corn, which had an average postprandial glucose response of 112.0 mg/dL. However, the average postprandial insulin response reported by Stull and Rodiek (1987) for the pelleted alfalfa and corn mixture was 22.9 μU/mL, and the postprandial insulin response in this research trial ranged from 34.4 to 54.2 μU/mL. Although several factors may explain this difference in insulin concentrations, such as different experimental conditions and diets, it is possible that the longer time of feeding (between 15 and 60 min) reported by Stull and Rodiek (1987) also influenced postprandial insulin concentrations.

Glucose concentrations are controlled by a variety of homeostatic mechanisms within horses (Hyypää, 2005); therefore, it was not surprising that glucose concentrations were less subject to substantial differences among the treatments when compared with the more dynamic response found for insulin. This is especially unremarkable given the moderate NSC percentage of our treatment feed (26%). However, the reduction PEAKG because of treatments that include obstacles indicates that glucose concentrations can be altered through feed delivery methods.

The WTR had low TCF in both experiments, possibly because the inclusion of water in the feed reduced the amount of chewing required by the horses and made swallowing the pelleted feed easier and faster. Despite having a low TCF, WTR prolonged TPI when compared with CON and WAFF. It is possible that the dilution of concentrated feed by water, which increased the volume of the feed, may have altered transit rates or digestion and absorption rates of glucose (although TPG was not different) and, thus, insulin response. The effects of digesta volume on digestion or absorption rates were not investigated in this experiment.

In Exp. 2, TCF decreased over the 4 d of ADT when horses were first introduced to regular, daily meals. However, over 4 d of the treatment phase, TCF fluctuated, albeit within 45 s. Therefore, TCF may be considered relatively stable after a phase of adaptation to consuming meals. The BALL and WAFF both increased average TCF when given with a single meal in Exp. 1. In Exp. 2, WAFF increased TCF when compared with all other treatments and BALL increased or tended to increase TCF when compared with WTR and CON, respectively, when given for 4 consecutive days. Therefore, obstacles in a feed bucket can be considered effective at maintaining increased TCF after multiple days of use. It is possible that 4-d treatment periods were insufficient to find substantial changes in TCF, and, therefore, longer-term studies are warranted.

Because rapid feed intake has been identified as a risk factor for choke in horses (Chiavaccini and Hassel, 2010), the ability of BALL and WAFF to increase TCF may indicate obstacles in a feed bucket as useful tools to reduce feed intake rates in horses prone to choke. However, choke did not occur in any of the horses in the experiments; therefore, specific recommendations regarding choke prevention cannot be made in this experiment.

A variety of commercially available feeder designs propose to slow feed intake in canines and felines, and 1 commercial feeder seems to be effective in slowing feed consumption time in horses. The bucket in that feeder has molded cups in the base, which allows feed to settle into the lowered portion, making this design similar to the WAFF treatment, and has been shown to increase time to consume meals considerably when compared with standard, flat-bottomed commercial feed buckets (Carter et al., 2012). However, this study only determined time to consume feed and did not measure the postprandial metabolic response to feeding under the different treatments.

Both BALL and WAFF treatments effectively increased TCF in Exp. 1 when given with a single meal, but WAFF was clearly more effective at increasing TCF when given under a more regular, daily feeding schedule in Exp. 2. Yet, BALL resulted in a greater number of changes in insulin concentrations in Exp. 1. Each treatment likely worked in different ways to increase TCF, which seems to be related to their respective ability to effectively increase TCF after multiple days of feeding and to beneficially alter postprandial metabolism.

The BALL is less effective at promoting long-term heightened TCF and potentially poses safety risks because of falling balls, and WAFF does not promote as many desirable alterations in glucose and insulin concentrations after concentrate meals. As a result, additional research and development is necessary to produce a feed delivery method that is more effective at both increasing the time it takes for horses to consume a meal and simultaneously attenuating postprandial glucose and insulin concentrations.
**Conclusions**

The time it takes horses to consume pelleted feed can be effectively increased by inclusion of obstacles in the feed buckets, and obstacles either above or below the feed also tend to decrease the peak glucose concentration after feeding. However, additional effects are found with obstacles placed above the feed, including decreased peak and total insulin concentrations and increased time to peak insulin concentration after feeding. This may be due to the location of the obstacles above the feed continuously restricting feed intake. Further research on even more effective and safe feed delivery methods that increase the time to consume feed in equines is warranted. However, this research demonstrates the potential of simple management techniques to reduce the risk of horses developing IR and associated conditions such as laminitis.

**LITERATURE CITED**


