Equine Exercise Physiology 3: 323–330, 1991

Glycemic and Endocrine Responses to Corn or Alfalfa Fed Prior to Exercise

A. RODIEK, S. BONVICIN, C. STULL and M. ARANA
Department of Animal Sciences and Agricultural Education, California State University, Fresno, Fresno, CA 93740 and [1]Department of Veterinary Medicine Extension, University of California, Davis, CA 95616, USA

ABSTRACT. In two separate experiments, fit and unfit horses were fed isocaloric amounts (4.1 Mcal DE) of corn or alfalfa 2 hours prior to a submaximal standard exercise test. Horses that began the exercise test with high blood glucose and insulin levels (corn) showed dramatic declines in both glucose and insulin at the start of submaximal exercise (cantering at heart rates of 130–150 bpm). Horses with lower glucose and insulin levels (alfalfa) at the start of exercise showed smaller declines in both glucose and insulin throughout exercise. Corn fed horses showed a greater and/or longer post-exercise rebound than alfalfa fed horses. Cortisol increased during exercise but was unaffected by diet. Both fit and unfit horses showed the same general responses.

Key words: Horses; glucose; insulin; cortisol; diet; fitness.

INTRODUCTION

The composition of a meal ingested prior to exercise may affect athletic performance by altering the blood and tissue concentrations of energy pathway metabolites. Blood glucose levels are regulated by insulin and cortisol as well as other hormones. Research on the glycemic effects of different feeds in resting[19] and exercising[1,6] horses has indicated that blood glucose levels may be altered by diet. As glucose is an important metabolic fuel during exercise, it would be of benefit to choose rations that would provide optimum glucose levels for athletic performance. The first step towards determining which feeds best enhance performance is to understand how diet, exercise and level of fitness of the horse affect the dynamics of glucose regulation.

MATERIALS AND METHODS

Two experiments were conducted to examine the effects of 2 diets and a standard exercise test (SET) on blood concentrations of glucose, insulin and cortisol in fit and unfit horses. In the first experiment, 2-year-old Quarter Horse geldings (500 kg) that had been started under saddle only 45 days prior to the experiment were used as unfit horses. The second experiment utilized mature Arabian geldings (500 kg) that were lesson horses in an equitation program. These horses were considered to be fit compared to the 2-year-old Quarter Horses, although their conditioning consisted only of relatively low intensity work (trotting and cantering).

Both experiments utilized 4 horses on 4 separate test days when the horses were fed either corn or alfalfa prior to a submaximal SET. These feeds have produced high and low levels of glycemia in previous studies.[1,19] The diets were pelleted and an amount calculated to provide 25% of the maintenance digestible energy requirement (4.1 Mcal)[15] was offered to each horse 2 hours prior to SET. The diets were randomly assigned and each horse ate each diet on 2 of the 4 test days.

On three occasions, unfit horses fed alfalfa refused more than 50% of the feed offered.

In unfit horses fed corn, however, only one horse refused more than 10% of the offered amount at any time. Among the fit horses, one horse refused about 70% of the offered corn on one occasion. At all other times horses ate all of the offered feed within the 1 hour feeding period.

The test days were spaced several days apart so that there would be no "carry-over" effect of dietary treatment from one test day to the next. Between test days, the unfit horses were fed a basal diet of chopped alfalfa and oat hays and a corn-based concentrate pellet while the fit horses were fed alfalfa hay. The horses were fasted from the morning basal meal of the previous day until the experimental meal on test days.

Feeding times were staggered by 1 hour so that all horses could be exercised with the same tack and heart rate (HR) meter 2 hours after eating. The horses were ridden in a SET which consisted of 5 min of walking, 5 min oftrotting and three 10 min bouts of cantering. All horses were ridden in an arena by riders of similar skill and weight. HR was monitored using a telemetric HR meter. Horses were walked and trotted at the speed they chose but were not asked to extend themselves during this warm-up period. Riders attempted to maintain HR between 130 and 150 bpm during the cantering. Once the SET began, horses were stopped only long enough to draw a blood sample, usually less than 1 min.

Analysis of variance by repeated measures was performed to determine the effects of test day, individual horse variation, diet and sampling time on the measured parameters within each experiment.[2] When significant F ratios were obtained, t-tests were used to test for individual treatment differences at the 0.05 level.

RESULTS

Unfit horses

Test day variation affected only the serum cortisol parameter. The mean cortisol concentration was higher on the first test day (15 μg dl^{-1}) than on subsequent test days (7 μg dl^{-1}). Averaged across all test days and horses, cortisol concentrations were higher when the horses were fed alfalfa than when the horses were fed corn, primarily due to the much greater cortisol responses on the first test day. Cortisol concentrations rose significantly when cantering began and remained elevated (above pre-feeding levels) for approximately 1 hour after the cessation of exercise (Fig. 1). Cortisol concentrations approximately doubled during exercise in both the corn and alfalfa fed horses.

Individual horse variation affected only the insulin data. One horse showed a higher mean insulin concentration (25 μU ml^{-1}) than the other 3 horses (10, 14, and 18 μU ml^{-1}).

Sampling time (repeated measures) had a highly significant effect ($p<0.01$) on all of the measured parameters in both experiments.

Although not significant, corn fed horses tended to have higher mean glucose and insulin concentrations than alfalfa fed horses ($p<0.12$ and $p<0.15$ for glucose and insulin, respectively). For both glucose and insulin, however, the interaction of diet and sampling time was highly significant ($p<0.01$).

During the 30 min pre-feeding period, the glucose concentration for all horses averaged 102 mg dl^{-1} with no difference between the horses fed corn or alfalfa (Fig. 1). After the meal was offered, glucose levels began to rise, reaching levels greater than pre-feeding within 45 min. Peak glucose concentrations were observed 90 min after feeding, with corn fed horses showing a larger peak value (133 mg dl^{-1}) than alfalfa fed horses (113 mg dl^{-1}).

At the start of the SET, horses fed corn had higher glucose levels than horses fed alfalfa (123 vs 110 mg dl^{-1}). However, glucose values began to decline as exercise progressed and by the end of 10 min of cantering both groups of horses had dropped to their lowest levels. At the end of the first bout (10 min) of cantering, glucose concentration in the corn fed horses (87 md dl^{-1}) was lower than the alfalfa fed horses (106 mg dl^{-1}).

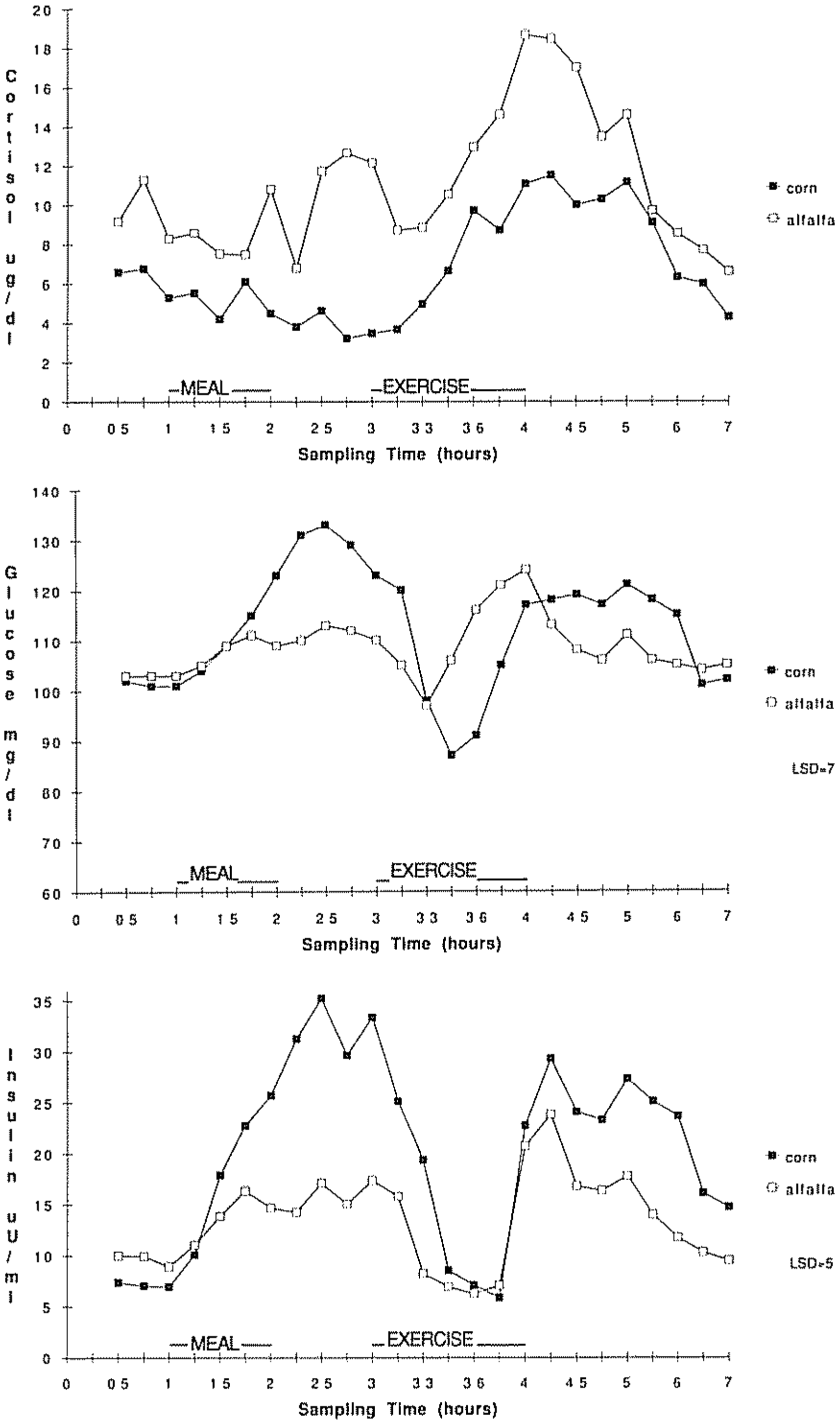

Fig 1 Mean serum cortisol, plasma glucose and serum insulin concentrations over time of unfit horses fed corn or alfalfa.

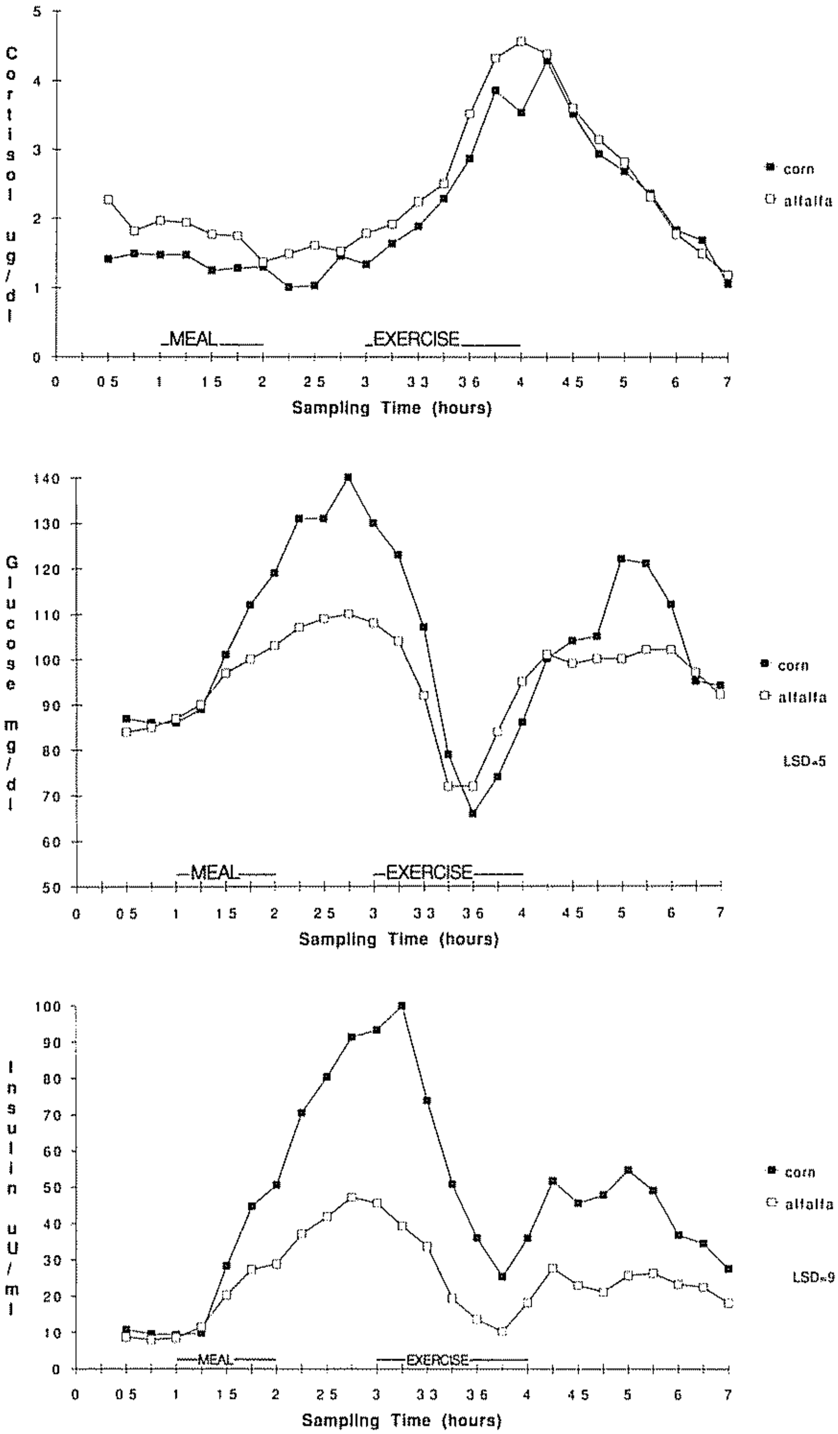

Fig. 2. Mean serum cortisol, plasma glucose and serum insulin concentrations over time of fit horses fed corn or alfalfa

At the end of the cantering period, the glucose concentration of the alfalfa fed horses was still greater (121 mg dl^{-1}) than the corn fed horses (105 mg dl^{-1}). Glucose levels rebounded quickly after cantering ceased, peaking 10 min after the end of cantering in the alfalfa fed horses (124 mg dl^{-1}) and 70 min after the end of cantering in the corn fed horses (121 mg dl^{-1}).

Within 30 min of the exercise being completed, the glucose levels in the alfalfa fed horses had returned to values not greater than pre-feeding. In the corn fed horses, however, glucose concentrations remained elevated above pre-feeding for 2 hours.

The insulin responses followed closely the glucose responses in the two diets. Pre-feeding insulin concentrations averaged 7 μU ml^{-1} for the horses fed corn and 10 μU ml^{-1} for the horses fed alfalfa (Fig. 1). After the meal was offered, insulin levels began to rise, reaching levels greater than pre-feeding within 30 to 45 min. Peak insulin concentrations were observed 90 min after feeding, with corn fed horses showing a larger peak value (35 μU ml^{-1}) than alfalfa fed horses (17 μU ml^{-1}).

Insulin values declined as exercise began, reaching lowest levels by the end of 20 min of cantering in the alfalfa fed horses and 30 min of cantering in the corn fed horses. In both groups, the lowest insulin values were about 6 μU ml^{-1}. Similarly both groups had very rapid rebounds in insulin concentration, reaching levels greater than pre-feeding by 10 min after the cessation of exercise and peak levels within 25 min after the end of cantering. Peak rebound insulin levels were greater in the horses fed corn (29 μU ml^{-1}) than in the alfalfa fed horses (24 μU ml^{-1}). Elevated insulin levels were maintained throughout the sampling day in corn fed horses while in horses fed alfalfa, insulin levels had declined to near pre-feeding levels by 1 hour after SET.

Fit horses

Test day variation did not significantly affect any of the measured parameters and individual horse variation affected only the insulin data, as 2 horses showed higher mean insulin concentrations (43 and 46 μU ml^{-1}) than the other 2 horses (24 and 30 μU ml^{-1}).

Dietary treatments significantly affected glucose and insulin concentrations, but had no effect on cortisol levels. In all horses, cortisol levels began to rise after the warm-up walk and trot and remained elevated throughout the SET and for 1 (alfalfa fed) or 2 (corn fed) hours after the SET (Fig. 2). Peak concentrations were reached at the end of the SET and in early recovery at levels approximately 2.5 times greater than the pre-feeding concentrations.

Pre-feeding glucose concentrations averaged 86 mg dl^{-1} with no difference between the horses fed corn or alfalfa (Fig.2). After the meal was offered, glucose levels began to rise, reaching levels greater than pre-feeding within 30 min and peaking 105 min after feeding. Peak glucose concentrations were greater in horses fed corn (140 mg dl^{-1}) than horses fed alfalfa (110 mg dl^{-1}).

Like the unfit horses, glucose values declined rapidly once exercise began. Both groups showed lowest glucose concentrations after 20 min of cantering. Corn fed horses again showed a lower value (66 mg dl^{-1}) than alfalfa fed horses (72 mg dl^{-1}).

Glucose levels began to rise after 20 min of cantering, reaching peak rebound levels of 122 and 102 mg dl^{-1}, respectively, for the corn and alfalfa fed horses approximately 1 hour after the SET.

Within 30 min after the exercise was completed, the glucose levels in the alfalfa fed horses had returned to values not greater than pre-feeding. In the corn fed horses, however, glucose concentrations remained elevated above pre-feeding for 2 hours.

Pre-feeding insulin concentrations averaged 9 μU ml^{-1} for both groups of horses (Fig. 2). Insulin levels rose to levels greater than pre-feeding by 30 min after the meal was offered and peak concentrations were observed 135 and 105 min after feeding, respectively, for the corn (100 μU ml^{-1}) and the alfalfa fed horses (47 μU ml^{-1}).

Insulin concentrations declined during the SET, reaching lowest values (25 μU ml^{-1} for corn and 10 μU ml^{-1} for alfalfa) after 30 min of cantering and rebounded during recovery. The fit horses appeared to show a greater insulin response to the diet and maintained higher insulin values during the entire test day than the unfit horses.

DISCUSSION

In the unfit horses, mean cortisol concentration was higher on the first test day than on subsequent test days. This was not unexpected as the 2-year-olds used in this study were generally inexperienced and were unaccustomed to the catheterization, blood sampling and SET procedures, especially on the first test day. The elevated cortisol concentrations of the horses fed alfalfa were due primarily to the greater cortisol levels in the 2 horses fed alfalfa on the first test day although the reason for this is unknown. Neither test day nor diet had an effect on cortisol concentrations in the fit horses.

Both fit and unfit horses showed elevated cortisol concentrations during exercise and for 1 hour after exercise. The timing of this cortisol peak is in close agreement with other studies.[5,12] The unfit horses appeared to have higher cortisol levels than the fit horses, but as the assays were run separately and under somewhat different conditions, it is hard to draw conclusions based on these data. Previous work[5,12] has shown no differences in peak cortisol levels in trained and untrained horses after a standardized exercise bout.

Peak glucose concentrations were observed 90 to 120 min after the meal was offered. The timing and magnitude of the glucose peaks in this study are in agreement with previous work[1,19] in which the same feeds and amounts were fed to 2-year-old horses. Post-prandial insulin peaks have been reported to occur in horses between 90 min and 4 hours after a meal.[7,8,19] In the present study, insulin concentrations peaked 90 to 135 min after the meal was offered. The insulin response curves for the two diets closely followed the glucose response curves. Glucose directly stimulates the release of insulin from the pancreas within 30 to 60 seconds after administration both *in vivo* and *in vitro*.[11] Insulin levels are known to mirror glucose levels in all species.[11]

Statistical comparisons between the two experiments were not made because the blood samples were analyzed in separate batches, with no common samples for comparison. Baseline and peak post-prandial glucose levels were similar in both experiments, but peak post-prandial insulin concentrations were approximately three times greater in the fit horses than in the unfit horses. The reason for this discrepancy is not known, although post-prandial insulin values in both the 20 to 30 and 80 to 100 μU ml^{-1} ranges have been previously reported.[8,16] A large individual variation among horses in insulin responses has been reported.[16] This variation was found in the present study as well.

Different studies have produced varied reports on the changes in blood glucose concentrations during exercise. Maximal exercise has been shown to increase plasma glucose[17] while submaximal exercise generally causes decreases in glucose levels.[4,12] It is generally accepted that the decline in blood glucose during exercise is due to an increased uptake and utilization of glucose by the working muscles. Studies in dogs have indicated that exercise itself increases glucose permeability of the muscle cell, even in the absence of insulin.[9] This information helps explain the decline in glucose concentrations during exercise in the present study even in the face of concomitant insulin declines.

Pre-exercise glucose ingestion in humans has a marked effect on blood glucose levels and muscle glycogen usage during exercise.[3,10] Ingestion of glucose 45 min before a 30 min bout of bicycling caused a significantly greater exercise glucose decline than fructose or placebo ingestion and stimulated greater muscle glycogen utilization during exercise than a placebo. Pre-exercise glucose ingestion was concluded to be deleterious to athletic performance as it decreased muscle glycogen stores.[10]

Glucose ingestion by humans 15 min prior to exercise raised both blood glucose and insulin levels immediately before exercise. In a manner similar to the present study, glucose and insulin concentrations declined to basal levels within approximately 10 min after the start of exercise and also showed both glucose and insulin rebounds after exercise.[3] It was proposed that the pre-exercise insulin level lowered blood glucose levels during exercise because the insulin had already been bound to the muscle cell membrane when exercise began.

Post-exercise hyperglycemia has been documented in horses[6,14,21] and rats.[18] The elevated cortisol levels of the horses during and after exercise indicate that hepatic glucose production was ongoing during and after exercise, as cortisol is known to promote hepatic gluconeogenesis.[20] Blood glucose levels reflect both hepatic glucose production and glucose uptake by the muscle.[18] When rats performed exercise of moderate intensity, glucose production remained above basal levels longer after exercise than glucose clearance (muscle uptake) resulting in a rebound increase in plasma glucose after the cessation of exercise. In the present study, glucose uptake by the muscles probably declined sharply when exercise stopped, but hepatic glucose production continued, as evidenced by the elevated cortisol levels for approximately 1 hour after the SET was completed. The dietary effects on the post-exercise glucose rebound are not entirely clear. Hepatic glucose production in the corn fed horses may have been greater than in the alfalfa fed horses due to higher blood glucose levels and presumably larger glucose deposition into the liver, prior to exercise.

The decline in serum insulin levels during exercise is most probably due to the effects of increased sympathetic innervation during exercise which inhibited the release of insulin from the pancreas.[3,13] Post-exercise hyperinsulinemia has been documented in man.[22] The insulin rebound has been attributed to the sudden withdrawal of sympathetic inhibition of the pancreas. Insulin levels would also be expected to increase concurrently with the post-exercise rebound hyperglycemia. This may partially explain the dietary influence on the post-exercise insulin levels.

In conclusion, it appears that corn and alfalfa, offered 2 hours before the SET, produced markedly different effects on blood glucose and insulin. Level of fitness did not appear to influence the responses to the diets, although the actual differences in fitness between the two groups of horses may not have been very great. Whether the practice of feeding high glycemia-inducing feeds prior to exercise has a deleterious effect on performance remains to be seen. The large decline in blood glucose during exercise after corn feeding may indicate a lack of glucose availability for work. However, the effects of duration and intensity of exercise and the timing of the meal before exercise must be investigated before conclusions can be drawn as to the values of various feeds for promoting or diminishing athletic performance. The effect of various diets on performance as well as the physiological effects need to be studied.

ACKNOWLEDGEMENTS

This work was supported in part by the California Agricultural Technology Institute. The technical assistance provided by Dr Wallace Liu, Dr Dennis Nef, Dr Stephen Wickler, Dr John Sherwin and Ms Lynn Goodman is gratefully acknowledged.

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