LECITHIN CONTAINING DIETS FOR THE HORSE: ACCEPTANCE, DIGESTIBILITY, AND EFFECTS ON BEHAVIOR

by

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(ABSTRACT)

Lecithins may improve the digestibility of high fat diets and the tractability of horses. Experiments were conducted to determine the acceptability, digestibility and effects on behavior of lecithin-containing diets. Seven young horses of light breeds were used for the studies.

The four concentrates consisted of corn, oats, beet pulp, trace mineralized salt, dried sugar cane molasses plus 10% added fat: corn oil (CO);soy lecithin-corn oil (SL\CO); soy lecithin-soybean oil (SL\SO); or soy lecithin-corn oil-soybean oil (SL\CO\SO). Half the ration was provided by chopped hay. The CO concentrate was the most palatable (P=.0001). The remaining three concentrates were palatable in the following order: SL\CO, SL\CO\SO, and SL\SO, with SL\CO diet preferred (P=.001) to SL\SO.

In the digestibility experiment, a complete mixed diet was fed containing chromic oxide as a marker. The control diet had no added fat: the others contained CO, SL\CO, or SL\SO at 10% by weight. Apparent digestibility was higher

in the control diet than in the others for dry matter (P=.0001). Apparent digestibilities of crude protein (P=.0002) and acid detergent fiber (P=.08) decreased with any of the three fats. In contrast, apparent digestibility of ether extract was increased (P=.0001) in the fat containing diets.

In the activity experiments, horses on the SL\CO diet were less spontaneously active (P=.0125) than horses on the control diet. Horses on the CO and SL\SO diet also had slightly lower activity levels (P=.125). Horses fed the SL\SO diet reacted less (P=.0625) than control horses to the opening umbrella. Horses fed CO and SL\CO diets showed trends towards less reactivity (P=.125 and P=.25, respectively), compared to the control horses.

These studies support the practical feasibility of using lecithins in diets for horses. Especially interesting would be studies of interactivity with trainers and riders.

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and
Elva Mae Taylor (1909-1992)

"Oh how wonderful it would be to be there..."

George Walton Holland (1892-1961)
and
Nellie Ada Holland (1894-1970)

"May the good Lord bless and keep you..."

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Introduction

Lecithins are best known as "health foods" in human diets. Dietary supplements of lecithin have been shown to reduce blood cholesterol. An emulsifying action has improved digestion, especially of high fat diets. Lecithin, like choline, may also improve some mental functions, such as memory and maze solving.

In biochemistry, lecithin usually refers to phosphatidylcholine, which is the main component of egg-lecithin. Phosphatidylcholine is like a triglyceride, except that the third fatty acid is replaced by a phosphate-choline group. The second fatty acid is predominantly linoleic acid.

In the feed industry, lecithins are by-products of the processing of seed oils. The polar lipid fraction is separated from the neutral fat, which consists almost entirely of triglycerides. Much of the polar lipid consists of lecithins. In addition to choline, other bases include inositol, ethanolamine, and serine in soy- and corn-lecithins.

In this study, the effect of lecithin on fat acceptance and digestion by horses will be evaluated to determine if lecithins would be a viable alternative to soluble carbohydrates in diets. Possible effects on behavior will also be studied to evaluate the use of lecithins to make horses more tractable and possibly improve attention span.

Review of Literature

Origin of Lecithins

Lecithins are the primary source of choline in the diet. The scientific community defines lecithin as phosphatidylcholine. However, in the food processing industry, lecithin means a mixture of polar lipids, such as phosphatides and other substances that contain phosphatidylcholine (Wurtman, 1979). Although lecithin can be found in minute amounts in many foods, the most common natural sources are eggs, liver, soybeans, wheat germ and peanuts.

Commercial lecithins come primarily from three main sources: soybeans, rapeseed and corn. Raw lecithin is extracted from the non-polar oil and is refined into many kinds of commercial lecithins. Soybeans are the preferred source of lecithin, not only because of a high level of phosphatidylcholine, but also because of high levels of mono- and polyunsaturated fatty acids (Bonacker, 1988).

The average composition of raw lecithin is 60-70% phospholipids, 27-37% oil, 0.5-1.5% moisture and 0.5-2.0% impurities (Bonacker, 1988). Commercial-grade lecithins usually contain 20-30% phosphatidylcholine and the remainder consists of other phospholipids and free fatty acids (Altfield et al., 1978).

Digestion of Lecithins

Phospholipids are digested in the intestine. Within the pancreatic secretions there are phospholipases which catalyze the hydrolysis of the fatty acid ester bonds (Houtsmuller, 1979; Vance, 1986). These enzymes must be activated, probably by trypsin, in the intestinal lumen. The products from the hydrolysis reactions include the following: free fatty acids, lysophospholipids, diglycerides, phosphatidic acid, phosphorylcholine and choline. These products can be used in synthesis of lipids, carbohydrates and proteins or can be absorbed and metabolized even further, depending on the requirements of the animal (Roberts and Dennis, 1989).

Use of Lecithins in Diets

Soy lecithin is an important by-product because of its many uses, such as an emulsifier, wetting agent, release agent, and as a dietary supplement. It can be a dense energy source for livestock. Soy lecithin is a source of both biotin and many tocopherols. Special lecithins rich in tocopherols have been used in livestock diets and pet foods as an antioxidant.

In livestock diets, a potentially important use of lecithin is to enhance the utilization of fats (triglycerides). Lecithin has the ability to emulsify fat, so it can facilitate the formation of micelles, and improve the digestion and absorption of various sources of fat. In this way, lecithin may actually enhance the use of other fats in the diet, as well as serve as a source of energy.

Laboratory Animal Diets. Much research has been done on the benefits of dietary lecithin in laboratory animals and humans. In rats, lecithin supplementation has been shown to decrease plasma cholesterol level (Ishida et al., 1988) from 84 mg/dl to 56 mg/dl. The diets contained 8% corn oil plus either 2% phosphatidylinositol from safflower seeds or soybean lecithin. The feeding of soy lecithin also decreased the level of triglycerides in the liver (41 mg/g vs 18 mg/g). These results suggested that lecithin may have a significant role in the regulation of lipid metabolism.

Soy lecithin may also reduce the absorption of cholesterol in the small intestine. In one study, rats were fed a hypercholesterolemic diet containing either saponins or polyunsaturated lecithin (Jiminez et al., 1990). Rats on the lecithin-containing diets had lower levels of plasma total cholesterol (TC) and triglycerides (TG) than rats on the control diet. The rats on the lecithin diet also had reduced levels of plasma very low density lipoprotein (VLDL), intermediate density lipoprotein (IDL) and low density lipoprotein (LDL) cholesterol. The plasma level of high density lipoprotein (HDL) was increased. Saponins only slightly decreased the plasma concentrations of VLDL's. The authors suggested that dietary lecithin affects the absorption of cholesterol in a favorable manner and may overcome some of the effects of a hypercholesterolemic diet.

In guinea pigs, O'Brien and Corrigan (1988) observed an increase in HDL and a decrease in TC in the plasma when they fed soy or egg lecithin as a supplement to hypercholesterolemic diets. On the lecithin-free diet, TC was 265 mg/dl and HDL-cholesterol (HDL-C) was 47 mg/dl. On the soy lecithin diet TC was 131 mg/dl and HDL-C was 58 mg/dl. When egg lecithin was used, TC was 191 mg/dl and HDL-C was 130 mg/dl. The authors suggested that the addition of either soy lecithin or egg lecithin alters the metabolism of dietary fat which would attenuate the adverse effects of a diet high in saturated fat.

Lecithin studies in humans have yielded mixed results concerning cholesterol. A beneficial increase in HDL and a decrease in TC were observed in hyperlipidemic people (Sirtori et al., 1985). These observations were not confirmed by Kesanieme and Grundy (1986). According to Knuiman et al. (1989), questions remain about the effect of supplemental lecithin on the metabolism of cholesterol in humans.

Pig Diets. Lecithins have been used in the diets of weanling pigs and, more recently, growing-finishing swine. One study was conducted on 330 crossbred weanling pigs (Van Wormer and Pollman, 1985). Edible-grade soy lecithin at the following levels: 0, 1.5, or 3.5% of the diet; was added to diets with and without 4% added choice white grease. When a low level of lecithin (1.5% of the diet) was added, there was no difference in average daily gain (ADG) or feed efficiency. No improvement of fat utilization was associated with either 1.5 or 3.5% lecithin. Perhaps the levels of lecithin (1.5 or 3.5% of the diet) were too low to elicit a measurable effect on fat utilization.

Similar results were obtained by Overland et al. (1993a). Addition of soy lecithin in soy oil at 2% of the diet did not improve the utilization of soy oil or the gain to feed ratio. The apparent digestibility of fat was increased significantly by soy oil ($P<.0001$) but only slightly by lecithin ($P<.1$).

A digestibility study (Jones et al., 1992) used 270 weanling pigs allotted to one of nine diets. Fat sources were added as 10%, by weight, of the diet. The diets were as follows: 1. control (no added fat); 2. control + soybean oil; 3. control + tallow; diets 4, 5, and 6, control + tallow with lecithin replacing 5, 10, or 30% of the tallow and diets 7,8 and 9, contained tallow with isolecithin replacing 5, 10, or 30% of the tallow. The apparent digestion of tallow was improved with the addition of lecithin (from 80.9 to 88.4%) and became comparable to that of vegetable fats, such as soy oil and coconut oil, which were tested in an earlier part of the same study. Addition of lecithin improved tallow digestibility more than isolecithin ($P<.008$). A slight but not significant increase in digestibility of soy oil was found with added lecithin. No improvement in post weaning growth performance was achieved with lecithin.

Another study used 240 growing-finishing crossbred pigs and diets containing soy oil and either 0, 1, 2, or 3% soy lecithin (Overland et al., 1993b). Soy lecithin had no effect on the ADG or the daily feed intake during the growing phase. An improved gain to feed ratio and a 7.5% increase in the apparent digestibility of fat was found during the finishing period, possible due to improved utilization of the diets.

In another study conducted by Overland et al. (1994), four diets contained either added rendered fat (0% and 6% of the diet), lecithin (0% and .24%) or a combination of the two. An increase in overall fat digestibility was associated with the inclusion of rendered fat ($P<.05$) but not lecithin.

The inconsistent results in studies of dietary lecithins in swine may be due in part to the source of lecithin or the amounts used in the diets. The emulsification properties, for example, may be affected by the source of the lecithin. Soy oil is also a very digestible source of fat in swine. The testing of lecithin with more indigestible sources of fat, such as tallow, showed an increase in digestibility (Jones et al., 1992).

Poultry Diets. Studies have been conducted to evaluate the effect of feed grade lecithin on the digestibility of nutrients and the metabolism of fat in the diets of chickens. A study using 40 male chicks and 8 diets containing either: (1) 5% added animal-vegetable fat (AVF), (2) 4.5% AVF + .5% soy lecithin, (3) 4.5% AVF + .5% corn lecithin, (4) 4% AVF + 1% soy lecithin, (5) 4% AVF + 1% corn lecithin, (6) 5% soy lecithin, (7) 5% corn lecithin, and (8) 5% poultry fat was devised to observe the effect of soy or corn lecithin on the metabolism of dietary fat (Donaldson and Ward, 1988). It was concluded that lecithins had no effect on the performance of broiler chicks. Performance was evaluated by weight gain and feed to gain ratio. A study by Polin (1980), however, showed an increase in the utilization of tallow as a nutrient when soy lecithin was added to chick diets at 2% of the diet. This result is similar to other studies with tallow previously reviewed and supports the potential use of lecithin to aid in the digestion of the fat content of diets. It appears that lecithin may be most useful in the utilization of less digestible fats in diets for monogastric species.

Cattle and Sheep Diets. A study using 12 Hampshire wethers was conducted to examine the effects of phospholipids on ruminal fermentation and nutrient digestion in sheep (Jenkins et al., 1989). Animals were randomly assigned to one of three diets. These diets contained either 2.4% corn oil (CO), 5.2% deoiled soybean lecithin (DOL) or 5.2% crude soybean lecithin (SL) on a dry matter basis. Results showed a slight decrease in energy, fiber and nitrogen digestion for the two lecithin diets when compared to the CO diet. However, there was an increase in the fat digestibility from 42% (CO) to 56% (DOL) or 55% (SL). It appears that the two lecithins were more digestible than the CO.

A follow-up study using 6 Hampshire wethers was done to compare the effects of lecithin and corn oil on the site of digestion and protein synthesis in sheep (Jenkins and Fotouhi, 1990). Sheep had both ruminal and duodenal cannulas. Each wether consumed three experimental diets in a 3 x 3 Latin Square. The diets were as follows: no added fat (control), 5.2% soybean lecithin (SL), and 2.4% corn oil (CO) on a dry matter basis. As in the previous study, added fat decreased ruminal digestibility of energy, fiber and fatty acids. However, the total tract digestibilities were not affected by the addition of fat. According to the authors, the addition of SL and CO had a sparing effect on the fat, and allowed it to be absorbed by the small intestine. Therefore, the hindgut of sheep may compensate for the decreased digestion in the rumen.

Further studies on the effects of added soy lecithin on digestion and utilization of diets by sheep have been conducted (Lough et al., 1991). The experimental animals were 43 Hampshire or Suffolk sired ram lambs which were assigned to one of the following diets: basal (BAS); BAS + 6% whole canola seed (CS); BAS + 4.9% deoiled soy lecithin (SL); or BAS + 6% whole canola seed + 4.8% deoiled soy lecithin (CSSL). With the SL added diets, there was a slight increase in daily feed intake and on the SL diet there was a slightly greater ADG. Lambs fed the CS, SL, and CSSL diets did not show any improvement in carcass characteristics and content of TC, HDL, and TG that would indicate that lecithins could be used to improve carcasses to meet the current human dietary guidelines.

Another study conducted by Lough et al. (1992) used

43 ram lambs to observe cholesterol content and fatty acid composition of carcasses when lecithin was added to the diet. They used the same diets mentioned in the previous study. Cholesterol content of the longissimus dorsi muscle on all 4 diets was similar. Saturated fatty acid (SFA) content was slightly lower, monounsaturated fatty acid (MUFA) content slightly lower, and polyunsaturated fatty acid (PUFA) content slightly higher for the SL diet than the basal (BAS) diet. In the subcutaneous adipose tissue, cholesterol content was lower on the SL diet. As within the muscle, SFA and MUFA were slightly lower and PUFA was slightly higher on the SL diet. From this study, there appears to be some potential benefit to feeding market animals diets containing lecithin. The authors concluded that it would be possible to produce a carcass the would be more desirable to some consumers than those currently on the market.

Research has also been conducted with cattle to examine the effects of a lecithin-containing diet on digestion and carcass composition. Zinn (1989) evaluated the effect of a lecithin-containing diet on feedlot cattle growth and performance. He used 228 crossbred steers in a 125-day feeding trial. Six dietary treatments were used: basal diet, basal + 4% yellow grease (YG), basal + 4% blended animal-vegetable fat (BVF), basal + 8% YG, basal + 8% BVF, and basal + 6% BVF and 2% crude corn-soy lecithin (CSL). There was a decrease of the feed to gain ratio on the fat supplemented diets. The decrease was linear with amount of fat in the diet: basal - 7.51 (lb fed to lb gained), 4% fat - 6.8 and 8% fat - 6.3 There was no effect of the added lecithin on the performance data of the steers. There were slight but not significant improvements in rib eye area and retail yield and a decrease in fat thickness and total % fat of the carcass for the steers fed lecithin. There was a slight improvement in carcass characteristics when lecithin was used to replace some of the added fat in the diet. This has also been observed in studies conducted on lambs (Lough et al., 1992) which were reviewed earlier. If the composition of carcasses were altered to fit more closely the current human dietary recommendations, there could be a beneficial effect on the livestock industry.

Following his work with sheep, Jenkins (1990) examined the use of lecithins in cattle diets. In one study, 4 Angus steers were placed in a 4x4 Latin Square study with the following diets: no added fat (control), control + hydrogenated fat (6.86% of dry matter), control + hydrogenated fat (6.11%) + lecithin (1.02%), and control + hydrogenated fat (5.32%) + lecithin (1.98%). Fat supplementation did not affect apparent total tract digestibilities for dry matter, organic matter or fiber.

There was a decrease in the total tract digestibility of fat with the addition of fat to the diet (85% for control, 65 to 67% for the fat-containing diets). The beneficial effect of added lecithin on fat digestion seen in many nonruminant studies was not seen in this study. The higher level of lecithin did lower plasma TG (52 mg/dl for 1% lecithin vs 47 mg/dl for 2% lecithin) and plasma TC (224 mg/dl for 1% lecithin vs 200 mg/dl for 2% lecithin) levels. The lowering of plasma levels of TG and TC are similar to what is observed when humans consume lecithins in their diet.

The effect of duodenally infused rapeseed oil or rapeseed oil plus lecithin on intestinal digestion was studied in 4 Holstein cows (Chillard et al., 1991). This was done in a crossover design so all cows received both treatments. There was a slight increase in digestibility of lipids and fatty acids when lecithin was added but no effect on the digestibility of other nutrients.

Horse Diets. Research in equine nutrition usually lags behind that of other domestic livestock. Until recently, no studies have been conducted on lecithin-containing diets in horses. Research has been started at Virginia Tech on the effects of lecithin on exercise (Taylor, unpublished data; Wilson, unpublished data). Increased utilization of dietary fat could be most helpful in horses that must perform for long periods of time (Rose et al., 1980). An increase in energy density and digestibility of the diet would decrease bulk in the stomach and especially, the large intestines (Potter et al., 1990; Ferrante and Kronfeld, 1992). Large amounts of soluble carbohydrates have been associated with digestive disturbances, such as colic, that are painful and sometimes fatal in the horse. A high carbohydrate diet can also contribute to laminitis (Baxter, 1992), exertional rhabdomyolysis (Turner, 1992) and developmental orthopedic disease (Williams, 1992) in horses. Although not documented, there has been speculation that diets high in soluble carbohydrates may also lead to so called "hot" behavior in some horses.

Because of these problems, research is being conducted to determine the potential advantages of replacing soluble carbohydrates with fats. Extensive research has been conducted on the digestibility of fats in horse diets (Bowman, 1977; McCann, 1987), and they have been shown to be digestible. There has also been research conducted on the utilization of fat as an energy source for exercise. although some reports indicate that fat is beneficial, not all show significant improvement (Custalow, 1992; Scott, 1992; Ferrante, 1994) Lecithins are of interest because of the possibility of improving the digestibility of relatively indigestible fats. Lecithins have also been documented as decreasing spontaneous activity and improving attention span in mice (Gozzo et al., 1992); a similar effect in horses could be valuable for trainers.

Lecithins and Behavior

There have been reports of lecithin and choline containing diets, or oral supplements of these substances having positive effects on behavior and memory (Growdon, 1986). These responses, such as improved memory and decreased spontaneous activity, have been observed in normal rats and mice and in humans with several forms of mental disorders such as Alzheimer's disease and tardive dyskinesia (Barbeau, 1979). However, consistent benefits have not been established, and favorable claims have often been questioned.

Memory and Learning. Studies have also been conducted to determine the effects of lecithin on behavior, memory and maze learning in laboratory animals. A study on 40 rats and their offspring evaluated the effect of soy lecithin supplementation on behavior in the developing rat (Bell and Slotkin, 1985). Pregnant rats were supplemented with 5% soy lecithin from day seven of gestation until the offspring were weaned. The litters were then maintained either on the lecithin diet or a control diet. Initially, the lecithin diet appeared to accelerate the brain maturation process. Supplemented rats learned to right themselves after being placed on their backs and to climb sooner than control animals. However, the supplemented animals eventually showed a delayed righting reflex (returning to an upright position after being placed on their backs).

In another study, groups of mice consuming diets containing lecithins matured faster mentally than control animals (Gozzo et al., 1982). Supplemented animals learned to avoid negative stimuli sooner than nonsupplemented groups. Supplemented animals also had less spontaneous activity than control animals.

In a third study, lecithin supplemented rats had earlier behavioral maturation and decreased activity levels, compared to nonsupplemented rats (Bell and Lundberg, 1985). The decreased activity level observed in rats and mice may be similar to the beneficial effects of supplemental choline on humans with hyperactive movement disorders. In a review by Mauron and Leathwood (1987), other studies were summarized in which phosphatidylcholine supplementation improved the ability of mice and rats to learn mazes and this could relate to the potential of phosphatidylcholine containing diet to enhance memory in humans.

Other studies have been conducted to observe the effect of lecithin "snacks" on the speed of the internal clock and memory storage processes in rats (Meck and Church, 1987). Rats given lecithin learned how to operate an apparatus that dispensed food faster and remembered how to operate the apparatus longer than control rats. This ability was retained after lecithin supplementation was discontinued.

Old age may enhance the learning response to dietary lecithin in mice (Karczmar, 1979). In one study, aged mice were fed a diet containing 25% lecithin (Golczewski et al., 1982). Other groups of aged and young mice did not receive lecithin. Mice were evaluated on their ability to learn the correct path through a maze. The aged supplemented mice learned almost as well as the young unsupplemented group. The aged control group had the most difficulty learning the maze.

Human Diseases. Decreasing levels or deficits of acetylcholine in the brain have been associated with several clinical syndromes including tardive dyskinesia and Alzheimer's disease (Mauron and Leathwood, 1987; Volicer and Herz, 1985). Acetylcholine is made from choline and acetyl coenzyme A in a reaction catalyzed by choline acetyltransferase. The use of choline as a supplement has increased blood and brain levels of acetylcholine in studies in mice and humans (Gelenberg et al., 1979; Karczmar, 1979). However, choline supplementation in mice that already had adequate levels of choline in the diet failed to increase brain acetylcholine concentrations (Wecker, 1990). Choline supplementation also has some unpleasant side effects, the most common being a fishy odor emanating from the subjects. Lecithin supplementation may have fewer side effects (Etienne et al., 1979).

In studies where supplementation of either choline or lecithin has increased synthesis of acetylcholine there has also been an increased release of acetylcholine into postsynaptic sites in the brain (Gelenberg et al., 1979; Christie et al., 1979). This increase in acetylcholine appears to be beneficial in the treatment of disorders involving hyperactive movement such as tardive dyskinesia (Barbeau, 1979; Karczmar, 1979).

Tardive dyskinesia is a disorder that is characterized by abnormal, involuntary choreoathetotic movements involving the tongue, lips, jaw, face, extremities and occasionally the trunk (Gelenberg, 1979). This is the brain disorder with the best documented improvements after lecithin or choline supplementation. Growdon et al. (1977) showed movement suppression in 9 of 20 patients with tardive dyskinesia after choline supplementation. In an additional study, phosphatidylcholine supplementation decreased movement in four other patients (Growdon et al., 1978).

Several other studies have shown similar beneficial effects (Gelenberg et al., 1979; Growdon, 1986).

In Alzheimer's disease, results of choline and lecithin supplementation have not been as consistent. It appears that supplementation must occur during the early stages of the disease for there to be any improvement in memory (Mauron and Leathwood, 1987). During advanced stages of the disease, structural changes of the brain occur that may make supplementation ineffective. Growdon (1986) reported that in studies conducted by more than twenty investigators where phosphatidylcholine or choline was used as a supplement there were no positive results. These studies all lasted from one to three months. In another study that lasted for six months, phosphatidylcholine supplementation appeared to retard some progression of the disease (Little et al., 1985).

The combination of lecithin with another drug, such as physostigmine, may improve memory function in Alzheimer's patients and may retard progression of the disease(Brinkman and Gershon, 1983; Thal et al., 1983). In other studies however, the combination of physostigmine and phosphatidylcholine did not retard or reverse memory loss (Growdon, 1986).

In conclusion, lecithin containing diets may affect behavior favorably in both humans and other animals.

Alzheimer's patients may have improved mental function and patients with hyperactive movement disorders may have decreased involuntary movement. The results with these two diseases, although not always consistent, indicate that further research should be conducted in this area. Studies in mice and rats have also shown improved memory and earlier maturation. Again, even though there are some conflicting results, there appears to be some potential for behavior modification with a lecithin containing diet.

Use of Chromium as an External Marker to Estimate Fecal Output in Digestibility Studies

Markers are used in digestion trials to help determine digestibility, intake and fecal output. In studies where intake is known, only one marker is needed to determine fecal output and digestibility. An ideal marker is a substance that is totally indigestible and unabsorbable, has no pharmacological action on the digestive tract, passes through the tract at a uniform rate, is readily determined chemically, and is preferably a natural constituent of the feed (Maynard et al., 1979). Chromic oxide (Cr_2O_3) is one of the most commonly used indicators (Prigge et al., 1981) although its reliability has been questioned due to its inability to adhere satisfactorily to the particulate phase of the digesta (MacRae, 1974), and to diurnal variation in excretion due to incomplete mixing of the digesta and chromic oxide (Langlands, 1975). However, chromic oxide has been used in equine studies (Moffitt, 1987; Martin et al., 1989; Custalow, 1992).

Summary

In laboratory animals such as rats, the benefits of feeding lecithins include decreasing the amounts of the "bad" cholesterols VLDL-C and LDL-C, and increasing the amount of "good" cholesterol HDL-C. If changes such as these occurred in the utilization of fat in human diets, there could be a decrease in the incidence of heart disease.

There are mixed reviews on the use of lecithins in the diets of livestock to increase digestion and utilization of fat in the diet. There may be more potential in using lecithin to increase the utilization of relatively indigestible fats such as tallow.

Lecithins have potential for behavior modification in humans and laboratory animals. In rats and mice, lecithin enriched diets improved memory function and facilitated behavior maturation. In patients with tardive dyskinesia, lecithin appears to decrease the frequency of spasmodic movements; in patients with Alzheimer's disease, lecithin supplements may improve memory and delay the onset of dementia.

OBJECTIVES

The overall objective of this research was to assess the potential value of lecithin in equine diets.

The specific objectives were to determine the effects of combinations of lecithin and oil in equine diets on:

1. Acceptance of diets.

2. Digestibility of diets.

3. Behavior of horses.

MATERIALS AND METHODS

The research was divided into three related experiments: acceptability, digestion, and behavior. Four fat combinations were tested in the palatability study, three in the digestibility and behavior studies.

Acceptability Experiment

The basal concentrate mixture was formulated to be similar to that used by Rich (1980); its composition is shown in Table 1. The four concentrates included the following fats at 10% by weight: (1) corn oil (CO); (2) soy lecithin, corn oil, soybean oil (SL\CO\SO); (3) soy lecithin, corn oil (SL\CO); (4) soy lecithin, soybean oil (SL\SO). Soy lecithin made up 50% of fats containing lecithin. Corn oil and soy oil made up the remaining 50%. In the SL\CO\SO diet, corn oil and soy oil both made up 25% of the fat. Composition of the lecithin and oil is in Appendix table 1. Corn oil was used as the reference fat, because it was the most palatable in a previous study (Rich, 1980).

Eight horses of mixed breeds, four fillies and four geldings, ranging in age from 2 to 4 years, were used. Breeds were as follows: two Arabians; two Anglo-Arabs; and four Thoroughbred-Quarter Horse crosses. The trial lasted

Table 1. Composition of concentrate mixtures used in the acceptability experiment (as fed basis)

Ingredient	IRN	% of Diet
Cracked corn	4-02-931	34.8
Crimped oats	4-03-309	34.7
Dried beet pulp	4-00-669	15.0
Dried molasses	4-04-695	5.0
Trace mineral mix[a]		.5
Fats		10.0

[a]Livestock Mineral 2:1, by Southern States Cooperative, Inc. Richmond, VA 23260

21 days, and feed intake was recorded daily. Initially, each animal was offered 2000g of each concentrate once daily for a limited time. This amount was varied according to the previous day's consumption to allow the horses to consume as much of an individual diet as they liked. Horses were fed the diets in individual feeding stalls, 8.5 m^2, at 700. The mixtures were offered in four separate, adjacent .6 m x .6 m compartments, cafeteria style, to allow the horses to choose freely between the four diets. The diets were randomly rotated among compartments to avoid the horses developing a location pattern. Length of time each horse was exposed to the diets varied according to the average length of time it took them individually to consume one half their daily energy requirements (NRC, 1989) of a similar concentrate prior to the beginning of this experiment. After the morning feeding, the horses were placed into a 60 m x 78 m dirt exercise lot until 1600, when they were again placed into their separate stalls to receive their daily hay ration. The hay was a mixed grass hay consisting primarily of timothy and was offered to provide one half the daily energy requirements. Horses were left in the stalls through the morning palatability trial. Water was provided free choice both in the exercise lot and in the stalls. Trace mineralized salt was provided free-choice in the exercise lot.

Concentrates were mixed weekly in a horizontal mixer. Hay was chopped in a high speed hammermill through a 2.5 cm screen to accustom the horses to chopped hay for the digestibility and behavior experiments.

The data on feed intakes were examined by analysis of variance using the GLM procedure of SAS, with horse, diet and horse*diet interaction in the model (SAS, 1990). Differences between means were tested by Tukey's multiple comparison procedure.

Digestibility Experiment

Horses similar to those used in the palatability experiment were utilized in the digestion trial. Some horses were replaced so they could be used in a training class. Eight horses, of mixed breeds, four gelding and four fillies, ranging in age from two to four years, were used. Breeds changed slightly from the acceptability experiment. In this experiment there were one Quarter Horse, one Thoroughbred, one Anglo-Arabian, two Arabians and three Thoroughbred-Quarter Horse crosses. Horses were assigned to two groups according to weight and were then randomly allotted to the four total mixed rations in a replicated 4 x 4 Latin square (Appendix table 2). One gelding was removed from the study as a result of his refusal to consume the diets and was not replaced.

Each test period lasted 21 days, the entire experiment for 12 weeks. The first week of each period was used for accommodation. Feed and fecal grab samples were collected every day during the last two weeks and frozen for later analysis. Chromium sequioxide was mixed into each diet to provide a .5% chromium concentration in the diet.

Horses were fed equal amounts of their assigned diet twice daily. The amount each horse was fed was initially the average caloric requirements for inactive horses (NRC, 1989). Horses were weighed weekly (Appendix table 3) and rations adjusted to maintain body weight Between the morning and evening feedings they were turned out into the dirt exercise paddock. Water was available free choice in both the stalls and the exercise lot. Trace mineralized salt was available in the exercise paddock.

The basal diet consisted of chopped mixed grass hay, equal parts corn and crimped oats, beet pulp, trace mineralized salt and sugar cane molasses (Table 2). It was formulated to exceed minimum daily requirements of a two year old horse at rest (the youngest horse on the study) with a mature weight of approximately 450 kg (NRC, 1989). The other three diets included corn oil (CO), a mixture of soy lecithin and corn oil (SL\CO), or a mixture of soy lecithin and soy oil (SL\SO) at 10% by weight. The composition of the fats is given in Appendix table 1.

Table 2. Composition of diets* used in digestibility and behavior experiments (%)

Ingredient	IRN	Control	CO	SL\CO	SL\SO
Hay		58.4	63.1	63.1	63.1
Cracked corn	4-02-931	13.5	8.0	8.0	8.0
Crimped oats	4-03-309	13.4	8.0	8.0	8.0
Dried beet pulp	4-00-669	6.2	5.5	5.5	5.5
Trace mineral mix		.5	.5	.5	.5
Chromic sequioxide		.5	.5	.5	.5
Wet molasses	4-04-696	8.0	-	-	-
Dried molasses	4-04-695	-	5.0	5.0	5.0
Fats		-	10.0	10.0	10.0

*CONTROL = control diet; CO = corn oil containing diet; SL\CO = soy lecithin\corn oil containing diet; SL\SO = soy lecithin\soy oil containing diet.

Minimal adjustments were made to maintain the contents of protein and fiber when fat was added. Processing and mixing of the diets was similar to that described for the palatability experiment except the chopped hay and concentrate mixtures were combined to provide a total mixed ration.

Feed and fecal samples were individually dried in a 100°C forced air oven. They were ground through a Wiley mill with a 2 mm screen and then through a Cyclone mill. Samples were then combined by week. Feed and feces were analyzed for dry matter (DM), ether extract (EE) and ash by the methods of A.O.A.C. (1990). Dry matter was determined by reduction to a constant weight in a forced air oven. Ether extract was determined by rinsing and boiling samples with methyl ether. Ash was determined by placing samples in a muffle furnace and heating to 300°C. Crude protein (CP) was determined using a Kjeldhal Automatic Analyzer after sample was digested in sulfuric acid. Acid detergent fiber (ADF) was determined using the method of Goering and Van Soest (1970). Cr, Ca, P, K, Zn, Cu, Na and Mg were determined using inductively coupled plasma spectrophotometry (ICP) after digestion with Nitric and Perchloric acid (Sandel, 1959).

Apparent nutrient digestibilities were then calculated using an equation (Maynard et al., 1979).

$$\text{Digestibility} = 100 - \left(100 \frac{\%\text{indicator in feed}}{\%\text{indicator in feces}} * \frac{\%\text{nutrient in feces}}{\%\text{nutrient in feed}}\right)$$

Estimates of digestible energy (DE) were calculated using the NRC (1989) and regression equations to estimate neutral detergent fiber (NDF) and nonstructural carbohydrates (NSC) of each diet. A more detailed explaination of how this was done is in Appendix 1.

Apparent digestibilities were compared using the GLM procedure of SAS with horse, diet, period and horse*diet in the model (SAS, 1990). Differences between least squared (LS) means were compared using orthogonal contrasts.

Behavior Experiments

Behavior experiments tested spontaneous activity and reactivity to a stimulus (Ralston, 1991). Trials were run during the last week of each feeding period to ensure that the animals were adapted to the diet.

Spontaneous activity was measured with pedometers (Trail Tale Horse Pedometer, Kel Instruments Co., Inc., Wyckoff, New Jersey), which were placed on the left front pastern of each horse during the last 5 days of each period. Readings were taken, and the pedometers were reset and placed back on the leg each morning before turnout. This was to provide an estimate of walking activity. A diagram of the pedometers and their placement can be seen in Figures 1 and 2. The miles each horse walked while on the control diet was compared to the miles walked on the other three diets.

Two types of tests were employed to evaluate reactivity. Response to physical pressure was determined by use of an apple penetrometer (Effegi Fruit Tester, McCormick Fruit Tech, Yakima, Washington). The penetrometer was used to apply pressure to a very specific point on the jaw or flank until the horse moved away from the pressure. The number of kg of pressure applied was recorded. A diagram of this instrument and where it was used are shown in Figures 3 and 4. This test was conducted one day during the last week of each trial.

The reaction to visual and auditory stimuli tests were conducted the last day of each digestion trial. One test compares the time it takes for an animal to walk a specified distance on a path with the time taken again when a disturbing stimulus was applied at the halfway point. In this study, the distance was 6.1 meters. The horses were also given a subjective score on their reaction to the disturbing stimulus (Appendix table 4). Separate reactivity scores were given by two assistants, who did not know which diet a horse was consuming. Two types of stimuli were used. The visual test was a brightly colored umbrella that was

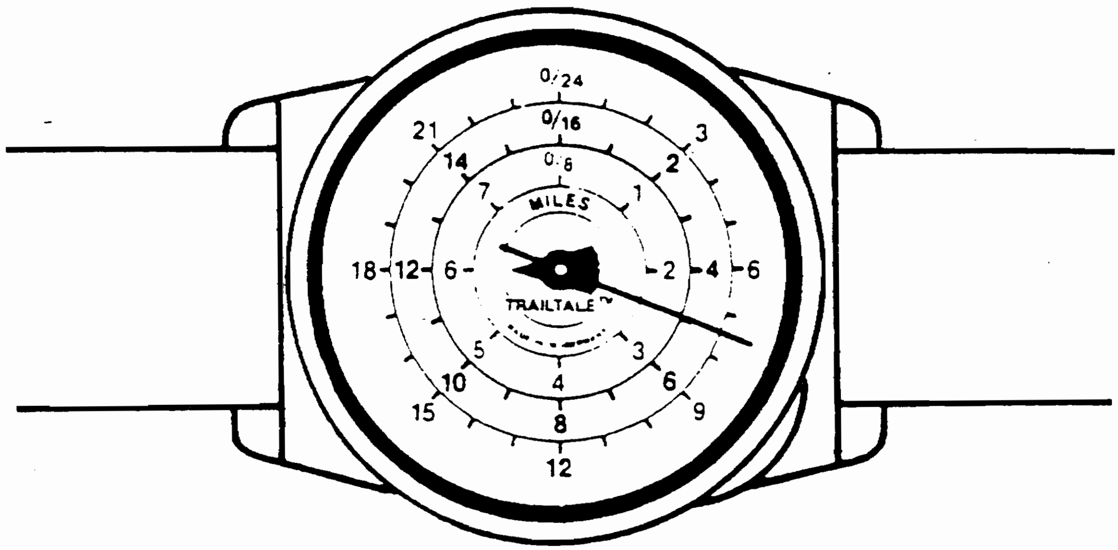

Figure 1. Diagram of "Trailtale" Horse Pedometer

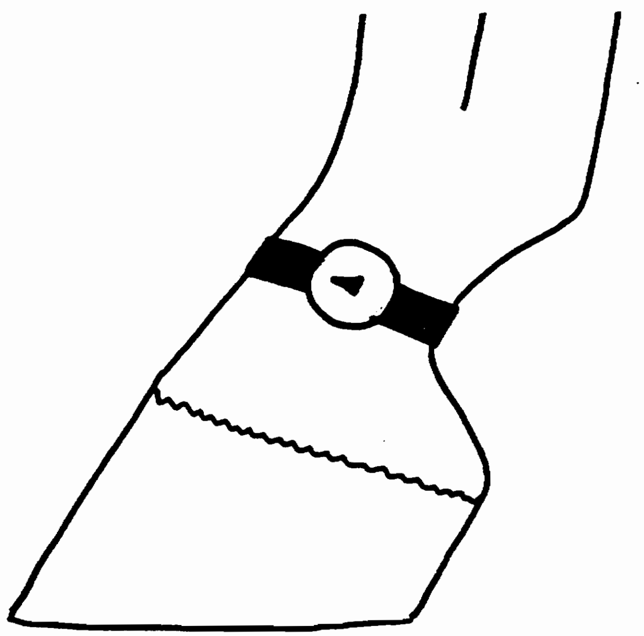

Figure 2. Placement of pedometer on outside of left front pastern

"Trailtale" Horse Pedometer is a product of:
Kel Instruments Co., Inc.
P.O. Box 54
Wyckoff, N.J. 07481

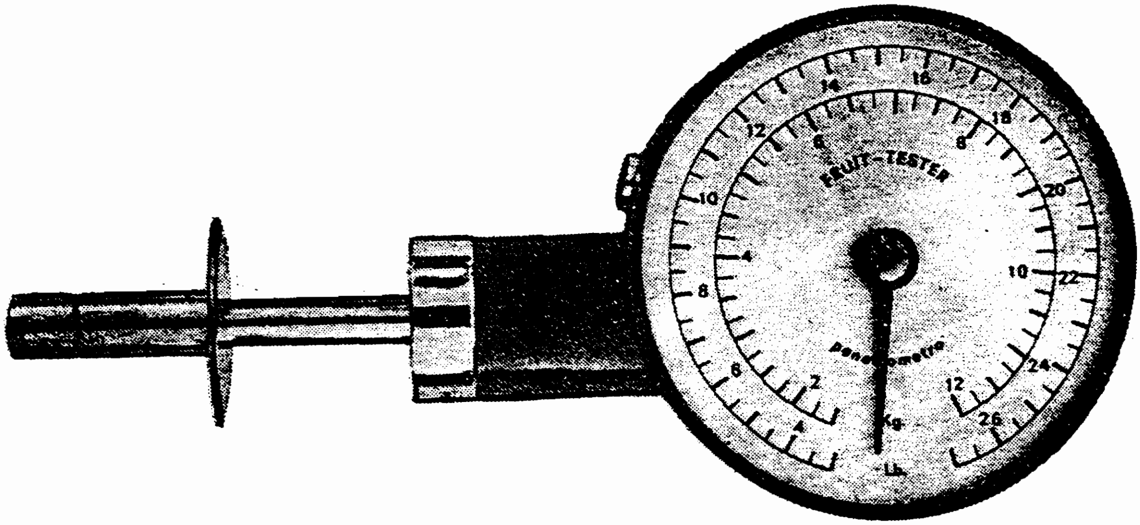

Figure 3. Diagram of McCormick Fruit Pressure Tester

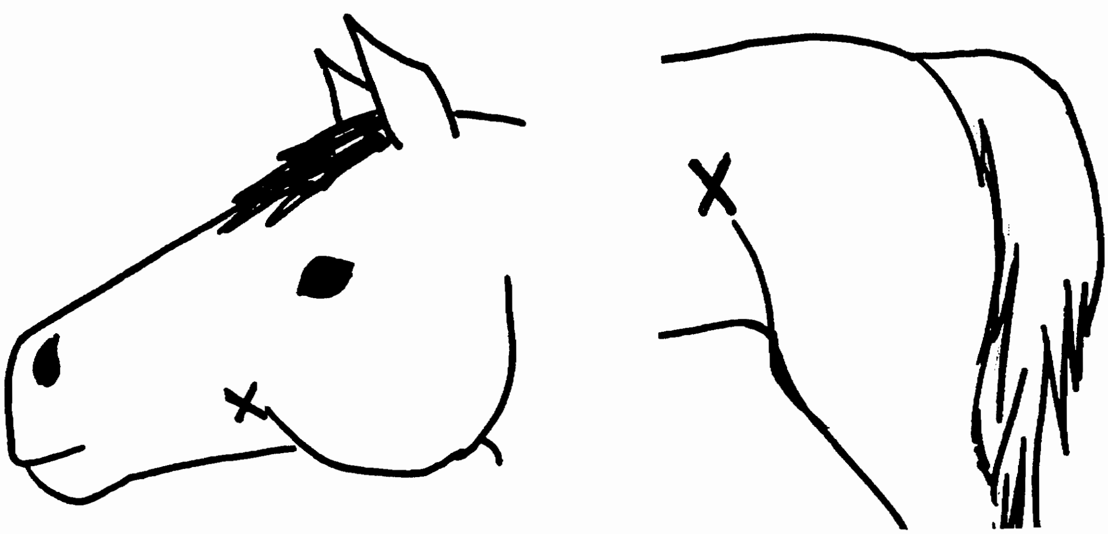

Figure 4. Locations on the horse where tester was used

McCormick Fruit Tester is a product of:
McCormick Fruit Tech
Refractometer - Fruit Pressure Testers
6111-A Englewood Ave.
Yakima, WA. 98908-2341

opened abruptly as the horse passed. The auditory test consisted of coins in a tin can that was shaken suddenly as the horse walked by. These tests were first designed by Dr. Stephen McKenzie, SUNY-Cobleskil.

Data from the behavior tests were analyzed using Wilcoxon's sign test (Ott, 1988) with all reactions compared to reaction while consuming the control diet.

Results and Discussion

Acceptability Experiment

Average voluntary intakes of each concentrate are given in Table 3. During the first 7 days, the (CO) diet was the most preferred (P<.0001). This diet was removed after the first week to force the horses to choose among the lecithin diets. Then the SL\CO diet was the most preferred (P=.001). The (SL\CO\SO) and (SL\SO) diets were third and fourth in preference, respectively. Daily intakes of individual concentrates by each horse are in Appendix table 5.

Palatability of fats have been expressed as corn oil equivalents (Rich, 1980). Intakes of SL/CO, SL/CO/SO, and SL/SO were 8.8, 8.7, and 4.3% of CO intake according to this approach (Table 4). During the second and third weeks, after the CO diet had been removed, the corn oil equivalents for SL/CO, SL/CO/SO, and SL/SO were 70, 57.5, and 40.6%, respectively, of the amount of the CO diet consumed during the first week. During the second and third weeks, if the two diets containing soy oil are compared to the SL\CO diet, relative palatabilities are 82.0% for the SL\CO\SO diet and 58.0% for the SL\SO diet. These results indicate that although the horses did not like the taste of the lecithins, they did learn to consume them. It appears that the horses found the diets palatable in relation to the amount of corn oil in the diet.

Table 3. Average voluntary intakes of concentrates in acceptability experiment (mean ± standard error)

Diet*	Intake, g/d (Week 1)	Intake, g/d (Weeks 2 and 3)
CO	1748.55 ± 197.95[a]	---
SL\CO	153.55 ± 62.45[b]	1227.23 ± 125.89[c]
SL\CO\SO	151.95 ± 73.72[b]	1005.23 ± 143.79[c,d]
SL\SO	74.53 ± 25.33[b]	710.24 ± 98.45[d]

*CO = corn oil containing diet; SL\CO = soy lecithin\corn oil containing diet; SL\CO\SO = soy lecithin\corn oil\soy oil containing diet; SL\SO = soy lecithin\soy oil containing diet

Values with different letters are significantly different.
[a,b] $P<0.0001$
[c,d] $P<0.001$

Table 4. Relative acceptability of fats (compared to corn oil)

WEEK 1

Diet*	Score
CO	100.0
SL\CO	8.8
SL\CO\SO	8.7
SL\SO	4.3

WEEK 2 and 3 (AVERAGED)

Diet*	Score	Score(omitting corn oil)
CO	100.0	---
SL\CO	70.0	100.0
SL\CO\SO	57.5	82.0
SL\SO	40.6	58.0

*CO = corn oil containing diet; SL\CO = soy lecithin\corn oil containing diet; SL\CO\SO = soy lecithin\corn oil\soy oil containing diet; SL\SO = soy lecithin\soy oil containing diet

Digestibility Experiment

As mentioned in the Materials and Methods section, apparent digestibilities were determined using Cr as a marker. Feed and fecal Cr values are presented in Appendix table 6. Average daily intakes for all diets are given in Table 5. Individual average intakes for all horses and diets are given in Table 6. Chemical composition of all diets is shown in Table 7. The apparent digestibility of the dietary components for each diet are given in Table 8. Actual daily intakes of all diets for all horses are in Appendix table 7.

Stools for all horses remained relatively normal. There were no chronic signs of diarrhea or greasy stools during the entire study. Some horses did have diarrhea on occasion, but it did not appear to relate to changes in the diet.

During the digestibility experiment there were some problem in the quality of the corn oil and the soy lecithin\corn oil. Some batches of the total mixed rations had to be remixed because of the horses' decreased intakes of these two diets. These problems did affect the average daily intake values presented in Table 6.

The addition of any form of fat significantly affected DM digestibility. The control diet had the highest DM digestibility at 64.53%. The SL\SO diet DM was the least

Table 5. Average daily intakes of diets during digestibility and behavior experiments (as fed)

Diet*	**Intake, g/day**
CONTROL	5689
CO	4455
SL\CO	4667
SL\SO	5409

*CONTROL = control diet; CO = corn oil containing diet; SL\CO = soy lecithin\corn oil containing diet; SL\SO = soy lecithin\soy oil containing diet.

Table 6. Average daily intakes of individual diets by each horse

Horse	Diet*	Intake, g/day
A	CONTROL	7235
	CO	5246
	SL\CO	4436
	SL\SO	5499
B	CONTROL	6993
	CO	2717
	SL\CO	5875
	SL\SO	5996
C	CONTROL	3243
	CO	2559
	SL\CO	3882
	SL\SO	5155
D	CONTROL	5357
	CO	4404
	SL\CO	4395
	SL\SO	4311
E	CONTROL	6863
	CO	5404
	SL\CO	4395
	SL\SO	5615
F	CONTROL	3897
	CO	5914
	SL\CO	4507
	SL\SO	6320
G	CONTROL	6270
	CO	4940
	SL\CO	5063
	SL\SO	4965

*CONTROL = control diet; CO = corn oil containing diet; SL\CO = soy lecithin\corn oil containing diet; SL\SO = soy lecithin\soy oil containing diet.

Table 7. Chemical composition of digestibility and behavior experiment diets*

Item	CONTROL	CO	SL\CO	SL\SO
Dry matter, %	89.09	91.31	91.48	91.54
Composition of dry matter, %				
Crude protein	11.30	10.52	10.45	10.52
Fat (ether extract)	2.58	9.95	10.22	10.08
Acid detergent fiber	27.61	26.68	27.38	27.82
Ash	7.11	6.69	6.71	6.86
Ca	.3960	.3970	.3761	.4369
P	.3025	.2565	.2951	.3267
K	.8677	.9539	.8370	.9255
Mg	.0500	.0450	.0480	.0480
Na	.0475	.0484	.0420	.0426
Zn	.0031	.0030	.0031	.0035
Cu	.0014	.0014	.0014	.0014
DE, Mcal/kg,				
Estimated from NRC (1989)	2.3	2.89	2.89	2.89
Calculated[a]	2.66	2.81	2.99	2.88

[a]Please see Appendix 1.

*CONTROL = control diet; CO = corn oil containing diet; SL\CO = soy lecithin\corn oil containing diet; SL\SO = soy lecithin\soy oil containing diet.

Table 8. Apparent digestibilities of diet* components

Component	CONTROL	CO	SL\CO	SL\SO
Dry Matter(%)	64.53[a]	53.45[b]	53.91[b]	53.26[b]
Crude Protein(%)	73.81[c]	63.30[d]	53.77[d]	65.21[d]
Acid Detergent Fiber(%)	80.50[e]	76.31[f]	79.14[e,f]	77.06[e,f]
Ether Extract(%)	65.30[g]	82.48[h]	80.37[h]	84.29[h]
Ash(%)	68.14	65.16	72.02	68.94

*CONTROL = control diet; CO = corn oil containing diet; SL\CO = soy lecithin\corn oil containing diet; SL\SO = soy lecithin\soy oil containing diet.

Values with different letters are significantly different.
a,b $P<.0001$
c,d $P<.0002$
e,f $P<.08$
g,h $P<.0001$

digestible at 53.26% (P=.0001) and the other two diets had similar DM digestibilities (CO=53.45% and SL\CO=53.91%). These results are the opposite of those found by Rich (1980); in her study, corn oil increased the DM digestibility of a similar diet. This difference could be due to the sampling technique, the laboratory analysis, the horses, or the diets. However, Li et al. (1990) observed a decrease in DM digestibility in swine when fat was added to the diet. Cera et al.(1988) also observed a decreased DM digestibility when corn oil was added to the diets of weanling pigs. Overland et al.(1994) and Jenkins (1990) observed no effect on DM digestibility when lecithin was added to the diets of either pigs or cattle.

There were some differences among ADF digestibilities of the diets. The control diet had the highest digestibility (80.50%) and the CO diet had the lowest ADF digestibility (76.31%). The SL\CO and SL\SO diets had similar digestibilities (79.14% and 77.06%, respectively). The control diet ADF was more digestible (P=.08) than the CO diet, but it was not much higher than the SL\CO or SL\SO diets. There were no differences (P=.28) between the two lecithin-containing diets. Jenkins et al. (1989) also observed a decrease in ADF digestibility between a diet containing only corn oil and a diet containing added lecithin with the lecithin appearing to improve ADF digestibility. However, Overland et al. (1994) and Jenkins (1990) did not show a change in fiber digestibility with the addition of lecithin to swine or cattle diets, respectively.

Crude protein digestibility was also lower and similar in diets containing added fat. Digestibility of CP in the SL\CO diet was 53.77%, in the CO diet it was 63.30%, and in the SL\SO diet it was 65.21%. The control diet had a crude protein digestibility of 73.81% and was higher than the other three diets (P=.0002). Jenkins et al. (1989) had similar results in sheep diets. When lecithin or corn oil was added to the diet, there was a larger decrease in crude protein digestibility for the lecithin-containing diet. It could be that the added fat may not affect digestion of the diet components as much as it decreases the absorption of nutrients. Fat may coat the digestive tract, therefore decreasing the amount of available lumen for absorption.

The apparent digestibility of EE was improved with the addition of any of the three fats. However, true ether extract digestibility was not affected as much (Table 9). All three were higher (P=.0001) than the control diet. Ether extract digestibility was 65.30% in the control diet. For the SL\CO, CO, and SL\SO diets the ether extract digestibilities were 80.37%, 82.48%, and 84.29%, respectively. Increased ether extract digestibility when fat was added to the diet of horses was also observed by

Table 9. Apparent vs true ether extract digestibility

Diet*	Apparent digestibility(%)	True digestibility(%)[a]
CONTROL	65.30	90.28
CO	82.48	63.69
SL\CO	80.37	62.94
SL\SO	84.29	68.71

*CONTROL = control diet; CO = corn oil containing diet; SL\CO = soy lecithin\corn oil containing diet; SL\SO = soy lecithin\soy oil containing diet.

[a]Calculated by the equation (Bryant, 1969):

$$TDF = 100 - 100\{[(FI + EFF) - TFF)]/(FI + EFF)\}$$

where TDF = true digested fat, FI = fat intake in feed, TFF = total fecal fat, EFF = endogenous fecal fat = .07 + .0321(fecal DM))

Rich (1980) and Bowman (1977). Similar improvements on ether extract digestibility have been observed in swine (Jones et al., 1992), sheep (Jenkins et al., 1989) and poultry (Polin, 1980).

Improved apparent EE digestibility is a result of the higher overall amount of fat in the diet and could also be attributed to the added fat sources being more digestible than the fat that is an inherent part of the diet components. However, true EE digestibility did not improve as much (Table 9). When calculating true digestibility, the control diet fat was very digestible (90.28%). The EE digestibility for the other three diets ranged from 62.94% (SL\CO) to 68.71% (SL\SO). From this, it appears that the lecithins may not be as digestible as the fat that is a natural part of the diet ingredients.

There was no effect (P=.78) of added fat on ash digestibility. Ash digestibility for the control diet was 68.14%. For the CO diet the digestibility was 65.16% which was lower (P=.09) than the lecithin-containing diets. Percent ash digestibility for the SL\CO and SL\SO diets was 72.02% and 68.94% (P=.47).

Digestible energy (DE) determinations (Table 7) were quite similar when estimated from the NRC and when calculated as in Appendix 1. This indicates that either method could be used to estimate DE in a diet and would give reliable results. A relatively simple method of determining nonstructural carbohydrates (NSC) or soluble carbohydrates would be useful if there were concerns that too much carbohydrate was being fed to a horse. With these methods, carbohydrate in the diet can be estimated and compared to other diets.

Weight changes for the horses were minimal throughout the study. The younger horses that were still maturing gained the most weight. Weight losses were observed when fat palatability was a problem. Weekly weights for horses are in Appendix table 3.

Behavior Experiments

Results from the pedometer and penetrometer experiments were suggestive by not conclusive. Weather and changes in season during the study could have contributed to this. There did not appear to be a correlation between breed, age, or response to any of the behavior tests. With the pedometers, there was a trend for 5 of the 7 horses to be more active on the control diet (Table 10). When on the SL\CO diet, there was a decrease (P=.0156) in spontaneous activity compared to when the horses were on the control diet. There was also a trend for horses on the control diet to require less pressure to respond to the penetrometer

Table 10. Spontaneous activity - Pedometer, miles/5 days

DIET*	HORSE						
	A	B	C	D	E	F	G
CONTROL	52	40	23	37	28	18	27
CO	29(-)	19(-)	23(-)	37	13(-)	29(+)	33(+)
SL\CO	28(-)	25(-)	22(-)	32(-)	24(-)	17(-)	22(-)
SL\SO	17(-)	34(-)	40(+)	22(-)	21(-)	34(+)	39(+)

*CONTROL = control diet; CO = corn oil containing diet; SL\CO = soy lecithin\corn oil containing diet; SL\SO = soy lecithin\soy oil containing diet.

CONTROL vs CO: P=0.125
CONTROL vs SL\CO: P=0.0156
CONTROL vs SL\SO: P=0.125

(Table 11). The amount of pressure required was higher (P=.0625) when horses were on the CO diet.

In the reactivity tests, when horses were consuming the control diet, they tended to receive higher subjective evaluation scores on the reactivity tests than when consuming the fat-containing diets (Table 12). Differences due to diet were found when the umbrella was the stimulus. For the SL\SO diet there was a lower score (P=.0625) for the horses than when they were fed the control diet. The can of coins tended to startle the animals about the same amount no matter what diet they were consuming. Comparison of walking times with or without stimulus were inconclusive (Table 13), as some animals would rush when stimulated while others would freeze in place.

The studies of spontaneous activity and reactivity give only one result with P<.05 but nine of fifteen results had P<.125 (Tables 10, 11 and 12). Collectively these results suggest, albeit mildly, that the fat supplemented diets reduced excitability. With a larger number of animals, greater differences may have been shown among diets. The inconclusiveness of the results could also be due to breed variability. With a group of horses of the same breed, more consistent responses may be seen. It is possible that more sophisticated techniques may be needed to evaluate

Table 11. Penetrometer pressure, kg

FLANK

DIET*	HORSE						
	A	B	C	D	E	F	G
CONTROL	7.3	3.4	6.8	8.8	4.5	10.0	5.1
CO	6.7(-)	12.5(+)	7.5(+)	12.5(+)	12.5(+)	8.6(-)	8.8(+)
SL\CO	7.8(+)	6.8(+)	5.8(-)	6.4(-)	8.0(+)	7.4(-)	7.8(+)
SL\SO	4.3(-)	7.4(+)	4.2(-)	12.0(+)	11.0(+)	4.2(-)	5.1

CONTROL vs CO: P=0.0625
CONTROL vs SL\CO: P=0.125
CONTROL vs SL\SO: P=0.25

HEAD

DIET*	HORSE						
	A	B	C	D	E	F	G
CONTROL	1.5	1.1	1.4	1.7	2.6	2.4	0.6
CO	2.1(+)	0.8(-)	1.2(-)	0.9(-)	2.4(-)	3.9(+)	2.7(+)
SL\CO	3.0(+)	1.1	1.5(+)	1.4(-)	1.7(-)	2.8(+)	2.0(+)
SL\SO	1.5	1.0(-)	1.8(+)	2.0(+)	1.5(-)	1.6(-)	2.5(+)

CONTROL vs CO: P=0.25
CONTROL vs SL\CO: P=0.125
CONTROL vs SL\SO: P=0.25

*CONTROL = control diet; CO = corn oil containing diet; SL\CO = soy lecithin\corn oil containing diet; SL\SO = soy lecithin\soy oil containing diet.

Table 12. Reactivity test scores

UMBRELLA

DIET*	HORSE						
	A	B	C	D	E	F	G
CONTROL	3	2	1.5	2.5	3	2	1
CO	1(-)	1.5(-)	3(+)	2.5	2(-)	1(-)	1
SL\CO	1.5(-)	3(+)	1(-)	3.5(+)	1(-)	2	1.5(+)
SL\SO	1.5(-)	1(-)	1(-)	3(+)	2(-)	1(-)	1.5(+)

CONTROL vs CO: P=0.125
CONTROL vs SL\CO: P=0.25
CONTROL vs SL\SO: P=0.0625

CAN WITH COINS

DIET*	HORSE						
	A	B	C	D	E	F	G
CONTROL	1	4	1.5	4	5	3	3.5
CO	2(+)	2(-)	1.5	5(+)	3.5(-)	5(+)	1.5(-)
SL\CO	1.5(+)	4.5(+)	1(-)	4	3(-)	1.5(-)	2(-)
SL\SO	2.5(+)	4.5(+)	3(+)	4	4(-)	3	3.5

CONTROL vs CO: P=0.25
CONTROL vs SL\CO: P=0.125
CONTROL vs SL\SO: P=1.00

*CONTROL = control diet; CO = corn oil containing diet; SL\CO = soy lecithin\corn oil containing diet; SL\SO = soy lecithin\soy oil containing diet.

Table 13. Time changes during reactivity tests (seconds)

Horse	Diet*	Umbrella	Stimulus Can with Coins
A	CONTROL	+2	+1
	CO	0	+1
	SL\CO	0	0
	SL\SO	+1	0
B	CONTROL	+1	+2
	CO	0	+1
	SL\CO	0	+4
	SL\SO	0	0
C	CONTROL	+1	0
	CO	0	+1
	SL\CO	0	-1
	SL\SO	0	0
D	CONTROL	+1	0
	CO	+1	+1
	SL\CO	0	-1
	SL\SO	0	-1
E	CONTROL	+1	-2
	CO	0	0
	SL\CO	0	0
	SL\SO	+1	-1
F	CONTROL	+1	0
	CO	-1	+7
	SL\CO	-1	0
	SL\SO	+2	-1
G	CONTROL	0	0
	CO	+1	+7
	SL\CO	0	+1
	SL\SO	0	-1

*CONTROL = control diet; CO = corn oil containing diet; SL\CO = soy lecithin\corn oil containing diet; SL\SO = soy lecithin\soy oil containing diet.

tractability - such as changes in blood pressure or heart rate, or changes in catecholamine levels in the blood.

Summary

The acceptability and digestibility of mixtures containing added lecithin were studied in horses. For acceptability, four diets containing 10% added fat were offered to eight horses in a cafeteria-style study. The fats were as follows: corn oil, soy lecithin\corn oil, soy lecithin\corn oil\soy oil, and soy lecithin\soy oil. When ranked in order of preference, the corn oil diet was the most preferred. The other three diets were preferred in the following order: soy lecithin\corn oil, soy lecithin\corn oil\soy oil, and soy lecithin\soy oil. Preference was correlated positively to the corn oil content of the diet in the palatability trials.

In the digestibility experiment, four total mixed rations containing 10% added fat were fed to eight horses in a 4 x 4 Latin square design. One horse was removed because of refusal to consume one of the diets. The control diet had higher (P=.0001) dry matter digestibility than any of the other three diets. The two lecithin containing diets had slightly higher fiber digestibility compared to the corn oil diet. The control diet had higher (P=.0002) crude protein digestibility than the other diets. Apparent digestibility of fat was higher (P=.0001) in the three fat-containing diets compared to the control.

Behavior tests were conducted during the last week of each of the four digestibility trials. Spontaneous activity was recorded for five days by a pedometer strapped to the left forepastern of each horse. When compared to the control diet, horses on the SL\CO diet exhibited less spontaneous activity (P=.0156). Although not significant, horses on the CO and SL\SO diet also had less spontaneous activity. When pressure was applied to each horse by a penetrometer on the flank or directly in front of the jaw, slightly more pressure was required to get a reaction (movement away from the pressure) when the horses were on the fat containing diets. Horses were also scored on their reaction to two different stimuli: an opening umbrella and a shaken can of coins. Horses on the SL\SO diet were less reactive (P=.0625) to the opening umbrella than when they were consuming the control diet. Although not significant, there were similar trends towards being less reactive when horses were on the other fat-containing diets.

Implications

The use of lecithin-containing diets is a viable alternative for owners trying to increase the energy density of their horses' diet although the lower DM and CP digestibilities may need to be compensated for by including a more digestible source of protein in the diet. These diets would be accepted by the horses and would be especially beneficial for endurance horses and race horses, where excess fiber and water in the G.I. tract is undesirable. Although never documented before, high fat diets have been implicated by several people as a means to decrease excitability in horses. The lecithin containing diets used in this study also appear to make horses more tractable. Less excitable horses would be beneficial in events such as dressage or even for the backyard pleasure rider.

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APPENDIX

Appendix 1. Estimates of soluble carbohydrates and digestible energy

Average values for each diet were used to estimate the digestible energy (DE) and apparent digestibility of energy. DE is usually defined by the following equation:

$$DE = GE - FE$$

where GE is the gross feed energy and FE is the gross fecal energy (Cheeke, 1991). Gross energy may be determined directly in feed and feces by bomb calorimetry. Alternatively, it may be calculated from proximate analysis for protein, fiber, fat, and carbohydrate.

Only measures of relatively indigestible or structural carbohydrates are included in proximate analysis, crude fiber (CF) in the Weende method, and acid detergent fiber (ADF) and neutral detergent fiber (NDF) in the Van Soest system (Van Soest, 1967). Soluble carbohydrate is obtained by difference:

$$NFE = 100 - (CP + ASH + EE + CF)$$

$$NSC = 100 - (CP + ASH + EE + NDF)$$

where NFE = nitrogen free extract, NSC = nonstructural carbohydrates, CP = crude protein and EE = ether extract.

The Virginia Tech DHIA Laboratory routinely analyzes for ADF instead of NDF or CF. Equations that predict NDF and CF from ADF have been derived using tabulated data (NRC,

1989) for hays (timothy and orchardgrass) and grains (corn, oats, wheat, barley, and soybean meal). The graphs are shown in Figures 5 and 6. The regression equations are as follows:

Timothy Hay (6 samples)

$CF = 23.72 + .287(ADF) \quad r^2 = .9083$

$NDF = 24.23 + 1.08(ADF) \quad r^2 = .9719$

Orchardgrass Hay (4 samples)

$CF = 11.98 + .642(ADF) \quad r^2 = .8078$

$NDF = 17.62 + 1.21(ADF) \quad r^2 = .7446$

Grains (6 samples)

$CF = -.59 + .789(ADF) \quad r^2 = .9936$

$NDF = 5.32 + 1.32(ADF) \quad r^2 = .7256$

These equations were used to determine NDF (from ADF), hence NSC, of the diets and feces by difference. Estimated fecal NSC approximated zero, so the digestibilities of NSC approached 100% for all diets. The GE of each diet was estimated by multiplying the percentages of each nutrient by standard GE densities.

$$GE(kcal/gDM) = 9.4(EE) + 5.65(CP) + 4.15(NDF) + 4.15(NSC)$$

Apparent digestibility of nutrients (Table 8) were multiplied by the standardized GE densities to give estimates of DE densities for each nutrient. Then, DE values were multiplied by the percent of each nutrient in the feed to give DE of the diet (kcal/100g DM) (Appendix tables 8, 9, 10, 11). Now the DE of the diet divided by the GE of the diet yields an estimate of digestibility of energy (Appendix tables 8, 9, 10, 11).

These estimated DE values were compared with DE values calculated from tabulated data (NRC, 1989). For example, if corn is 10% of the diet, the DE value of 3.49(DM) would be multiplied by .1 and would indicate that corn supplies .349 Mcal DE/kg in the diet.

For the control diet, the calculated DE value (NRC, 1989) was slightly lower than that estimated from the present data, 2.30 and 2.66 Mcal/kg DM, respectively. Even closer agreement between calculated (NRC, 1989) and estimated DE (Appendix tables 9, 10, 11) was found for the fat containing diets. Calculated DE for the fat containing diets was 2.89 Mcal/kg DM (NRC, 1989). Estimated values were 2.81 Mcal/kg DM (CO), 2.99 Mcal/kg DM (SL\CO), and 2.88 Mcal/kg DM (SL\SO), One interesting note is that the SL\CO diet had the highest calculated DE, 3.01 Mcal/kg DM, and the highest apparent energy digestibility (65.47%) (Appendix table 10). This would indicate that the SL\CO diet would be an easily digested diet for exercising horses. A diet very similar to this has been used in equine exercise trials at the Virginia Polytechnic Institute and State University.

Appendix table 1. Fatty acid and phosphatide composition of fats* used in the experiments

Item	CO	SO	SL\CO	SL\CO\SO	SL\SO
Fatty acids % (relative composition)					
Palmitic(16:0)	18.0	14.0	13.4	11.8	11.6
Palmitoleic(16:1)	-	-	0.1	-	-
Stearic(18:0)	3.0	6.0	3.4	4.1	2.8
Oleic(18:1)	28.0	23.0	21.3	21.3	23.0
Linoleic(18:2)	50.0	48.0	57.4	53.4	56.0
Linolenic(18:3)	-	9.0	1.9	7.3	4.3
Arachidonic(20:0)	-	-	0.1	-	-
Phosphatides (gm per 100 gm product)					
Total phosphatides (acetone insoluble)			31.5	30.8	31.4
Phosphatidylcholine			7.8	8.1	7.3
Phosphatidylethanolamine			6.3	1.5	5.0
Phosphatidylinositol			5.0	8.3	6.7
Other phosphatides (including phosphatidic acid), sterols, sugars, etc. - by difference			12.4	12.9	12.4
Soybean oil			18.0	33.0	50.0
Corn oil			50.0	33.0	-

*CO = corn oil; SO = soy oil; SL\CO = soy lecithin\corn oil; SL\CO\SO = soy lecithin\corn oil\soy oil; SL\SO = soy lecithin\soy oil

Analysis conducted by: Ulrike Pfeiffer, Lucas Meyer, Hamburg, Germany; Bob Pavlak, Lucas Meyer, Decatur, Illinois; David Sklan, Hebrew University, Rehovot, Israel.

Appendix table 2. Arrangement of Latin squares

Latin Square 1. (Four heaviest horses)

		HORSE NUMBER			
		*	F	A	B
TRIAL NUMBER	1	SL\CO	SL\SO	CTL	CO
	2	SL\SO	CTL	CO	SL\CO
	3	CO	SL\CO	SL\SO	CTL
	4	CTL	CO	SL\CO	SL\SO

Latin Square 2. (Four lightest horses)

		HORSE NUMBER			
		D	E	C	G
TRIAL NUMBER	1	SL\CO	SL\SO	CO	CTL
	2	SL\SO	CO	CTL	SL\CO
	3	CO	CTL	SL\CO	SL\SO
	4	CTL	SL\CO	SL\SO	CO

Letters refer to diets as follows:

CTL - Control Diet (no added fat)
CO - Corn Oil
SL\CO - Soy Lecithin\Corn Oil
SL\SO - Soy Lecithin\Soybean Oil

*Horse dropped from digestibility and behavior experiments

Appendix table 3. Weekly weights (kg)

ACCEPTABILITY EXPERIMENT

Date Weighed	Horse A	B	C	D	E	F	G	H
1/27/92	373	411	434	369	397	391	410	320
2/3/92	381	406	435	375	398	386	406	327
2/10/92	384	410	427	375	395	389	408	330

DIGESTIBILITY AND BEHAVIOR EXPERIMENTS

Date Weighed	Horse A	B	C	D	E	F	G
3/2/92	410	439	369	398	380	457	330
3/9/92	402	425	370	386	381	448	320
3/16/92	393	418	357	380	379	442	320
3/23/92	395	393	345	381	382	444	324
3/30/92	391	380	330	380	381	445	323
4/6/92	389	394	323	370	381	426	323
4/13/92	393	399	325	373	390	426	323
4/20/92	384	402	329	370	382	427	324
4/27/92	386	407	339	372	394	432	323
5/4/92	392	407	339	369	392	435	324
5/11/92	386	410	325	366	393	404	327
5/18/92	379	412	331	374	384	422	328
5/25/92	383	415	332	377	393	432	323
6/1/92	385	420	337	382	395	436	325

Appendix table 4. Behavior study observation scale

Score	Description
1	The horse shows no reaction or interest in the stimulus.
2	The horse looks in the direction of the stimulus but has no other reaction.
3	The horse jumps when the stimulus is applied but does not try to run away.
4	The horse jumps away from the stimulus and tries to leave.
5	The horse completely loses control and tries to flee or refuses to move from the spot (is frozen in place due to fear).

Appendix table 5. Daily intakes of individual concentrates by each horse - acceptability experiment (grams per day)

Corn oil diet

Date	Horse A	B	C	D	E	F	G	H
1/24/92	1149	1461	696	921	1261	1003	922	1734
1/25/92	799	1981	1020	1662	1374	1188	1144	1702
1/26/92	1464	2474	940	1192	1309	1780	1416	2466
1/27/92	1073	2122	1806	1644	1982	2486	1941	2908
1/28/92	1229	2963	1009	1448	906	1906	2494	3462
1/29/92	1531	2583	447	1851	1469	1575	2893	3462
1/30/92	1940	2981	1528	1752	1992	1846	2126	3472
AVERAGE	**1312**	**2366**	**1064**	**1496**	**1470**	**1683**	**1848**	**2749**

Soy lecithin\corn oil\soy oil diet

Date	Horse A	B	C	D	E	F	G	H
1/24/92	67	65	18	-66	4	-5	-32	-34
1/25/92	904	430	106	-26	4	-7	15	124
1/26/92	884	226	22	-7	-6	-5	74	410
1/27/92	1458	-9	40	-7	8	3	993	21
1/28/92	18	50	397	-88	-60	-2	171	-11
1/29/92	1	118	491	21	-7	0	373	51
1/30/92	944	165	265	-85	6	54	-37	2
1/31/92	955	656	244	0	582	-4	255	44
2/1/92	1108	997	599	137	814	395	640	385
2/2/92	1005	1118	786	0	908	837	781	987
2/3/92	1184	1480	794	635	1198	1153	999	1180
2/4/92	1199	1789	788	883	1486	1357	988	1447
2/5/92	187	1961	592	978	1487	1008	1423	1756
2/6/92	116	2086	627	892	1444	966	1226	1284
2/7/92	21	1605	614	917	1582	1133	1367	1467
2/8/92	275	1766	869	734	1583	1047	1323	1648
2/9/92	254	1527	577	361	1780	745	975	1956
2/10/92	528	1777	852	614	1968	982	1158	2121
2/11/92	104	1923	808	349	917	388	1268	1542
2/12/92	122	1977	783	969	1531	623	877	1824
2/13/92	454	1798	937	970	1774	902	1160	1895
AVERAGE								
WEEK1	**611**	**149**	**191**	**-37**	**-7**	**5**	**222**	**80**
WEEK2,3	**537**	**1604**	**705**	**583**	**1361**	**823**	**1031**	**1395**

Appendix table 5. (cont.)

Soy lecithin\corn oil diet

Date	Horse A	B	C	D	E	F	G	H
1/24/92	37	125	17	18	14	2	34	-4
1/25/92	66	285	38	43	-12	-8	48	41
1/26/92	18	1774	31	4	4	9	111	175
1/27/92	25	28	228	10	10	7	496	8
1/28/92	1808	225	44	20	-5	-1	54	0
1/29/92	472	27	268	-13	-4	-9	459	73
1/30/92	721	245	435	0	0	0	-10	108
1/31/92	1064	1091	540	38	130	517	765	402
2/1/92	1079	1090	743	67	974	978	679	991
2/2/92	1390	1464	1139	926	1183	1136	724	1182
2/3/92	1487	1782	1282	554	1499	1420	992	1488
2/4/92	1460	1978	1588	874	1123	1362	865	1743
2/5/92	1762	2262	897	1254	1795	954	1400	1937
2/6/92	1891	2364	1204	983	1979	808	1555	2217
2/7/92	1800	2292	1488	763	1148	899	1490	2443
2/8/92	1647	1371	1468	765	1497	1033	771	1646
2/9/92	1584	1259	1029	-8	627	664	193	1479
2/10/92	1405	1748	1206	43	1160	847	1415	845
2/11/92	1388	1882	1341	581	1387	1135	1307	1737
2/12/92	1262	1687	1183	615	1390	1070	1264	1352
2/13/92	1710	1927	1371	925	1448	545	1242	1792
AVERAGE								
WEEK1	**450**	**387**	**152**	**12**	**1**	**0**	**170**	**57**
WEEK2,3	**1494**	**1724**	**1177**	**599**	**1239**	**954**	**1112**	**1518**

Soy lecithin\soy oil diet

Date	Horse A	B	C	D	E	F	G	H
1/24/92	380	384	22	1	3	5	44	-6
1/25/92	53	236	-13	-33	-8	-9	8	174
1/26/92	11	126	43	6	-5	-23	217	162
1/27/92	3	122	200	82	2	65	488	52
1/28/92	-1	28	30	14	-3	-2	60	1
1/29/92	240	448	-8	10	-12	-19	-19	196
1/30/92	0	96	238	-18	0	-12	38	77
1/31/92	951	80	556	1013	68	-4	141	468
2/1/92	712	984	551	1148	968	5	16	971
2/2/92	843	719	828	349	429	827	322	1156
2/3/92	828	967	606	859	1000	967	103	1304
2/4/92	887	1184	742	652	543	515	705	903

Appendix table 5. (cont.)

Soy lecithin\soy oil diet

Date	Horse							
	A	B	C	D	E	F	G	H
2/5/92	1142	1415	377	677	228	131	626	219
2/6/92	1357	1646	393	677	509	576	281	480
2/7/92	1440	585	524	484	35	562	590	35
2/8/92	1133	217	547	186	19	496	481	448
2/9/92	1524	503	442	335	666	606	182	777
2/10/92	1636	921	546	91	925	901	441	948
2/11/92	1518	1133	513	243	611	1008	91	1149
2/12/92	1802	1304	699	497	617	1126	530	1407
2/13/92	1972	1278	852	597	943	1295	813	723
AVERAGE								
WEEK1	**98**	**206**	**73**	**9**	**-3**	**1**	**119**	**94**
WEEK2,3	**1268**	**924**	**584**	**558**	**540**	**644**	**380**	**785**

Appendix table 6. Chromium concentrations in feed and fecal samples

Feed Cr concentration (ppm)

Diet*	Period 1	Period 2	Period 3	Period 4
CONTROL	2125	1850	2150	2375
CO	2700	3150	3325	2700
SL\CO	2550	3400	3000	2850
SL\SO	2625	3600	3025	3800

Fecal Cr concentration (ppm)

Diet	Horse	Period	Cr value
CONTROL	A	1	6300
	B	3	5900
	C	2	4900
	D	4	8200
	E	3	6200
	F	2	4150
	G	1	6450
CO	A	2	6000
	B	1	3150
	C	1	6500
	D	3	8500
	E	2	5600
	F	4	6650
	G	4	6100
SL\CO	A	4	6650
	B	2	5900
	C	3	3350
	D	1	6500
	E	4	6550
	F	3	4150
	G	2	7200
SL\SO	A	3	6900
	B	4	6650
	C	4	7950
	D	2	8200
	E	1	6500
	F	1	5650
	G	3	6350

Appendix table 7. Daily intakes of individual diets by each horse - digestibility and behavior experiments (grams per day)

Control diet

Day Number	Horse\Trial Number A\1	B\3	C\2	D\4	E\3	F\2	G\1
1	3761	6781	4152	5380	5886	3184	3239
2	7522	7552	2613	5380	6431	2156	6478
3	7522	7552	2926	5380	7292	5908	6478
4	7522	7552	3330	5380	7292	1342	6478
5	7470	7552	2994	5380	7292	2731	6413
6	7418	7552	3167	5433	7292	2330	6348
7	7418	7585	3989	5486	7370	3157	6348
8	7418	7618	4002	5486	7448	3070	6348
9	7418	5809	3383	5486	5724	3925	6348
10	7418	5809	2907	5486	5724	4460	6348
11	7418	5809	2653	5486	5724	4260	6348
12	7359	5809	3129	5486	5724	4039	6348
13	7300	7622	3016	5486	6681	3987	6348
14	7300	7626	1900	5506	6672	2687	6348
15	7300	7626	3017	5526	7430	4399	6348
16	7300	7626	2521	5526	7430	3957	6348
17	7300	7626	2758	5526	7430	4226	6348
18	7300	7626	3332	5526	7430	4466	6348
19	7313	7626	4274	5526	7430	6848	6374
20	7326	7626	4800	5526	7430	6854	6400
21	7326	6865		5526	6677		6400
22	7326			5526			6400
23	7326			2763			6400
24	7326						6400
25	7326						6400
26	7300						6393
27	7274						6386
28	7274						6386
AVERAGE	**7235**	**7183**	**3243**	**5357**	**6848**	**3897**	**6053**

Corn oil diet

Day Number	Horse\Trial Number A\2	B\1	C\1	D\3	E\2	F\4	G\4
1	5788	3192	2829	4327	5782	5866	5064
2	5788	4395	3747	4328	5782	5866	5064
3	5788	990	1573	4326	5782	5866	5064
4	5788	1992	1870	4326	5782	5866	5064
5	5764	1807	1999	4326	5787	5866	5064
6	5740	2712	2718	4326	5792	5957	5068

Appendix table 7. (cont.)

Corn oil diet

Day Number	Horse\Trial Number A\2	B\1	C\1	D\3	E\2	F\4	G\4
7	5740	2000	1668	4336	5792	6048	5072
8	5740	6240	5668	4346	5792	6048	5072
9	5740	6240	5668	4346	5792	6048	5072
10	5740	6240	5668	4346	5792	6048	5072
11	5740	6240	5668	5426	5792	6048	5072
12	5761	6203	5601	4346	5839	6048	5072
13	5782	3988	3405	4330	5886	6048	5072
14	5782	918	1547	4314	5886	6100	5047
15	5782	504	86	4314	5886	6152	5022
16	4537	502	1027	4314	5886	6152	5022
17	2807	784	747	4314	3528	6152	5022
18	3891	836	866	4314	3330	6152	5022
19	4039	694	1072	4314	4024	6152	5022
20	3185	789	1171	4314	4146	6152	5022
21		*3665	*3217	4847		6152	5022
22		2155	2735			6152	5022
23		1453	1539			3076	2511
24		1175	772				
25		1166	788				
26		1986	1164				
27		2000	1785				
28		2500	2500				
AVERAGE	**5246**	**2717**	**2559**	**4404**	**5404**	**5914**	**4940**

*Fed new CO diet mix Day 20 PM. No data Day 21 due to human error.

Soy lecithin\corn oil diet

Day Number	Horse\Trial Number A\4	B\2	C\3	D\1	E\4	F\3	G\2
1	3278	5772	5926	2308	2974	6922	5084
2	2050	5722	5254	4616	525	6136	5084
3	-35	5722	5252	4616	750	6134	5084
4	1350	5772	5252	4616	1475	6134	5084
5	1625	5850	5252	4554	680	6134	5070
6	-50*	5928	5252	4492	-710*	6134	5056
7	1000	5928	5304	4492	1000	6161	5056
8	5602	5928	5356	4492	5830	6188	5056
9	5602	5928	4678	4492	5830	5094	5056

*Mixed new SL\CO diet Day 6. Fed Day 6 (evening feeding)

Appendix table 7. (cont.)

Soy lecithin\corn oil diet

Day Number	Horse Number\Trial Number A\4	B\2	C\3	D\1	E\4	F\3	G\2
10	5602	5928	4678	4492	5830	5094	5056
11	5602	5928	5356	4492	5830	6188	5056
12	5602	5954	5356	4461	5830	6188	5056
13	5602	5980	5360	4430	5830	6186	5056
14	5602	5980	4938	4430	5830	6184	5056
15	5623	5748	38	4430	5877	-21	5056
16	5644	5370	1463	4430	5924	569	5056
17	5644	5980	968	4430	5924	1000	5056
18	5644	5980	915	4430	5924	1795	5056
19	5644	5995	625	4435	5924	715	5061
20	5644	6010	617	4440	5924	1775	5066
21	5644		3680	4440	5924	3933	
22	5644			4440	5924		
23	5644			4440	5924		
24	2822			4440	2962		
25				4440			
26				4435			
27				4430			
28				4430			
AVERAGE	**4436**	**5875**	**3705**	**4395**	**4510**	**4507**	**4822**

Soy lecithin\soy oil diet

Day Number	Horse\Trial Number A\3	B\4	C\4	D\2	E\1	F\1	G\3
1	5688	6104	5216	4430	2886	3237	5067
2	5688	6104	5216	4430	5576	6474	5070
3	5114	6104	5216	4430	4792	6474	4297
4	4951	6104	5216	4430	5488	6474	4581
5	4707	6104	5216	4308	5670	6428	4533
6	5248	6112	5248	4186	5782	6382	5066
7	5729	6120	5280	4186	5782	6189	5061
8	5710	6120	5280	4186	5782	6145	5056
9	5710	6120	5280	4186	5782	6382	5056
10	5710	6120	5280	4186	5782	6382	5056
11	5710	6120	5280	4186	5782	6382	5056
12	5710	6120	5280	4271	5772	6350	5056
13	5724	6120	5280	4356	5647	6318	5044
14	5738	6136	5286	4356	5762	6318	5032
15	5738	6152	5292	4356	5762	6318	5032
16	5738	6152	5292	4356	5762	6318	5032

Appendix table 7. (cont.)

Soy lecithin\soy oil diet

Day	Horse\Trial Number						
Number	A\3	B\4	C\4	D\2	E\1	F\1	G\3
17	5738	6152	5292	4356	5762	6318	5032
18	5738	6152	5292	4356	5762	6318	5032
19	5738	6152	5292	4341	5777	6329	5032
20	5738	6152	5292	4326	5792	6340	5032
21	3908	6152	5292		5792	6340	5048
22		6152	5292		5792	6340	
23		3076	2646		5792	6340	
24					5792	6340	
25					5792	6340	
26					5787	6345	
27					5782	6350	
28					5782	5679	
AVERAGE	**5499**	**5746**	**5155**	**4106**	**5615**	**6102**	**4965**

Appendix table 8. Estimate of DE for the control diet.

Diet Component	%	GE of Nutrient (kcal/g)	GE of Diet (kcal/100gDM)	Apparent Digestibility %	DE of Nutrient (kcal/g)	DE of Diet (kcal/100gDM)
EE	2.58	9.4	24.25	65.30	6.14	15.84
CP	11.3	5.65	63.85	73.81	4.17	47.12
NDF	48.94	4.15	203.10	36.06[a]	1.50	73.41
NSC	31.29	4.15	129.85	100.0	4.15	129.85
ASH	7.11	-	-	-	-	-
	100.0		421.06			266.22

[a]NDF apparent digestibility calculated from:
(%NDF in Feed - %NDF in Feces)/%NDF in Feed

GE = 4.21 Mcal/kg DM

DE = 2.66 Mcal/kg DM

Calculated DE from NRC = 2.30 Mcal/kg DM

Apparent digestibility of DE = 266.22/421.06 = 63.23%

Appendix table 9. Estimate of DE for the CO diet.

Diet Component	%	GE of Nutrient (kcal/g)	GE of Diet (kcal/100gDM)	Apparent Digestibility %	DE of Nutrient (kcal/g)	DE of Diet (kcal/100gDM)
EE	9.95	9.4	93.53	80.37	7.55	75.12
CP	10.52	5.65	59.44	53.77	3.04	31.98
NDF	48.43	4.15	200.98	36.07	1.50	72.65
NSC	24.41	4.15	101.30	100.0	4.15	101.30
ASH	6.69	-	-	-	-	-
	100.0		455.25			281.05

[a]NDF apparent digestibility calculated from:
(%NDF in Feed - %NDF in Feces)/%NDF in Feed

GE = 4.55 Mcal/kg DM

DE = 2.81 Mcal/kg DM

Calculated DE from NRC = 2.89 Mcal DE/kg DM

Apparent digestibility of DE = 281.05/455.25 = 61.74%

Appendix table 10. Estimate of DE for the SL\CO diet.

Diet Component	%	GE of Nutrient (kcal/g)	GE of Diet (kcal/100gDM)	Apparent Digestibility %	DE of Nutrient (kcal/g)	DE of Diet (kcal/100gDM)
EE	10.22	9.4	96.07	80.37	7.55	77.16
CP	10.45	5.65	59.04	53.77	5.62	58.73
NDF	49.25	4.15	204.39	32.20	1.34	66.00
NSC	23.37	4.15	96.99	100.0	4.15	96.99
ASH	6.71	-	-	-	-	-
	100.0		456.49			298.88

[a]NDF apparent digestibility calculated from:
(%NDF in Feed - %NDF in Feces)/%NDF in Feed

GE = 4.56 Mcal/kg DM

DE = 2.99 Mcal/kg DM

Calculated DE from NRC = 2.89 Mcal/kg DM

Apparent digestibility of DE = 298.88/456.49 = 65.47%

Appendix table 11. Estimate of DE for the SL\SO diet.

Diet Component	%	GE of Nutrient (kcal/g)	GE of Diet (kcal/100gDM)	Apparent Digestibility %	DE of Nutrient (kcal/g)	DE of Diet (kcal/100gDM)
EE	10.08	9.4	94.75	84.29	7.92	79.83
CP	10.52	5.65	59.44	65.21	3.68	38.71
NDF	49.76	4.15	206.50	36.48	1.51	75.14
NSC	22.78	4.15	94.54	100.0	4.15	94.54
ASH	6.86	-	-	-	-	-
	100.0		455.23			288.22

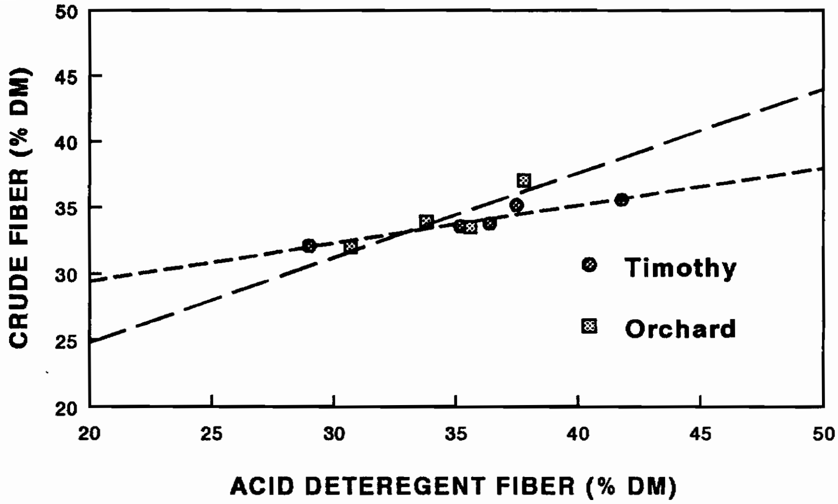
[a]NDF apparent digestibility calculated from:
(%NDF in Feed - %NDF in Feces)/%NDF in Feed

GE = 4.55 Mcal/kg DM

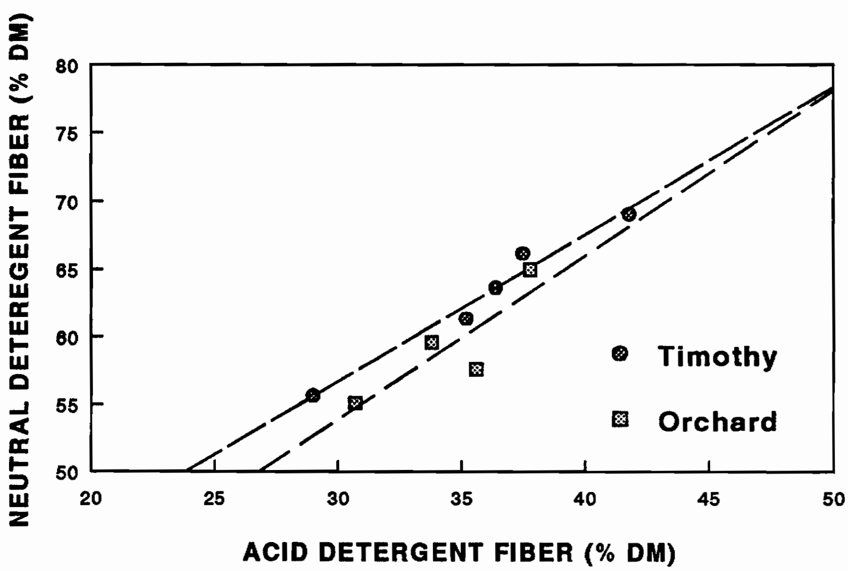
DE = 2.88 Mcal/kg DM

Calculated DE from NRC = 2.89 Mcal/kg DM

Apparent digestibility of DE = 288.22/455.23 = 63.31%

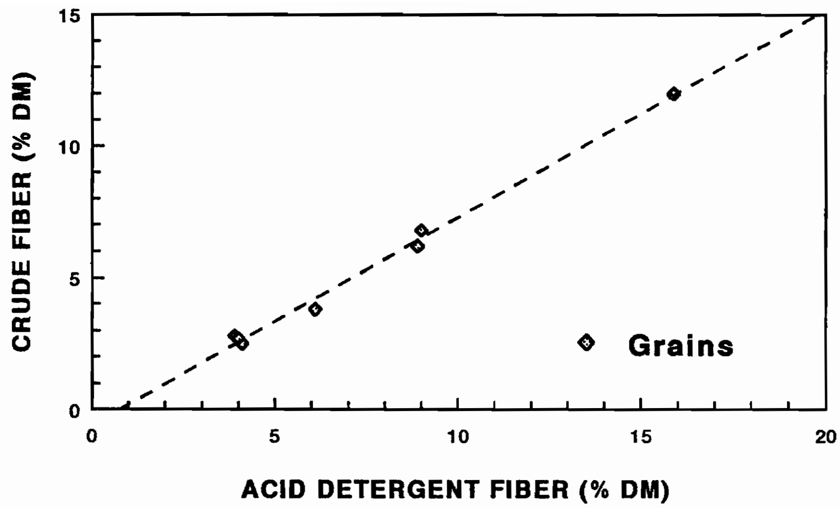


(a)

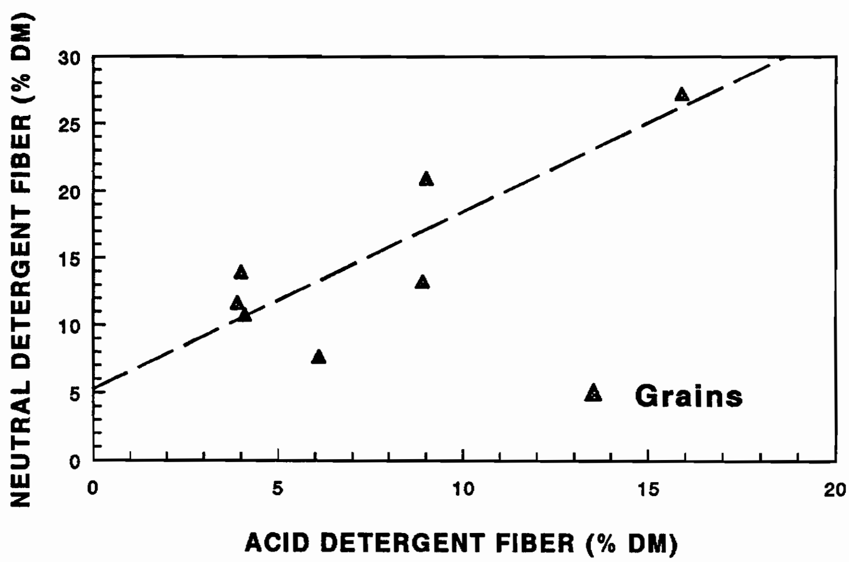


(b)

Figure 5. Linear relationships of forage ADF and CF (a) and forage ADF and NDF (b).



(a)



(b)

Figure 6. Linear relationships of grain ADF and CF (a) and grain ADF and NDF (b).

VITA

Janice Lee Holland, daughter of Richard and Mary Holland, was born December 13, 1968, in Ridgewood, New Jersey. She graduated from Cedar Cliff High School in June 1986. She entered The Pennsylvania State University, State College, Pennsylvania in August 1986. In May 1990 she received her B.S. in Animal Production from Penn State. The author began her graduate study in Animal Science (Equine Nutrition) at Virginia Polytechnic Institute and State University in August 1990.

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