An Abstract of the Thesis of

Rebecca J. Hix for the degree of Masters of Science in Animal Science and Toxicology. Presented on October 29, 1999. Title: Effects of Saponin-containing Extracts on Fat Digestibility, Growth, and Nutrient Availability in Domestic Fowl.

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Dr. Peter R. Cheeke

Numerous properties of *Yucca schidigera and Quillaja saponaria* have been studied with respect to the saponins in the plant. These saponins are present in the extract as well and have been utilized commercially in the food and cosmetic industry for various products. Saponins have detergent-like properties in the presence of water. The detergent-like behavior of saponins plays a major role in their membranolytic properties. In addition, emulsification effects on fat which are characteristic of surfactant-type substances, may occur as well. Three studies were conducted using adult roosters, growing broiler chicks, and growing Japanese quail. Various effects of supplementing *Yucca schidigera* in the diets of these birds were studied such as: growth performance, overall health, and nutrient availability. An additional experiment was conducted comparing effects of *Quillaja saponaria* and *Yucca schidigera* extracts on body weight and fat digestibility in adult roosters.

Addition of *Yucca schidigera* extract to high fat diets (tallow-based) increased lipid excretion in roosters, broilers, and quail. In roosters, dose of yucca extract affected excretion of lipid but no dose effects were seen in broilers or quail. Fat digestibility was not significantly affected by addition of saponins to the diet of adult roosters. However, fat digestibility was reduced in broilers and quail consuming a high fat diet. In general,

level of dietary fat seemed to play a role in the effects of *Yucca schidigera* supplementation in growing birds. Addition of *Yucca schidigera* to high fat diets resulted in decreased plasma levels of vitamin A and E in broiler chicks.

Effects of Saponin-containing Extracts on Fat Digestibility, Growth, and Nutrient Availability in Domestic Fowl

By

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Rebecca J. Hix, Author

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Dedication

This thesis is dedicated to my parents, Bob and Barb Hix, for allowing me the freedom to experience life and for providing me with pride and courage to follow my dreams.

Effects of Saponin-containing Extracts on Fat Digestibility, Growth, and Nutrient Availability in Domestic Fowl

I. Introduction

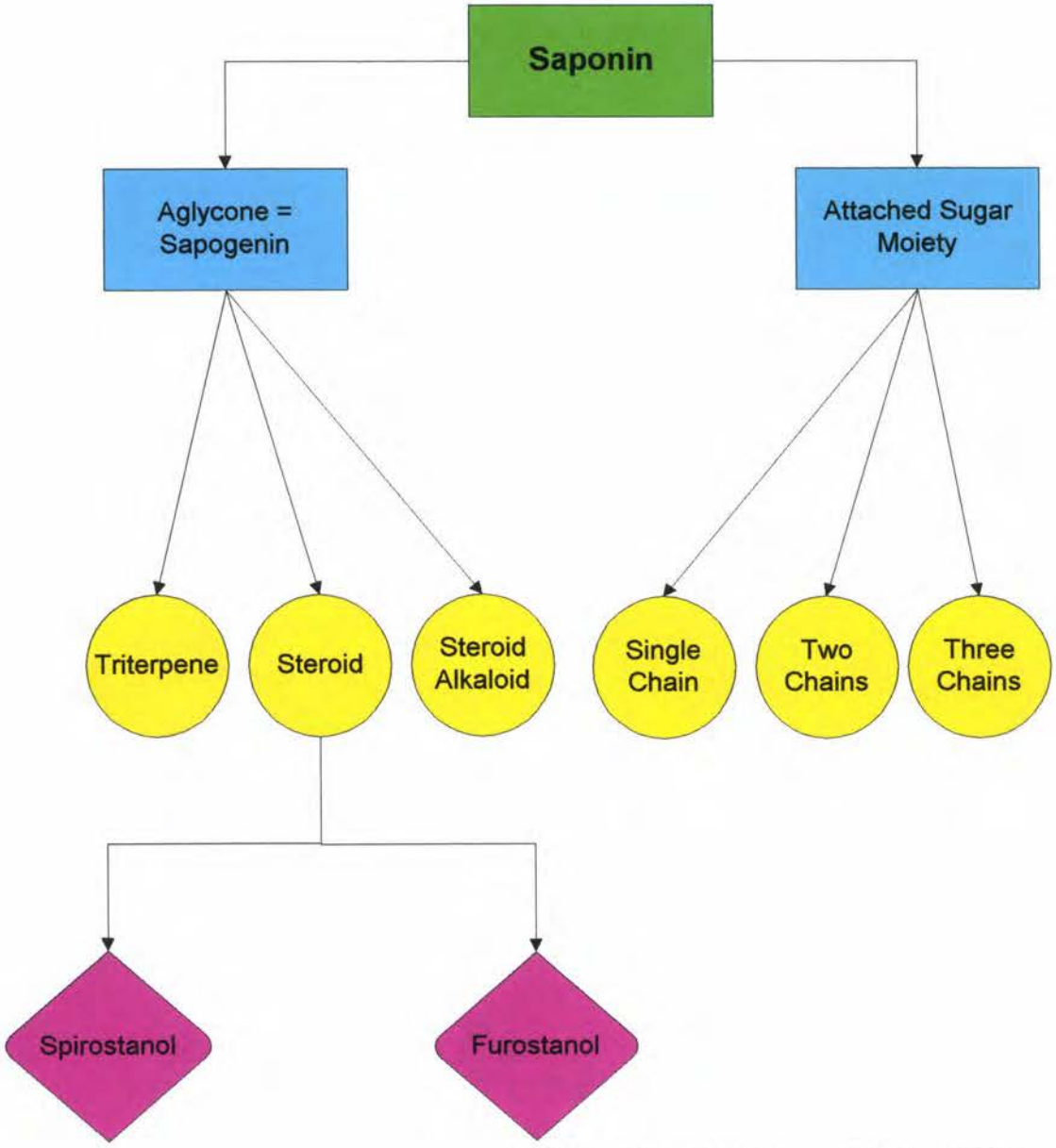
Yucca schidigera, often referred to as Mohave Yucca, is an herbaceous plant that grows in southwestern deserts of North America as well as in parts of Central America. This plant is utilized as the source of *Yucca schidigera* extract. *Quillaja saponaria* is a tree that grows in parts of South America (indigenous to Chile). This plant is used as the source of *Quillaja saponaria* extract. Numerous properties of *Yucca schidigera* and *Quillaja saponaria* have been studied with respect to the saponins in the plant. These saponins are present in the extract as well and have been utilized commercially in the food and cosmetic industry for various products. Saponins exist in many plants that are commonly consumed by humans and they are also abundant in various forages consumed by animals. Saponins are classified as glycosides, being composed of carbohydrate and noncarbohydrate (aglycone) portions (Cheeke, 1971). Saponins have detergent-like properties in the presence of water. These properties exist because the carbohydrate portion of the molecule is water–soluble and the aglycone portion is fat-soluble (Cheeke, 1971). The detergent-like behavior of saponins plays a major role in their membranolytic properties. In addition, emulsification effects on fat which are characteristic of surfactant-type substances, may occur as well.

Some plants contain saponins with a triterpenoid aglycone while others contain steroidal aglycones. *Yucca schidigera* contains saponins belonging to the steroidal class and *Quillaja saponaria* contains saponins with a triterpenoid aglycone. It is important to

realize that when one refers to a **saponin**, specifically, this does not imply that the plant **extract** is being considered. Some plant extracts contain saponins with the actual saponin content being largely unknown. Confusion can result from assuming that activity seen in conjunction with the extract is the same activity exerted by the saponin fraction itself. The effects that are observed from utilizing extracts from *Yucca schidigera* and *Quillaja saponaria* are specific to the extract and not entirely due to the saponins that are present in them. A number of saponins have been identified in *Y. schidigera* but the list remains incomplete. Many saponins have also been identified in *Q. saponaria.* Quillaic acid has been identified as the aglycone of these structures (Price et al. 1987). All of the saponins exhibit similar core chemical structures (steroidal or triterpenoid aglycone) but differ in their attached carbohydrate portions, making each saponin unique. The biological activity of saponins is influenced by the carbohydrate side chain (Cheeke, 1998). Figure 1 shows a schematic diagram of saponins (Hostettman and Marston, 1995).

Desert King International (DKI) is a company that specializes in commercial production of *Yucca schidigera* and *Quillaja saponaria* products. Yucca powders are formed solely by mechanical means and do not involve any chemical extraction. These products are made from the stem of the plant. DK Sarsaponin 30 is the feed grade form of the *Yucca schidigera* extract and contains no preservatives or additives. It has a guaranteed "saponin" content of > 6.0%, reported in the product's technical data sheet made available by DKI. The extract is advertised as an animal feed supplement useful for reducing ammonia levels and enhancing livestock and poultry performance. DKI recommends that the product be incorporated into premixes, basal feed, concentrates, and

Figure 1: Structure of Saponins



Derived from Hostettman and Marston, 1995

complete feeds at 70-120g/ton of finished ration. The suggested usage for broilers, specifically, is 65g/1000kg feed. DK Sarsaponin is also available in a liquid form that contains the pure extract of the plant, as does the powder form. *Quillaja saponaria* extract is commonly used as a foaming agent in the beverage industry and cosmetic industry.

Saponins have been shown to influence nutrient digestion and absorption in a variety of ways. Mechanisms of action involved in these effects are not clearly defined. It has been determined that saponins form insoluble complexes with cholesterol and inhibit the availability of bile salts (Oakenfull, 1986). These interactions may exert effects on micelle formation and thus, impair the absorption of fat and fat-soluble compounds (Jenkins and Atwal, 1994). These trends in saponin behavior prompted the decision to investigate the potential effects that *Yucca schidigera* extract (containing steroidal saponins) might have on the digestibility of fat in three different types of domestic fowl. Three studies were conducted using adult roosters, growing broiler chicks, and growing Japanese quail. Various effects on growth performance, overall health, and nutrient availability in these birds were also examined. An additional experiment was conducted comparing effects of *Quillaja saponaria* and *Yucca schidigera* extracts on body weight and fat digestibility in adult roosters. The results of these studies are summarized in the chapters that follow.

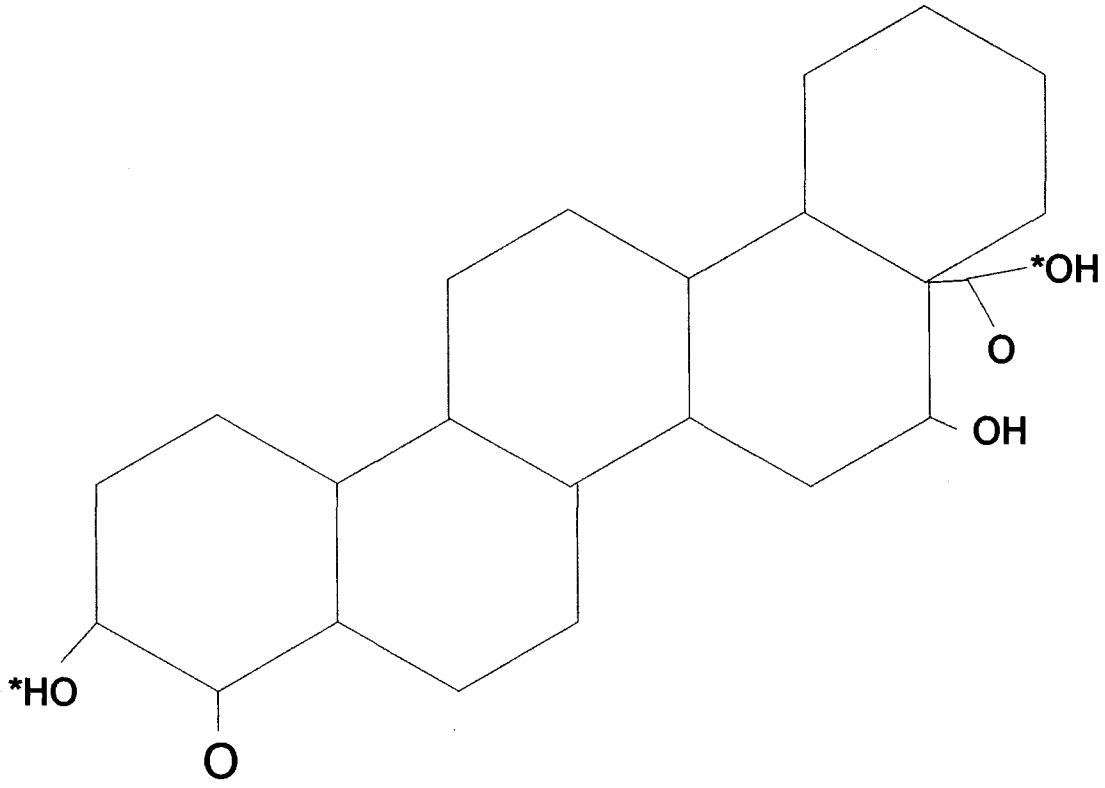
II. Literature Review

II.1 Chemical and Physiological Properties of Saponins

Saponins are compounds that occur naturally in many plants and possess detergent-like properties (the name saponin is derived from the word "soap"). Saponins vary in their chemical structures and a large amount of research has been conducted in the last decade to attempt to isolate and identify saponins found in plants. A saponin consists of a hydrophobic nucleus (steroidal or triterpenoid) attached to hydrophilic groups (carbohydrate side chains). Figure 1 shows a diagram of saponins (Hostettmann and Marston, 1995). Saponins are generally classified by the chemical structure of their nucleus (aglycone). Thus, there are steroidal saponins and triterpenoid saponins. Figure 2 shows the chemical structure of a triterpene aglycone (*Quillaja saponaria*) and figure 3 is the structure of a steroidal aglycone (*Yucca schidigera*). Although saponins have diverse chemical structures, they possess some common characteristics. Examples of common traits are bitter taste (associated with reduced palatability to some animals), formation of stable foams in aqueous solutions (detergent-like properties), toxicity to mollusks and fish (piscicidal and molluscicidal uses), ability to form complexes with bile acids and cholesterol (Figure 4; Sidhu and Oakenfull, 1986), and interaction with cell membranes (red blood cell hemolysis and rumen defaunation). These will be discussed in further detail in sections that follow.

Within a plant, high concentrations of saponins tend to be found in the roots and among growing shoots. However, this trend is variable depending on the species of plant. For example, *Quillaja saponaria* contains high levels of saponins in its bark, hence, the common reference to "soap bark". In alfalfa, saponin content of the roots

Figure 2: Structure of Quillaic Acid (triterpenoid aglycone of *Quillaja Saponaria)*



*Carbohydrate sidechain connected at these carbons

Figure 3: Structure of a Steroidal Aglycone *(Yucca schidigera)*

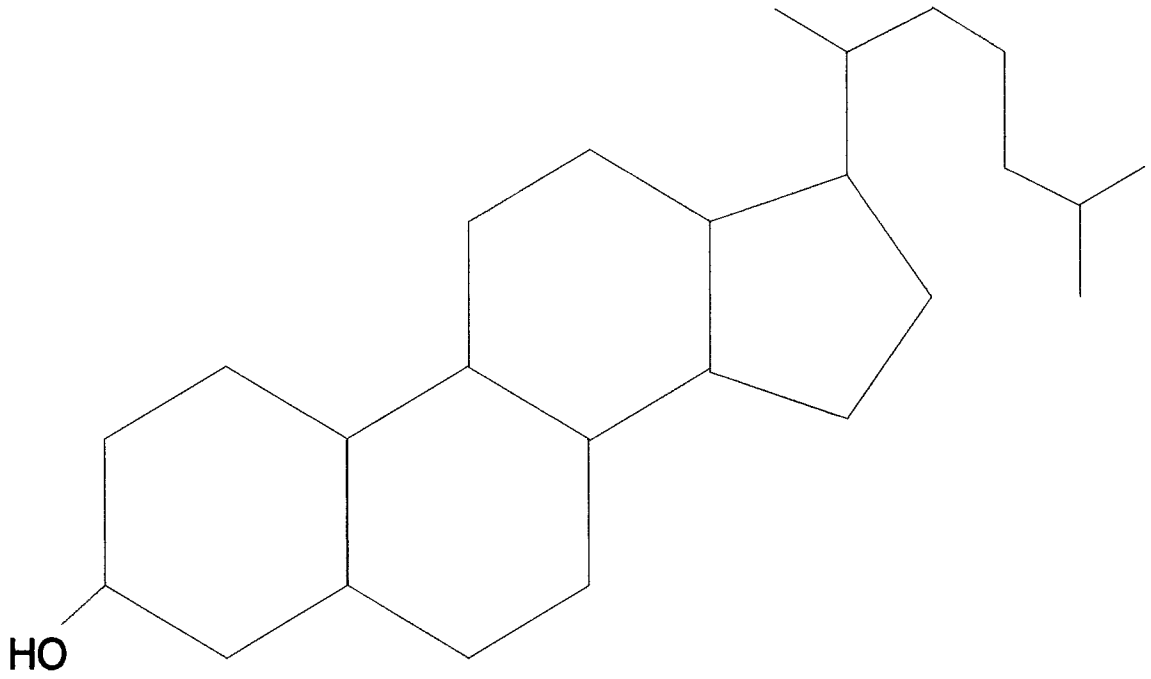
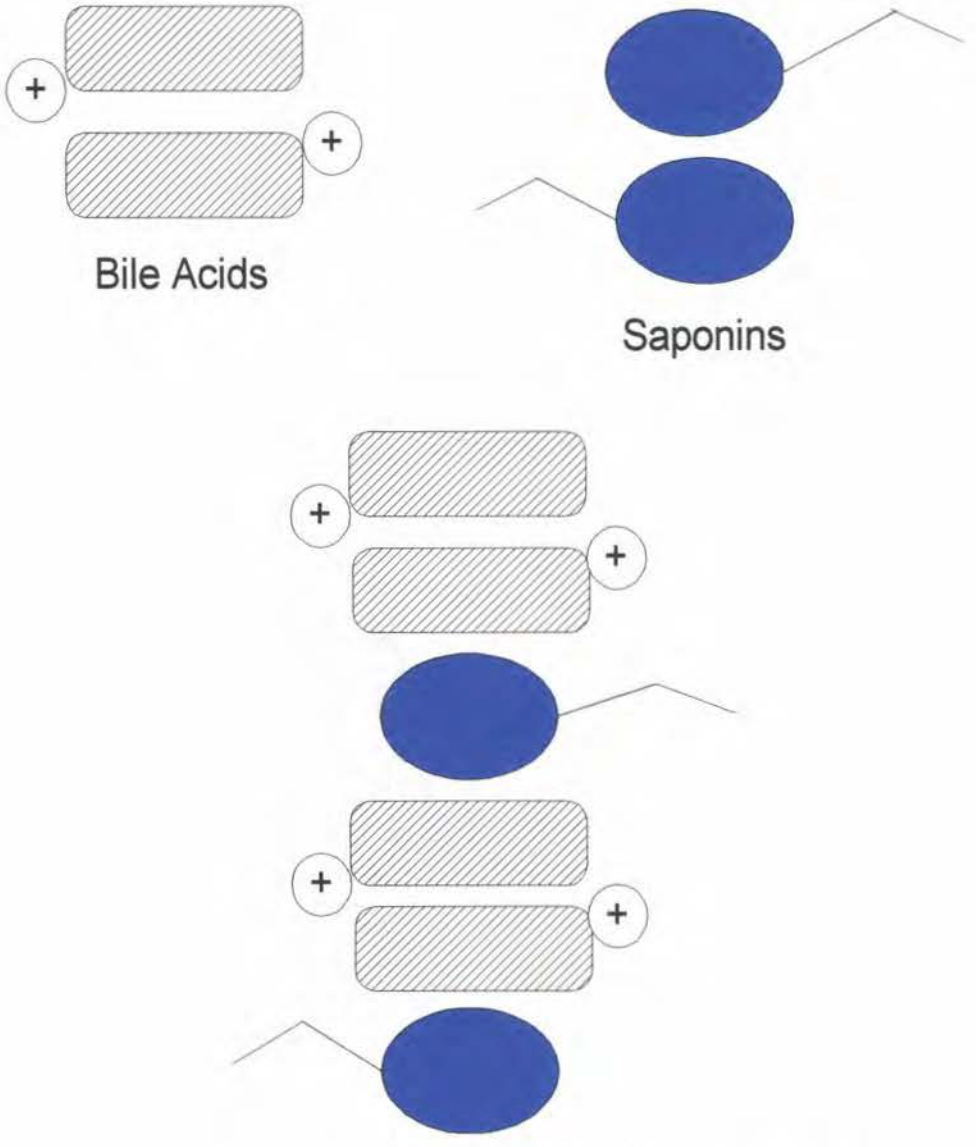


Figure 4: Schematic Diagram of the Structure of a Mixed Micelle



Sidhu and Oakenfull, 1986

transfers to the foliage during flowering and in response to environmental factors (Cheeke, 1998). Saponins may play an ecological and protective role in plants since they possess properties that deter herbivory by insects and animals. Thus, this may be the reason for higher concentrations of saponins in vulnerable parts of the plants or rapidly growing portions of plants. Providing plants with natural defense mechanisms such as saponins, ensures a better chance of survival and reproduction for vulnerable species within the plant kingdom.

Along with their potential roles in plants, saponins are also toxic to insects, fungi, fish, and mollusks. These properties were reviewed by Oakenfull and Sidhu in 1989 and will be discussed briefly. The toxicity of saponins to insects appears to be linked to membrane-related events (eg., inhibition of water resorption from the hind gut in locusts). The toxicity of saponins to insects is variable and depends on the source of saponin, the susceptibility of the insect, and the part of the plant that the insect is feeding on. Saponins could be used as insecticides for crops and plants that are vulnerable to predation. In the case of fungi, saponins show signs of toxicity via interactions with cell membranes. Saponins that have a high affinity for complexing with cholesterol also show strong antifungal properties. Fungi that lack cholesterol in their membranes do not appear as vulnerable to the toxicity associated with saponins. The toxicity of saponins to fish appears to be related to interactions with the membranes of the gills. It is thought that saponins penetrate the gill membranes, causing increased permeability and paralysis of the gills, resulting in asphyxiation and death of the fish. Fish toxicity is common among detergent-like substances and surfactants. In addition, the toxicity of saponins to mollusks

is most likely correlated to changes in plasma membrane permeability similar to those occurring in fish.

Saponins bind with cholesterol to form insoluble complexes. This well-known trait is directly correlated to the poor absorption of saponins from the gastrointestinal tract. Because of their binding affinity, saponins are 10 to 1000 times less toxic orally than when given by intravenous injection (Oakenfull and Sidhu, 1989). In vivo experiments performed by Gestetner *et* al. (1968) showed that ingested soybean saponins are not absorbed into the blood as saponins or sapogenins in chicks, rats, and mice. Therefore, the primary digestive effects of saponins in non-ruminant animals are seen in the small intestine (Cheeke, 1995). These effects will be covered in detail in sections II.2 and II.3. Effects of saponins on ruminant digestion will be discussed here briefly.

Much effort has been placed on research involving the roles of saponins in ruminal bloat and rumen fermentation. A few proposed modes of action have been considered. Ruminal bloat is a condition that occurs commonly in cattle on pasture (also referred to as "pasture bloat"). The rumen becomes filled with gases that accompany a frothy foam that causes distention of the rumen and great discomfort to the animal. The detergent properties characteristic to saponins may play a significant role in creating the stable foam that is seen during bloat. It has also been proposed that feeding saponins in the diet could have a direct effect on protozoa in the rumen and thus, exhibit a defaunation ability in ruminants. Defaunation is the removal of protozoa in the rumen to attempt to increase microbial efficiency (especially for high concentrate feeds) and protein utilization. It is thought that saponins disrupt protozoal membranes by binding with cholesterol in the membranes, thus causing the membranes to break down. The

rumen bacteria would not be affected by this type of interaction because prokaryotic cells do not contain cholesterol, thus avoiding the binding potential with saponins (Cheeke, 1995). Clarke *et* al. (1969) observed that defaunation in cattle reduced the incidence and severity of bloat. It is interesting that saponins could play a causative role in bloat and also an inhibitory role, depending on what type of saponin is present and the modes of action involved.

Saponins have potential to affect rumen fermentation by exhibiting effects on nitrogen metabolism. *Yucca schidigera* contains saponins and has shown signs of ammonia-binding capabilities in the rumen. However, the active binding component of the extract has not been clearly defined. It has been proposed that yucca extract decreases rumen ammonia by directly binding ammonia in the rumen (Hussain and Cheeke, 1995) or by reducing proteolysis of bacterial protein (Wallace *et* al., 1994). Among ruminants, there is potential for species differences to exist when considering effects of saponins on digestion processes and nutrient absorption.

II.2 Effects of Saponins on Lipid and Cholesterol Metabolism

The hypocholesterolemic effects of saponins and their tendency to interact with the formation of micelles have been areas of research for many years. Factors such as chemical structure of saponins, plant source of saponins, dietary level of saponins, presence of various nutrients, and test species are all confounding variables in this area of research. Although hypocholesterolemic effects have been observed in many species, the mode of action has not been clearly defined. This summary will focus on effects of saponins on lipid and cholesterol metabolism in nonruminant animals.

The cholesterol-complexing properties of some saponins may play a role in lipid metabolism and thus, the interest in studying these effects is common. Reshef *et* al. (1976) conducted a study on mice and quail, looking at the effects of alfalfa and soybean saponins on lipid metabolism. In mice, no effects on growth occurred with consumption of saponins except for the mice receiving 0.5% cholesterol-precipitable alfalfa root saponins. The growth retardation that was seen in this group could be prevented by adding 0.5% cholesterol to the diet. It was noted that the alfalfa root saponins contained 10% medicagenic acid while the cholesterol-precipitated saponin mixture contained 29% medicagenic acid. Previous studies have associated the biological effects of alfalfa saponins with their medicagenic acid content; thus, these results supported those findings. Lipid metabolism appeared to be affected by addition of saponins to the diet. Mice receiving alfalfa saponins showed an increase in fecal lipid content with the increase being more prominent in females. Fecal cholesterol levels were also increased in mice receiving saponins in their diet. Also, there was a decrease in liver cholesterol in these animals. It was proposed that saponins affect emulsification of lipids and interfere with micelle formation which is needed for absorption of lipids through the intestinal wall. Decreases in cholesterol were explained by the interaction and complexing of saponins with endogenous cholesterol (passing from the liver to the gut) to cause the reabsorption of cholesterol to be inhibited or reduced. Thus, increases in fecal cholesterol occur.

Growth depression in quail was observed in the group receiving the 0.5% cholesterol-precipitated alfalfa root saponins (same trend as mice). No effects on growth were observed in quail receiving other saponins. Once again, the decrease in growth was attributed to the medicagenic acid content of the saponins. Unlike mice, quail showed no

depression in lipid digestibility nor in recirculation of cholesterol from the intestine to the blood. The cholesterol content in liver and blood was unaffected by consumption of saponins. Lipid biosynthesis in the livers of quail did not change with the inclusion of saponins in their diet. However, a significant rise in lipid content of the livers occurred in quail receiving saponins. Interestingly, female mice receiving saponins in their diet showed decreased lipid content in their livers with increased lipid biosynthesis occurring as well. In quail, cholesterol content of livers and blood was unaffected by the presence of saponins. Mice showed a decrease in liver cholesterol levels with addition of saponins to their diet. Reshef *et* al. (1976) concluded that a saponin-cholesterol complex is formed in the gut of mice but not quail and that the mode of action used by alfalfa saponins in lipid and cholesterol metabolism is different between these animals.

Oakenfull *et* al (1979) studied the effects of *Saponaria* saponins (derived from the European soapwort) on lipid and cholesterol metabolism in the rat. Interactions between saponins and bile acids were considered as well. Growth was depressed in rats receiving saponins along with additional cholesterol in their diets. Addition of saponins (without addition of cholesterol) to the diet showed no effects on growth. No independent action of saponins on plasma cholesterol levels was apparent, but when saponins and cholesterol were consumed together, a significant decrease in plasma cholesterol occurred. This same interaction was seen in plasma lipid concentrations. Saponins lowered liver cholesterol levels in rats being fed a high cholesterol diet. No effects of saponins on liver cholesterol were seen in rats receiving control diets. Secretion of bile was increased twofold with the addition of cholesterol and the addition of cholesterol + saponins. Adding saponins to the control diet (no added cholesterol) had

no effect on bile secretion. Increased bile acid secretion was seen with the addition of cholesterol to the diet and a larger increase was seen when saponins were added along with cholesterol. Rates of fecal excretion of bile acids and neutral sterols in rats followed this trend:

control < control + saponins < added cholesterol < cholesterol + saponins

Addition of saponins to both control and high cholesterol diets appeared to change the profile of fecal bile acids. It appeared that addition of saponins resulted in a shift towards larger amounts of primary bile acids rather than secondary bile acids present in the feces. Primary bile acids are synthesized in the liver while secondary bile acids are derived from the primary bile acids via intestinal bacteria. It was concluded that this effect of saponins on the profile of fecal bile acids indicates a specificity in the adsorption of bile acids by saponins (Oakenfull *et* al., 1979).

A study was conducted by Oakenfull *et* al. (1986) to examine the effects of saponins (soybean and *Quillaja saponaria*) on preventing dietary hypercholesterolemia in rats. Saponins from each source were added to a control diet (no added cholesterol) and to a diet with added cholesterol. A decrease in plasma cholesterol was seen by addition of quillaja saponins to the control diets but soybean saponins showed no effect. Both types of saponins reduced plasma cholesterol for the rats on the high cholesterol diets. Quillaja saponins decreased liver cholesterol for both the control and high cholesterol diets while soybean only showed a lowering effect for the high cholesterol diets. Soybean saponins added to both the control diet and the high cholesterol diet resulted in an increase in excretion of bile acids. Rats receiving quillaja saponins showed no change in the excretion of bile acids but showed a large increase in the excretion of neutral

sterols (control and high cholesterol diets). In rats fed quillaja saponins, the bile acid profile was not altered in either the control diet or the high cholesterol diet. However, soybean saponins caused an increase in the proportion of primary bile acids for both diets. Thus, it was concluded from this study that there are differences between types of saponins in bile acid specificity.

A study was conducted on rats and gerbils to examine the effects of oat saponins on plasma and liver lipids (Onning and Asp, 1995). No differences in feed intake or body weights were apparent for rats and gerbils receiving saponins in their diet when compared to those that were not receiving saponins. In rats receiving the high dose of saponins (.7 g/kg), levels of lipid in the liver were decreased but no changes in levels of plasma lipids were seen. Oat saponins had no significant effects on plasma cholesterol levels in rats or gerbils. Onning and Asp (1995) proposed that oat saponins play no significant role in blood hypocholesterolemic effects of oats but that these effects may be attributed to other components such as β-glucans.

Similar findings to the studies discussed above regarding the effects of saponins on lipid and cholesterol metabolism have been found in species other than rodents. Topping *et* al. (1980) looked at the effects of saponins on lipid and cholesterol metabolism in the pig. Unlike the common procedure of adding saponins to the diet, this study incorporated saponins (European Soapwort) into the drinking water. No effects of saponins were seen on plasma lipids or cholesterol. However, consistent with results from other species of animals and types of saponins, a substantial increase in fecal bile acids (280%) and neutral sterols (240%) resulted from consumption of saponins. Also, an increase in the proportion of primary bile acids in the feces (250%) occurred with

addition of saponins to the diet. The mode of action involved in these results was defined as the ability for saponins to bind bile acids so that they are no longer available to the gut microflora for conversion to secondary bile acids (Topping *et* al., 1980).

Morgan *et* al. (1972) examined the interactions between dietary saponin (Digitonin and *Gypsophylla*) and cholesterol metabolism in the chick. *Gypsophylla* and digitonin saponins (dietary level of 0.25%) depressed growth and lowered plasma cholesterol levels. For both of these saponins, addition of cholesterol to the diet reversed the growth inhibition while addition of 3β-hydroxy-3β-cholestanol (similar to cholesterol in chemical structure) was not able to reverse the growth inhibition seen with digitonin. It was proposed from this study that the hypocholesterolemic effect of saponins seen in the chick may be due to saponins causing an increase in excretion of sterols or bile acids.

An experiment examining the effects of protein source and saponins on lipid metabolism in rabbits was conducted by Pathirana *et* al. (1981). There were no effects seen on plasma lipid levels by type of dietary protein source or saponin supplementation. Saponins increased excretion of sterols but only in the diets containing soybean protein (not in diets containing milk protein). There was no effect on the excretion of cholesterol, coprostanol, or β-sitosterol by differing protein sources. Also, no effects on the excretion of bile acids (cholic, lithocholic, and deoxycholic) resulted from addition of saponins to the diets of rabbits. The results from this study were not in agreement with previous studies and theories on effects of saponins on lipid and cholesterol metabolism. Hindgut fermentation involved in the digestive processes of rabbits may be associated with different modes of actions for saponins in lipid and cholesterol metabolism.

Jenkins and Atwal (1994) conducted an experiment on broiler chicks observing the effects of dietary saponins on lipid and cholesterol metabolism. Three sources of saponins were used, two being triterpene saponins (*Gypsophylla* and *Quillaja*) and a steroidal saponin (*Yucca schidigera* extract referred to as sarsaponin). Saponins were included in the diet at a concentration of 0.1%, 0.3%. and 0.9%. Addition of sarsaponin at all three levels to the diet exhibited no effects on weight gain, feed intake, dry matter (DM) digestibility, lipid digestibility, or excretion of neutral sterols or bile acids. Chicks receiving *Gypsophylla* saponins at 0.3% and 0.9% showed decreases in weight gain and feed intake. Decreases in DM and lipid digestibility occurred at the 0.9% dose. Also, an increase in cholesterol excretion was observed and appeared to increase linearly to increasing saponin levels. The same trends in DM and lipid digestibility and cholesterol excretion that were seen with *Gypsophylla* saponins were also seen with *Quillaja* saponins. Decreases in chick weight and feed intake occurred with *Quillaja* saponins at the 0.9% dietary level. Jenkins and Atwal (1994) concluded that, " dietary saponins are effective in reducing blood cholesterol concentrations when the levels are high due to a high dietary intake of cholesterol, and this reduction is caused by an interference with the absorption of cholesterol and bile acids."

II.3 Effect of Saponins on Nutrient Availability

It has been proposed that the mechanism by which saponins exert effects on growth inhibition in animals is due to the reduced palatability of feed containing saponins (Cheeke *et* al., 1983). Thus, reduced feed consumption as a result of decreased palatability has been seen with saponin-rich feeds. However, it has also been proposed that decreased growth and performance in animals consuming saponins could be caused

by the inability for the animal to absorb or metabolize essential nutrients effectively (Southon *et* al., 1988). Southon *et* al. (1988) examined the effects of saponins (*Gypsophylla*) on mineral status in the rat. Rats were fed a basal diet, a low-Zn diet, a low-Fe diet , and then saponins were added to each one of these diets at 20g/kg. Thus, there were six experimental diets in total. Decreased weight gains were seen in rats being fed the low-Zn + saponin diet when compared to the control diet. All other diets showed no effects on weight gain. The Zn status of the rats receiving saponins was not different from their respective control groups. Mean liver Fe concentration and total liver Fe were lower in animals receiving saponins in their diets. Two possible mechanisms of action were mentioned in this study regarding the lower Fe levels seen in saponin-fed animals. First, the decreased Fe levels seen in the liver could be caused by saponins forming complexes with dietary nutrients making them unavailable for absorption. Second, long-term consumption of saponins may cause changes in the intestinal mucous membranes, thus hindering the transport and absorption of essential nutrients. Since no effect on the Zn status was seen in this study, further research should be conducted to identify mechanisms involved.

Effects of saponins on gut permeability and active transport of nutrients were examined in vitro by Johnson *et* al. (1986). Four different types of saponins were used in the experiment. Three triterpenoid saponins were: *Gypsophylla* (isolated from the root), *Saponaria officianalis* (European soapwort), and soy saponins (taken from soybean meal). α-Tomatine (found in green tomatoes) represented a steroidal saponin. *Gypsophylla* saponin inhibited the carrier-mediated transport of galactose and increased the uptake of the passively-transported L-isomer of glucose. *Gypsophylla* saponin also

induced a rapid decline in glucose-stimulated transmural potential difference (PD) along the mucosal surface of the jejunum. Reduced transmural potential differences were also seen in the presence of *Saponaria* saponins and α-tomatine saponins. Soy saponins did not have a significant effect on PD. In addition, the presence of *Gypsophylla* saponins resulted in the uptake of PEG 4000, a polymer that is normally not absorbed from the small intestine. It was proposed that some saponins may interact and permeabilize the absorptive cells of the intestinal membrane. Thus, increasing the permeability of the intestinal membrane could inhibit active transport of nutrients and also allow absorption of substances that are normally deemed non-absorbable by the brush-border membrane of the small intestine.

Effects of saponins on fat-soluble vitamin availability (A and E) were studied in the chick by Jenkins and Atwal (1994). Triterpenoid saponins (gypsophila and quillaja) at a dietary level of 0.9% resulted in decreased vitamin E concentrations in the plasma. Liver vitamin E concentration was reduced by the addition of gypsophila and quillaja saponins at dietary levels of 0.1%, 0.3%, and 0.9%. Also, plasma retinol, liver retinol, and vitamin A palmitate levels in the liver were all decreased by the addition of triterpenoid saponins at 0.9%. The steroidal saponin, sarsaponin, reduced liver vitamin A palmitate levels at the 0.9% level. The mechanisms involved in the reduction of vitamin A and E levels in plasma and liver seen with the consumption of dietary saponins have not been identified. A proposed explanation for the reduction in fat-soluble vitamins seen in this study suggested that increases in the excretion of fat and binding of bile acids would reduce micelle formation and absorption of fat-soluble vitamins.

III. Materials and Methods

III.1 Rooster Study

III.1.1 *Animals, Diets, and Collection of Samples*

Thirty individually caged adult Leghorn roosters were used in a three-phase feeding trial. Each phase involved a different fat source. Phase one used tallow as the fat source, phase two used coconut oil, and phase three used soybean oil. The reasoning behind this diet formulation was to examine the effects of *Yucca schidigera* (containing steroidal saponins) and *Quillaja saponaria* (containing triterpenoid saponins) extracts on the digestibility of fats of varying saturation levels. Tallow and coconut oil were the most saturated sources of fat, and soybean oil was the least saturated. Birds were randomly assigned to dose groups at the beginning of each phase of the trial. A preliminary period of three days was included in the 7-day duration of each feeding trial to ensure that adaptation to the experimental diet occurred and no residue of previously consumed feed was present in the digestive tracts of the roosters.

The basal diet of the roosters was a commercial mash feed with 10.5% protein and approximately 3% fat. Addition of tallow, coconut oil, and soybean oil at 10% to the basal diet resulted in an experimental diet consisting of approximately 13% total fat. *Yucca schidigera* and *Quillaja saponaria* extracts were obtained from Desert King International and utilized in a liquid form. The extracts were added to the basal diet at two different levels: 200ppm and 1000ppm (mg/kg feed). A control diet containing no added extracts was fed for each fat source as well. Birds were fed 200g of experimental feed per day. Feed not consumed was weighed back. Individual bird weights were taken both before and after each phase of the feeding trial.

Quantitative collection of excreta from each rooster began on the fourth day of each phase of the feeding trial and was carried out once a day for four days thereafter. A tray method was used for total excreta collection for each bird. After each daily collection, each excreta sample was placed in a sealed container and frozen pending preparation for analyses.

III.1.2 *Laboratory Analyses*

The pooled excreta samples from each bird were dried in a forced air oven at 55°C, weighed, and ground. Fat content of both feed and excreta was determined via ether extraction as described in the Official Methods of Analysis (Association of Official Analytical Chemists). Feed intake and excreta weights were reported on a DM basis. Fat content of feed and excreta were analyzed on a 100% dry matter basis. Apparent fat digestibility (%) was calculated using the following equation: AD = (TFI-TFE)/TFI *100. where TFI is total fat INTAKE and TFE is total fat in EXCRETA.

III.1.3 *Statistical Analyses*

The data were analyzed using the Statistical Analysis System (SAS) by the General Linear Models Procedure (ANOVA with repeated measures). Significance of differences between means was analyzed by using least square means analysis based on the t-distribution of data. P-values $< .05$ were considered statistically significant.

III.2 Broiler Study

III.2.1 *Animals, Diets, and Collection of Samples*

Unsexed broiler chicks of a commercial strain were housed in individual battery cages (8 birds per cage) which provided a controlled environment as well as accommodating fecal collection trays. Twelve cages, 12.5 sq. ft. in dimension, housed 8 animals per cage and represented six experimental diets in duplicate. Ninety-six birds were utilized in total. The duration of the study was 5 weeks (a typical growing cycle of commercial broilers). Animals were wing-banded on the first day of data collection to ensure that individual observations could be recorded. Birds were observed daily for overall health and weighed every 7 days for 5 weeks. Feed and water were offered ad libitum. Feed intake, excreta weight, dry matter digestibility, fat content of excreta and fat digestibility were considered on a per cage basis. Feed weighback occurred at the end of each week. Excreta for each cage was collected and quantified, via dropping pans, for a 24-hour period every 4 days. Excreta and feed samples were frozen and stored pending analyses. At the termination of the trial, all birds were sacrificed and individual blood samples taken directly from the jugular vein. Plasma samples were stored at -15°C.

A two-phase feeding regime was implemented to accommodate for starter and grower phases of the broiler growth cycle. The starter ration consisted of approximately 21% protein and 3% fat. This ration was fed for 2 weeks. The finisher ration provided approximately 18.5% protein and 3% fat and was fed for 3 weeks. Both of these commercial mash feeds were corn-based and prepared at a local feed mill. A commercial vitamin-trace mineral premix was added at 0.325% of the basal diet. Animal tallow was used as the fat source for those diets requiring added fat. *Yucca schidigera* powder (DK

Sarsaponin 30) was obtained from Desert King International and added to the basal diet at two different levels: 100mg/kg feed and 500 mg/kg feed.

Six experimental diets were fed in this study. The control diets contained no added fat and three levels of yucca powder: no yucca, 100ppm yucca, and 500ppm yucca. The tallow diets all contained approximately 10% added fat (beef tallow) to the basal diet and three levels of yucca powder: no yucca, 100ppm yucca, and 500ppm yucca. Table 1 shows results from the quantitative analysis of various constituents for each experimental diet. Each diet was assigned randomly to 2 different cages. Thus, 16 birds received each experimental diet.

III.2.2 *Laboratory Analyses*

Excreta samples were dried in a forced air oven at 55°C, weighed, and ground. Fat content of both feed and excreta was determined via ether extraction as described in the official methods of analysis (Association of Official Analytical Chemists, 1980). Feed intake and excreta weights were reported on a DM basis. Fat content of feed and excreta were analyzed on a 100% dry matter basis. Thus, fat digestibility results are all adjusted for moisture content of actual feed and excreta. In calculating fat digestibility for each pen, feed intake was multiplied by the % fat in the feed and excreta amounts were multiplied by the % fat in the excreta. Therefore, the equation used to calculate fat digestibility was as follows: [(Feed intake)(% fat in feed)-(Excreta weight)(% fat in excreta)]/(Feed intake)(% fat in feed). Protein content of feed was determined utilizing the Kjeldahl analysis as described in the official methods of analysis (Association of Official Analytical Chemists, 1980). Energy content of each diet was established by using a bomb calorimeter and followed the official methods of analysis published by the Association of Official Analytical Chemists.

Table 1: Quantitative Analysis of Fat, Moisture, Protein, and Energy Content for Broiler Diets

Feed Descr.	% Fat	% Moisture	% Protein	Gross Energy (Kcal/Kg)
Starter Ration				
Control	3.4	10.5	21.6	3871.1
Control-low YP	3.4	10.6	22.0	3841.4
Control-high YP	3.3	10.6	20.5	3795.5
Tallow-cont	13.3	9.7	20.7	4384.4
Tallow-low YP	11.9	9.9	21.3	4299.0
Tallow-high YP	13.2	9.8	20.8	4355.3
Finisher Ration				
Control	3.2	12.1	16.7	3815.6
Control-low YP	3.0	11.9	16.6	3758.5
Control-high YP	2.9	11.9	16.6	3806.3
Tallow-cont	13.1	11.3	16.4	4243.1
Tallow-low YP	17.1	32.6	16.6	4253.6
Tallow-high YP	15.7	29.6	16.7	4302.1

YP = Yucca Powder

Vitamin E and A in the forms of α-tocopherol and retinol were analyzed in plasma samples from each individual bird. The procedure used an internal standard method and the supernate was analyzed via reverse phase HPLC (Craig et al., 1992).

III.2.3 *Statistical Analyses*

The data were analyzed using the Statistical Analysis System (SAS) by the Generalized Linear Model Procedure (ANOVA with repeated measures) considering the Huynh-Feldt assumption (Kuehl, 1994). Significant differences between means were analyzed by the least square means test based on the t-distribution of the data for each variable of the study. Results from the plasma data were analyzed using two-way analysis of variance and differences between means were analyzed using Tukey's Studentized Range Test. P-values $< .05$ were considered statistically significant.

III.3 Quail Study

III.3.1 *Animals, Diets, and Collection of Samples*

A commercial strain of 180 unsexed Japanese Quail (*Coturnix coturnix*) was obtained for this study. Birds were housed in battery cages to provide a controlled environment as well as accommodating excreta collection trays. Thirty chicks were present in each individual cage (6 cages total). The quail were wing-banded on the first day of data collection to ensure that individual observations could be recorded. They were observed daily for overall health and weighed every seven days for the duration of 4 weeks. Feed intake, excreta weight, dry matter digestibility, fat content of excreta and fat digestibility were considered on a per cage basis (30 birds). Feed weighback was collected at the end of each week. Excreta was collected and quantified for each cage via

dropping pans, every 4 days for a 24-hour period. Feed and excreta samples were frozen and stored pending analyses. Feed and water were offered ad libitum for the duration of the study. At the end of the trial, the birds were returned to the departmental quail flock.

Quail were fed a corn-based mash diet containing approximately 21% protein and 3% fat, prepared at a local feed mill. A commercial vitamin-trace mineral premix was included into the basal diet at .325%. Animal tallow was used as the fat source for those experimental diets requiring added fat. *Yucca schidigera* powder (DK Sarsaponin 30) was obtained from Desert King International and was added to the basal diet at two different levels: 100mg/kg feed and 500 mg/kg feed.

Six experimental diets were fed in this study. The control diets contained no added fat and three levels of yucca powder: no yucca, 100ppm yucca, and 500ppm yucca. The tallow diets all contained approximately 10% added fat (animal tallow) to the basal diet and three levels of yucca powder: no yucca, 100ppm yucca, and 500ppm yucca. Table 2 shows results from the quantitative analysis of various constituents for each experimental diet. At the start of the study, each cage (30 birds) was randomly assigned a different experimental diet.

III.3.2 *Laboratory Analyses*

Excreta samples were dried in a forced air oven at 55°C, weighed, and ground. Fat content of both feed and excreta was determined via ether extraction as described in the official methods of analysis (Association of Official Analytical Chemists). Feed intake and excreta weights were reported on a DM basis. Fat content of feed and excreta

Table 2: Quantitative Analysis of Fat, Moisture, Protein, and Energy Content for Quail Diets

Feed Descr.	% Fat	% Moisture	% Protein	GE (Kcal/Kg)
Control	3.4	9.8	22.0	3526.1
Control-low YP	3.5	9.7	21.4	3828.8
Control-high YP	3.3	9.6	21.1	3833.2
Tallow-cont	13.4	8.8	20.7	4316.7
Tallow-low YP	11.4	8.7	21.3	4357.3
Tallow-high YP	12.8	9.2	20.8	4435.7
Tallow-cont2	13.0	9.0	20.9	4326.9
Tallow-low2 YP	15.1	9.0	20.6	4368.3
Tallow-high2 YP	14.8	8.8	20.5	4356.1

YP = Yucca Powder
2 = Second Mixing

were analyzed on a 100% dry matter basis. Thus, fat digestibility results are all adjusted for moisture content of actual feed and excreta. In calculating fat digestibility for each pen, feed intake was multiplied by the % fat in the feed and excreta amounts were multiplied by the % fat in the excreta. Therefore, the equation used to calculate fat digestibility was as follows: [(Feed intake)(% fat in feed)-(Excreta weight)(% fat in feces)]/(Feed intake)(% fat in feed). Protein content of feed was determined utilizing the Kjeldahl analysis as described in the Official Methods of Analysis (AOAC). Energy content of each diet was established by using a bomb calorimeter and followed the published method described by the AOAC.

III.3.3 *Statistical Analyses*

The growth data was analyzed using the Statistical Analysis System (SAS) by the General Linear Models Procedure (ANOVA with repeated measures). Differences in means were analyzed using least square means based on the t-distribution. P-values $< .05$ were considered significant. Due to lack of repetition in the experimental unit for all other data, statistical analyses could not be performed. Therefore, the actual data collected per pen, throughout the four weeks, is reported in the "Results" section of this paper and notable trends within data sets are discussed.

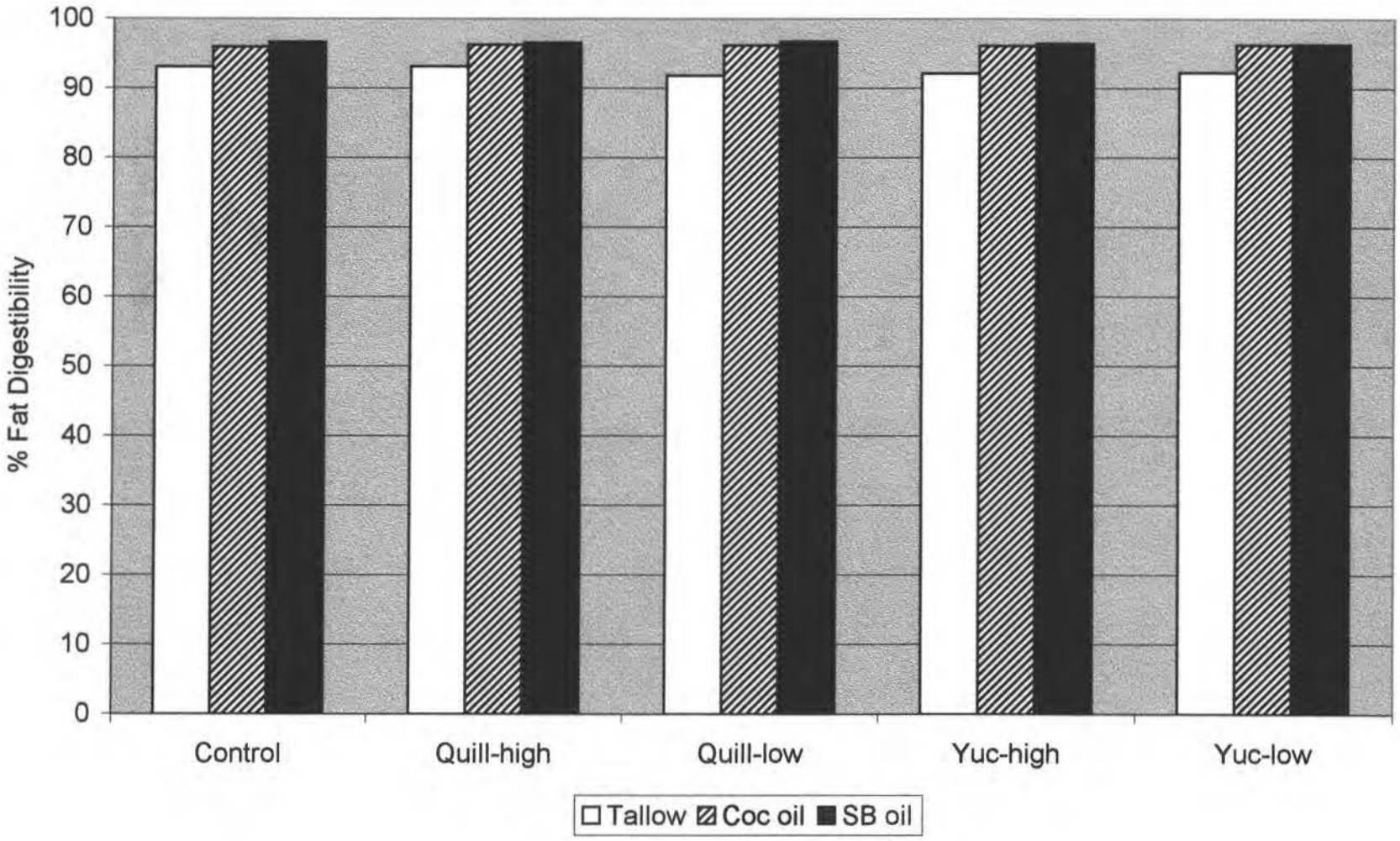
IV. Results

IV.1 Rooster Study

The source of saponin, either *Yucca schidigera* or *Quillaja saponaria*, and dose levels of saponin, 200(low) or 1000(high) mg extract/kg feed, had no significant effects on fat digestibility ($P = .8744$). Fat source, independent of dose, significantly affected fat digestibility ($P = .0001$). This was an expected result since highly saturated fats have been characterized by low digestibility rates when compared to unsaturated fats. Fat digestibilities in each dose group were significantly different for tallow diets compared to coconut oil diets ($P = .0001$) and tallow diets compared to soybean oil diets ($P = .0001$). However, coconut oil diets did not exhibit significant differences in fat digestibility from the soybean oil diets ($P = .2511$). Fat digestibility values are expressed as mean values based on 6 birds per dose group within each fat source and reported on a percent basis. Adding either supplement (Yucca or Quillaja) to diets containing the same fat source had no significant effect on fat digestibility. Figure 5 shows fat digestibility (%) for each dose group and fat source.

Dose had an insignificant effect on feed intake ($P = .0717$), as did fat source ($P = .6361$). Dose, coupled with fat source, showed no significant effects on feed intake ($P = .9194$) and appeared even less significant than the two variables occurring alone. Within the tallow diet, roosters receiving a high dose of *Yucca schidigera* had significantly higher intake levels than those in the low dose group (486.33g and 374.33g)($P = .021$). Feed intake values are expressed as mean values based on 6 birds per dose group within

Figure 5: Fat Digestibility (%) in Roosters

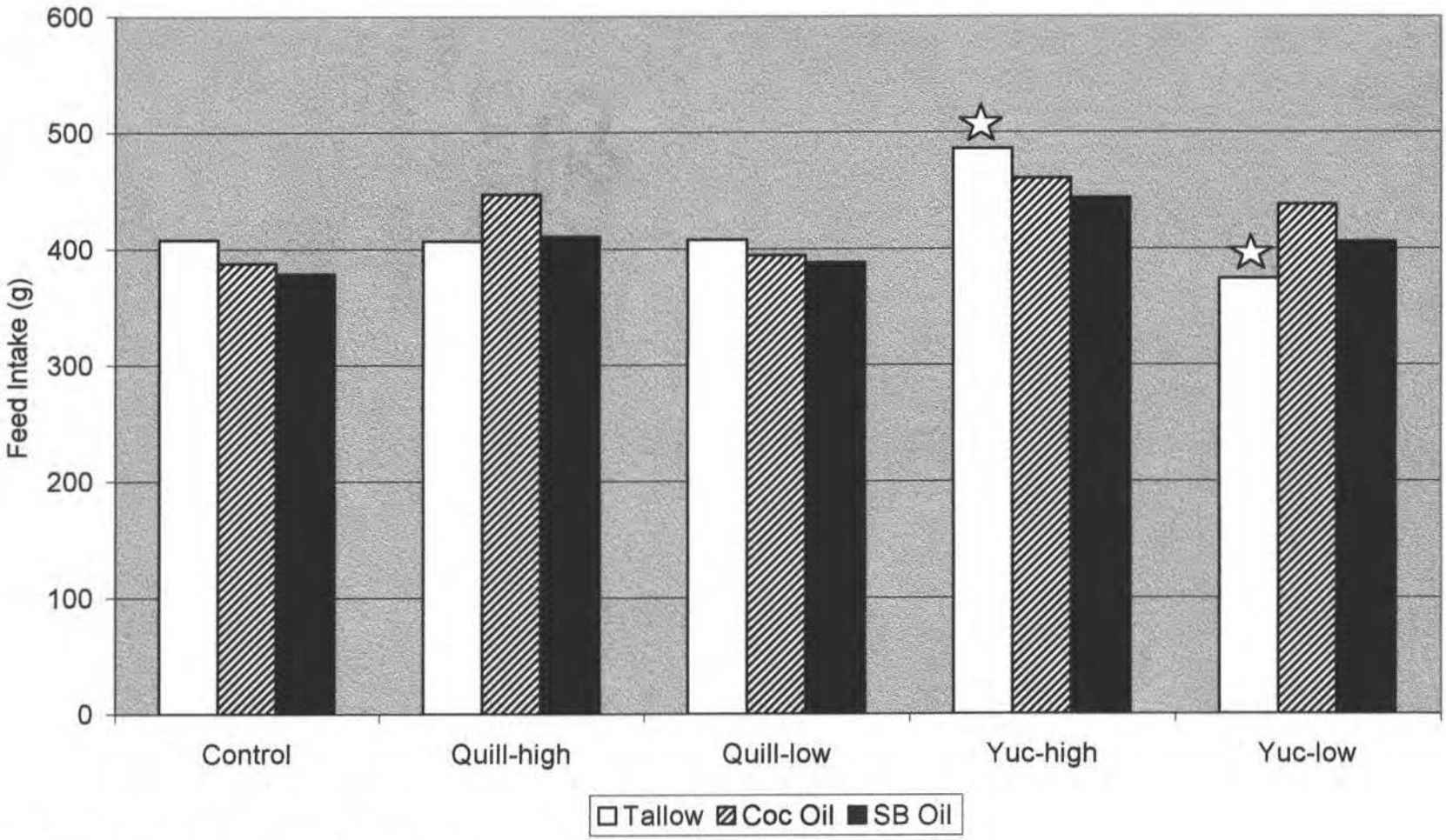


each fat source. Figure 6 shows feed intake levels for each dose group within each fat source.

Neither dose ($P = .0948$) nor fat source ($P = .1499$) affected excreta weights. Dose coupled with fat source exhibited no significant effects on excreta weights ($P = .5343$) and appeared less significant when considered together than individually. Excreta weights for birds on tallow diets were not significantly different from those on coconut oil or soybean diets ($P = .1216$ and $P = .7979$). The excreta weights for coconut oil compared to soybean oil diets were not significantly different either ($P = .0723$). In the tallow diets, a significant difference in excreta weights existed between low and high dose groups ($P = .005$). Roosters receiving *Yucca schidigera* at a high level exhibited larger excreta weights than those on the low dose diet (120.33g vs. 84.77g). Excreta weights are expressed as mean values for 6 birds per dose group within each fat source. Figure 7 shows mean excreta weights for each dose group within each fat source.

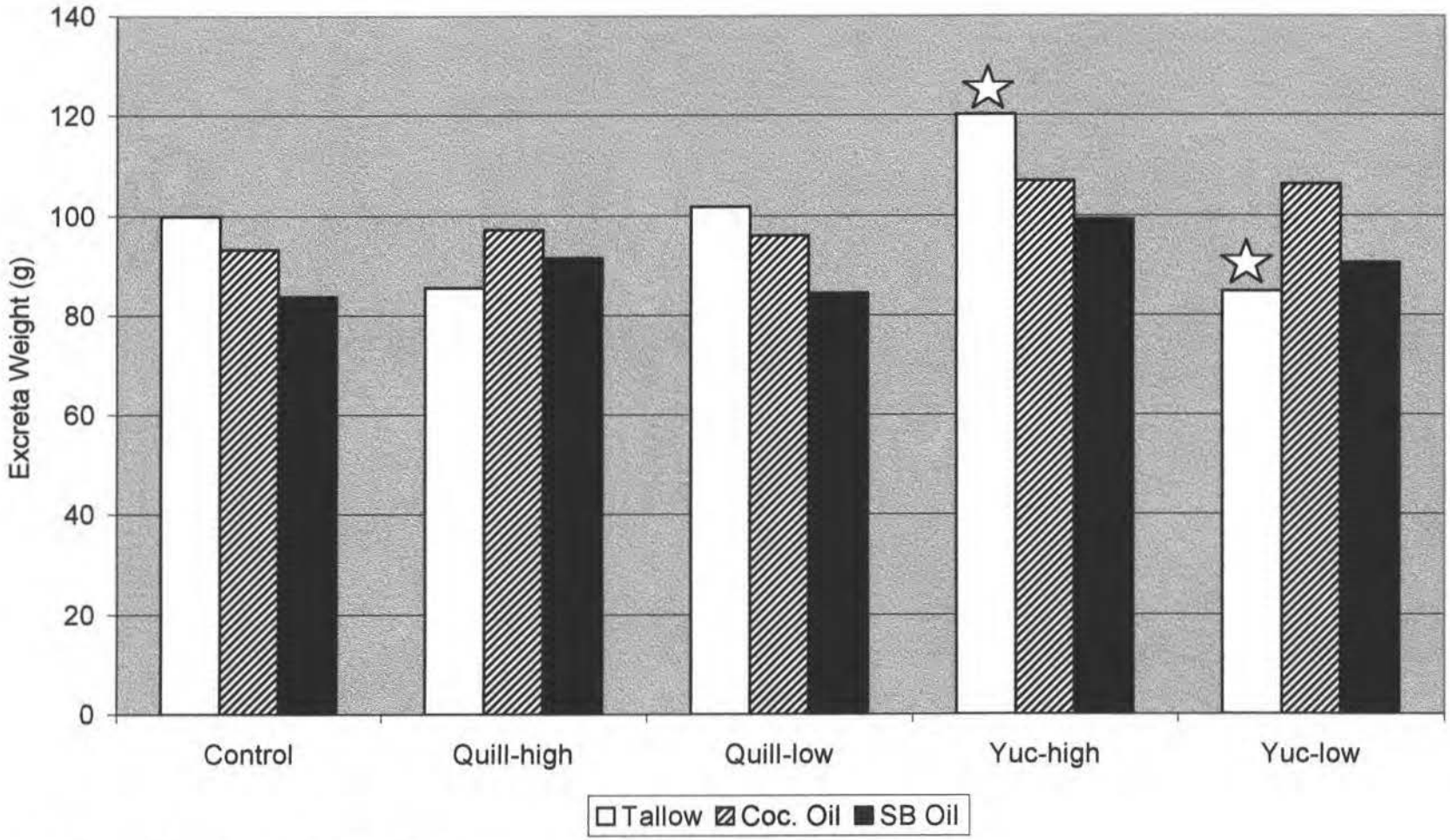
Fat source had very significant effects on the amount of fat present in the excreta ($P = .0001$). Excreta fat levels in tallow diets were significantly different from coconut oil diets ($P = .0001$) and from soybean oil diets ($P = .0001$). No significant differences existed between coconut oil diets and soybean oil diets ($P = .4744$). Dose effects on the amount of fat in excreta were insignificant ($P = .7488$), as were the effects exhibited by both dose and fat ($P = .802$). Within the tallow diet, roosters in the control group showed significantly lower levels of fat in their excreta when compared to those receiving *Yucca schidigera* at a low level (3.66% vs. 4.29%)($P = .041$). Amount of fat in excreta is expressed as a mean value for 6 birds per dose group within each fat source. Figure 8 represents fat levels in excreta for each dose group and fat source.

Figure 6: Feed Intake (g) for Roosters



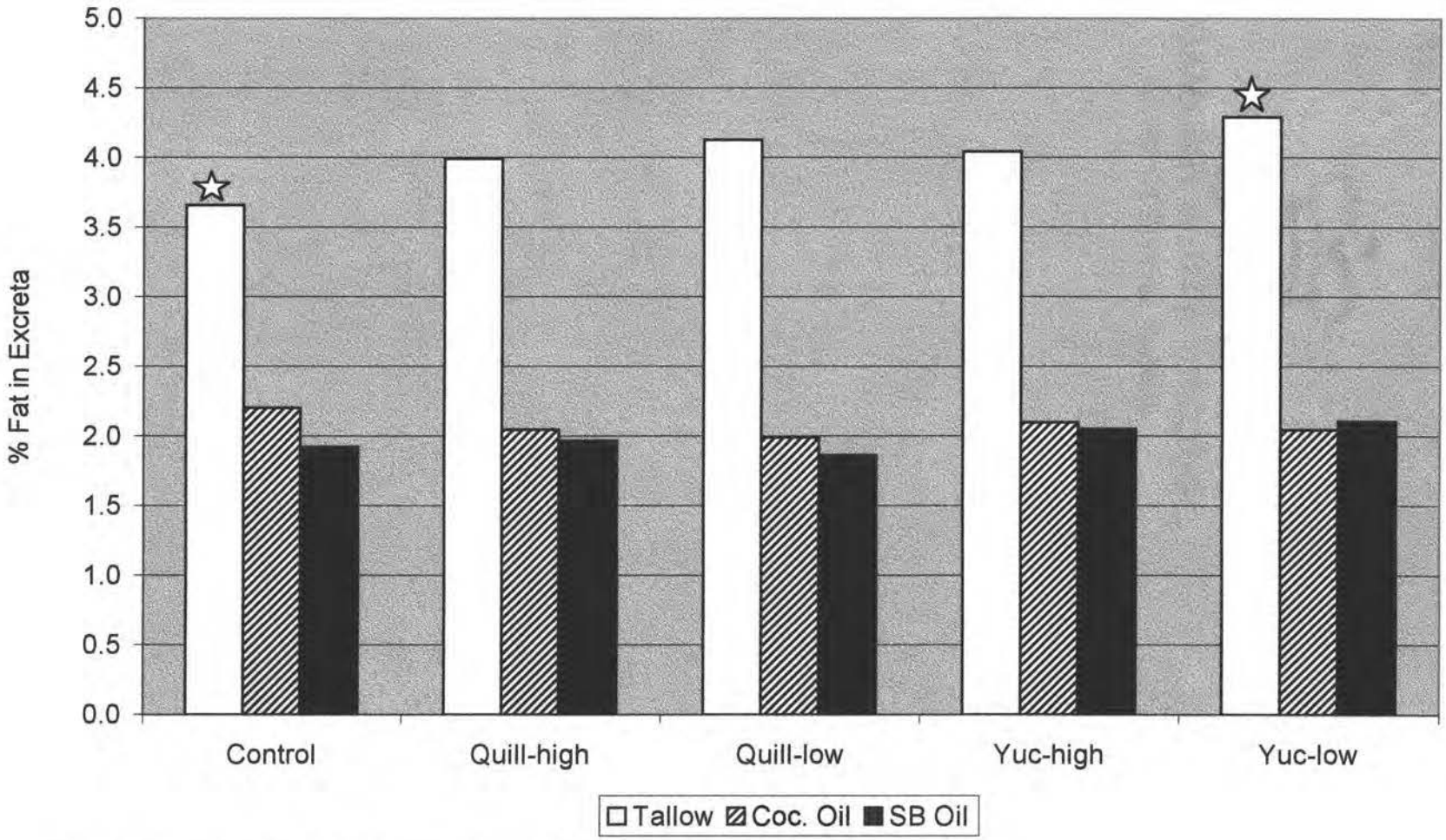
Statistical significance ($P < .05$) is represented by a star symbol.

Figure 7: Excreta Weights (g) for Roosters



Statistical significance ($P < .05$) is represented by a star symbol.

Figure 8: Fat Content of Excreta (%) in Roosters



Statistical significance ($P < .05$) is represented by a star symbol.

IV.2 Broiler Study

Fat digestibility (FD) was calculated over eight collection periods for each pen and the mean value for each diet (2 pens) was then examined. After the first collection, fat digestibility was higher in the control diets when compared to the high-fat control diets ($P = .0045$). Birds receiving control low-dose diets showed higher fat digestibility than those receiving low-dose high-fat diets did ($P = .0007$). Also, fat digestibility values were higher for control high-dose diets than for high-dose high-fat diets ($P = .0002$). Significant differences existed in FD between birds on the control diet (no added fat or Yucca) and those on the high-fat low-dose diet ($P = .0045$). After the second collection, differences within the high-fat diet were evident. FD of the control group (no Yucca) was significantly higher than the high-dose group (96.9% vs. 93.69%; $P = .0009$). The low-dose group had higher values for fat digestibility than the high- dose group as well (96.50% vs. 93.69%; $P = .0036$). Also, FD of the control high-dose diet was 96.47% while the high-fat high-dose diets were producing a digestibility value of 93.69% ($P = .004$). No significant differences between fat digestibility existed after the third or fourth collection for any of the diets. Following collection 5, differences in fat digestibility were evident within the high-fat diets. The birds receiving a low dose of Yucca showed higher FD values than those receiving a high dose of Yucca did ($P = .0088$). No significant differences in fat digestibility were seen after the sixth collection between any of the diets. Although differences between dose groups within the high-fat diets existed after the seventh collection (control > high-dose and low-dose > high-dose; $P = .0017$, .0085), no differences were noted after the final collection. Thus, following the last collection, no significant differences in fat digestibility were evident among any of the

experimental diets. Figure 9 shows mean fat digestibility values (%) for each diet throughout the duration of eight collections.

Dry Matter Digestibility (DMD) was calculated for each collection period (8 collection periods total) for each pen. The mean values for each diet were then considered (2 pens). Figure 10 shows DMD values for each diet throughout all eight collections. After the first collection, DMD was lower for control diets (89.88%) when compared to control low-dose diets (91.25%)($P = .0471$). Following the second collection, birds receiving the control high-dose diet (no added fat) had higher DMD values than birds on the high-fat high-dose diet, 95.44% and 94.06%, respectively ($P = .0463$). No significant differences in DMD were evident between any of the diets after the 3rd and 4th collections. For collection 5, birds within the high-fat diets showed significant differences in DMD. Birds receiving the control diet (no added Yucca) had higher DMD than those receiving a high-dose of Yucca (94.76% vs. 92.77%; $P = .0049$). Also, the low-dose diet showed higher DMD than the high-dose diet (95.28% vs. 92.77%; $P = .0005$). Birds receiving the high-dose of Yucca but differing fat levels in their diets exhibited the following DMD values: 95.66% for the control diet and 92.77% for the high-fat diet ($P = .0001$). DMD values after the 6th collection showed differences within the high-fat diets: control > low-dose > high-dose (94.91%, 93.35%, and 92.63%). Birds receiving the low dose of Yucca showed significantly different DMD for the control diet and the high-fat diet (95.26% and 93.35%; $P = .0067$). The same trend was evident in the high-dose diets: low-fat (95.61%) and high-fat (92.63%)($P = .0001$). After collection 7, high-fat diets showed the following trends in DMD: control > low-dose > high-dose (94.81%, 92.78%, and 90.85%, respectively). Birds on the control low-dose

Figure 9: Fat Digestibility (%) in Broilers

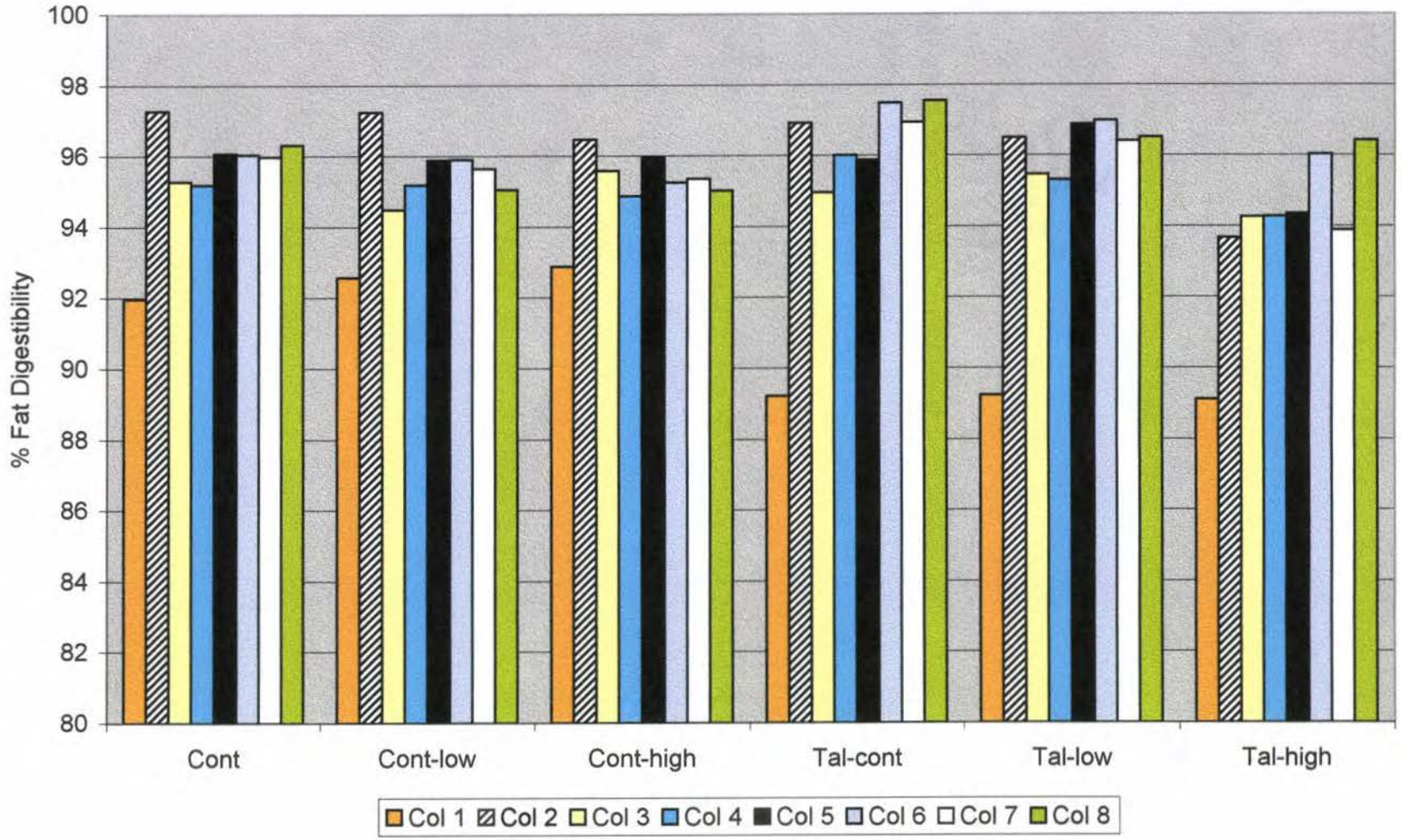
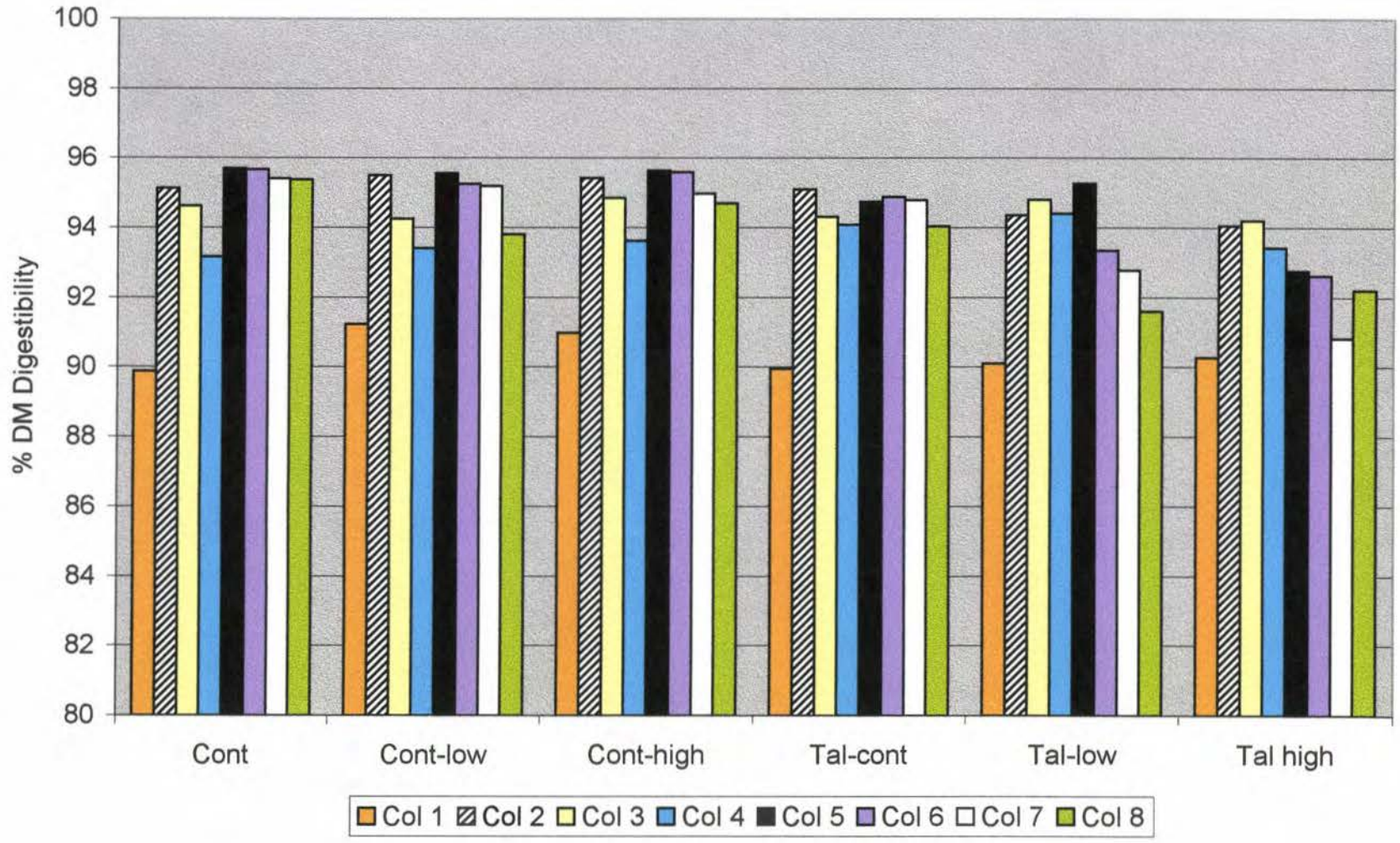


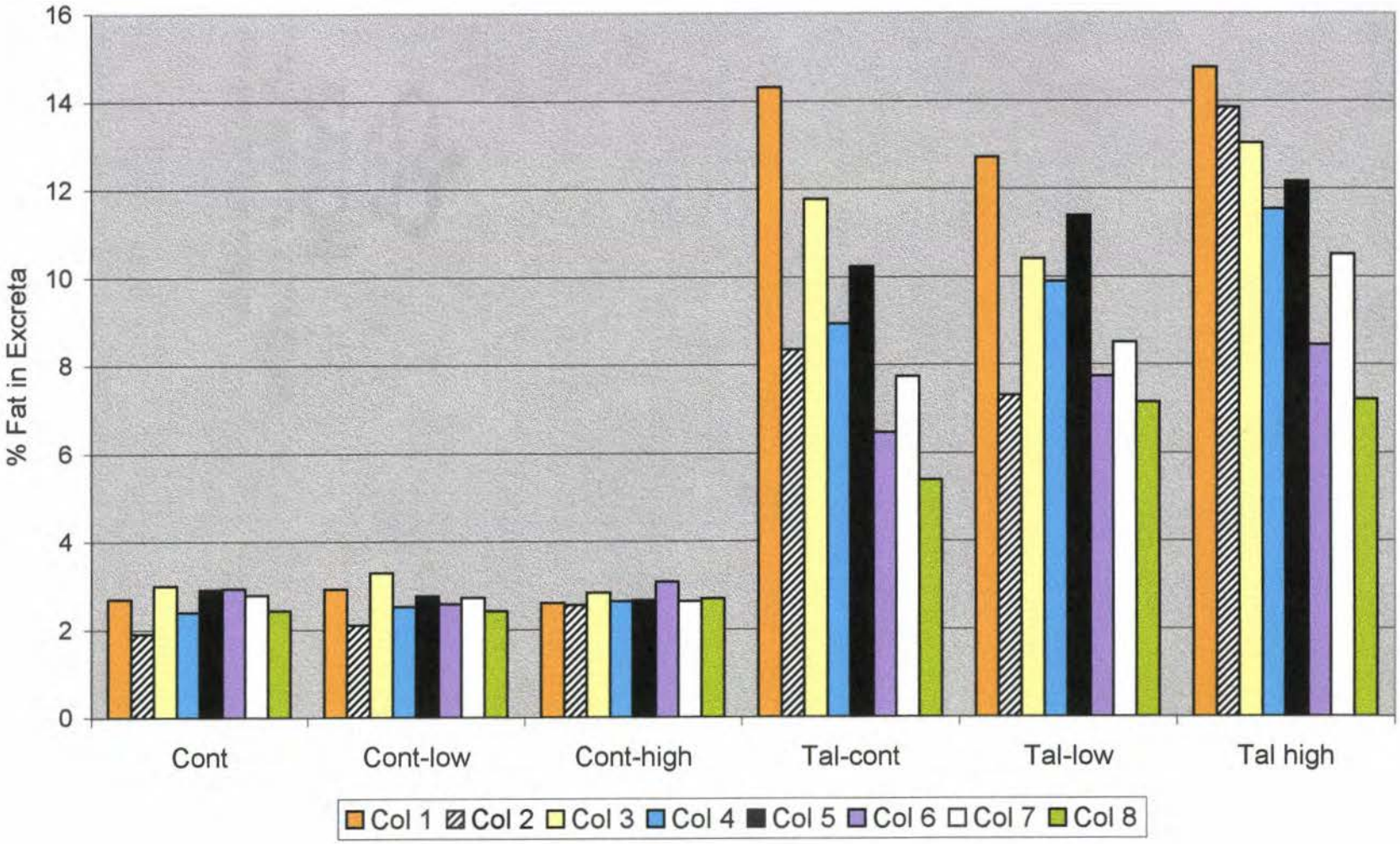
Figure 10: DM Digestibility (%) in Broilers



diet had higher DMD than the high-fat low-dose diet ($P = .0008$). Also, the high-dose diets had significantly different DMD values between control and high-fat (94.99% vs. 90.85%; $P = .0001$). Finally, DMD for birds receiving low-fat control diets was higher than those receiving the control low-dose diet ($P = .0243$). The trend in DM digestibility for the high-fat diets were as follows: control > low-dose and high-dose > low-dose (94.05% vs. 91.62% and 92.22% vs. 91.62). Birds on the low-dose of Yucca showed significantly different DMD between fat sources: control (93.83%) and high-dose (91.62%)(P = .002). Those receiving the high dose of Yucca also had differences in DMD between fat sources: control (94.71%) and high-fat (92.22%)($P = .0006$).

The percentage of fat present in excreta (EF) was examined for each collection period (8 collections total). Figure 11 shows this data for the duration of the study. Significant differences within the same fat source will be discussed. Comparisons between the control and high-fat diets will not be discussed since amount of fat in excreta directly relates to amount of fat in the diet. Thus, birds consuming high fat diets showed higher excretion of fat than those on the control diets regardless of addition of Yucca extract. Following the initial collection period, birds receiving high-fat diets showed differences in the amount of fat excreted between the low-dose and high-dose groups. Those getting a low-dose of Yucca had less fat in their excreta than those on the high-dose diet, 12.73% and 14.77%, respectively ($P = .052$). After the 2nd collection, differences in excreted fat were evident among the high-fat diets. The trend in data was as follows: control > low-dose and high-dose > low-dose (8.36% vs. 7.32% and 13.86% vs. 7.32%). Following collection 3, the high-fat low-dose diet showed a lower excretion of fat than the high-fat high-dose diet ($P = .0136$). Collection 4 showed a higher

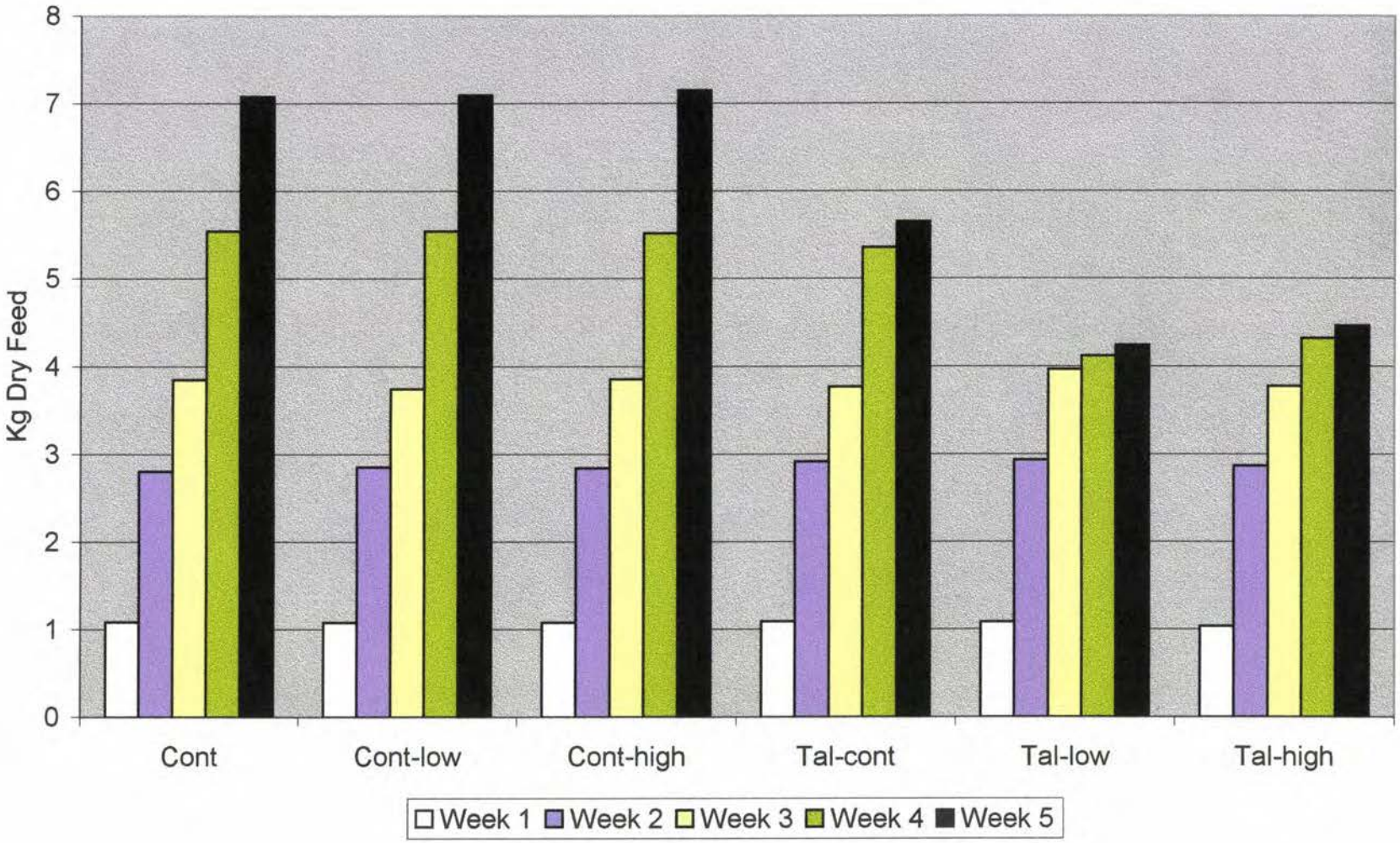
Figure 11: Fat Content of Excreta (%) in Broilers



excretion of fat in the high-fat high-dose diet when compared to the high-fat control diet ($P = .0151$). This trend remained consistent through the seventh collection period. In addition, collection 7 resulted in a difference in fat excretion between the high-fat low-dose diet and the high-fat high-dose diet (8.51% vs. 10.51%; $P = .0571$). Upon cessation of the study, no significant differences in fat excretion existed within the diets of a fat source. As expected, significant differences between fat sources were apparent throughout the duration of the study but these differences are characteristic of the extreme variation in fat level being consumed.

Feed intake is expressed in Figure 12 for each diet, throughout 5 weeks, and recorded on a DM basis (kg). No significant differences in feed intake were present between diets during the first three weeks of the experiment. During the fourth week, the high-fat low-dose diet showed the lowest intake results compared to all other diets (4.12kg). Within the high-fat diets, the birds on the control diet showed significantly higher intakes than both the low-dose and the high-dose diets: 5.36kg, 4.12kg, and 4.33kg, respectively ($P = .0001$). The difference in intakes between the high-fat low-dose diet and the high-fat high-dose diet was not significant. Within the control diets, no significant differences existed between dose groups for feed intake. Birds receiving a low dose of yucca in their diet had significant differences in feed intake levels when comparing the control and high-fat diets. Those on the high-fat diet had lower intakes than those on the control diet (4.12kg vs. 5.45kg; $P = .0001$). In the high-dose groups, birds on the control diet showed higher intakes than birds on the high-fat diet (4.33kg vs. 5.52 kg; $P = .0001$). The differences in feed intake between control and high-fat diets were expected since the higher energy/caloric content of high-fat feed fulfills the needs of

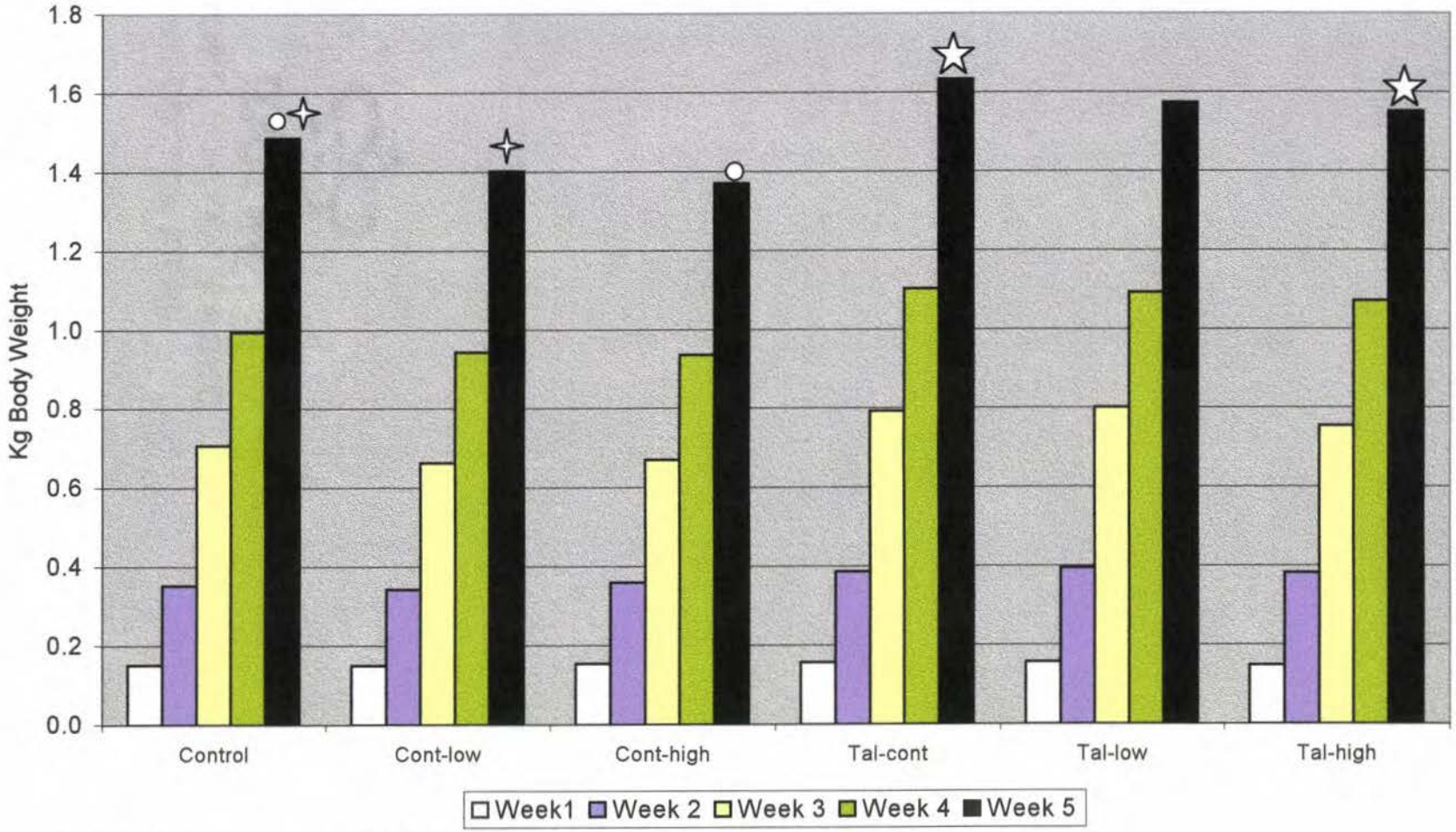
Figure 12: Feed Intake (Kg) for Broilers



the animals much more efficiently than feed that is low in fat. During the 5th week of the experiment, no differences in feed intake levels were seen between dose groups of the control diets. However, within the high-fat diets, birds on the control diet had higher intake levels than both the low-dose and high-dose birds: 5.66kg, 4.25kg, and 4.47kg, respectively ($P = .001$). The difference between the low-dose and high-dose groups was not significant. The high-fat low-dose birds exhibited the lowest intake levels of all diets, which was seen in week 4 as well. The intake levels of the control diets were higher than the high-fat diets in corresponding dose groups. This trend was expected.

Body weights for the 5-week duration of the study are expressed in Figure 13. No significant differences existed between any of the diets during the first and second week of the study. After the third week, birds on the control diets showed lower body weights than those on the high-fat diets for each dose group. This trend was consistent through the fourth week as well. Following the fifth and final week of the study, the birds on the high-fat diets were still showing greater body weights than birds on the control diets, however, significant differences also existed between dose groups within these diets. Body weights of birds receiving control diets exhibited the following trend: control > low-dose > high dose (1.49kg, 1.40kg, and 1.37kg). The differences were significant between the control and low-dose groups ($P = .0297$) as well as the control and the high-dose groups ($P = .0029$), but not significant between low-dose and high-dose groups ($P = .4146$). Within the high-fat diets, birds receiving the high dose of Yucca had significantly lower body weights than the birds receiving the control diet (1.64kg vs. 1.55kg; $P = .0340$). The differences in weights between the control and low-dose groups as well as

Figure 13: Broiler Body Weights (Kg)



Statistical significance ($P<.05$) is represented by identical symbols.

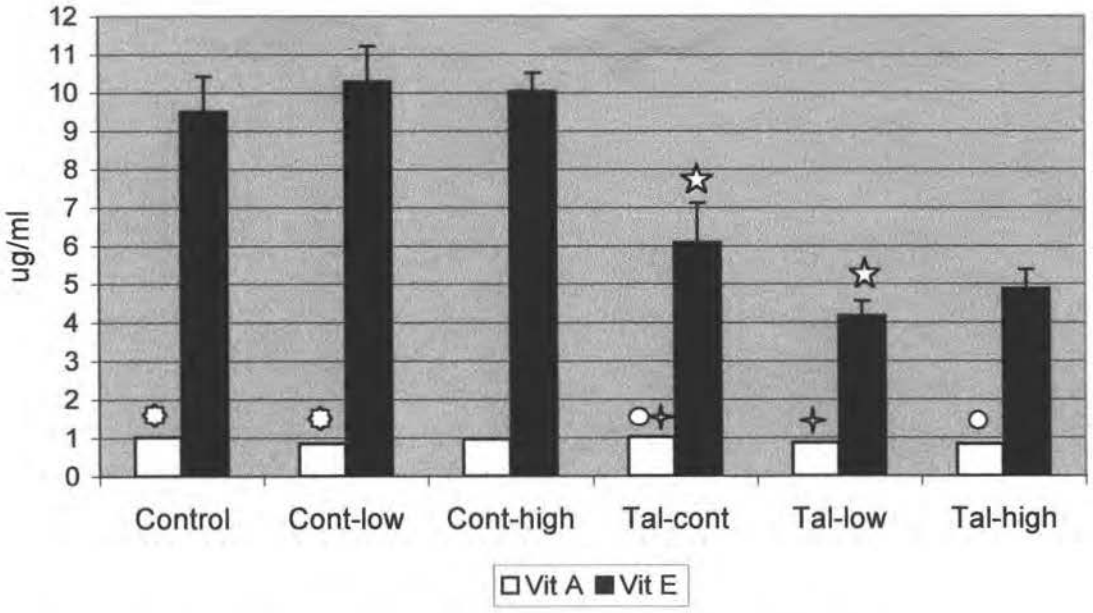
the low-dose and high-dose groups were apparent but insignificant ($P = .1188$ and $P = .5668$).

Vitamin A and E levels were analyzed in the plasma. The plasma was collected on the last day of the fifth week from each bird and results were pooled for each diet. Statistical significance between means was determined by using a t-test. Figure 14 and table 3 show plasma vitamin levels for each experimental diet. Vitamin A levels were lower than Vitamin E levels in general, however, significant differences exist between diets. Birds on the control diet (no added Yucca or fat) had significantly higher vitamin A levels than those on the control diet receiving a low dose of Yucca (1.02ug/ml and 0.85ug/ml; $P = .013$). Within the high-fat diets, birds receiving no Yucca extract showed higher levels of vitamin A in the plasma when compared to those receiving the low-dose of Yucca (1.02ug/ml and .873ug/ml; $P = .008$). Also, birds on the high-dose of Yucca exhibited lower vitamin A levels than the birds receiving no Yucca (1.02ug/ml and .83ug/ml; $P = .003$). Birds receiving the low-dose of Yucca and those on the high-dose of Yucca did not show significant differences in plasma vitamin A levels within the control diets and high-fat diets. Vitamin E levels in plasma were higher in the control diets than in the high-fat diets. Within the control diets, no significant differences were seen between dose groups, although the trend in data shows that both the low-dose and high-dose birds exhibited higher levels of plasma vitamin E levels than the control birds. This trend was not statistically significant. Within the high-fat diets, birds receiving no Yucca showed significantly higher levels of vitamin E in their plasma compared to birds

Table 3: Mean Plasma Vitamin A and E Levels in Broilers

Diet	VitA(ug/ml)	SE	VitE(ug/ml)	SE
Control	1.02	0.05	9.49	0.92
Cont-low	0.85	0.04	10.28	0.94
Cont-high	0.97	0.05	10.03	0.49
Tal-cont	1.02	0.04	6.08	1.03
Tal-low	0.87	0.04	4.17	0.38
Tal-high	0.83	0.04	4.88	0.49

Figure 14: Levels of Plasma Vitamin A and E in Broilers



Statistical Significance (P < .05) is represented by identical symbols.

on the low-dose diet (6.08ug/ml and 4.17ug/ml; $P = .05$). No other significant differences existed between dose groups in the high-fat diets. It should be noted that vitamin E results were much more variable than vitamin A results. The reason for this variability is unknown.

IV.3 Quail Study

The results of this study could not be analyzed statistically due to lack of replications in the experimental unit. In other words, each cage received a specific treatment, but no replicate cages were included in the experimental design. Body weight of the birds is the only component of this study that was analyzed statistically since the experimental unit in this case was each animal (n = 180). However, physical trends in the data collected for feed intake, dry matter digestibility, fat digestibility, and amount of fat in excreta will be discussed. Apparent differences between treatments will be recognized although statistical significance cannot be considered.

Body weights were analyzed using a General Linear Models Procedure by SAS and significant differences were examined by Least Square Means based on the t-distribution. Week, dose, and fat source played a significant role in the linear trend of the data ($P = .0001$). No significant differences in body weights existed initially. After the first week, birds on the high-fat diets showed significant differences between dose groups. The weights of the control birds were significantly higher than those receiving a low dose of Yucca ($P = .0408$). Also, birds in the high dose group had higher body weights than those on the low dose of Yucca ($P = .020$). Comparing bird weights across fat sources, body weights were significantly higher for the control low-dose group when

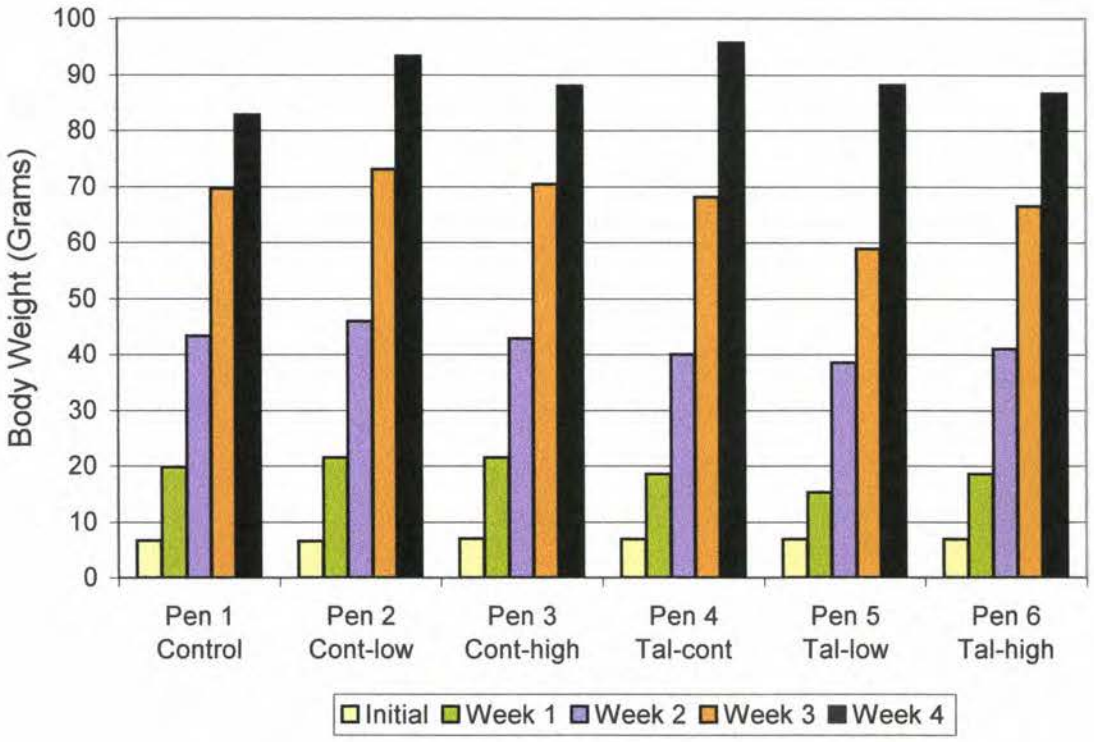
compared to the same dose group in the high-fat diet ($P = .058$). In addition, the weights of birds in the control high-dose group were significantly higher than those birds receiving the high-fat low-dose diet ($P = .0014$). After the second week, similar trends existed for body weights. Birds on the high-fat diets showed significant differences between the low-dose group and the high-dose group ($P = .0296$). Those on the low dose of Yucca weighed less than those on the high dose (38.5g vs. 41.0g). Comparing fat sources, birds on the control low-dose diet were significantly heavier than those on the high-fat low-dose diet, 46.0g and 38.6 g, respectively ($P = .0272$). Body weights were higher for the control high-dose group when compared to the high-fat low-dose group ($P = .0097$). Differences in body weights between diets existed through week 3 with similar trends to the weeks prior (Refer to Figure 15). Final body weights of the quail were significantly different between the following groups: within the high fat diets, the low-dose groups had significantly lower body weights than those birds receiving no Yucca (95.7g vs. 88.2g; $P = .0007$). Across fat sources, body weights were lower for the control diet when compared to the high-fat control diet (82.7g vs. 95.7; $P = .0076$). In addition, the high-fat control diet provided significantly higher body weights than the control diet with a high dose of Yucca (95.7g vs. 88.0g; $P = .0003$). Table 4 shows mean body weights for each diet during the 4-week duration and Figure 15 represents the trends in quail body weights throughout time (n = 30 for each mean within a diet).

Feed intake appeared to decrease for the high-fat groups during the second week of data collection through the fourth week of collection. The feed intake of the high-fat high-dose birds seemed to be lower after four weeks when compared to all other treatments. Within the high-fat diets, feed intake did not seem to differ over time until

Table 4: Mean Body Weights (Grams) in Quail

	Control Pen 1	*Cont-low Pen 2*	*Cont-high Pen 3*	*Tal-cont Pen 4*	*Tal-low Pen 5*	*Tal-high Pen 6*
Initial	6.65	6.54	6.94	6.84	6.85	6.89
Week 1	19.82	21.46	21.54	18.47	15.22	18.54
Week 2	43.35	45.98	42.83	40.01	38.46	40.99
Week 3	69.66	73.05	70.45	68.07	58.86	66.53
Week 4	82.75	93.21	87.96	95.68	88.11	86.61

Figure 15: Mean Body Weights (Grams) in Quail



the fourth week of the experiment. The high-dose group (500ppm Yucca) exhibited decreased feed intake when compared to the low-dose group (100ppm Yucca) and the control group: 1605.27g (high-dose), 1716.96g (low-dose) and 1972.64g (control) were the observed values for feed intake for these treatment groups during the fourth week. Within the diets containing no added fat, the group receiving 100ppm Yucca exhibited increased feed intake during the fourth week in comparison to the control group and the high-dose group (500ppm Yucca). The following values are the observed feed intake levels (week 4) for the high-dose, low-dose, and control groups, respectively: 2016.8g, 2475.4g, and 2151.9g. When comparing feed intake levels between control diets and high-fat diets, the high-fat diets with added Yucca (both low and high doses) appeared to be consistently lower than the corresponding dose levels in the control diets. Significance of these differences cannot be determined. Figure 16 presents mean values for feed intake throughout time for each treatment group (n = 30).

Dry matter digestibility (DMD) showed no consistent trends or differences between treatment groups over time. During the second data collection period, the group receiving the high-fat low-dose (100ppm Yucca) diet, showed a dramatic decrease in DMD when compared to all other treatment groups. This notable trend can be observed in Figure 17, which shows DMD values throughout the six collection periods for all treatment groups.

Within the high-fat diets, fat digestibility appeared lower in the groups receiving both doses of Yucca when compared to the control group. However, this trend was only evident during the first four collections and then dissipated during the last two collection periods. In the control diets, the control group (no added Yucca) showed decreased fat

Figure 16: Quail Feed Intake (grams)

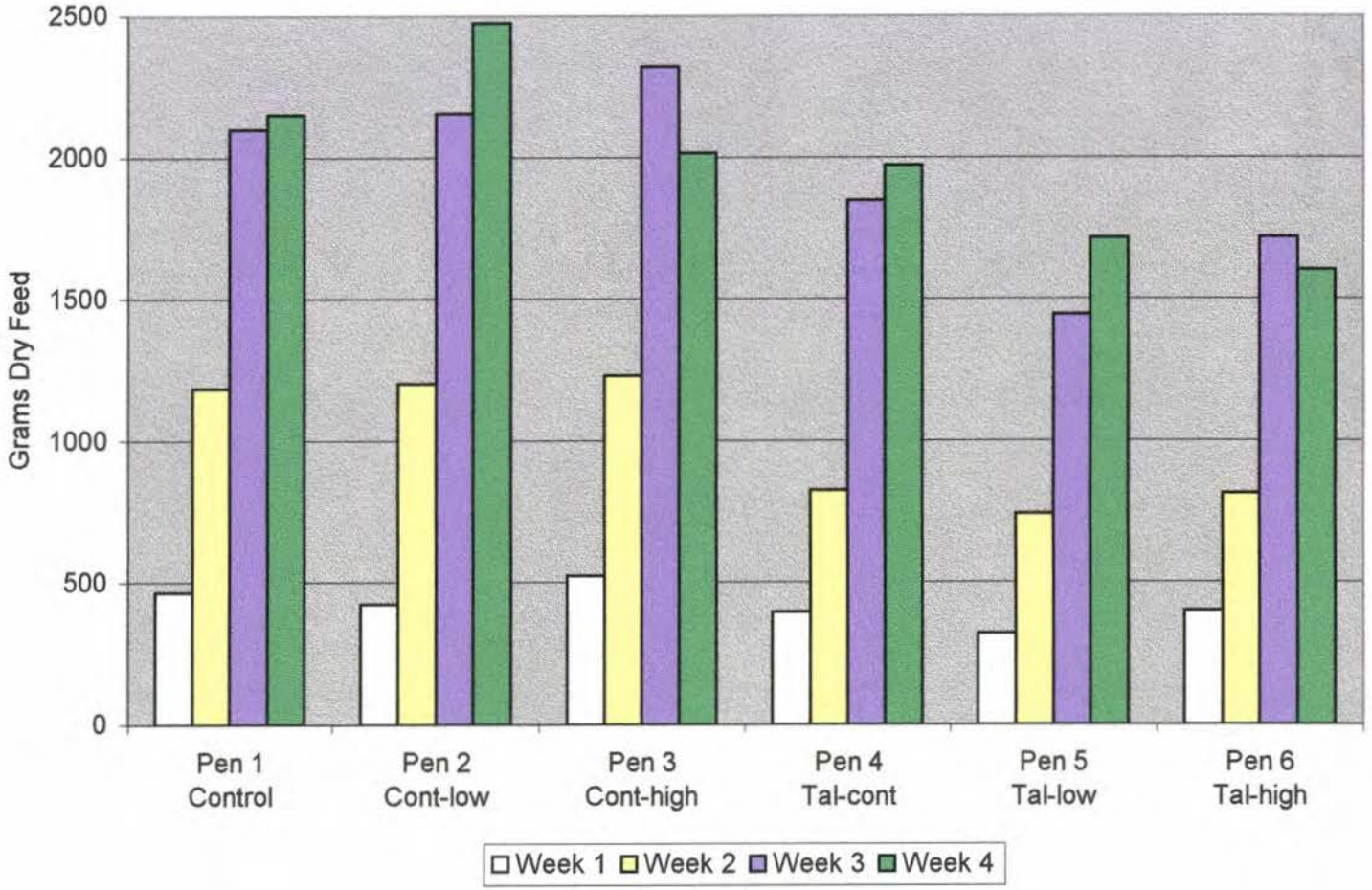
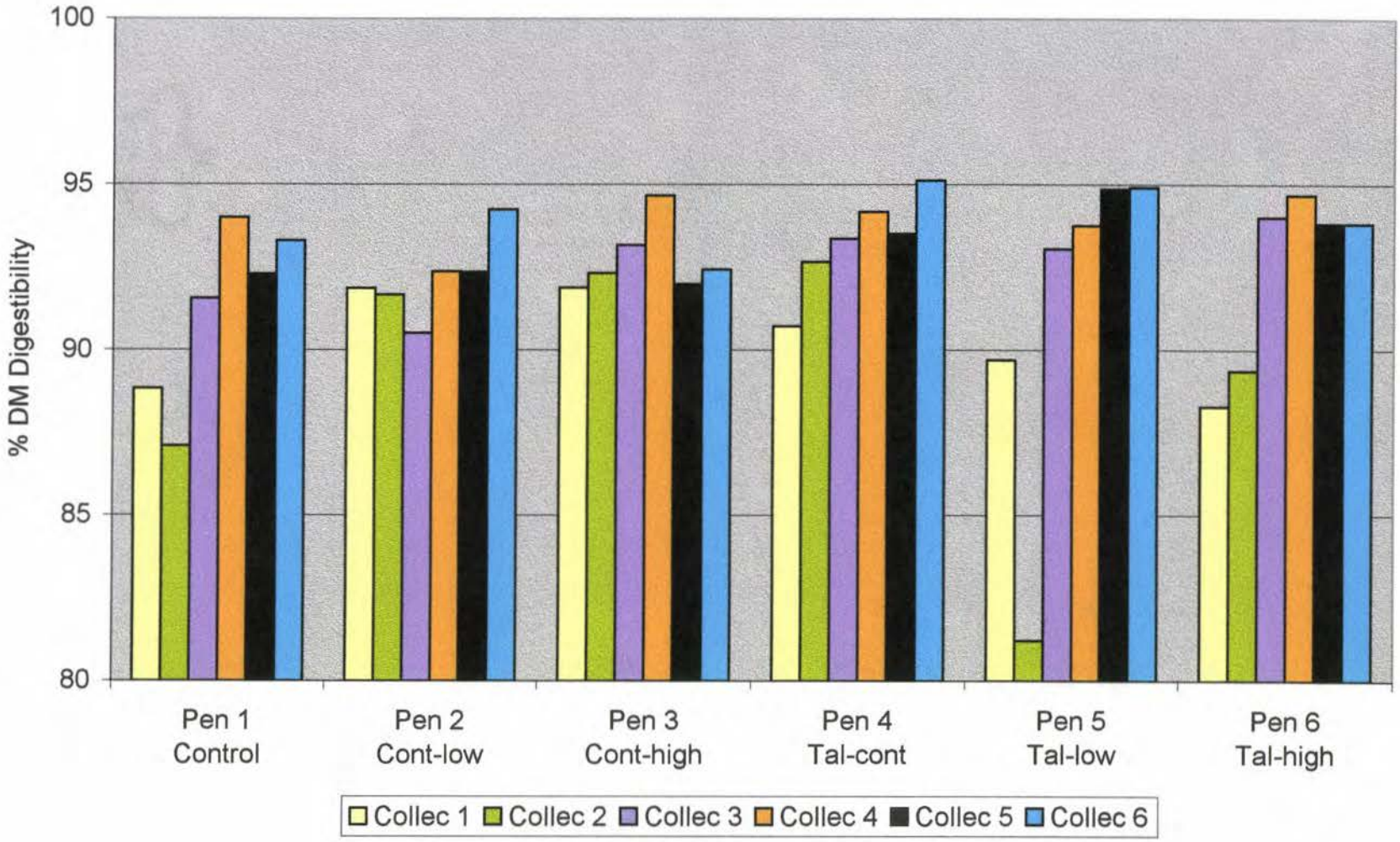


Figure 17: Dry Matter Digestibility (%) in Quail



digestibility during the first two collections when compared to the groups receiving both low and high doses of Yucca. Furthermore, upon reaching the last collection period, the control group had increased fat digestibility when compared to the low and high-dose groups. Figure 18 presents fat digestibility data for each treatment group over time.

The amount of fat present in the excreta for each treatment group throughout a four-week duration appears in Figure 19. The birds receiving control diets exhibited decreased fat excretion when compared to those receiving high-fat diets. These results were expected. No apparent differences in fat excretion appeared between dose groups in the control diets. However, in the high-fat diets, it appeared that during the 3rd and 4th collections, an almost linear increase in fat excretion became evident from control, low-dose, and high-dose groups, respectively. An increase in fat excretion remained evident during the 5th collection period between the control group and added Yucca groups within the high-fat diets (no apparent difference between low and high-dose groups was observed).

Figure 18: Fat Digestibility (%) in Quail

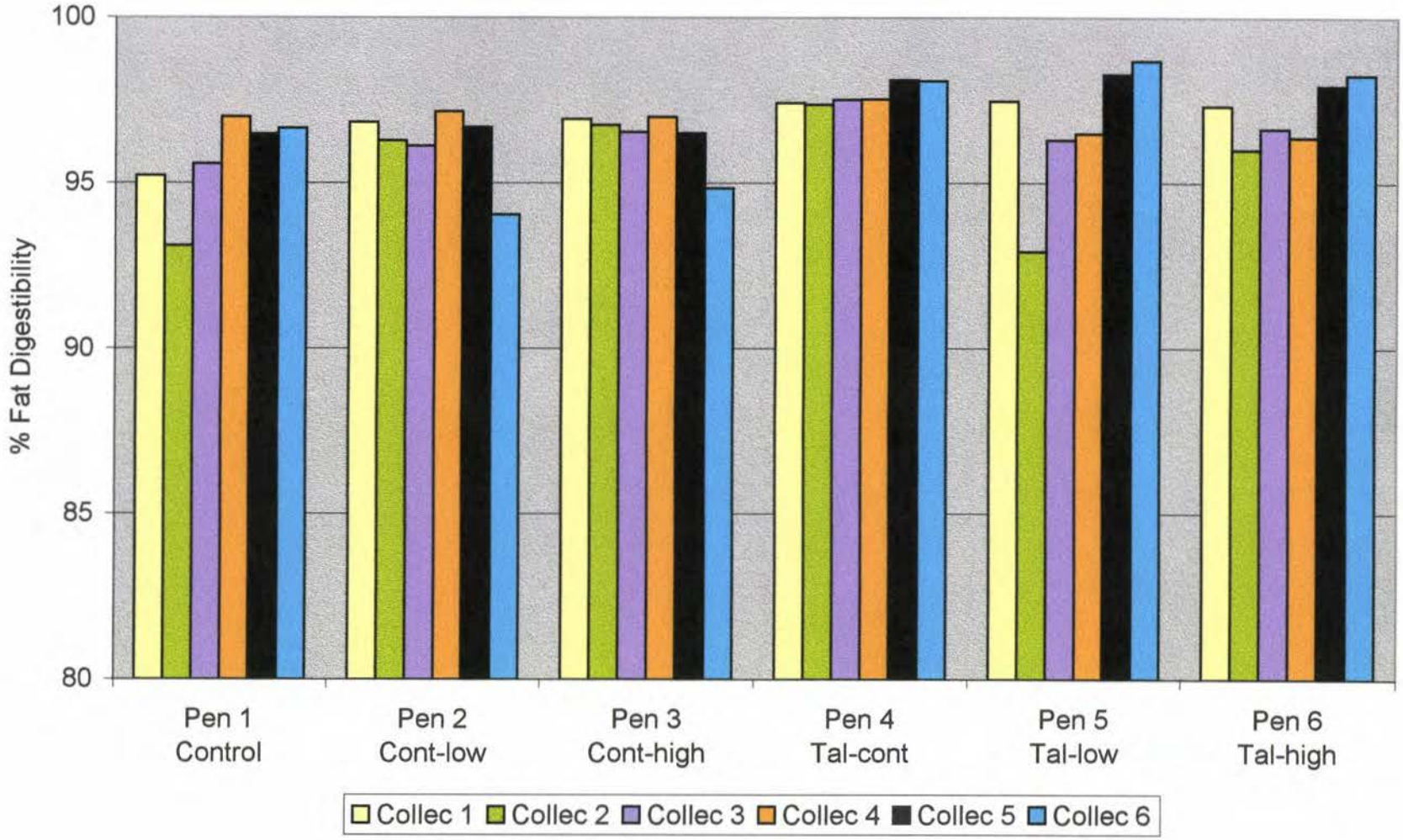
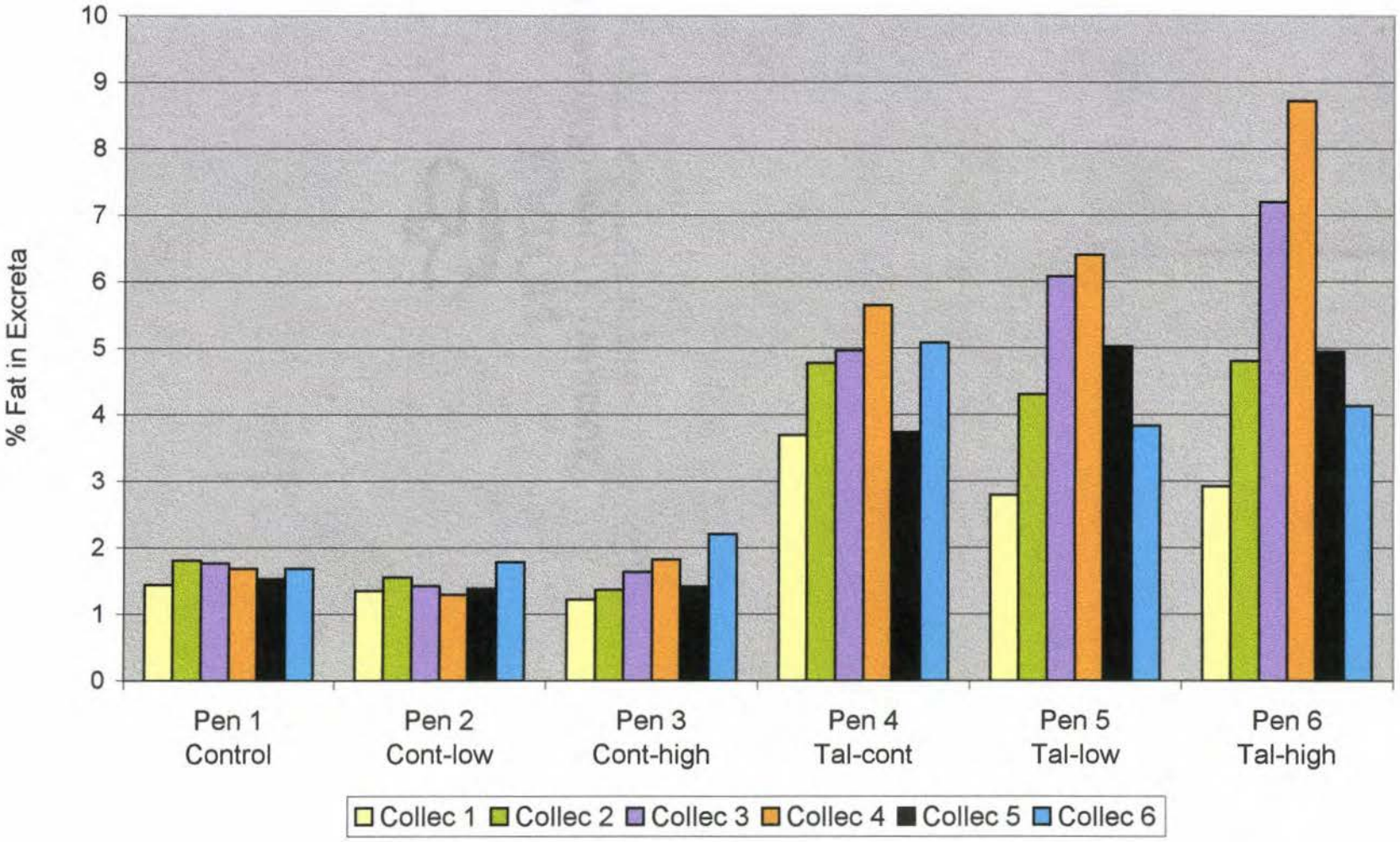


Figure 19: Fat Content of Excreta (%) in Quail



V. Discussion

Fat digestibility (FD) showed different trends in each species from addition of fat and saponin-containing extracts to the diet. FD in roosters was not affected by adding either *Yucca schidigera* or *Quillaja saponaria* to high fat diets. These birds maintained a fat digestibility level over 90% for all diets (with or without extracts). For growing broilers, changes in fat digestibility occurred over time. After the first 4 days, chicks on the control diets (no added fat) showed higher FD than those on tallow diets for each dose of yucca, respectively. However, following the second collection, chicks on the tallow diets receiving a high dose of yucca had lower fat digestibility than the low dose group and the control group. No differences in FD existed between any of the groups during the third and fourth collections. After the fifth collection, birds on the tallow diets receiving a high dose of yucca, had lower FD than the low dose group and the control group (the same trend seen after the second collection). A decrease in fat digestibility was also observed in studies conducted by Jenkins and Atwal (1994) on broiler chicks. However, the decrease in fat digestibility was only apparent in chicks receiving triterpenoid saponins (Quillaja and Gypsophylla) and no effects on FD were seen with addition of yucca saponins. The decreases in FD observed in this study are in agreement with those seen in the study conducted by Jenkins and Atwal (1994) but yucca saponins appear to show the same effects as the triterpene saponins. In the present study, no differences in fat digestibility were seen after the sixth collection (8 collections total). Fat digestibility in broilers remained above 90% for all experimental diets following the second collection. Quail showed inconsistent trends in FD over time. In general, quail on the high fat diets showed higher fat digestibility values within each dose group when

compared to the control diets (no added fat). For the first four collections, the high fat diets receiving yucca (low and high) showed lower FD than the control (no yucca). However, this trend reversed during the fifth and sixth collection and quail receiving low and high doses of yucca had higher fat digestibility values than the control group within the tallow diets. Following the final collection, fat digestibility decreased in quail receiving the low and high doses of yucca within the control diets (no added fat) when compared to those receiving no yucca. FD in quail remained above 90% throughout the duration of the experiment. The research that was conducted by Reshef *et* al. (1976) on quail showed that lipid digestibility was unaffected by addition of saponins to their diet. However, the results of this study show that addition of saponins to diets of varying fat levels results in a decrease in fat digestibility for low fat diets and an increase in fat digestibility for high fat diets. Reshef *et* al. (1976) also concluded that the role of saponins in the lipid metabolism of quail is different than mice. In the present study, quail show different trends in fat digestibility with addition of saponins to their diet than roosters and broilers do. Thus, species differences are apparent here as well.

Feed intake for roosters was unaffected by addition of yucca and quillaja extracts to high fat diets containing soybean oil and coconut oil as the fat sources. In the case of tallow, roosters showed higher intake levels when a high dose of yucca was incorporated into the diet as compared to those receiving a low dose. The low dose of yucca added to the tallow diet decreased feed intake to a level less than that of the roosters on the control dose. In broilers, addition of yucca to the control diets (no added fat) showed no effect on feed intake. However, quail receiving a low dose of yucca added to the control diet showed increased feed intake compared to the high dose and control dose birds. This

difference only existed after four weeks. Feed intake decreased in broilers on the high fat diets for the low and high dose groups compared to the control dose group, but this trend was only apparent after four weeks. Quail shared the same trends in feed intake as broilers did for the high fat diets and these were apparent after three weeks. Research done by Jenkins and Atwal (1994) shows that saponins from different sources have different effects on feed intake for broiler chicks. Chicks receiving yucca saponins did not exhibit changes in feed intake while those receiving quillaja and gypsophylla saponins experienced a decrease in intake levels. In the present study, feed intake for roosters, broilers, and quail was decreased and increased by addition of saponins to the diet, but dependent on dietary fat level and source of dietary fat. Addition of varying levels of saponins to diets of swine, rats, chickens, and rabbits has been shown to decrease feed intake in past studies (Cheeke *et* al. 1977, 1983; Heywang *et* al. 1954; Jenkins and Atwal 1994; Leamaster and Cheeke 1979; Peterson 1950). The increase in feed intake seen in roosters on a high-dose of yucca in this study is not in agreement with results from these prior studies.

Roosters exhibited an increased rate of fat excretion when given a low dose of yucca compared to those receiving no yucca for the tallow diets. No differences in fat excretion were seen between other dose groups within the tallow diets or for all doses of coconut oil and soybean oil diets. In broilers, addition of yucca at a high dose resulted in increased excretion of fat throughout the duration of the study. However, this trend only existed in the high fat diets and not in the control diets (no added fat). Yucca had no effect on fat excretion in the control diets of broilers. Quail showed increased fat excretion in the high fat diets when yucca was supplemented, however, upon the final

collection period, this trend reversed. Thus, quail receiving low and high doses of yucca exhibited decreased excretion of fat compared to those which were not receiving yucca in their diet. As in the case of broilers, no differences in fat excretion were seen between dose groups of the control diets (no added fat) in quail. Addition of yucca to high fat diets (tallow-based) appears to increase fat excretion in roosters, broilers, and quail. These findings are consistent with results from studies done by Reshef *et* al. (1976) where increases in fecal lipid content occurred in mice receiving saponins in their diet. Research done by Topping *et* al. (1980), Oakenfull *et* al. (1979), Reshef *et* al. (1976) and Morgan *et* al. (1972) showed that saponins bind with bile acids and cholesterol causing increases in excretion of bile acids and also increases in cholesterol excretion. The binding of saponins to bile acids could have an effect on excretion of fat as well. Binding of bile acids with saponins would decrease the availability of bile acids to emulsify fat in the gut and lipid would then be excreted instead of absorbed. The present study shows that quail overcome the increase in fat excretion over time while broilers do not. These results show possible species differences in effects of saponins on lipid metabolism which was also seen in the work of Reshef *et* al (1976). Jenkins and Atwal (1994) found that addition of cholesterol and saponins to the diet increased the excretion of cholesterol but that the effects were not as pronounced when cholesterol was not added to the diet. This trend may occur for dietary lipid as well. The present study showed increased lipid excretion in all three types of birds but only when fat and saponins were added to the diet.

Addition of saponin-containing extracts to high fat diets of roosters had no effect on body weights. Broilers on the high fat diets showed higher body weights for each dose group compared to those on control diets (no added fat) after three weeks. Addition

of yucca to the control diets showed a decrease in body weights for broilers receiving low and high doses of yucca compared to those receiving no yucca during the fifth week. Also, within the high fat diets, broilers receiving no yucca exhibited higher body weights than those on the high dose of yucca. Quail also showed decreased body weights within the high fat diets when supplemented with both doses of yucca compared to those receiving no yucca. This trend was only seen after the fourth week. These decreases in body weights might be attributed to decreased feed intake in these groups. Oakenfull *et* al. (1979) saw a decrease in body weights for rats receiving both saponins and cholesterol in their diet but no changes in body weight for the rats not receiving added cholesterol. This body weight trend seen with cholesterol might also exist with dietary lipid based on the current results seen in birds.

Plasma vitamin A levels in broilers were affected by addition of *Yucca schidigera* to the control diets and the high fat diets. Birds receiving no yucca showed higher levels of plasma vitamin A than those receiving low doses of yucca in both control and high fat diets. Within the high fat diets, birds receiving a high dose of yucca exhibited lower plasma vitamin A levels than those receiving no yucca. However, differences between low and high doses were not apparent for vitamin A levels. Plasma vitamin E levels were not different among dose levels for the control diets (no added fat). Within the high fat diets, birds receiving no yucca showed higher plasma vitamin E levels than those receiving a low dose of yucca. In addition, birds on the high dose of yucca appeared to have lower vitamin E levels than the control but these were not statistically significant. These results are in agreement with the findings of Jenkins and Atwal (1994). Addition of *Yucca schidigera* extract to the diets of growing broilers seems to significantly decrease

plasma vitamin A and E levels when birds are receiving a high fat diet, however, dose level does not seem significant (no apparent difference between low and high). In the study conducted by Jenkins and Atwal (1994), only saponins at a dietary level of 0.9% showed effects on plasma vitamin A and E levels. Thus, the present study shows that saponins added to a high fat diet affect plasma vitamin A and E levels at a low dose (0.1%) and high dose (0.5%) but no dose-response relationship is apparent. These effects were not examined in roosters or quail, therefore, species comparisons could not be made.

It is evident in these studies that *Quillaja saponaria* and *Yucca schidigera* extracts do not affect fat digestibility, feed intake, or body weights in adult roosters. *Yucca schidigera* extract did show effects on fat excretion in roosters receiving a high fat diet (tallow-based). Addition of yucca to a high fat diet seems to affect fat digestibility, feed intake, body weights, and fat excretion in growing broiler chicks and quail but these trends change throughout the growing cycle of each. In general, level of dietary fat seems to play a role in the effects of *Yucca schidigera* supplementation in growing birds. Effects of yucca on fat excretion , feed intake, and growth were more pronounced in the birds receiving added fat in their diet compared to no added fat. In the case of fat-soluble vitamin availability, it is apparent that addition of yucca into low fat and high fat diets affected the level of vitamin A present in the plasma. Plasma vitamin E levels were unaffected by the addition of yucca to diets with no added fat while birds receiving a high fat diet and a yucca supplement showed decreased levels of plasma vitamin E. No differences were seen between dose groups for plasma vitamin A and E levels in low fat

and high fat diets. The low dose exhibits the same effect as the high dose. Thus, increasing the dose of the extract does not increase the response.

VI. Conclusions

In the present studies, factors such as age, stage of production, level of dietary fat, dose level of saponin-containing extract, species, and time should all be considered in the interpretation of results. Addition of *Yucca schidigera* extract to high fat diets (tallow-based) increased lipid excretion in roosters, broilers, and quail. In roosters, dose of yucca extract affected excretion of lipid but no dose effects were seen in broilers or quail. Quail overcame the increase in lipid excretion over time while the broilers did not. Fat digestibility was not significantly affected by addition of saponins to the diet of adult roosters. However, fat digestibility was reduced in broilers and quail consuming a high fat diet. In general, level of dietary fat seemed to play a role in the effects of *Yucca schidigera* supplementation in growing birds. Addition of *Yucca schidigera* to high fat diets resulted in decreased plasma levels of vitamin A and E in broiler chicks.

Saponins from various plant sources have not shown consistent effects on lipid and cholesterol metabolism in different species of animals. Further research on modes of actions of saponins in different species should be investigated. If decreased performance and production result from decreases in nutrient availability and absorption seen with supplementation of saponin-containing extracts to diets of animals, then serious consideration should be taken in using these supplements for animal agriculture. If, in fact, saponins have the ability to bind bile acids and increase the excretion of fat, this could play a beneficial role in human nutrition as a means for fighting obesity since dietary fat would not be absorbed and stored in the body. On the other hand, if saponins bind fat-soluble nutrients thus making them unavailable for absorption, this could have detrimental effects on both human and animal nutrition by inducing nutritional

deficiencies. Further research is necessary in order to establish valid conclusions about the effects of saponin-containing extracts on various parameters of growth and performance in domestic fowl. Recognizing and defining modes of action and chemical specificity of saponins is a crucial next step in this realm of scientific research.

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APPENDIX

Table 1. Plasma Vitamin A Levels (ug/ml) in Broilers

	Control Pen 1	*Control* Pen 2	*Cont-low* Pen 3	*Cont-low* Pen 4	*Cont-high* Pen 5	*Cont-high* Pen 6	*Tal-cont* Pen 7	*Tal-cont* Pen 8	*Tal-low* Pen 9	*Tal-low* Pen 10	*Tal-high* Pen 11	*Tal-high* Pen 12
Mean	1.06	0.98	0.92	0.79	0.98	0.96	0.97	1.09	0.91	0.83	0.80	0.87
SE	0.07	0.06	0.06	0.05	0.08	0.05	0.05	0.04	0.06	0.05	0.05	0.07
Median	1.05	0.96	0.94	0.82	0.94	0.91	1.02	1.08	0.88	0.83	0.82	0.82
SD	0.21	0.18	0.18	0.14	0.22	0.13	0.14	0.09	0.16	0.12	0.15	0.20
Sample Var.	0.04	0.03	0.03	0.02	0.05	0.02	0.02	0.01	0.02	0.02	0.02	0.04
Range	0.56	0.51	0.46	0.39	0.59	0.38	0.4	0.23	0.46	0.38	0.4	0.55
Minimum	0.79	0.71	0.67	0.59	0.69	0.84	0.74	0.97	0.72	0.66	0.55	0.63
Maximum	1.35	1.22	1.13	0.98	1.28	1.22	1.14	1.2	1.18	1.04	0.95	1.18
Count	8	8	8	8	8	7	8	6	8	7	8	8

Table 2. Plasma Vitamin E Levels (ug/ml) in Broilers

	Control Pen 1	*Control* Pen 2	*Cont-low* Pen 3	*Cont-low* Pen 4	*Cont-high* Pen 5	*Cont-high* Pen 6	*Tal-cont* Pen 7	*Tal-cont* Pen 8	*Tal-low* Pen 9	*Tal-low* Pen 10	*Tal-high* Pen 11	*Tal-high* Pen 12
Mean	6.77	8.55	9.39	7.52	10.07	9.98	5.92	4.23	4.24	4.11	5.39	4.37
SE	0.56	0.87	0.68	1.25	0.71	0.72	0.49	0.70	0.58	0.51	0.75	0.63
Median	6.23	8.10	9.82	7.78	9.99	9.82	5.72	3.39	4.00	3.67	4.70	4.14
SD	1.37	2.12	1.80	2.80	2.02	1.89	1.28	1.72	1.65	1.36	2.12	1.78
Sample Var.	1.88	4.50	3.23	7.84	4.07	3.58	1.65	2.97	2.73	1.85	4.51	3.15
Range	3.45	5.68	4.5	5.71	5.82	5.08	3.640	4.31	5.23	3.26	6.62	4.34
Minimum	5.48	6.3	6.68	4.55	6.97	7.63	4.54	2.94	2.66	2.59	2.54	2.43
Maximum	8.93	11.98	11.18	10.26	12.79	12.71	8.18	7.25	7.89	5.85	9.16	6.77
Count	6	6	7	5	8	7	7	6	8	7	8	8

Table 3. Broiler Body Weights (Kg)

	Cont Pen 1	Cont Pen 2	Cont-low Pen 3	Cont-low Pen 4	Cont-high Pen 5	Cont-high Pen 6	Tal-cont Pen 7	Tal-cont Pen 8	Tal-low Pen 9	Tal-low Pen 10	Tal-high Pen 11	Tal-high Pen 12
Week 1	0.15	0.15	0.14	0.16	0.15	0.16	0.16	0.15	0.15	0.16	0.14	0.15
Week 2	0.36	0.35	0.33	0.35	0.35	0.37	0.39	0.38	0.40	0.40	0.37	0.40
Week 3	0.72	0.70	0.66	0.67	0.65	0.70	0.79	0.80	0.81	0.79	0.74	0.77
Week 4	1.01	0.98	0.96	0.93	0.91	0.96	1.07	1.14	1.10	1.09	1.04	1.10
Week 5	1.50	1.47	3.11	3.07	2.87	3.15	3.53	3.59	1.58	1.57	1.51	1.59

Table 4. Fat Digestibility (%) in Broilers

Collect #	Cont Pen 1	Cont Pen 2	Cont-low Pen 3	Cont-low Pen 4	Cont-high Pen 5	Cont-high Pen 6	Tal-cont Pen 7	Tal-cont Pen 8	Tal-low Pen 9	Tal-low Pen 10	Tal-high Pen 11	Tal-high Pen 12
1	91.33	92.62	92.72	92.43	93.73	92.06	89.04	89.42	91.85	86.62	90.51	87.73
2	97.19	97.37	97.38	97.12	96.44	96.50	97.04	96.84	97.11	95.89	92.39	94.98
3	95.43	95.14	94.10	94.91	95.93	95.24	95.10	94.83	95.59	95.36	94.56	93.98
4	95.18	95.22	95.31	95.09	94.07	95.69	96.34	95.69	96.32	94.31	94.81	93.78
5	95.78	96.38	94.87	96.92	95.87	96.12	97.00	94.77	97.10	96.66	93.52	95.22
6	95.92	96.20	95.81	96.01	96.46	94.05	97.57	97.43	97.31	96.67	95.70	96.37
7	96.03	95.95	95.45	95.85	94.88	95.86	96.87	97.02	96.36	96.47	92.53	95.25
8	96.50	96.14	95.06	95.06	95.19	94.87	97.81	97.29	96.97	96.08	96.87	95.98

Table 5. Dry Matter Digestibility (%) in Broilers

Collect #	Cont Pen 1	Cont Pen 2	Cont-low Pen 3	Cont-low Pen 4	Cont-high Pen 5	Cont-high Pen 6	Tal-cont Pen 7	Tal-cont Pen 8	Tal-low Pen 9	Tal-low Pen 10	Tal-high Pen 11	Tal-high Pen 12
1	89.58	90.18	91.68	90.82	91.46	90.54	89.08	90.83	91.08	89.15	90.27	90.31
2	95.04	95.23	95.56	95.46	95.48	95.39	95.44	94.80	94.78	93.96	93.48	94.64
3	95.00	94.27	94.00	94.52	95.18	94.55	94.44	94.20	94.44	95.19	94.17	94.25
4	93.48	92.85	93.64	93.21	93.01	94.24	94.40	93.79	94.57	94.27	93.06	93.81
5	95.89	95.54	94.46	96.67	95.23	96.09	96.04	93.48	95.05	95.51	92.16	93.38
6	96.11	95.26	95.36	95.16	96.67	94.55	94.59	95.22	93.59	93.11	92.50	92.76
7	95.72	95.13	95.44	94.98	94.87	95.10	95.01	94.60	92.86	92.70	90.89	90.81
8	95.29	95.49	94.58	93.07	94.40	95.01	94.49	93.60	91.32	91.91	92.48	91.95

Table 6. Excreta Weights (Grams) in Broilers

Collect #	Cont Pen 1	Cont Pen 2	Cont-low Pen 3	Cont-low Pen 4	Cont-high Pen 5	Cont-high Pen 6	Tal-cont Pen 7	Tal-cont Pen 8	Tal-low Pen 9	Tal-low Pen 10	Tal-high Pen 11	Tal-high Pen 12
1	125	108	104	124	111	123	142	110	107	141	107	126
2	114	105	100	109	104	106	105	117	120	142	137	126
3	155	172	180	170	145	169	175	174	175	154	169	181
4	238	254	227	248	246	213	210	211	201	212	243	223
5	191	200	247	153	210	174	178	264	198	182	302	265
6	217	256	255	271	178	289	295	232	266	286	315	315
7	278	312	294	331	323	306	302	262	307	303	401	400
8	344	356	401	520	409	354	364	304	382	334	346	346

Table 7. Fat Content of Excreta (%) in Broilers

Collect #	Cont Pen 1	Cont Pen 2	Cont-low Pen 3	Cont-low Pen 4	Cont-high Pen 5	Cont-high Pen 6	Tal-cont Pen 7	Tal-cont Pen 8	Tal-low Pen 9	Tal-low Pen 10	Tal-high Pen 11	Tal-high Pen 12
1	2.84	2.57	3.01	2.84	2.44	2.79	13.33	15.34	10.83	14.63	12.86	16.68
2	1.93	1.88	2.03	2.19	2.61	2.52	8.63	8.08	6.57	8.06	15.37	12.35
3	3.11	2.89	3.39	3.20	2.80	2.90	11.72	11.84	9.41	11.42	12.29	13.81
4	2.52	2.28	2.54	2.49	2.82	2.48	8.68	9.23	8.03	11.77	9.86	13.23
5	3.26	2.58	2.77	2.77	2.49	2.85	9.94	10.53	10.06	12.74	13.00	11.35
6	3.34	2.55	2.70	2.46	3.06	3.13	5.89	7.06	7.19	8.29	9.02	7.89
7	2.95	2.64	2.98	2.47	2.87	2.43	8.23	7.25	8.74	8.28	12.90	8.12
8	2.36	2.51	2.72	2.13	2.47	2.95	5.21	5.57	5.98	8.32	6.56	7.86

Table 8. Feed Intake (Kg) in Broilers

	Control Pen 1	Control Pen 2	Cont-low Pen 3	Cont-low Pen 4	Cont-high Pen 5	Cont-high Pen 6	Tal-cont Pen 7	Tal-cont Pen 8	Tal-low Pen 9	Tal-low Pen 10	Tal-high Pen 11	Tal-high Pen 12
Week 1	1.09	1.08	1.02	1.14	1.02	1.14	1.16	1.02	1.02	1.15	1.00	1.07
Week 2	2.81	2.81	2.81	2.90	2.77	2.92	2.95	2.88	2.91	2.97	2.78	2.96
Week 3	3.86	3.84	3.72	3.77	3.74	3.97	4.02	3.51	3.95	3.98	3.72	3.83
Week 4	5.55	5.54	5.53	5.56	5.45	5.59	5.63	5.09	4.12	4.12	4.19	4.46
Week 5	7.10	7.06	7.08	7.12	7.15	7.16	6.61	4.70	4.38	4.11	4.61	4.32

Table 9. Fat Digestibilities (%) in Quail

	Control	*Cont-low*	*Cont-high*	*Tal-cont*	*Tal-low*	*Tal-high*
	Pen 1	Pen 2	Pen 3	Pen 4	Pen 5	Pen 6
Collec 1	95.22	96.84	96.93	97.43	97.48	97.32
Collec 2	93.10	96.29	96.76	97.38	92.93	96.01
Collec 3	95.58	96.13	96.55	97.53	96.30	96.64
Collec 4	97.00	97.17	97.00	97.54	96.50	96.38
Collec 5	96.49	96.70	96.51	98.13	98.29	97.94
Collec 6	96.65	94.05	94.85	98.09	98.70	98.28

Table 10. Dry Matter Digestibilities (%) in Quail

	Control	*Cont-low*	*Cont-high*	*Tal-cont*	*Tal-low*	*Tal-high*
	Pen 1	Pen 2	Pen 3	Pen 4	Pen 5	Pen 6
Collec 1	88.84	91.86	91.89	90.73	89.70	88.29
Collec 2	87.11	91.67	92.32	92.67	81.23	89.37
Collec 3	91.55	90.52	93.17	93.37	93.05	94.02
Collec 4	94.00	92.37	94.67	94.18	93.75	94.69
Collec 5	92.29	92.36	92.00	93.51	94.87	93.82
Collec 6	93.30	94.24	92.44	95.13	94.91	93.83

Table 11. Excreta Weights (Grams) in Quail

	Control	*Cont-low*	*Cont-high*	*Tal-cont*	*Tal-low*	*Tal-high*
	Pen 1	Pen 2	Pen 3	Pen 4	Pen 5	Pen 6
Collec 1	52	35	43	38	34	48
Collec 2	116	75	73	55	107	67
Collec 3	114	128	99	65	57	55
Collec 4	114	145	112	92	75	76
Collec 5	162	172	176	122	77	105
Collec 6	146	140	155	96	84	100

Table 12. Feed Intake (Grams) in Quail

	Control	*Cont-low*	*Cont-high*	*Tal-cont*	*Tal-low*	*Tal-high*
	Pen 1	Pen 2	Pen 3	Pen 4	Pen 5	Pen 6
Week 1	466.4	426.2	524.7	397.3	323.0	403.8
Week 2	1186.4	1204.9	1229.8	827.7	745.4	815.8
Week 3	2102.8	2155.7	2320.1	1848.8	1444.6	1721.1
Week 4	2151.9	2475.4	2016.8	1972.6	1717.0	1605.3

Table 13. Fat Content of Excreta (%) in Quail

	Control	*Cont-low*	*Cont-high*	*Tal-cont*	*Tal-low*	*Tal-high*
	Pen 1	Pen 2	Pen 3	Pen 4	Pen 5	Pen 6
Collec 1	1.45	1.36	1.23	3.70	2.80	2.93
Collec 2	1.81	1.56	1.37	4.78	4.31	4.81
Collec 3	1.77	1.43	1.64	4.97	6.08	7.20
Collec 4	1.69	1.30	1.83	5.65	6.41	8.72
Collec 5	1.54	1.39	1.42	3.74	5.03	4.95
Collec 6	1.69	1.79	2.21	5.09	3.84	4.14

Table 14. Quail Body Weights (Grams)

	Control	*Cont-low*	*Cont-high*	*Tal-cont*	*Tal-low*	*Tal-high*
	Pen 1	*Pen 2*	*Pen 3*	*Pen 4*	*Pen 5*	*Pen 6*
Initial	6.65	6.54	6.94	6.84	6.85	6.89
Week 1	19.82	21.46	21.54	18.47	15.22	18.54
Week 2	43.35	45.98	42.83	40.01	38.46	40.99
Week 3	69.66	73.05	70.45	68.07	58.86	66.53
Week 4	82.75	93.21	87.96	95.68	88.11	86.61

Table 15. Rooster Body Weights (Kg): Tallow Diets

Initial

	Control	*Quill-high*	*Quill-low*	*Yuc-high*	*Yuc-low*
Mean	2.291	2.381	2.412	2.192	2.208
SE	0.148	0.165	0.139	0.106	0.137
Median	2.223	2.291	2.472	2.155	2.200
Sdev	0.363	0.404	0.341	0.261	0.337
SamVar	0.131	0.164	0.116	0.068	0.113
Count	6	6	6	6	6

Final

	Control	*Quill-high*	*Quill-low*	*Yuc-high*	*Yuc-low*
Mean	2.306	2.397	2.419	2.215	2.109
SE	0.129	0.145	0.148	0.090	0.085
Median	2.291	2.291	2.517	2.223	2.064
Sdev	0.315	0.355	0.361	0.221	0.208
SamVar	0.099	0.126	0.131	0.049	0.043
Count	6	6	6	6	6

Table 16. Rooster Body Weights (Kg): Coconut Oil Diets

Initial

	Control	*Quill-high*	*Quill-low*	*Yuc-high*	*Yuc-low*
Mean	2.344	2.313	2.366	2.139	2.533
SE	0.261	0.158	0.143	0.124	0.117
Median	2.268	2.177	2.313	2.041	2.517
Sdev	0.639	0.388	0.351	0.303	0.286
SamVar	0.408	0.151	0.123	0.092	0.082
Count	6	6	6	6	6

Final

	Control	*Quill-high*	*Quill-low*	*Yuc-high*	*Yuc-low*
Mean	2.397	2.321	2.306	2.132	2.487
SE	0.209	0.151	0.142	0.115	0.110
Median	2.268	2.200	2.336	2.064	2.449
Sdev	0.513	0.369	0.348	0.283	0.270
SamVar	0.263	0.136	0.121	0.080	0.073
Count	6	6	6	6	6

Table 17. Rooster Body Weights (Kg): Soybean Oil Diets

Initial

	Control	*Quill-high*	*Quill-low*	*Yuc-high*	*Yuc-low*
Mean	2.306	2.480	2.359	2.525	2.079
SE	0.218	0.161	0.110	0.201	0.086
Median	2.087	2.427	2.359	2.404	2.041
Sdev	0.534	0.395	0.269	0.492	0.210
SamVar	0.285	0.156	0.072	0.242	0.044
Count	6	6	6	6	6

Final

	Control	*Quill-high*	*Quill-low*	*Yuc-high*	*Yuc-low*
Mean	2.336	2.502	2.404	2.555	2.147
SE	0.201	0.146	0.107	0.158	0.101
Median	2.109	2.472	2.404	2.404	2.064
Sdev	0.493	0.356	0.261	0.387	0.248
SamVar	0.243	0.127	0.068	0.150	0.061
Count	6	6	6	6	6

Table 18. Feed Intake (g) for Roosters: Tallow Diets

	Control	*Quill-high*	*Quill-low*	*Yuc-high*	*Yuc-low*
Mean	407.8	406.8	408.0	486.3	374.3
SE	41.2	49.6	40.5	27.4	24.8
Median	438.5	405.5	391.0	473.5	356.5
Sdev	100.8	121.5	99.2	67.2	60.8
Minimum	276	209	305	413	314
Maximum	529	542	549	580	482
Count	6	6	6	6	6

Table 19. Feed Intake (g) for Roosters: Coconut Oil Diets

	Control	*Quill-high*	*Quill-low*	*Yuc-high*	*Yuc-low*
Mean	387.8	447.7	394.3	461.0	438.0
SE	23.3	39.5	24.1	28.2	36.3
Median	372.5	411.0	367.0	484.0	458.5
Sdev	57.1	96.7	59.0	69.1	88.9
Minimum	328	335	346	334	291
Maximum	462	587	491	534	521
Count	6	6	6	6	6

Table 20. Feed Intake (g) for Roosters: Soybean Oil Diets

	Control	*Quill-high*	*Quill-low*	*Yuc-high*	*Yuc-low*
Mean	378.5	410.7	388.5	444.0	406.0
SE	24.5	23.8	27.0	28.0	47.7
Median	400.5	412.0	374.5	443.5	416.5
Sdev	60.0	58.4	66.1	68.6	116.9
Minimum	265	313	306	337	263
Maximum	428	482	499	535	585
Count	6	6	6	6	6

Table 21. Fat Digestibility (%) in Roosters: Tallow Diets

	Control	*Quill-high*	*Quill-low*	*Yuc-high*	*Yuc-low*
Mean	93.08	93.18	91.86	92.20	92.34
SE	0.46	0.91	0.61	0.46	1.08
Median	93.16	92.68	92.03	91.89	92.37
Sdev	1.13	2.22	1.37	1.14	2.64
Minimum	91.72	91.22	89.99	91.00	89.41
Maximum	94.49	97.49	93.72	94.31	96.59
Count	6	6	5	6	6

Table 22. Fat Digestibility (%) in Roosters: Coc. Oil Diets

	Control	*Quill-high*	*Quill-low*	*Yuc-high*	*Yuc-low*
Mean	95.93	96.31	96.21	96.14	96.28
SE	0.64	0.49	0.39	0.38	0.23
Median	96.04	96.08	96.22	95.99	96.13
Sdev	1.56	1.19	0.96	0.93	0.57
Minimum	93.58	95.21	94.48	94.89	95.69
Maximum	98.00	98.41	97.21	97.74	97.11
Count	6	6	6	6	6

Table 23. Fat Digestibility (%) in Roosters: SB Oil Diets

	Control	*Quill-high*	*Quill-low*	*Yuc-high*	*Yuc-low*
Mean	96.68	96.58	96.77	96.40	96.35
SE	0.21	0.21	0.15	0.16	0.50
Median	96.48	96.73	96.75	96.44	96.70
Sdev	0.52	0.50	0.36	0.39	1.22
Minimum	96.19	95.89	96.35	95.73	94.55
Maximum	97.47	97.13	97.18	96.82	97.59
Count	6	6	6	6	6

Table 24. Fat Content of Excreta (%) in Roosters: Tallow Diets

	Control	Quill-high	Quill-low	Yuc-high	Yuc-low
Mean	3.66	3.99	4.13	4.04	4.29
SE	0.22	0.20	0.30	0.25	0.41
Median	3.63	4.16	4.09	4.14	4.06
Sdev	0.54	0.50	0.68	0.62	1.01
Minimum	3.05	3.08	3.16	2.94	3.28
Maximum	4.35	4.42	5.02	4.81	5.94
Count	6	6	5	6	6

Table 25. Fat Content of Excreta (%) in Roosters: Coc. Oil Diets

	Control	Quill-high	Quill-low	Yuc-high	Yuc-low
Mean	2.21	2.05	1.99	2.10	2.05
SE	0.17	0.17	0.19	0.09	0.13
Median	2.22	1.99	1.98	2.12	2.18
Sdev	0.41	0.42	0.46	0.23	0.31
Minimum	1.62	1.55	1.48	1.82	1.53
Maximum	2.66	2.55	2.75	2.46	2.30
Count	6	6	6	6	6

Table 26. Fat Content of Excreta (%) in Roosters: SB Oil Diets

	Control	Quill-high	Quill-low	Yuc-high	Yuc-low
Mean	1.92	1.97	1.87	2.05	2.11
SE	0.11	0.11	0.08	0.08	0.31
Median	1.99	1.90	1.89	1.97	1.84
Sdev	0.28	0.26	0.20	0.20	0.75
Minimum	1.55	1.69	1.59	1.85	1.42
Maximum	2.25	2.32	2.14	2.40	3.33
Count	6	6	6	6	6