DIGESTIBILITY BY LAMBS OF A FORMALDEHYDE TREATED COTTONSEED OIL EMULSION AND ALFALFA HAY TALLOW DIETS

by

Lee Alan Shell

A Thesis Submitted to the Faculty of the

DEPARTMENT OF ANIMAL SCIENCES

In Partial Fulfillment of the Requirements
For the Degree of

MASTER OF SCIENCE
WITH A MAJOR IN ANIMAL SCIENCE

In the Graduate College

THE UNIVERSITY OF ARIZONA

1 9 7 6

STATEMENT BY AUTHOR

This thesis has been submitted in partial fulfillment of requirements for an advanced degree at The University of Arizona and is deposited in the University Library to be made available to borrowers under rules of the Library.

Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the major department or the Dean of the Graduate College when in his judgment the proposed use of the material is in the interests of scholarship. In all other instances, however, permission must be obtained from the author.

SIGNED: Lee A Shull

APPROVAL BY THESIS DIRECTOR

This thesis has been approved on the date shown below:

William H. Hale
WILLIAM H. HALE
Professor of Animal Sciences

28 Jan 1976
Date

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation to his major professor, Dr. William H. Hale, for his supervision and counseling throughout the duration of this graduate program and for assistance in the design and implementation of studies reported in this thesis. Sincere appreciation is also extended to Dr. Forrest D. Dryden for his assistance throughout the course of this study. Acknowledgment also goes to the staff and graduate students of the Department of Animal Sciences for their assistance whenever needed.

The author also wishes to thank his wife, Leslee, for her continued encouragement and moral support which made this study possible.

TABLE OF CONTENTS

LIST OF TABLES

ABSTRACT

Experiments were conducted to determine the utilization by lambs of a formaldehyde treated casein:cottonseed oil emulsion (PPCSO) in a 60% concentrate diet and tallow in a coarsely ground alfalfa hay diet.

In Experiment I, PPCSO was added at the rate of 8% and 12% to the diets of three lambs. Four lambs each were allotted to diets containing no added fat and 8% cottonseed oil (CSO). Lipid digestibility was greater ($P < .05$) for lambs consuming the CSO diets as compared to the control lambs. Cottonseed oil digestibility was similar among treatments and averaged 93.2%. Digestibility of the other proximate fractions of the diets were not different among treatments.

In Experiment II four lambs each were allotted to ground alfalfa hay diets with either 1%, 10%, or 20% added tallow. Lipid digestibility was improved ($P < .05$) at the 10% and 20% tallow levels over the 1% level. Tallow digestibility was higher ($P < .05$) for the 10% level than for the 20% level (96.5% vs. 81.5%). Fecal soaps were greater ($P < .05$) for lambs fed the 20% level as compared to the other treatments. Dry matter intake and digestibility of the other proximate fractions were similar among treatments.

INTRODUCTION

Meat products from ruminants have been under attack by the medical profession because of their suspect relationship to serum cholesterol levels and cardiovascular ailments in man. This relationship is thought to result from the high proportion of saturated fat found in ruminant products. The fatty acid composition of fat in various species of ruminants is relatively constant despite the fact that fat in ruminant diets primarily contains high levels of unsaturation. However, biohydrogenation of the unsaturated fatty acids in the rumen results in most of the fatty acids being absorbed in the saturated form.

A reduction of ruminant monounsaturated fat with a corresponding increase in polyunsaturated fat has been achieved by feeding protein:vegetable oil homogenates treated with formaldehyde. Formaldehyde treatment of the homogenate produces cross-linkages in the protein rendering the homogenate insoluble at pH 7 and results in resistance of the emulsified fat to biohydrogenation in the rumen. The abomasal pH of 2-3 will cause the cross-linkaged formaldehyde protein particle to break, releasing the unsaturated fat which is then available for hydrolysis and absorption in the small intestine.

Initial work done by Scott et al. (1970) showed that goats fed a formaldehyde treated casein:safflower oil homogenate increased the level of linoleic acid in both plasma fatty acids and milk fat. Numerous research projects have since evolved using similar homogenates to increase the unsaturation of fat produced by ruminants. However, little literature is available concerning the digestibility and utilization of diets containing high levels of added fat, especially with respect to fat ingestion and excretion.

Experiments I and II were conducted with lambs to find what effects high levels of added tallow and cottonseed oil would have on diet digestibility. Experiment I reports on the digestibility of a casein:cottonseed oil homogenate (30:70) treated with 2.5% formaldehyde and fed to lambs as part of a 60% concentrate. Experiment II was conducted to evaluate the digestibility of tallow added at levels of 1%, 10%, and 20% to an all roughage (ground alfalfa) diet.

LITERATURE REVIEW

Protected Protein Studies

Research in the area of protected protein supplements has slowly evolved from heat and steam treatments of various proteins to the studies of Ferguson, Hemsley, and Reis (1967) using formaldehyde treatment of casein. Earlier research with heat treatment of proteins generally indicated that nitrogen retention in the ruminant was increased while ammonia production in the rumen decreased. Metabolism and degradation studies with various proteins fed to ruminants have been reviewed by Hatfield (1970), Smith (1969), and Cuitun (1974).

Ferguson et al. (1967) conducted solubility tests on casein treated with 4% formaldehyde for one hour, washed and dried at 60 C. The formaldehyde treated casein was tested at pH 6. It showed 17% solubility compared to 92% for the untreated casein. Ammonia loss was 11% for treated casein versus 96% for the untreated casein during a 24 hour *in vitro* incubation with rumen microorganisms. Sheep ruminally administered the treated or untreated casein showed no ammonia-nitrogen increase for the treated casein as compared to 25 mg ammonia-nitrogen/100 ml rumen fluid for the untreated casein. Wool production increased 70% with the

treated casein when compared to a basal diet containing wheaten and lucrene chaff (50:50).

The possibility of formaldehyde having an adverse effect on rumen microorganisms, thus interfering with ammonia release of treated proteins, has been evaluated by Dinius, Lyon, and Walker (1974). Rumen fluid, taken from a steer on a high concentrate diet, was used to test the ammonia reduction of treated or untreated casein. Total ammonia release in a 21 hour incubation period was 173 mg per gram dry matter for the untreated casein compared to 2 mg with the treated casein. When treated and untreated samples were combined (0.1 gram treated plus 0.1 gram untreated casein) and incubated, the ammonia release was approximately one-half the total ammonia produced from the untreated (0.2 gram) sample. Formaldehyde had not interfered with the microbial degradation of the untreated casein.

Studies involving the metabolic fate of formaldehyde in casein:fat supplements have been reported by Mills et al. (1972). Feeding sheep a spray-dried safflower oil:casein homogenate treated with C^{14} formaldehyde resulted in 60% to 80% of the C^{14} consumed metabolized to carbon dioxide and methane. Another 11 to 27% was excreted in feces with 5 to 6% occurring in urine. Small amounts of C^{14} were detected in the tissue and milk of treatment animals, however the C^{14} was no longer in the form of formaldehyde. These workers

concluded that the amount of C^{14} expired as methane or carbon dioxide and the amount excreted in the feces are regulated by the reaction time of the formaldehyde and protein prior to feeding. The bond strength of formaldehyde in protein becomes irreversible with time, resulting in less microbial degradation of the protein in the rumen, the longer the protein is in the presence of formaldehyde. Czerkawski (1969) found that a certain proportion of C^{14} would appear in methane, implying that methanogenic bacteria are capable of converting C^{14} formaldehyde from the homogenate. From these studies it is highly probable that ruminants can metabolize formaldehyde with no significant accumulation of this compound in the carcass or milk.

Faichney (1971) found that formaldehyde treatment of casein fed to lambs resulted in an increase ($P < .01$) in live weight gains compared to an untreated casein diet. Lambs receiving 10% treated casein in the diet grew faster (166 g per day vs. 154 g per day) and required less feed (5.9 kg/kg gain vs. 6.4 kg/kg gain) than lambs fed untreated casein. Carcass fat was proportionally lower (49.4 g/day vs. 51.1 g/day) and carcass protein higher (17.0 g/day vs. 14.8 g/day) in the live weight gains of lambs fed the treated product. Apparent nitrogen digestibility was depressed in lambs fed the treated product (70% vs. 75%) however, the increase in fecal nitrogen was offset by a decrease in urinary nitrogen excreted. There was no difference in the

rate of wool growth between lambs fed the untreated homogenate and those fed the treated homogenate, but the depressed tissue growth of the young lambs receiving the untreated casein suggested extensive degradation of casein in the rumen.

Protected Protein:Fat Studies

Cook et al. (1970) prepared a safflower oil:casein homogenate using equal parts of each component. The homogenate was spray-dried with formalin (37% formaldehyde solution) at the rate of 50 ml/kg of dry homogenate and stored in polyethylene bags for at least 24 hours prior to testing. An *in vivo* study using eight lambs (six treatment and two control) was conducted. Control and treatment lambs were fed similar basal diets except for the addition of homogenate as 20% of the treatment diet. One-half of the lambs on each diet were slaughtered after three weeks and the remaining four lambs at six weeks. Results showed a three to five fold increase in linoleic acid (C18:2) in depot fat of the treatment lambs with the greatest incorporation of C18:2 in the perinephric fat (18.6% vs. 4.4%). There was little change in unsaturation between three and six weeks suggesting a rapid exchange between plasma fatty acid triglycerides and depot fatty acids of young lambs.

Similar results were obtained with growing steers fed formaldehyde treated casein:safflower oil homogenate

(Faichney et al., 1972). Twenty, nine-month old Friesian steers were used to measure the incorporation of C18:2 in body fat. Two steers were slaughtered to give base line data and the remaining steers were divided into two groups. One group was fed a diet containing 20% of a protected casein:safflower oil homogenate (1:1) and the other group was given a control diet containing no casein or safflower oil. Three steers were slaughtered from each group at two, four, and eight weeks of the trial. There was little increase of C18:2 into the fat of the control group. In the treated animals, C18:2 incorporated in the fat increased over the fifty-six day period, but the response tended to decline with feeding time. Linoleic acid in the perirenal, subcutaneous, and omental fat was increased three to four times above similar fat from the control animals. Linoleic acid was 39% of the fatty acids in perirenal fat, this level of C18:2 was higher ($P < .01$) than that found in either subcutaneous or omental fat. This observation is supported by similar results obtained by Cook et al. (1970) and shows that deep body fats have higher levels of C18:2 than external fat when feeding protected fat homogenates.

Scott, Cook, and Mills (1971), using two abomasal fistulated goats, measured the protection of a formaldehyde treated linseed oil:casein homogenate against biohydrogenation. The goats were fed the treated homogenate for four days then switched to an untreated linseed oil:casein

homogenate. Abomasal contents were analyzed for fatty acids and showed C18:2 to be approximately 32% of the total lipid content in treatment goats compared to 1.1% and 1.5% when the goats were fed the untreated homogenate or no homogenate, respectively. Extensive hydrogenation had occurred with the untreated linseed oil:casein homogenate.

In a companion study (Scott et al., 1971), C18:2 values for both perirenal and subcutaneous fat were 28-29% in sheep fed a casein:safflower oil homogenate (1:1) treated with formaldehyde. The value for perirenal fat is similar to that reported by Jagusch (1975) when high levels of protected ground sunflower seed were fed to sheep. However, these values are high compared to those reported by Faichney, Scott, and Cook (1973) and Cook et al. (1970). Cook et al. (1970) fed a casein:safflower oil homogenate to sheep and reported C18:2 values of 18.6% in the perinephric and 13.9% in the subcutaneous fat after six weeks of feeding the homogenate. Control lamb values were 4.4% and 3.7% C18:2 in the perinephric and subcutaneous fat, respectively.

Safflower oil:casein homogenate (1:1) was tested *in vitro* with rumen fluid by Dinius, Lyon, and Walker (1974) to determine protection given the unsaturated fatty acids by formaldehyde additions (1, 2, 4, and 8% of the casein by weight prior to spray-drying). Results were similar at the 4 and 8% level of formaldehyde addition. After incubation the percentage C18:2 in the fermentation vessels of

the above treatments was approximately twice the amount of the untreated casein:safflower homogenate (approximately 16-24% C18:2 at 1% through 8% treatment levels) indicating that formaldehyde afforded protection against biohydrogenation of the unsaturated fatty acids.

Using safflower seed kernels, Scott et al. (1972) developed a method of protecting the lipid of the kernel from biohydrogenation following these steps: (1) homogenize the kernel in water, (2) add sodium hydroxide (1.0-1.5% by weight of kernel), (3) add sodium caseinate (10-20% by weight of kernel, (4) add lecithin (1% by weight of the oil), and (5) add formaldehyde (4% by weight of the protein). Two separate procedures were developed: one a gel product containing 40-45% total solids, the second a spray-dried product which in the liquid state contains 20% solids as described by Scott et al. (1971). In vivo trials using lactating goats showed the gel product was more palatable than the spray-dried product. The control group averaged 3.7% C18:2 in the milk while the corresponding spray-dried and gel values were 20.5% and 28.7%, respectively. The high C18:2 content in the milk of goats fed the gel product appeared to be related to the higher lipid intake.

Scott et al. (1970) fed a formaldehyde treated casein:linseed oil homogenate (1:1) to goats and cows. Linoleic acid (C18:3) in goats' milk was increased above the

untreated supplement approximately 18.6 percentage units; however, C18:2 showed only a 1-2 percentage unit increase. The C18:3 and C18:2 in the milk of cows fed treated casein: safflower oil homogenate was increased approximately 16.0 and 6.5 percentage units, respectively, over the level found in milk of the control cows fed lucerne chaff and oats. In a later study using one goat and one cow, a formaldehyde treated casein:safflower oil homogenate increased C18:2 by 33 percentage units for both animals, while C18:3 remained constant. The fluctuation in C18:2 and C18:3 values in milk is highly dependent on the vegetable oil utilized in the protected protein:fat homogenate.

Jagusch (1975) found C18:2 incorporation in perirenal fat to increase almost directly with increasing amount of homogenate when a commercially prepared formaldehyde treated ground sunflower seed:casein homogenate was fed in sheep diets. Two trials were conducted: one with Coopworth sheep for a 40-day period, and the second with Polled Dorset for 30 days. Linoleic acid values in the perirenal fat were 3.3, 9.6, 13.5, and 13.0% when the supplement was fed at the rate of 0, 129, 268, and 337 g/day. Feed refusals at higher levels of supplementation by the Coopworth sheep caused a depression in C18:2 incorporation. Results of the second trial were more dramatic with homogenate fed at the rate of 0, 147, 236, and 257 g/day resulting in 4.8, 17.2, 23.2, and 27.7% C18:2 in the perirenal fat of the Dorset lambs. The

lower level of unsaturation in depot fat seen in trial one was probably a result of lower protection (60% vs. 80%) of the lipid in the formaldehyde sunflower seed:casein homogenate.

Garrett et al. (1975) fed lambs for 69 days a commercially prepared formaldehyde treated safflower oil homogenate containing 21% C18:2 at 40% of the diet. Linoleic acid in tailhead fat biopsies averaged 3-4% for the control lambs over the trial period, while treatment lamb values were 11.6% and 20.4% at 27 and 69 days, respectively. Steers fed the supplement at 33% of the diet also showed the greatest change in C18:2 compared to control animals. Control steers averaged 2.3% C18:2 in tailhead fat biopsies over the 154 day trial, while the treatment group ranged from 5.2% at day 9 to 16.7% at 154 days.

Dinius, Oltjen, et al. (1974) used six treatments to evaluate the utilization of a formaldehyde casein:safflower oil homogenate fed to steers weighing 230 kg. The treatments were 5% or 10% casein, 10% or 20% unprotected safflower oil:casein, and 10% or 20% protein protected safflower oil homogenate. Lambs fed the 10% and 20% protein protected safflower oil homogenate incorporated 12.6% and 10.6% of C18:2 into kidney and subcutaneous fat tissue, respectively. These levels were significantly higher than for steers fed the untreated casein:safflower oil homogenate which averaged 2.3% C18:2 in both fat tissues. Tailhead fat

biopsies taken at 42 days also revealed that protection was adequate with the treated safflower oil:casein homogenate (11.1% vs. 2.9%).

In a companion trial (Dinius, Oltjen, et al., 1974) four rumen fistulated steers weighing 474 kg were fed either 5.7% casein, 11.4% unprotected safflower oil:casein, or 11.4% protected safflower oil:casein homogenate to determine the animals' response to fatty acid incorporation in tailhead fat. Tailhead biopsies at 48 days revealed little change between the first two treatments. However, C18:2 in the protected safflower oil:casein treatment was 5.8% as compared to 2.9% for the unprotected safflower oil treatment. This response of mature steers to C18:2 incorporation into tailhead fat was much slower than with the previous study conducted with young steers weighing 230 kg.

Protected Protein:Fat Digestibility Studies

Hogan, Connell, and Mills (1972) reported on the digestion by lambs of a safflower oil:casein homogenate treated with formaldehyde as described by Scott et al. (1971). Feeding the protected homogenate at 20% of the diet increased the intake of long chain fatty acids by 68 grams per day and nitrogen by 9 grams per day above the control diet composed of chopped lucerne hay. The total linoleic (C18:2) and linolenic (C18:3) acid ingested was approximately 73 grams per day in the treated product diet;

however biohydrogenation in the rumen decreased this amount by 45% to 41 grams. This latter amount was absorbed almost completely in the small intestine leaving 2.6 grams of C18:2 and C18:3 in the remaining digesta. Apparent organic matter and nitrogen digestibilities were 71.6% vs. 66% and 82.4% vs. 78.4%, respectively, in the treated and control groups. Rumen digestion of the organic matter and nitrogen was depressed 25 and 20 percentage units, respectively, in lambs fed the treated product. However, digestion of the treated diet distal to the rumen was much greater than for the control group, offsetting the lower rumen digestion of the treated homogenate. The formaldehyde treated casein: safflower oil homogenate included as 20% of the diet increased metabolizable energy 30%, net energy 38%, and amino acids 70% over the roughage diet fed to the control group. The decrease in polyunsaturation of the protected homogenate prior to the time it enters the intestinal tract has been discussed by Scott et al. (1971). They proposed that the encapsulated oil droplets near the surface of the homogenate particles are biohydrogenated in the rumen of animals fed treated protein:vegetable oil homogenates.

Faichney et al. (1973) used lambs to study the effect of formaldehyde treated:casein:safflower oil homogenate fed at the rates of 0, 75 g, and 150 g of the diet per day. When the homogenate was fed at the rate of 75 g/day, the apparent digestibility of organic matter,

nitrogen, lipid, and gross energy increased; however, acid detergent fiber digestibility was not significantly different from lambs fed the control diet containing equal parts chopped lucerne hay and crushed oats. Calculating the digestion coefficients of nitrogen, lipid, and gross energy of the homogenate, assuming the basal diet digestibilities are constant, revealed that the 75 g level of homogenate had been almost completely digested. At the second level of supplementation (150 g), lower values were reported for the apparent digestibility of the homogenate.

Additional data from this study (Faichney et al., 1973) showed C18:2 in depot fat increased ($P < .05$) at both levels of supplementation as compared to the fat in the control lambs. The mean C18:2 content of the control, 75 g, and 150 g per day treatments, was 6.5 g, 35.7 g, and 42.6 g per kg live weight, respectively. Lambs fed the higher level of homogenate ingested twice as much lipid as the lower level, however there was no difference ($P > .05$) between either group in C18:2 incorporation into fat as plotted against lipid intake. Lambs fed the homogenate at the rate of 150 g/day approached maximum incorporation of C18:2 earlier in the trial, thereby retaining a lower proportion of the ingested C18:2 than the first level of supplementation (45% vs. 53% retained C18:2). It was also noted that the deeper body fat had a higher level of C18:2 than the external fat in lambs fed the homogenate, thus

supporting the earlier studies of Faichney et al. (1972) and Cook et al. (1970).

Cuitun et al. (1975) studied the digestibility and performance by steers fed an 80% concentrate diet with the inclusion of 6% formaldehyde treated casein (treatment I), 6% treated casein plus 6% safflower oil (treatment II), and 12% treated casein:safflower oil homogenate (treatment III). Dry matter digestibility was lowest for treatment II, reflecting poor digestibility of the added safflower oil. Protein and lipid digestibilities were highest for treatment III; thus, workers concluded that the protection afforded the homogenate allowed higher absorption of safflower oil from the small intestine. The apparent increase in nitrogen digestibility was not explained, except as possibly being related to particle size of the casein. When lipid digestibility of the homogenate was calculated by difference, treatment III was 27.5 percentage units higher than treatment II. Control steers, treatment I, had higher ($P < .05$) average daily gains and dry matter intake values than treatment III, but neither treatment I nor treatment III were different from treatment II. The lower average daily gains of steers fed treatments II and III were attributed to depressed dry matter and caloric intake of the safflower oil diets. This study suggested that protection of dietary fat from biohydrogenation did not increase digestible energy or dry matter intake over the unprotected oil, thus indicating

the inability of cattle to digest high levels of poly-unsaturated safflower oil.

Digestion and Utilization of Unprotected Fat Diets

Addition of animal or vegetable fat to ruminant diets reduces dustiness, increases caloric density, and may improve energy utilization of the diet by depressing methane production. It is usually an economical method of increasing caloric density of the diet. Animal fat has been used with success in many feeding regimes in the United States at levels of 2 to 5% of the diet. However, levels greater than 5 or 6% are not accepted well by cattle and may depress animal performance probably due to reduced feed intake, and interference with cellulose digestion in the rumen. Sheep are able to utilize higher levels of fat than cattle, and levels of 4 to 6% may enhance daily gain and decrease feed required per unit of gain (Hale, 1975). It has been noted that high fat, low roughage diets are not as well utilized as high fat, high roughage diets (Brethour, Sirny, and Tillman, 1958; Cameron and Hogue, 1968). Figroid (1971), in an excellent review of fat addition to ruminant diets, indicates that high levels of fat tend to lower crude fiber and nitrogen free extract digestibilities while increasing the formation and excretion of fecal soaps. Figroid conducted a series of digestion trials with steers in which 0, 5, 10, and 15% animal fat were added to a 60,

75, or 90% concentrate diet. Results showed dry matter intake as a per cent of body weight decreased with increasing fat and concentrate levels. Apparent dry matter, gross energy, and lipid digestibilities decreased with increased fat and concentrate levels. Crude protein and acid detergent fiber were reduced with increased levels of concentrate, but not with increasing fat levels. Fecal soaps, expressed as a per cent of ingested lipid, increased with increasing diet fat levels; however, the increase was only significant ($P < .05$) through the 10% fat level. The 10% and 15% fat levels were not different ($P > .05$) from each other.

Andrews and Lewis (1970) studied the utilization of various commercial fats fed to lambs. Digestion trials were conducted with lambs fed a basal diet of chopped hay, barley meal, and extracted soyabean meal (50/40/10) with five pounds per hundred pounds addition of the following: beef tallow, hydrolyzed animal and vegetable fat (HEF), herring oil, soyabean oil, and maize oil. Fecal lipids were appreciably more saturated than the corresponding dietary lipids. With the exception of the herring and maize oil, stearic acid levels were more than 50% of the fecal lipids. The apparent lipid digestibility values were as follows: beef tallow, 78.5%; HEF, 70.8%; herring oil, 77.1%; soyabean oil, 78.0%; and maize oil, 70.3%. Digestion coefficients corrected for the dietary and fecal lipids of lambs fed the basal diet were as follows: beef tallow, 85%; HEF,

74%; herring oil, 84%; soyabean oil, 83%; and maize oil, 78%. These workers suggest that a smaller amount of free fatty acids would enter the intestinal tract from fats than from HEF; therefore, larger amount of free fatty acids from HEF were available for absorption than could be utilized at any one time in the intestine. This might account for the lower digestibility of the HEF compared to the other fats used in the treatment diets.

Macleod and Buchanan-Smith (1972) fed lambs four diets to determine the digestibility of dry flaked or melted hydrogenated tallow, saturated fatty acids, and soybean oil. The basal diet was composed of 56% ground grass-hay and 34% ground barley. In the first set of trials, 3% flaked tallow was compared with 3% soybean oil while the control group was fed the basal diet. Lipid digestibilities of the added fat treatments were estimated by subtracting the basal lipid digestibility of control lambs. Soybean oil was more digestible ($P < .01$) than flaked tallow (98% vs. 34%). In a second set of trials, hydrogenated tallow, flaked or melted, was added at 4.8% to the basal diet. A third comparison was made using saturated fatty acids added at 4.8% to the basal diet. Melted tallow mixed with the concentrate portion of the diet improved lipid digestibility greater than the flaked tallow (42% vs. 34%). However, the melted tallow digestibility was lower ($P < .05$) than the blended saturated fatty acids (65% vs. 42%). Dry matter and gross energy

digestibilities were depressed ($P < .05$) with hydrogenated tallow, whereas saturated fatty acids lowered ($P < .05$) the dry matter and crude fiber digestibilities as compared to the control diet. The tallow in this study was 99% hydrogenated which is a higher percentage of saturation than the usual tallow fed to ruminants. It is possible that the physical form of the tallow allowed a major portion of the fat to escape rumen hydrolysis. The capacity to solubilize and the lipolysis of triglycerides in the intestine is limited in the ruminant and may result in decreased utilization of the fat (Lough, 1970).

Johnson and McLlure (1972) conducted a series of digestion trials with lambs fed saturated and unsaturated fats in high and low roughage diets. Lambs were allotted the following treatment diets: (1) high roughage, (2) high roughage plus 6% hydrolyzed animal and vegetable fat (HEF), (3) low roughage, (4) low roughage plus 6% HEF, (5) low roughage plus 8% HEF, (6) low roughage plus 6% corn oil, and (7) low roughage plus 6% HEF. The concentrate portion of diet 7 was ground corn and not steamed flaked corn as contained in the other low roughage diets. Lambs in the first digestion trial fed diets 2, 3, and 4 gained faster than lambs fed the basal roughage diet. Addition of 6% fat in diet 2 supplied sufficient additional energy to offset the lower cellulosic form of energy in diet 1. Lambs on both high roughage diets had a higher feed to gain ratio

than lambs fed diets 3 and 4 because they consumed approximately 35% more diet. Digestibility of high roughage diets was not improved with the addition of 6% HEF. Lambs in a second set of digestion trials fed diet 5 (8% HEF) gained significantly slower than the control group fed diet 3. Feed required per unit of gain was improved, but not significantly when compared to the diet containing 6% corn oil. Lambs fed the low roughage diets did not show higher gains with the addition of 6% HEF or corn oil. Cellulose digestibility was significantly depressed for the lambs consuming the low roughage diets as compared to high rougage diets 1 and 2.

Klett, Hansen, and Sherrod (1972) fed steers a basal ration containing 87% concentrate with 0, 2, and 4 per cent animal tallow to evaluate the effect tallow had on steer performance. There was a trend for steers consuming the 4% tallow diet to have depressed gains in comparison to the steers fed the diets containing 0 and 2% tallow. Feed consumption did decrease ($P < .05$) with increased levels of tallow; however, feed conversion favored both diets containing tallow.

EXPERIMENTAL PROCEDURES

Experiment I: Preparation of Cottonseed Oil Homogenate

The casein:cottonseed oil homogenate was prepared using the following procedures: (1)

1. The acid precipitated casein was dissolved in distilled water (1 part casein:7 parts water) by adding sufficient 25% NaOH solution to adjust the mixture to a pH of 7.
2. The casein solution was allowed to sit at least 12 hours before adding the cottonseed oil to give a 30:70 casein:cottonseed oil mixture.
3. The mixture was heated to 45-50 C and homogenized twice using a Manton-Gaulin model 15M-8TBA two-stage homogenizer at 3000 p.s.i. of pressure.
4. A 37% formaldehyde solution was stirred into the homogenate at the rate of 2.5% formaldehyde by weight of the casein.
5. The resulting gel was sealed in plastic containers and refrigerated for at least 24 hours. The homogenate gel was ground into small particles through a meat grinder fitted with 3/8-inch openings prior to mixing with the remaining diet ingredients. The

final product contained 67.6% water, 22.6% cottonseed oil, and 9.8% casein by weight.

Digestion Trial

Fourteen lambs averaging 29.4 kg were randomly allotted to three treatment groups. Four lambs each were allotted to the control diet and the 8% cottonseed oil (CSO) diet, while the remaining six lambs were fed the 8% protein protected cottonseed oil homogenate (PPCSO). Diet formulation and chemical analyses are shown in Table 1. At 55 days the lambs fed the 8% PPCSO diet were divided into two groups of three lambs each. One group remained on the 8% PPCSO diet and the other three lambs were fed a 12% PPCSO diet. Lambs were fed to approximately 50 kg and slaughtered.

The lambs were adjusted to their respective diets prior to transfer into metabolism crates. Two lambs from one treatment and one lamb from each of the other treatments were placed in the crates during each trial period. A preliminary 4-5 day crate adjustment period was followed by a 6-day collection period. Lambs were fed twice daily at 0730 hours and 1530 hours. Feed intake was adjusted to an estimated 90% of the ad libitum intake prior to placing lambs in the metabolism crates.

One hundred and fifty-gram samples of each diet were collected daily at the 1530 hours feeding during the collection period. These samples were dried at 50 C in a

Table 1. Experimental Diets; Experiment I

Item	Control	Control Plus 8% CSO[a]	Control Plus 8% PPCSO[b]	Control Plus 12% PPSCO[b]
Ground Alfalfa Hay %	40.0	40.0	40.0	40.0
Steam Processed Milo %	53.8	45.7	42.4	36.7
Molasses %	6.0	6.0	6.0	6.0
Biofos %	0.2	0.3	0.2	0.2
Cottonseed Oil %	--	8.0	--	--
Casein:Cottonseed Oil Product[c] Dry Matter Basis, %	--	--	11.4	17.1
Total	100.0	100.0	100.0	100.0
Chemical Analyses, Dry Matter Basis				
Protein %	13.4[d]	12.9	15.5	15.5
Lipid %	7.1[d]	15.1[e]	15.0[e]	18.8[f]
Gross Energy Kcal/gram	4.0[d]	4.6[e]	4.7[e]	4.9[f]
Acid Detergent Fiber %	17.1[d]	15.5[e]	15.4[e]	15.4[e]

[a]Cottonseed oil.

[b]Protein Protected Cottonseed Oil.

[c]Casein:cottonseed oil (30:70) treated with a 37% formaldehyde solution at the rate of 2.5% formaldehyde by weight of the casein.

[d,e,f]Means on the same line with unlike superscripts are significantly different ($P < .05$).

forced air oven for 48 hours then bulked to give a composite sample for each diet fed. Fecal samples were collected daily at 1430 hours. Total feces excreted daily by each lamb was weighed, thoroughly mixed, and a 250-400 g aliquot was dried by the same method employed to dry feed samples. The dried samples were bulked to give a composite feces sample for each lamb. Oven dried feces and diet composites were ground through a 2 mm mesh screen in a Wiley mill.

Lipid was extracted from feed and feces samples and fecal soap content was calculated as described by Figroid (1971). Fatty acid composition of lipid extracts were analyzed by gas-liquid chromatograph (Beckman GC-5 chromatograph) following the procedures outlined by Cuitun (1974). Dry matter and crude protein values were determined according to A.O.A.C. (1965). Acid detergent fiber was determined according to Van Soest (1963). Gross energy of feed and feces was determined using a Parr adiabatic bomb calorimeter.

Least squares analysis of variance was conducted on the data collected in the digestion trial, and Student-Newman-Keul's multiple range tests and Pearson correlations were performed to compare treatment means.

Experiment II: Digestion Trial

A digestion trial was conducted with lambs by Dr. W. H. Hale in 1962 to study the digestibility of a roughage

diet containing various levels of tallow. Dry matter, crude protein, crude fiber, and fat digestibilities were determined at the completion of the digestion trial according to methods outlined in the A.O.A.C. (1955). Gross energy digestibility was not determined. The significance of fecal soaps as an energy loss in ruminants was not fully understood at the time the digestion trial was conducted. Feed and feces samples remaining after the initial analysis in 1962 were stored in glass containers at -10 C during the interim period. When the feed and feces samples were opened in 1975, no rancidity was detected by smelling the samples. Gross energy and fecal soap values were determined as in Experiment I to evaluate the digestibility of a saturated (Experiment II) vs. unsaturated fat (Experiment I) diet.

The digestion trial involved twelve lambs weighing 46.5 kg. The lambs were randomly allotted by weight to three treatment diets containing alfalfa hay with commercial grade tallow added at the rate of 1, 10, and 20 per cent of the diet (Table 2). Tallow was added to the hay as it was ground. The lambs were fed their respective diets continuously for the 50-day study. The digestion trial was conducted in the same manner as decribed in Experiment I.

Table 2. Experimental Diets; Experiment II

Item	Control	Control Plus 10% Tallow	Control Plus 20% Tallow
Ground Alfalfa Hay %	99	90	80
Tallow %	1	10	20
Chemical Analysis, Dry Matter Basis			
Protein %	18.2[a]	17.0[b]	15.8[c]
Lipid[d] %	11.1[a]	16.8[b]	25.3[c]
Gross Energy Kcal/gram	4.4[a]	4.8[b]	5.2[c]
Crude Fiber %	20.5[b]	19.5[b]	15.6[a]

[a,b,c]Means on the same line with unlike superscripts are significantly different ($P < .05$).

[d]Lipid extraction with chloroform:methanol: hydrochloric acid, 60:40:1 (v/v/v).

RESULTS

Experiment I: Digestion Trial

There were no significant differences ($P > .05$) among the four treatments for dry matter, crude protein, gross energy, and acid detergent fiber digestibility by the lambs (Table 3). However, there was a tendency for dry matter, crude protein, and gross energy digestibility of the three diets containing cottonseed oil (CSO) to increase when compared to the control diet. The addition of the casein:cottonseed oil emulsion treated with formaldehyde (protein protected cottonseed oil, PPCSO) or unprotected CSO to the control diet tended to lower acid detergent fiber digestibility. Total digestible nutrients of the diets containing CSO were improved ($P < .05$) as compared to the control diet. Nitrogen free extract digestibility was similar for all treatment diets.

Lipid digestibility was increased ($P < .05$) with the addition of PPCSO or unprotected CSO when compared to the control diet (Table 3). There was no difference ($P > .05$) among the diets containing CSO with respect to lipid digestibility. The protection afforded by the formaldehyde treated casein:cottonseed oil homogenate was verified by the increased incorporation of unsaturated fatty acids in the adipose tissue taken from tail biopsies of

Table 3. Digestion Coefficients and Total Digestible Nutrients; Experiment I

Item	Control	Control Plus 8% CSO	Control Plus 8% PPCSO	Control Plus 12% PPCSO
Number of Lambs[a]	4	4	6	2
Dry Matter Digestibility %	74.9	77.2	76.8	76.5
Protein Digestibility %	64.8	59.3	69.9	73.6
Gross Energy Digestibility %	71.9	75.8	76.8	76.9
Lipid Digestibility %	57.0[b]	77.7[c]	79.2[c]	78.9[c]
Acid Detergent Fiber Digestibility %	50.0	46.6	47.2	46.1
Total Digestible Nutrients (TDN) %	76.9[b]	87.0[c]	87.1[c]	91.6[c]
Nitrogen-Free Extract Digestibility %	91.3	91.6	91.8	91.8
Cottonseed Oil Digestibility Calculated by Difference %	--	93.6	96.2	89.9

[a]Lambs fed the first level of protein protected cottonseed oil (PPCSO) were divided at 55 days into two groups: one group of three lambs remained on initial diet while the remaining three were placed on the diet containing 12% PPCSO. Digestion data were collected from only 2 lambs fed the 12% PPCSO diet.

[b,c]Means on the same line with unlike superscripts are significantly different ($P < .05$).

lambs at various times during the study (Mata Hernandez, 1975).

Cottonseed oil digestibility, determined by difference (Crampton, 1956), was essentially the same for lambs fed the diets containing unprotected CSO, 8% PPCSO, and 12% PPCSO; 93.6%, 96.2%, and 89.9%, respectively. The higher level of PPCSO addition to the diet caused a slight depression in CSO digestibility of 7.0% when compared to the diet containing 8% PPCSO.

Dietary lipid ingested and fecal lipid values for the four treatments are given in Table 4. Lambs fed the diet containing 8% PPCSO ingested approximately 30-34 grams more CSO per day than the lambs fed the diet containing 8% unprotected CSO, and 80-85 grams more than the control lambs. Lipid excretion was similar in all treatments, however lambs fed the control diet excreted more lipid as might be expected due to low lipid digestibility of the control diet.

Fecal soaps calculated as a percentage of the excreted feces were not different ($P > .05$) among treatments and the average value for all treatments was 5.8%. Fecal soaps calculated as a percentage of the ingested lipid were lower ($P < .05$) for the CSO treatments than the control treatment (21.0% vs. an average of 8.1% for the diets containing CSO). This reduction is probably the result of increased lipid ingestion with a corresponding tendency for

Table 4. Lipid, Fatty Acid; and Fecal Soap Values; Experiment I

Item	Control	Control Plus 8% CSO	Control Plus 8% PPCSO	Control Plus 12% PPCSO
Lipid Ingested (gm/day)	92.8	142.4	176.3	172.3
Lipid Excreted (gm/day)	40.0	32.2	36.3	35.6
Lipid Digested (gm/day)	52.8	110.2	140.0	136.7
Fecal Soaps (gm/day)	19.5	13.3	14.6	11.8
Fecal Soap as a Percentage of the Excreted Dry Matter %	5.9	6.2	5.3	5.7
Fecal Soap as a Percentage of the Ingested Lipid %	21.0[a]	9.3[b]	8.3[b]	6.8[b]
Palmitic Acid in the feces (gm/day)	11.3	8.0	10.4	8.8
Stearic Acid in the feces (gm/day)	6.3[a]	13.1[b]	13.6[b]	19.4[b]
Linoleic Acid in the feces (gm/day)	7.6	5.8	5.6	3.7
Linolenic Acid in the feces (gm/day)	2.8[a]	0.9[b]	1.2[b]	0.8[b]
Total Unsaturated Fatty Acids in the feces (gm/day)	15.7[a]	8.2[b]	8.9[b]	5.7[b]

[a,b]Means on the same line with unlike superscripts are significantly different ($P < .05$).

fecal soaps to decrease or remain constant, thus giving a much lower percentage value.

Total unsaturated fatty acids in the feces were lower ($P < .05$) for lambs fed the CSO diets than lambs fed the control diet (Table 5). Stearic acid (C18:0) in the feces of lambs fed the diets containing cottonseed oil was increased ($P < .05$) when compared to lambs fed the control diet. However, linoleic acid (C18:2) was higher ($P < .05$) for lambs fed the control diet. The increase of C18:0 in the feces of lambs fed the unprotected CSO diet can probably be attributed to hydrogenation of the CSO in the rumen and colon. The increase of C18:0 in the feces of lambs fed diets containing PPCSO can probably be attributed to an increase in absorption of oleic acid (C18:1) and C18:2 in the intestine. This conclusion is supported by observations of increased unsaturation of depot fat of lambs fed the PPCSO diet. Microbial hydrogenation of the unabsorbed unsaturated fatty acids in the colon and the incorporation of C18:0 into the microbial structure of the microorganisms existing in the colon would also contribute to the increased C18:0 level in the feces of lambs fed PPCSO diets.

The addition of unprotected CSO and PPCSO to the control diet tended to lower the total percentage of unsaturated fatty acids in the diet as compared to the control diet (Table 5). However, the actual ingestion of

Table 5. Major Fatty Acid Profile of Feed and Feces; Experiment I

Fatty Acids[a]	Control		Control Plus 8% CSO		Control Plus 8% PPCSO		Control Plus 12% PPCSO	
	Diet	Feces	Diet	Feces	Diet	Feces	Diet	Feces
	%	%	%	%	%	%	%	%
Myristic (C14:0)	0.6	3.7	1.0	3.0	1.0	2.6	0.9	1.6
Myristoleic (C14:1)	--	7.3	--	2.6	--	3.0	--	1.3
Pentadecanoic (C15:0)	--	4.2[c]	--	2.0[b]	--	2.3[b]	--	1.1[b]
Palmitic (C16:0)	20.1	28.2	31.1	24.8	27.7	28.6	29.3	24.7
Palmitoleic (C16:1)	1.3	5.9	0.8	2.2	0.8	2.8	0.7	2.1
Heptadecanoic (C17:0)	--	3.9[c]	--	2.3[b]	--	2.7[bc]	--	1.6[b]
Stearic (C18:0)	3.2	15.7[b]	4.0	40.8[c]	3.3	37.4[c]	4.0	55.4[c]
Oleic (C18:1)	26.0	18.9	22.2	18.1	20.1	15.4	21.4	10.5
Linoleic (C18:2)	41.7	7.1[c]	40.9	2.7[b]	46.8	3.4[b]	43.7	2.2[b]
Linolenic (C18:3)	7.1	--	--	--	--	--	--	--
Total Unsaturated[d]	76.1	39.2[c]	63.9	25.6[b]	67.7	24.6[b]	65.7	16.1[b]

[a]Fatty acid extraction with Chloroform:Methanol:Hydrochloric acid (60:40:1).

[b,c]Means on the same line with unlike superscripts are significantly different ($P < .05$).

[d]Total unsaturated fatty acids are calculated as a percentage of all fatty acids, some of which are not shown in this table.

unsaturated fatty acids above the level of the control lambs (70.6 g) was increased approximately 22%, 42%, and 38% for the 8% unprotected CSO, 8% PPCSO, and 12% PPCSO treatments, respectively.

Simple correlation analysis conducted across treatments revealed that fecal soap values as a percentage of the ingested lipid were negatively correlated ($P < .05$) with gross energy (-.88) and per cent lipid of the diet (-.93), gross energy digestibility (-.75), and lipid digestibility (-.96). Fecal soaps as a percentage of the ingested lipid were positively correlated ($P < .05$) with linoleic acid (+.80) and the total percentage of unsaturated fatty acids in the feces (+.79). These correlations across treatments and the fact that the control lambs had a significantly higher ($P < .05$) percentage of the unsaturated fatty acids in their feces as compared to the lambs fed the CSO diets helps to solidify the finding that fecal soaps calculated as a percentage of the ingested lipid are negatively related to the lipid and gross energy digestibilities. There also appears to be a positive correlation between unsaturated fatty acids found in the feces and fecal soap values calculated as a percentage of the ingested lipid.

Performance

The performance data of the lambs fed the various diets appears in Table 6. The purpose of this trial was not

Table 6. Performance Data of Lambs; Experiment I

Item	Control	Control Plus 8% CSO	Control Plus 8% PPCSO	Control Plus 12% PPCSO
Number of lambs	4	4	3	3
Days on trial	84	84	84	40
Feed consumed per day per lamb, kg	1.54	1.21	1.41	1.12
Gross energy, kcal/day	6.2	5.6	6.6	5.5
Average weight gain per lamb, kg	19.8	16.8	20.6	6.8
Average daily weight gain per lamb, gm	236	200	245	191
Feed required per pound of gain, kg	6.5	6.0	5.8	5.9

to collect performance data; however, an estimate of the feeding value of the diets can be made. Performance data of lambs fed diets containing 8% and 12% PPCSO were computed by extrapolating gains and feed consumption on a daily basis by averaging the gain and feed intake. Blood samples, fat biopsies, and digestion crate time were the same for all lambs during the 84-day trial. Lambs fed the 8% PPCSO diet consumed 14% more of the diet with an 18% increase in live weight gain as compared to the positive control group fed the 8% unprotected CSO diet. Lambs fed the 12% PPCSO diet and the 8% unprotected CSO diet had similar average daily gains and feed consumption values while lambs fed the control diet with no added oil had average daily gains similar to the 8% PPCSO treatment (236 g and 245 g, respectively). Daily feed consumption by the control lambs was the highest for all the treatments (1.54 kg), being 8% greater than the 8% PPCSO treatment (1.41 kg), and approximately 24% greater than the 12% PPCSO or the 8% CSO treatments.

Lambs consuming the 8% PPCSO diet gave the lowest feed requirements (5.8 kg/kg gain) of the four treatments, followed closely by lambs fed the 12% PPCSO diet (5.9 kg/kg gain). Lambs consuming the PPCSO diets were 10-11% more efficient in feed conversion than lambs fed the control diet with no added CSO (6.5 kg/kg gain). Feed requirements varied little between the CSO treatments with average daily

gain favoring the 8% PPCSO treatment and feed consumption the unprotected CSO and 12% PPCSO treatments. Palatability and/or acceptability of the diets containing 8% unprotected CSO and 12% PPCSO was probably the cause of reduced gains and depressed dry matter intake.

Experiment II: Digestion Trial

Chemical analysis of the diets fed in experiment II are presented in Table 2. Lipid analysis based on the chloroform:methanol:hydrochloric acid extraction procedure showed the control diet contained 11.1% extractable lipid. This value was higher than anticipated and is presently unexplainable. It appears that the addition of tallow to the alfalfa hay prior to grinding was in excess. However, the validity of the experiment was retained with results showing diet differences among treatments.

Results of the digestion study conducted with lambs fed an all roughage diet formulated with coarsely ground alfalfa hay and three levels of animal tallow showed no differences ($P > .05$) among treatments for dry matter, crude protein, crude fiber, and gross energy digestibilities Table 7). Nitrogen free extract digestibility was similar for both the control and 10% tallow diets but was significantly increased ($P < .05$) with addition of 20% tallow to the ground alfalfa hay diet. Total digestible nutrients of the diets were significantly different ($P < .05$) among the

Table 7. Digestion Coefficients and Total Digestible Nutrients; Experiment II

Item	Control	Control Plus 10% Tallow	Control Plus 20% Tallow
Number of lambs	4	4	4
Dry Matter Digestibility %	63.6	63.6	62.5
Protein Digestibility %	74.4	74.9	74.1
Gross Energy Digestibility %	61.9	62.4	64.5
Crude Fiber Digestibility %	31.1	30.4	28.0
Lipid Digestibility %	54.6[a]	68.4[b]	64.5[b]
Nitrogen Free Extract Digestibility %	68.5[a]	68.8[a]	73.6[b]
Total Digestible Nutrients (TDN) %	58.6[a]	71.1[b]	82.9[c]
Tallow Digestibility calculated by difference %		96.5[b]	81.5[a]

[a,b,c]Means on the same line with unlike superscripts are significantly different ($P < .05$).

treatments with the control diet being lowest at 58.6% and the 20% tallow diet highest at 82.9%. The 10% tallow treatment diet had an intermediate TDN value of 71.1%.

Lambs fed the 10% and 20% tallow diets ingested 47% and 125% more lipid per day, respectively, than the control lambs. However, lambs fed the control and 10% tallow diets excreted similar amounts of lipid while lambs fed the 20% tallow diet excreted 70-72% more lipid per day (95 g vs. 55 g).

Lipid digestibility was higher ($P < .05$) for the lambs fed the 10% or 20% tallow diets as compared to lambs fed the control diet, but there was no difference ($P > .05$) between the 10% and 20% tallow diets. Tallow digestibility, calculated by differences, was higher ($P < .05$) for lambs fed the 10% tallow diet as compared to lambs fed the 20% tallow diet (96.5% vs. 81.5%).

Fecal soaps (Table 8), calculated as a percentage of the excreted dry matter, were significantly increased ($P < .05$) when lambs were fed the 20% tallow diet as compared to lambs fed the control and 10% tallow diets. However, fecal soaps calculated as a percentage of the ingested lipid were approximately equal for the control and 20% tallow diets, but were lower ($P < .05$) for lambs fed the 10% tallow diet. Fecal soaps were approximately 65% of the fecal lipid from lambs fed the 20% tallow diet, and were

Table 8. Lipid Digested and Fecal Soap[a] Values; Experiment II

Item	Control	Control Plus 10% Tallow	Control Plus 20% Tallow
Lipid Ingested (gm/day)	119.0	175.2	268.5
Lipid Excreted (gm/day)	54.0	55.6	95.2
Lipid Digested (gm/day)	65.0	119.6	173.3
Fecal Soaps (gm/day)	24.1	23.2	62.0
Fecal Soaps as a Percentage of the Excreted Dry Matter %	6.2[b]	6.1[b]	15.6[c]
Fecal Soaps as a Percentage of the Excreted Lipid	44.8[b]	41.8[b]	65.2[c]
Fecal Soaps as a Percentage of the Ingested Lipid %	20.2[c]	13.2[b]	23.1[c]
Lipid in the Feces %	13.8[b]	14.6[b]	23.8[c]

[a]Chloroform-methanol-hydrochloric acid lipid extract minus chloroform-methanol lipid extract.

[b,c]Means on the same line with unlike superscripts are significantly different ($P < .05$).

higher ($P < .05$) when compared with lambs fed the control and tallow diets.

There were no performance data available for the study; however, dry matter consumption by the lambs during the 6-day collection period of the trial showed each treatment averaging 1041 grams. The lambs initially weighed between 51 and 52 kg each but final weights were not recorded.

DISCUSSION

Experiment I

The daily caloric intake (megcal. gross energy) and average daily gains by lambs fed the 8% unprotected CSO or the 12% PPCSO diets are very similar (Table 4). Lambs fed the control and 8% PPCSO diets had a 13% higher average caloric intake and daily gains were 19% higher than lambs fed the 8% unprotected CSO or the 12% PPCSO diets. The depressed feed consumption and caloric intake by lambs fed the diet containing 8% unprotected CSO may be due to the effect of the unsaturated CSO on the rumen activity. The depressed feed and caloric intake by lambs fed the 12% PPCSO diet is more difficult to explain. The acceptability of the diet may have some effect on feed intake; however, the PPCSO should have little or no effect on the microbial activity of the rumen. Figroid (1971) suggests that for steers, lipid consumption would not go above a certain level regardless of the level of lipid in the diet. It is possible that some type of feedback mechanism may be present at the site of lipid absorption or cellular transport which would depress lipid ingestion. It was shown in Table 3 that lambs fed the 8% and 12% PPCSO diets ingested, digested, and excreted similar amounts of lipid. The cottonseed oil digestibility

calculated by difference showed a slight depression of 7% by lambs fed the 12% PPCSO diet as compared to lambs fed the 8% PPCSO diet.

Lipid digestibility by lambs consuming the 8% unprotected CSO diet does indicate that lambs will consume and digest higher levels of added fat in the diet than usually considered feasible. This finding is also supported by the fact that the CSO digestibility, calculated by difference, was 93.6% for lambs fed the 8% unprotected CSO as compared to 96.2% for lambs fed the 8% PPCSO diet. Cottonseed oil digestibility by lambs fed the 8% unprotected CSO diet and the 8% PPCSO diet are not in agreement with values obtained by Cuitun (1974) in which digestibility by steers of safflower oil was increased 67% (from 41.3 to 68.9%) when oil was protected as compared to the unprotected safflower oil treatment. Steers were fed an 80% concentrate diet containing 6% safflower oil either protein protected or unprotected, while the lambs in this study were fed a 60% concentrate diet containing 8% unprotected CSO or 8% PPCSO. Lipid digestibility comparisons are probably not entirely valid due to diet differences; however, there appears to be a relationship between specie and lipid digestibility. At the present time, there are no comparative data regarding ovine and bovine lipid digestibilities.

Digestibility coefficients were similar among all treatments with the exception that lipid digestibility by

the lambs fed the control diet was significantly lower ($P < .05$) when compared to lambs fed the CSO-containing diets. The low lipid digestibility by lambs fed the control diet is to be expected based on the availability of the fat and waxes present in the feedstuff and the high level of insoluble soaps formed. The increase ($P < .05$) in fecal soaps as a percentage of the ingested lipid by the control lambs over lambs consuming the CSO diets (21% vs. 8.1%) is probably due to the lower ratio betweein lipid and soap forming minerals present in the intestine. Figroid (1971) found fecal soaps to be 12.2% of the ingested lipid when steers were fed a 60% concentrate diet with no added fat (4.0% natural lipid). This is approximately three-fifths the value found for lambs fed the 60% concentrate control diet (21.0%) which contained 7.1% natural lipid. Figroid (1971) also found fecal soaps to be 35.5% of the ingested lipid of steers fed a 60% concentrate diet with 10% added animal fat. This value for fecal soaps is almost four times the value found for lambs in this study which consumed a 60% concentrate diet with 8% added unprotected CSO. It is difficult to draw any conclusions regarding fecal soap values when comparing cattle and sheep since no literature is available on this topic. However, it does appear that lambs will digest more fat probably due to less soap re-formation once the lipid leaves the abomasum, which may be due to a pH difference between species in the duodenum.

Based strictly on digestibility data and fatty acid analysis, there appears to be only small variations between lambs fed the 8% unprotected CSO and the 8% PPCSO diets, with a small rise in cottonseed oil digestibility for lambs fed the 8% PPCSO diet. It is important to remember that lambs fed the 8% PPCSO diet consumed 30-34 grams more lipid per day, ingested 200-210 grams more diet per day, and gained approximately 45 grams more live weight per day than lambs fed the 8% unprotected CSO diet.

Faichney et al. (1973) conducted a digestion trial similar to the present study with the exception that a spray dried safflower oil:casein (1/1) homogenate was used and lambs were fed 600 grams per day of basal ration of equal parts crushed oats and chopped lucerne hay. Lipid digestibility for lambs fed the basal diet was 57.8%, a value almost identical to the one of 57.9% obtained in the present study. When 75 grams of the spray dried supplement or 5.6% protein protected safflower oil was added to the basal diet, lipid digestibility increased to 83.4% with the safflower oil being 95.3% digestible. At the last level of supplementation, 150 grams per day or 10% added protein protected safflower oil, lipid digestibility showed a slight increase to 85.7%, and safflower oil digestibility was lowered to 92.2%. Most of these values are very similar to those obtained in this study; however, the values for lipid digestibility of the diets are 5 to 9% higher than those

found in the present digestion trial. Extractable lipid in both studies was determined using chloroform, methanol: hydrochloric acid procedures. Diet formulation was probably the significant difference between the two studies, although the method of preparation and vegetable oil used in the supplement could also be an important factor to consider when comparing the studies.

When comparing the present lamb study with that of a steer study conducted by Cuitun (1974), many differences in the digestibility data are evident. The steers were fed an 80% concentrate diet with either 6% untreated safflower oil or 6% protein protected safflower oil which had been commercially prepared. Results of the steer trial showed dry matter, protein, and gross energy digestibilities to be different ($P < .05$) between the treated and untreated safflower oil treatments; however, lipid digestibility was not different ($P > .05$), probably due to animal variations within treatments. The lipid digestibility of the steers fed the untreated safflower oil (46.5%) was extremely low when compared to lambs fed the unprotected CSO diet (77.7%) in this study. It is also imperative to remember that the lambs were consuming a 60% concentrate diet containing 15% extractable lipid versus steers consuming an 80% concentrate diet containing 9% extractable lipid. Comparisons between the protein protected treatment diets of the two trials tend to be more closely correlated with respect to lipid

digestibility when only three of the five steers consuming the protein protected diet are considered. Lipid digestibility for these three steers was approximately 70%, not markedly different from that obtained in the present study (79%).

Although it is difficult to compare the trials conducted at The University of Arizona between species, the results tend to suggest that lambs are capable of ingesting and digesting proportionally larger quantities of lipid than steers.

Experiment II

The digestion trial data from this study do indicate significant differences in lipid digestibility and lipid parameters associated with the addition of tallow to the all roughage diet. Performance data were not available for this study, but based on dry matter intake and excretion by the lambs while confined to digestion crates, it appears that all diets were equally acceptable and/or palatable. Dry matter digestibility was almost identical among the treatments.

Lipid digestibility was not different ($P > .05$) between lambs fed the 10% and 20% tallow diets, but it is important to realize that lambs fed the 20% tallow diet ingested 53% or 93 grams more lipid per day than lambs fed the 10% tallow diet. Approximately 58% of the 93 gram

increase was digested by the lambs with the remainder being excreted probably as fecal soaps. Fecal soaps calculated as a percentage of the excreted lipid and as a percentage of the fecal dry matter were greater ($P < .05$) for lambs fed the 20% tallow diet as compared to the control and 10% tallow treatments. The actual increase in grams of fecal soap between the 10% and 20% tallow treatments (38.8 grams or 56%) is almost equal to the increase in fecal lipid between the two treatments (39.6 gm). This suggests that fecal soaps may comprise the major portion of fecal lipid after a certain dietary lipid level has been surpassed, unless consumption decreases.

When fecal soap values were calculated as a percentage of the ingested lipid, both the control and 20% tallow diets were similar and greater ($P < .05$) than the values found for lambs fed the 10% tallow diet. This tends to suggest that there is a point of maximum lipid utilization of the dietary fat. In summary, fecal soap values calculated as a percentage of the excreted dry matter or fecal lipid are fairly constant and indicate high utilization of the ingested fat until a certain level of ingested fat is reached. At this point, approximately 16.8% extractable lipid in this study, the lower utilization of the tallow by the lambs resulted in a significant proportion of the ingested lipid being excreted as fecal soaps. Supportive evidence to this summation is the fact that tallow

digestibility calculated by difference was greater ($P < .05$) for lambs fed the 10% tallow diet as compared to lambs fed the 20% tallow diet.

It is difficult to determine the exact mechanism(s) involved in the depression of lipid utilization at high levels of fat intake. Figroid (1971) has shown that increasing dietary fat level will lower rumen pH, which may have an inhibitory effect on microbial activity. However, the present study with lambs does not indicate a lower level of microbial activity since only lipid digestibility was adversely affected and not the other digestibility coefficients determined for lambs fed the 20% tallow diet. It does appear that an increased quantity of insoluble fecal soaps are formed in the intestine due to a high fatty acid: mineral ratio which renders the fatty acids unavailable for intestinal absorption. This high ratio may be the main reason for the lower dietary lipid digestibility and also tallow digestibility of lambs fed the 20% tallow diet versus the 10% tallow diet.

The present study is not in complete agreement with Figroid (1971) in which he found that increasing dietary fat levels within a concentrate level would depress feed consumption calculated as a percentage of the steers' body weight.

SUMMARY

Two digestion experiments were conducted with fattening lambs in two separate trials to determine the utilization of a formaldehyde treated protein:cottonseed oil emulsion in a 60% concentrate diet and animal fat added at three levels to an all roughage (ground alfalfa hay) diet.

In experiment I a casein:cottonseed oil homogenate (30:70) treated with formaldehyde was fed in gel form to determine its effect on digestion coefficients of a 60% concentrate diet. The control diet fed to four lambs contained no added oil. The second group of four lambs were fed the control diet with 8% unprotected cottonseed oil (CSO). Six lambs were initially started on the control with 8% protein protected cottonseed oil (PPCSO) added, with three lambs raised to a 12% PPCSO diet after 54 days on trial.

Dry matter, crude protein, and gross energy digestibilities and total digestible nutrients (TDN) tended to increase when lambs were fed diets containing CSO, however not significantly ($P > .05$). Acid detergent fiber tended to decline with the addition of CSO to the control diet, but again this was a non-significant trend ($P > .05$).

Lipid digestibility was lower ($P < .05$) for lambs fed the control diet when compared to lambs fed diets

containing CSO. Cottonseed oil digestibility calculated by difference was 93.6% for the unprotected CSO treatment, 96.2% for the 8% PPCSO treatment, and 89.9% for the 12% PPCSO treatment. Lambs fed the 8% PPCSO diet ingested 30-34 grams more lipid per day than lambs fed the 8% unprotected CSO diet.

Fecal soaps calculated as a percentage of the excreted dry matter were similar for all treatments and averaged 5.8%. Fecal soaps calculated as a percentage of the ingested lipid were greater ($P < .05$) for lambs fed the control diet compared to lambs fed diets containing CSO. The total percentage of unsaturated fatty acids in the feces was also greater ($P < .05$) for the control lambs compared to lambs fed the CSO diets.

The protection afforded by the formaldehyde treated casein:cottonseed oil homogenate was verified by the increased incorporation of unsaturated fatty acids in the adipose tissue taken from tail biopsies of lambs at various times during the study (Mata Hernandez, 1975).

The trial was not conducted to collect performance data; however, excellent gains were recorded for all lambs. Dry matter intake was lowest for lambs fed the 8% unprotected CSO and 12% PPCSO diets. Average daily gains were also lower for the 8% unprotected CSO and 12% PPCSO treatments as compared to the other two treatments, but not significantly so ($P > .05$). Feed requirements were highest

for the control lambs (6.5 kg/kg gain) and lowest for lambs fed the 8% PPCSO diet (5.8 kg/kg gain). Since the lambs were group fed, statistical analysis of the feed intake and feed requirements could not be determined.

Experiment II was conducted to determine what effect the addition of high levels of added tallow to a ground alfalfa hay diet would have on digestion coefficients of the diet. The digestion trial was conducted by Dr. William H. Hale in 1962. At the time this trial was conducted, there were no procedures for the determination of fecal soaps. Feed and feces samples were frozen until 1975 at which time the chemical analyses could be completed. The treatments were: (1) control, with 11.1% extractable lipid; (2) control plus 10% tallow, 16.8% extractable lipid; and (3) control plus 20% added tallow containing 25.3% extractable lipid. Tallow was added to the alfalfa hay prior to grinding.

Dry matter intake and dry matter, gross energy, protein, and crude fiber digestibilities were similar ($P > .05$) among all treatments while confined in digestion crates. Lipid digestibility was improved ($P < .05$) with the addition of tallow at the 10% and 20% levels compared to the control treatment. Fecal soaps calculated as a percentage of the excreted lipid were greater ($P < .05$) for lambs fed the 20% tallow diet (65%) as compared to lambs fed the control (44%) and 10% tallow (42%) diets.

Total digestible nutrients (TDN) were different ($P < .05$) among treatments. The 20% tallow diet had the highest TDN value and the control diet the lowest (82.9% vs. 58.6%). The increase in TDN was due mainly to increased lipid component values, however nitrogen free extract digestibility was greater ($P < .05$) for lambs fed the 20% tallow diet as compared to the control and 10% tallow treatments.

Based on dietary lipid digestibility, tallow digestibility and fecal soap parameters, tallow was maximumly utilized when incorporated in an all roughage diet at the 10% level. Fecal soaps were constant until dietary extractable lipid exceeded 16.8% of the diet. It was also found that the increase in fecal lipids due to an excess of dietary lipid resulted in most of the increased fecal lipid being fecal soaps.

REFERENCES

Andrews, R. J., and D. Lewis. 1970. The utilization of dietary fats by ruminants. I. The digestibility of some commercially available fats. J. Agric. Sci. 75:47.

A.O.A.C. 1955. Official Methods of Analysis (8th Ed.). Association of Official Agricultural Chemists. Washington, D. C.

A.O.A.C. 1965. Official Methods of Analysis (10th Ed.). Association of Official Agricultural Chemists. Washington, D. C.

Brethour, J. R., R. J. Sirny, and A. D. Tillman. 1958. Further studies concerning the effects of fats in sheep rations. J. Anim. Sci. 17:171.

Cameron, C. W., and D. E. Hogue. 1968. Effect of varying dietary corn oil and hay-grain ratio on lamb growth and fat characteristics. J. Anim. Sci. 27:553.

Cook, L. J., T. W. Scott, K. A. Ferguson, and I. W. McDonald. 1970. Production of polyunsaturated ruminant body fats. Nature 228:178.

Crampton, E. W. 1956. Applied animal nutrition, pp. 103-108. W. H. Freeman and Co., San Francisco, Calif.

Cuitun, L. L. 1974. The utilization of protein protected fats by ruminants. Ph.D. dissertation. The University of Arizona, Tucson.

Cuitun, L. L., W. H. Hale, Brent Theurer, F. D. Dryden, and J. A. Marchello. 1975. Protein protected fat for ruminants. I. Digestion and performance in fattening steers. J. Anim. Sci. 40:691.

Czerkawski, J. W. 1969. Methane production in ruminants and significance. Wld. Rev. and Dietetics 11:240.

Dinius, D. A., C. K. Lyon, and H. G. Walker, Jr. 1974. In vitro evaluations of protein and protein-safflower oil complexes treated with formaldehyde. J. Anim. Sci. 38:467.

Dinius, D. A., R. R. Oltjen, C. K. Lyon, G. O. Kohler, and H. G. Walker, Jr. 1974. Utilization of a formaldehyde treated casein-safflower oil complex by growing and finishing steers. J. Anim. Sci. 39:124.

Faichney, G. J. 1971. The effect of formaldehyde-treated casein on the growth of ruminant lambs. Aust. J. Agric. Res. 22:453.

Faichney, G. J., H. L. Davies, T. W. Scott, and L. J. Cook. 1972. The incorporation of linoleic acid into the tissues of growing steers offered a dietary supplement of formaldehyde-treated casein:safflower oil. Aust. J. Biol. Sci. 25:205.

Faichney, G. J., T. W. Scott, and L. J. Cook. 1973. The utilization by growing lambs of a casein safflower oil supplement treated with formaldehyde. Aust. J. Biol. Sci. 26:1179.

Ferguson, K. A., J. A. Hemsley, and P. J. Reis. 1967. Nutrition and wool growth. The effect of protecting dietary protein from microbial degradation in the rumen. Aust. J. Sci. 30:215.

Figroid, W. C. 1971. The effect of energy intake level on the digestibility of high energy rations by cattle. Ph.D. dissertation. The University of Arizona, Tucson.

Garrett, W. N., Y. T. Yang, Walter Dunkley, and L. Smith. 1975. Production of polyunsaturated ruminant meat. (Abst.) J. Anim. Sci.

Hale, W. H. 1975. Sheep and cattle utilization of high fat diets. Unpublished data. Department of Anim. Sci., The University of Arizona, Tucson.

Hatfield, D. D. 1970. Achieving the potential of high quality dietary proteins for ruminants. Feedstuffs 42 (52:23).

Hogan, J. P., P. J. Connell, and S. C. Mills. 1972. The digestion of safflower oil:casein particles protected against ruminal hydrogenation in sheep. Aust. J. Agric. Res. 23:87.

Jagusch, K. T. 1975. Production of lamb with poly-unsaturated depot fats (from feeding a dietary supplement of formaldehyde-treated ground sunflower seed). New Zealand J. of Agric. Res. 18:9.

Johnson, R. R., and K. E. McLlure. 1972. High fat rations for ruminants. I. The addition of saturated and unsaturated fats to high roughage and high concentrate rations. J. Anim. Sci. 34:501.

Klett, R. H., K. R. Hansen, and L. B. Sherrod. 1972. Roughage source-tallow levels in steer rations. (Abst.) J. Anim. Sci. 34:907.

Lough, A. K. 1970. Aspects of lipid digestion in the ruminant. A. T. Phillipson (Ed.), Physiology of Digestion and Metabolism in the Ruminant. Oriel Press, Newcastle Upon Tyne, England.

Macleod, G. K., and J. G. Buchanan-Smith. 1972. Digestibility of hydrogenated tallow, saturated fatty acids and soybean oil-supplemented diets by sheep. J. Anim. Sci. 35:890.

Mata Hernandez, Antonio. 1975. Unpublished data. Dept. of Anim. Sci., The University of Arizona, Tucson.

Mills, S. C., L. R. Sharry, L. J. Cook, and T. W. Scott. 1972. Metabolism of (14C)-formaldehyde when fed to ruminants as an aldehyde-casein-oil complex. Aust. J. Biol. Sci. 25:807.

Scott, T. W., P. J. Bready, A. J. Royal, and L. J. Cook. 1972. Oil seed supplements for the production of poly-unsaturated ruminant milk fat. Search 3:170.

Scott, T. W., L. J. Cook, K. A. Ferguson, I. W. McDonald, R. A. Buchanan, and G. L. Hills. 1970. Production of poly-unsaturated milk fat in domestic ruminants. Aust. J. Sci. 32:291.

Scott, T. W., L. J. Cook, and S. C. Mills. 1971. Protection of dietary polyunsaturated fatty acids against microbial hydrogenation in ruminants. J. Amer. Oil Chem. Soc. 48:358.

Smith, R. H. 1969. Reviews of the progress of dairy science. Section G. General, nitrogen metabolism and the rumen. Dairy Res. 36:20.

Van Soest, P. J. 1963. Use of detergents in the analysis of fibrous feeds. II. A rapid method for the determination of fiber and lignin. J. Assn. Official Agr. Chem. 46:829.