COMPOSITION AND PALATABILITY OF TISSUES FROM LAMBS FED PROTECTED OLIVE, LINSEED AND COTTONSEED OIL

by

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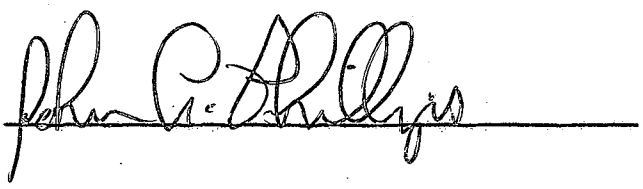
SIGNED: 

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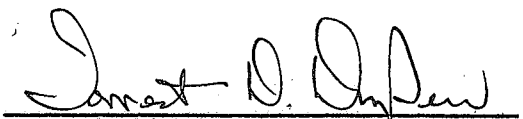

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ABSTRACT

Sixteen lambs of mixed breed and sex were randomly assigned to four diet groups. The diet groups included: (1) control basal diet of milo-alfalfa, (2) control diet plus 8% protected cottonseed oil (8% PCO), (3) control diet plus 8% protected olive oil (8% POO), and (4) control diet plus 8% protected linseed oil (8% PLO). Subcutaneous fat biopsies and blood samples were collected and serum lipid, insulin and glucagon levels determined. Internal, intermuscular, intramuscular and subcutaneous fats were collected. Two independent sensory panels evaluated either leg roasts or loin chops for acceptability.

Supplementation of oil resulted in elevating ($P < .05$) the levels of C18:1, C18:2 and C18:3, characteristic of the individual oils, in all lamb tissues studied. The fat biopsies accurately reflected changes which occurred in the body tissues. Both roasts and loin chops from the 8% PCO and 8% PLO lambs were least ($P < .05$) desirable because they possessed an oily aroma and flavor. The 8% POO lambs were not different ($P > .05$) from the control group but possessed a more bland, beef-like flavor. Serum lipid levels increased ($P < .05$) in all oil supplemented lambs. Serum glucagon and insulin levels increased ($P < .05$) for all lambs regardless of dietary treatment.

INTRODUCTION

The flavor of meat from lambs (Park, Murray and Stanley 1974) and steers (Ford, Park and Ratcliff 1976) has been altered by the feeding of dietary oils protected from rumen fermentation. Park et al. (1974) found that lambs supplemented with protected safflower oil were different ($P < .05$) from conventionally fed lambs and were characterized by a sweet-oily aroma. In the cooked meat and fat from these lambs, 4-hydroxy-cis-6-enoic acid lactone and trans, trans-2,4-decdien-1-al were isolated and implicated with the sweet-oily aroma and flavor. Steers fed protected sunflower oil (Ford et al. 1976) were found to have lower ($P < .05$) ratings in evaluation of all flavor properties. The volatile components of beef were reported to have less ($P < .05$) 4-hydroxy-cis-6-enoic acid lactone than lambs with other components being equal ($P > .05$).

Studies of this type have in most cases involved the use of crude oil preparations which have been subjected to little or no refinement. The use of food quality oils, which have received a common degree of refinement, may reduce the possibility of incorporating impurities in the adipose tissues of lambs. Also, it was of interest to determine if the use of different oils with various fatty

acid compositions could result in favorable flavor changes characteristic of the individual oil.

The purpose of this study was to investigate the effects of the supplementation of food quality oils protected from rumen fermentation on: (1) meat flavor properties, (2) fatty acid composition of tissue lipids, (3) the rate of change in fatty acid composition of subcutaneous fat, (4) animal performance and (5) level of circulating serum lipid, insulin and glucagon of lambs.

LITERATURE REVIEW

Rumen Action

The digestive capabilities of the ruminant animal make it possible for them to utilize certain plant components more effeciently and to a greater extent than monogastrics. This is accomplished by the conversion of a component, which is undigestable by mammalian enzymes, to one that is by the actions of microbial enzymes. An example of this is native cellulose which is hydrolyzed by cellulase enzymes which can be produced by cellulolytic bacteria (Underkofler, Kitts and Smith 1953).

Along with making the ruminant animal more effecient in the utilization of some components, the rumen microflora also decreases the efficiency with which some nutrients are utilized. There is a degradation of higher quality proteins in the rumen to ammonia, which is absorbed in large quantities and excreted in the urine (McDonald 1952). Also, the levels of nutrients may be self-limiting. Levels of fat higher than 5-7% cause increased production of fecal soaps and depress ration digestibility in sheep (Czerkawski, Blaxter and Wainman 1966a,b) and cattle (Figroid 1971). As a result of this latter situation, several techniques have been developed for the protection of proteins and lipids from the action of the rumen microorganisms.

Protein-lipid Protection

In recent years, processes for the protection of protein and protein-lipid homogenates from rumen fermentation have been developed. These processes generally involve the spray drying of oil droplets encapsulated in sodium casienate, or an appropriate protein, and then treating with formaldehyde (Scott, Cook and Mills 1971). The spray drying techniques were those developed for the production of butter powders. It was found that a level of 2% formaldehyde on a protein basis gave complete protection for a period of 20 hours in-vitro (Scott et al. 1971).

Treatment of sodium casienate with formaldehyde results in cross-linking of protein molecules which forms a stable product at a basic or neutral pH. Since the rumen is fairly neutral in pH, the treated protein can not be hydrolyzed by rumen microorganisms. When the treated protein enters the abomassum, which has an acidic pH, it is assumed the cross-linking between protein molecules is broken. Therefore, the protein is digested as in monogastrics. It was found (Scott et al. 1970) that one could encapsulate oil droplets in a protein coat, then treat the product with formaldehyde and protect the polyunsaturated fatty acids of the oil from hydrogenation in the rumen.

The majority of lipids available from plant sources are unsaturated, but undergo substantial hydrogenation in the rumen before absorption and deposition in the animal

tissues (Scott et al. 1971). This technique of protein-lipid protection presents a way in which to alter fatty acids available for absorption and deposition within the animal. In-vivo studies indicate that little hydrogenation takes place when ruminants are fed a formaldehyde-treated casien: oil supplement (Scott et al. 1970 and Dinius, Lyon and Walker 1974).

Supplementation of Protected Oils

The supplementation of various protected oil products has been studied by several researchers within the last decade. The general results of such trials have been the incorporation of more unsaturated fatty acids in the depot fats, serum lipids, and milk than is normally found in ruminant animals. The unsaturated fatty acids incorporated by the ruminant animals is dependent upon the composition of the particular oil being fed. Trials have been run using several oils and the findings are listed by oils as follows.

Linseed Oil

Scott et al. (1970) reported that the proportion of linolenic acid was increased from 1-2% to 21-25% in the milk fat of goats and cows upon the supplementation of formaldehyde treated casien:linseed oil product. In a follow-up study, protected linseed oil was infused into the abomassum of sheep (Scott et al. 1971) and blood plasma triglyceride studies were conducted. It was noted that linoleic acid

increased from a pre-infusion level of 3.4% to a 9.6% level five hours after infusion. Also, the pre-infusion level of linolenic acid was 5.2% and increased to 26.2% five hours post-infusion. After eleven hours post-infusion, the proportions of linoleic and linolenic acids had returned to the pre-infusion levels. This indicated a rapid absorption of the treated fatty acids from the intestine and that fat digestion was not impaired by the formaldehyde treatment (Scott et al. 1971).

Safflower Oil

It was reported by Scott et al. (1970) that elevated (from 2-3% to 28-29%) levels of linoleic acid in lamb depot fats was achieved by the supplementation of protein protected safflower oil. Linoleic acid in milk has been increased tenfold with an increase in total fat of 0.5% by the supplementation of protected safflower oil (Plowman et al. 1971). Similar results were obtained by feeding protected safflower oil to lactating dairy cows (Bitman et al. 1973).

The effect of formaldehyde treated casien:safflower oil on fatty acid constituents of plasma, serum, muscle, liver, and adipose tissue of cattle and sheep were investigated by Cook, Scott and Pan (1972) and Faichney (1971). A three to twenty-fold increase in linoleic acid was found in the tissues of both lambs and cattle.

It has been reported that a three to five-fold increase in the proportion of linoleic acid in perinephric, messenteric, and subcutaneous fats in lamb was obtained by supplementing a protected safflower oil-casein product (Scott et al. 1970 and Cook et al. 1970). The incorporation of linoleic acid in the tissues was assumed to be fairly rapid, since the change in depot fat composition from feeding the lambs six weeks as opposed to three weeks was not greatly different. At the end of three weeks of feeding, the lambs on the oil product had mesenteric fat which contained 11.3% linoleic acid as compared to lambs on the product for six weeks having 15.7% linoleic acid. Control lambs had 1.9 to 3.0% linoleic acid in their mesenteric fat.

Scott et al. (1971) reported substantial alteration of the depot fats of lambs upon supplementation of a protected safflower oil-casien product. The proportion of linoleic acid was found to increase from 2-3% to 28-29% in the perenial and subcutaneous fats, as a result of feeding the product. Corresponding decreases were noted in palmitic, stearic, and oleic acids within these tissues.

The incorporation of linoleic acid in the tissues of growing steers fed a formaldehyde-treated casien:safflower oil supplement was studied by Faichney et al. (1972) and Faichney, Scott and Cook (1973). These studies substantiated earlier research on the incorporation of linoleic acid into tissue lipids. It was also found that the rate of

incorporation in each tissue was described by a curve of diminishing increments and the level of incorporation in body tissues was observed to be higher than those tissues nearer the body surface.

Since the protein and lipid in the supplement are protected from ruminal fermentation, the digestion of the nutrients must take place in the abomassum. It has been found that protected casien:safflower oils are digested as well, with the exception of a slight depression in protein digestibility, as the non-protected oil product by sheep (Faichney et al. 1973) and cattle (Dinius, Oltien et al. 1974).

Sunflower Seed Oil

Ford, Park and McBride (1975) compared lambs fed sunflower seed oil protected with formaldehyde treated casein to lambs on pasture and feedlot diets. The linoleic acid content of the subcutaneous fat at slaughter after 39 and 55 days of feeding was 17.0 ±1.1% and 19.8 ±1.5%, respectively, in supplemented lambs as compared to 2.5 ±0.8% in normal feedlot lambs.

A fatty acid profile of tailhead fat was determined on lambs fed protein protected sunflower oil for periods of zero, one, two, three, four, five, and six weeks (Park, Ford and Ratcliff 1975). An increase of twenty-fold was reported in the proportion of linoleic acid from the first to the last period of feeding. It was observed that the incorporation

of linoleic acid into the tissue occurred at a faster rate in the first few weeks of supplementation as compared to the latter weeks.

Hogan and Hogan (1976) evaluated formaldehyde-treated sunflower seed oil:casein supplements fed to lambs. These researchers observed that carcasses of lambs fed the supplement were significantly ($P < .05$) heavier and contained more lipid and long chain fatty acids than conventionally fed lamb. With increasing levels of intake (of the sunflower seed supplement), from 0 to 33% of the ration, correspondingly higher proportions of linoleic acid were deposited in the tissues. There was a tendency for the proportion of linoleic acid to be lower in subcutaneous fats and higher in perenial fat which substantiated the reports of Faichney et al. (1972) and Faichney et al. (1973) on the incorporation of linoleic acid in the tissues of growing steers.

Angus steers were fed a formaldehyde-treated casein: sunflower oil supplement in a study by Ford et al. (1976) and the changes in fatty acid composition of subcutaneous and perenephric fats were measured. A ten-fold increase in the proportion of linoleic acid in the subcutaneous fat was reported along with a twenty-fold increase in linoleic acid in perenephric fat.

Park, Ford and Ratcliff (1976) reported an increase in the proportion of linoleic acid from 2.6% to 20.5% in

the subcutaneous tailhead fat samples obtained from lambs. A protected sunflower seed oil:casein product had been fed to the lambs used in this study, which was a follow-up study of earlier research.

Cottonseed Oil

Hernandez (1976) found that supplementing lamb diets with formaldehyde-treated casein:cottonseed oil significantly increased the level of linoleic acid in plasma lipid, subcutaneous fat, mesentery fat, kidney fat, and intermuscular fat depots. Also, significant ($P < .05$) increases were noted in the level of linoleic acid in intramuscular and liver lipids.

This study was substantiated by research (F. D. Dryden, J. A. Marchello and A. M. Hernandez, personal communications 1977) in which different levels of protected cottonseed oil were fed to lambs. Significant increases ($P < .05$) in the level of linoleic acid were found in serum lipid, subcutaneous fats, perenephric fats, and inter and intramuscular fats.

Influence of Protected Oil Supplementation on Milk Fat

There have been many studies investigating the influence that the feeding of protected oils has on the composition and palatability of milk, milk fat, and milk products. The effects of protected lipids on milk were first studied by Scott and Cook (1970) and Scott et al. (1970)

upon the development of the technique for protein-lipid protection. It was noted that fatty acids protected from biohydrogenation were absorbed and found in substantial quantities in milk from goats and cows fed the product.

Changes in Fat Composition

By feeding protected linseed oil to goats and cows during early lactation, Scott and Cook (1970) and Scott et al. (1970) found a ten-fold increase in the proportion of linoleic acid in the milk. The proportion of linolenic acid in milk was increased ten-fold by supplementing a protected safflower oil product to Holstein cows (Plowman et al. 1971). In the latter study, linoleic acid increased from 3 to 35% of the total fatty acids in the milk. Similar research by Bitman et al. (1973), in which an increase from 2-3% to 35% in linoleic acid was obtained by supplementing lactating cows with protein protected safflower oil, lends support to the findings of Plowman et al. (1971). Very similar results were obtained by feeding cracked sunflower seeds treated with formaldehyde (Scott et al. 1972) and formaldehyde-treated casein:safflower oil (Cook, Scott et al. 1972). Dryden et al. (1971) reported that the level of protected safflower oil supplementation had a direct effect on the proportion of linoleic acid found in milk fat.

Douglas et al. (1973) fed a preparation of formaldehyde treated full-fat soy flour and sweet whey to lactating

dairy cows. After a period of four days, the linoleic acid content of the milk increased from 2.7% to 10.2%. By including soybean meal in the preparation, a level of 12.1% was reached at the end of a four day period.

Changes in Flavor and Shelf-life

The influence that feeding protected oils exerts on milk and cheese flavor, and shelf-life has been studied by several researchers. Cheddar cheese has been produced from milk obtained from cows fed a protected safflower oil supplement (Wong et al. 1973). Cheddar and other cheeses, containing 30% linoleic acid, were found to have body and flavor defects. These problems were less noticable in cheeses with 12-16% linoleic acid. However, these cheeses were significantly lower ($P < .05$) in flavor score and cheese flavor than was a control product. The flavor defects were attrib uted to autooxidation of linoleic acid in the products.

Oxidized flavors have been found as characteristics of unsaturated milk. A study by King et al. (1971) demonstrated that milk which contained 13.6% linoleic acid was initially free of flavor defects at the time of milking. Spontaneous oxidized flavors developed in the milk from 50% of the cows on protected oil rations. These researchers added copper sulfate to samples from cows on the control and experimental diets to induce oxidation. A strongly oxidized flavor developed in all milk samples from cows fed

the protected oils after 24 hours. However, it was found that milk from the control cows was resistant to oxidation by copper sulfate in a 24 hour period.

In another study in which protected full-fat soy flour and whey had been fed, an oxidized flavor was insignificant immediately following milking, but its intensity increased to a definite-pronounced flavor after four days of refrigerated storage (Douglas et al. 1973). This oxidized flavor was not found in conventionally produced milk. Research by Ratcliffe and Bartsch (1974) tends to substantiate this finding. Oxidized flavors were noted to develop in milk from cows fed a protected sunflower seed supplement, whereas no oxidized flavor was noted in milk from control animals.

A research project conducted in Beltsville, Maryland by Goering et al. (1975) points out that milk obtained from cows fed a protected safflower oil supplement readily developed off-flavors. The off-flavors were predominantly of an oxidized nature and were attributed to the autooxidation of linoleic acid in the milk. Supplementation of cows with α-tocopheryl acetate or direct addition of α-tocopherol to the milk prevented the development of oxidized flavors.

In a trial involving Holstein cows in early lactation which were fed a formaldehyde treated soybean meal:animal tallow product, it was determined that formaldehyde,

cholesterol, and milk flavor were not influenced by the feeding of the supplement (MacLeod, Yu and Schaeffer 1976). However, the oxidized flavor reported in other studies was assumed to be a result of the oxidation of linoleic and linolenic acids. Animal tallow is very low in these fatty acids as compared to seed oils.

Influence of Protected Oil Supplementation on Meat

Many studies have been conducted on the production of polyunsaturated meats by the feeding of protein protected oils. However, only a few of these studies have reported on the flavor characteristics of the unsaturated meats.

Changes in Fatty Acid Composition

Cook, Scott et al. (1972) reported that elevated levels of linoleic acid were found in the M. Psoas major muscle of steers fed a formaldehyde treated casein:safflower oil supplement. Accompanying this increase was a corresponding decrease in the proportions of palmitic, oleic, and linolenic acids. No consistent change was found in the proportion of stearic acid. These results have been supported by similar results obtained from supplementing protected safflower oil to lambs (Faichney 1971; Hogan, Connel and Mills 1972; and Faichney, Scott and Cook 1973) and steers (Dinius, Oltien and Sattle 1974; Dinius, Lyon and Walker 1974; and Park et al. 1976). Similar results have been

obtained by feeding protected cottonseed oil to lambs (Hernandez 1976 and Dryden, personal communication).

Changes in Meat Flavor and Acceptability

Mills et al. (1972) determined that formaldehyde was metabolized by ruminants when fed as formaldehyde treated casein. No formaldehyde or its metabolic products were found deposited in the tissues of lambs when a radioactive labeled formaldehyde:casein product was fed. Therefore, it is assumed that the feeding of formaldehyde has no influence on the flavor of meat or milk from animals fed a formaldehyde treated product.

It has been reported that the overall desirability of beef was not affected when safflower oil was abomassally administered to steers (Dinius, Oltien and Sattle 1974). No differences ($P > .05$) were detected between treatments for aroma, flavor, texture, tenderness or juiciness. These findings are supported by a similar study in which steers were supplemented with a protein protected safflower oil product (Dinius, Lyon and Walker 1974).

Contrary to these findings, Park et al. (1974) reported that cooked meat from lambs fed diets with protected safflower oil, high in linoleic acid, were strikingly different from conventionally fed lambs. It was characterized by a sweet-oily aroma according to the report. This aroma was found to be associated with the cooked fat and was

evident in the volatile fraction obtained from the cooked fat by the cold-finger distillation. Two major components were isolated from the fraction which were thought to influence the flavor and aroma. The compound 4-hydroxy-cis, 6-enoic acid lactone was considered to be largely responsible for the sweet flavor-note of the meat. The origin of this compound is obscure since it was not found in the feeds. The other component, trans, trans-2, 4-decadien-1-al, was considered to contribute an oily or chicken-oily aroma to the supplement fed lamb. This component is a prominent oxidation product of linoleic acid and is believed to be produced upon cooking since its aroma was not evident in fresh meat.

Ford et al. (1975) compared meat from lambs fed a protected sunflower seed oil supplement to that from pasture and feedlot fed lambs. Roast samples from all treatments were tasted both hot and cold. The meat from supplemented lambs was found less desirable than that produced in a conventional manner. In the cooked samples of the supplemented lamb, an unsaturated δ-dodecalactone and trans, trans-deca-2,4-dienal were found. These were believed to be partly responsible for the oily character of the flavor and aroma of the supplemented lamb.

Similar data has been obtained by Park et al. (1975) when a sunflower seed oil supplement was fed to lambs for

varying periods (zero to six weeks) of time. As the length of feeding increased, a significant decrease ($P < .05$) was found in scores for aroma, flavor and acceptability. Also, cis-γ -dodec-6-enolactone, trans, trans-deca-2,4-dienal, and an unsaturated γ -dodecalactone were isolated from the volatile components of the supplemented lambs.

Ford et al. (1976) supplemented steers with protein protected sunflower seed oil. The supplemented steers were found to have significantly ($P < .05$) lower ratings in evaluation of all flavor properties. The difference in supplemented beef and lamb volatile components was that beef had less (0.1 ppm:1.0 ppm) cis-γ -dodec-6-enolactone than lamb.

Results which substantiate these findings were reported by Park et al. (1976) in a study to evaluate the effects of protected sunflower seed oil and safflower oil on lamb flavor. Both products resulted in a decrease in flavor and aroma intensity and gave the meat oily aromas and flavor characteristics which were attributed to the presence of abnormally high levels of deca-2,4-dienal in the cooled meat.

Dryden, Marchello and Hernandez (personal communications 1977) found that lamb supplemented with protected cottonseed oil was less desirable in flavor and aroma than control lamb.

Meat from steers and lambs fed protected sunflower seed oil with up to 20% linoleic acid was utilized for studying the oxidation changes during frozen storage of this type of product (Bremner et al. 1976). It was found that peroxide development in high linoleic meat was much more rapid than in conventional meat stored at -10°C. However, storage at -20°C greatly reduced peroxide development. Evaluation by taste panel demonstrated that high linoleic meat (stored at -10°C) developed rancid flavors and odors two to three times faster than conventional meat stored in the same manner.

MATERIALS AND METHODS

General

Six Rambouillet, six Suffolk and four Hampshire lambs with an initial average weight of 30.3 kg were randomly alloted to four groups of four lambs each and assigned to different diets. The diets were as follows: Control, 60% concentrate diet; PCO, control diet plus 8% protected cottonseed oil; POO, control diet plus 8% protected olive oil; PLO, control diet plus 8% protected linseed oil (Table 1). Oils were of food grade quality, thereby eliminating impurities that may have been present in more crude preparations. The protected product was fed at a level which supplied a level of 8% oil to the diets.

All lambs were fed the control diet for an initial two week period, then the lambs were group fed their respective diets for a 46 day period prior to slaughter. The initial two week period allowed all lambs an adjustment period to the control diet before blood samples for serum lipid and hormone analysis and biopsy samples were collected at the start of the 46 day trial.

Table 1. Experimental Diets[a].

Ingredient	Control	Percent Composition 8% PCO	8% POO	8% PLO
Ground Alfalfa Hay	40.0	40.0	40.0	40.0
Steam Processed Milo	53.8	42.4	42.4	42.4
Molasses	6.0	6.0	6.0	6.0
Biofos	0.2	0.2	0.2	0.2
Protected Olive Oil[b]	--	--	11.4	--
Protected Linseed Oil[b]	--	--	--	11.4
Protected Cottonseed Oil[b]	--	11.4	--	--

[a] PCO = cottonseed oil product, POO = olive oil product, PLO = linseed oil product (percentages refer to oil content of diet).

[b] Oil products (70% oil:30% casein, H_2O:casein ratio 7:1), percent on 100% dry matter basis.

Preparation of Formaldehyde-treated Casein:Oil Products

The casein:oil products were prepared as follows:

1. Acid precipitated sodium caseinate was dissolved in distilled water (1 part casein: 7 parts water) by adding sufficient 25% sodium hydroxide (w/v) to adjust the mixture to a pH of 7.0 ±0.3. The solution was allowed to stand overnight to insure the complete hydration of the casein.
2. The appropriate oil (cottonseed, olive or linseed) was added to the casein solution to give a 30:70 casein:oil mixture which was then placed in a 10 gallon steam jacketed kettle and heated to 50°C.
3. The mixture was homogenized twice using a Manton-Gaulin Model 15M-8TBA two-stage homogenizer at 2.2×10^8 kg per square meter of pressure.
4. Formaldehyde was stirred into the homogenate (2.5% formaldehyde or 6.8% formalin by weight of casein).
5. The oil products were sealed in plastic containers and refrigerated for at least 24 hrs. The gelled product was ground through a meat grinder with 1 cm openings prior to mixing with the remainder of the ration ingredients.

The final oil products contained 67.6% water, 33.6% cottonseed, olive or linseed oil, and 9.8% casein by weight. In mixing the product with feed, 20.7 kg of the product was

mixed with 51.7 kg of feed and allowed to air dry. This resulted in 58.3 kg of feed which contained 8% added oil by weight.

Sample Collection

Blood Plasma and Serum

Blood samples were collected on days 0, 14, 28, and 42 from the jugular vein of each lamb, using a California bleeding needle, prior to the 7:00 am feeding. The samples were collected in 50 ml test tubes containing 1.2 mg EDTA-Na_2 per ml of blood to prevent clotting or 2 mg benzamindine hydrochloride hydrate per ml of blood to prevent destruction of the glucagon. These samples were used for the determination of insulin, glucagon and total serum lipid levels. The plasma was separated by centrifugation at 10,000 rpm for 10 min at 4°C. The plasma was immediately drawn off with a syringe and placed in Nalgene bottles and frozen at -18°C until further analysis.

Subcutaneous Tailhead Fat Biopsy

Individual subcutaneous tailhead fat biopsy samples were obtained just prior to starting oil supplementation (day 0) and at days 14, 28 and 46. Approximately 1-5 gm of subcutaneous fat was removed from the tailhead region at each sampling date.

Lidocaine was injected subcutaneously in the upper tailhead region as a local anesthetic. A 3 cm incision was made with a scalpel on alternate sides of the animal at different sampling periods for the removal of the sample. The incision was covered with sulfa-urea powder and closed by Michel suture clips, then sprayed with KRS. Combiotic was administered to each sampling period to help prevent infections. After the application of these methods, all incisions remained closed and no infections were observed.

Carcass Fat Samples

During slaughter, fat samples were collected for fatty acid analysis. The fourth tailhead fat sample was taken at this time by removing a 5 gm sample of adipose tissue from the tailhead region, avoiding scar tissue from prior biopsies. Other tissue samples collected at this time were mesentary fat, kidney fat, and heart fat. Carcass samples collected for lipid analysis during processing (after a seven day aging period) were: a crosssection of the center portion of the Triceps brachii (TB), the section of the Longissimus dorsi (LD) between the ninth and eleventh ribs, seam fat adjacent to the TB, seam fat adjacent to the semimembranosus (SM), subcutaneous fat from the LD, and subcutaneous fat from the TB. Muscle samples obtained at this time for sensory panel evaluation were two loin double chops, 1.9 cm thick, from the area of the 12th and 13th ribs

and one leg roast, 3.2 cm thick, from the center portion of the wholesale leg from each lamb.

All carcass samples for lipid analysis were placed in plastic bags, frozen, and stored at -20°C. All samples for sensory evaluation were individually wrapped in polyethylene freezer paper stored at -20°C until evaluated.

Chemical Analysis

Lipid Extraction Methods

Plasma. Duplicate 2 ml whole plasma samples were extracted with chloroform-methanol (2:1, v/v) according to the procedure of Folch, Lees and Sloane-Stanley (1957). After evaporation in a vacuum oven at 50°C, the weights of the extracted lipids were recorded and the samples stored in solution with chloroform at -18°C in sealed vials until further analysis.

Intramuscular Fat. Two 10 gm samples from the TB and LD from each lamb were homogenized and total lipid extracted with chloroform-methanol according to the modified method of Ostrander and Dugan (1961) as outlined by Leander (1975). Ten ml aliquots from each extract were used for weight determinations. These samples were dried, weighed and stored as the plasma lipids were.

Subcutaneous, Intermuscular, Biopsy and Internal Fat. Fat samples of approximately 1 gm from kidney, heart, mesentary, seam, biopsy and subcutaneous fats were knife cut into small pieces and extracted with chloroform-methanol (2:1, v/v), using the same methods as for plasma lipid extraction.

Feed Extractions. Five gm duplicate samples of each ration were extracted using the chloroform-methanol-acid method as outlined by Figroid (1971). For fatty acid composition of the feeds see Tables 2 and 3.

Plasma Insulin

Insulin determinations were made using a slightly modified radioimmunoassay procedure of Wright et al. (1971). The labeled antigen, ^{125}I porcine insulin, was purchased from Cambridge Nuclear Radiopharmaceutical Corporation, Billerica, Massachusetts and the bovine antibody produced in the guinea pig was purchased from Miles Laboratories, Inc., Elkhart, Indiana.

Serum Glucagon

The radioimmunoassay of glucagon was conducted according to the method of Aguilar-Parada, Eisentraut and Unger (1969), except that benzamidine was used as a proteolytic inhibitor as suggested by Ensinck et al. (1972). The labeled antigen, ^{125}I glucagon, was purchased from Nuclear

Table 2. Percent Lipid, Moisture and Fatty Acids of Experimental Diets[a].

Content	Diets			
	Control	8% PCO	8% POO	8% PLO
Lipid[b]	3.3	8.5	11.7	10.1
Moisture	9.9	17.3	16.5	17.2
Fatty Acids				
14:0	.4	.8	.2	.2
14:1	.2	---	.1	.1
15:0	.1	.1	.1	.1
I16	.1	.1	---	.1
16:0	18.0	18.9	15.7	9.2
16:1	1.7	.9	1.3	.5
17:0	.4	.2	.3	.2
I18	2.1	.2	.4	---
18:0	2.4	2.9	2.6	4.4
18:1	27.3	24.0	62.7	26.4
18:2	42.0	49.8	14.1	19.0
18:3	7.3	2.2	2.5	39.8
TU[c]	78.5	76.9	80.7	85.8

[a] PCO = cottonseed product, POO = olive oil product, PLO = linseed oil product (percentages refer to oil content of diet).

[b] Calculated on 100% dry matter basis.

[c] Total Unsaturated fatty acids.

Table 3. Fatty Acid Composition of Oils[a].

Fatty Acid	Cottonseed Oil	Linseed Oil	Olive Oil
14:0	1.0	<0.05	<0.05
16:0	18.5	6.3	14.6
16:1	0.6	0.2	1.4
17:0	0.1	0.1	<0.05
I18:0	0.1	<0.05	0.5
18:0	2.5	4.6	2.9
18:1	19.4	24.8	72.1
18:2	57.8	14.6	7.4
18:3	<0.05	49.5	1.1

[a] Weight percent of total fatty acid.

Medical Laboratory, Dallas, Texas and the specific pancreatic glucagon antiserum (30K) from the laboratory of Dr. Roger Unger, University of Texas Health Science Center and Veterans Administration Hospital, Dallas, Texas.

Esterification

The lipid extracts of tissue, depot and feed lipids were trans-esterified by a modified combination of the methods of Bowyer et al. (1963) and Marchello, Dryden and Ray (1968). A 50 mg sample of lipid in solution with chloroform was mixed with 2 ml of benzene, 4.5 ml of 5% (v/v) sulfuric acid in super dry methanol, flushed with nitrogen, tightly capped and well mixed. The tubes containing samples were placed in a 90°C water bath for 2.5 hrs, with occasional shaking. The tubes were then cooled after which 4 ml of distilled water was added to each tube. The methyl esters were extracted from the solution by the addition of 5 ml of petroleum ether, shaking well and centrifugation at 1500 rpm for 10 min. The petroleum ether layer was pipeted off and placed in sealed vials until analyzed by gas-liquid chromatography.

Thin-layer Chromatography

Methyl esters of intramuscular and feed lipids were purified so that a minimum base line and maximum repeatability on subsequent gas chromatography could be obtained.

This was accomplished by thin-layer chromatography of the methyl esters obtained from the trans-esterification of approximately 50 mg of extracted lipid. A 5 ml aliquot of chloroform-methyl ester mixture was spotted on a 20x20 cm pre-activated (1 hr at 100°C) and pre-coated (0.25 mm silica gel F-254) (E. Merck Ag., Darmstad, Germany) thin-layer plates. The plates were developed in a filter paper lined glass tank using a solvent of petroleum ether (30-70°C) diethyl ether-acetic acid (80:10:5, v/v/v) (Bowyer et al. 1963). After development of the plates and evaporation of the solvent, the plates were sprayed lightly with .05% (w/v) solution of Rhodamine 6 G in ethanol (Skipski et al. 1967) and viewed under ultraviolet light for identification and marking of the methyl ester band. The methyl ester bands were identified with the aid of standards and were eluted from the silica gel once with 3 ml of petroleum ether after mixing and centrifugation at 1500 rpm to settle the silica gel. Methyl esters were stored in sealed vials at -18°C until analyzed by gas-liquid chromatography.

Gas-liquid Chromatography

Two Beckman GC-5 gas chromatographs were used for analysis of the fatty acid esters. Both gas chromatographs were equipped with hydrogen flame detectors. Dual, 1.83 m (3.2 mm O.D.) coiled, stainless steel columns, packed with

100-120 mesh chromosorb W (HP) as the stationary phase and 5% Silar 5 CP as the liquid phase were used. The carrier gas (nitrogen) flow rates were approximately 25 ml/min and the column temperature was 175°C. The inlet temperature was 250°C, with the detector and detector lines operated at 250°C.

Identification of the methyl esters in each sample was accomplished by comparison of the retention times with those of a standard solution of known composition run through the same gas chromatograph. The recorder for each gas chromatograph was equipped with a disc integrator which was used as an aid in the computation of the weight percent of each methyl ester in the sample.

Sensory Panel Evaluation

The University of Arizona Evaluation

Lamb leg roasts were roasted in separate, open pans on the center rack of standard General Electric ovens. The oven temperatures were set at 163°C and the roasts were cooked to an internal temperature of 71°C, determined by Models 42 SC and 4002 SB temperature probes from the Yellow Springs Instrument Company, Yellow Springs, Ohio. After cooking the roasts were placed in separate pans, covered with aluminum foil, and held in a portable steam table. Samples from the roasts of about 1.25x1.25x3.75 cm were cut

from the SM muscle. These samples were excised so as to be free of connective tissue and seam fat. The cut samples were held in the juices from the cooked roasts until served for evaluation to prevent moisture loss. Prior to serving, one sample from each treatment group on each sample day was placed in coded souffle cups and were served in a random order.

The sensory panel consisted of 12 members who had been selected from the faculty and staff of The University of Arizona. The only restriction on the selection of members was that they could not have a definite dislike for lamb. The members of the panel ranged in age from 20 to 50 years of which six were females and six were males.

The only training the panel received was accomplished during a special session in which samples of lamb roasts from commercially produced lamb were evaluated. The roasts were prepared as outlined for the samples.

Evaluation was based on a hedonic scale from 1 to 9 (Figure 1). The scale was numerically scored by the use of a transparent grid. Aroma, juiceness, tenderness, flavor and overall evaluation were the characteristics evaluated.

Armour Food Company Evaluation

A 12 judge panel evaluated loin chops for aroma and flavor using a nine point hedonic scale (1=dislike extremely, 9=like extremely). The panel was a highly trained

MEAT EVALUATION

1-4____ Judge____ Sample____

(Very Undesirable) 1 (Very Desirable) 9

5____ Aroma _____

6____ Juiciness _____

7____ Tenderness _____

8____ Flavor _____

9____ Overall _____

Comments:

Figure 1. Meat Evaluation Form.

research panel used for sensory evaluation of the Armour-Dial Research Center in Scottsdale, Arizona. Four samples, one lamb from each dietary treatment, were evaluated during each of four sessions held over a two day period. Samples were presented to judges one at a time.

Aroma was evaluated by lifting the edge of the watch glass, covering the beaker containing the sample, and sniffing. Flavor was evaluated by consumption of the entire sample.

Thirty-two judges were screened for the selection of the 12 member panel. For selection, judges were asked to evaluate four lamb loin samples obtained from two stores. Loin chops from one store were frozen and imported from New Zealand; those from the other store were fresh. Judges were selected on their ability to replicate scores and score samples in the middle range of the scale, yet differentiate between store samples.

Loin chops were thawed 19 to 22 hours prior to evaluation. Three loin chops from one animal of each treatment were prepared for each session. The chops were broiled on a heat setting of medium broil, 8.75 cm from the heat source, to an internal temperature of 71°C. Chops were turned after six minutes and total cooking time was 12 minutes.

The LD muscle was excised from the loin chop and subcutaneous fat removed from the edges for evaluation

purposes. The LD muscle was then cut into four equal sections (approximately 1.9x1.9x2.5 cm) and presented to judges in 50 ml beakers covered by a watch glass.

Panelists evaluated the lamb samples in taste panel booths, under incandescent white lights. Forks were provided and Tonopah drinking water and breadsticks were supplied to cleanse the mouth between samples.

Statistical Analysis of Data

Statistical analysis of all data was accomplished by the analysis of variance according to Nie et al. (1975) and Klecka, Nie and Hull (1975). Duncan's Multiple Range Test was conducted to compare treatment means.

In the statistical analysis of tailhead biopsy samples, diets were nested within periods and periods within diets. Carcass fatty acids, muscle lipids and muscle fatty acids were analyzed by nesting locations within diets and diets within locations.

The sensory panel data obtained at The University of Arizona were analyzed by nesting judges within diets and diets within judges. The Armour Food Company sensory evaluation data were analyzed using a nested analysis of variance and a two-way analysis of variance model. The two-way analysis of variance model was used because it resulted in a smaller residual mean square.

RESULTS AND DISCUSSION

Subcutaneous Tailhead Fat Biopsy Fatty Acids

The means for the major fatty acids from tailhead fat biopsy samples are presented in Table 4 by period within each experimental diet. Analysis of samples obtained bi-weekly from the control lambs revealed that no consistent changes ($P > .05$) occurred in the proportions of fatty acids of this depot due to the feeding of the milo-alfalfa basal diet during the 46 day trial. However, lambs supplemented with 8% PCO, 8% POO and 8% PLO revealed consistent increases ($P < .05$) during the trial in the levels of oleic (C18:1), linoleic (C18:2), linolenic (C18:3) and/or total unsaturated fatty acids. In most cases, accompanying these increases, a corresponding decrease ($P < .05$) was noted in the level of myristoleic (C14:1), palmitic (C16:0) and/or stearic (C18:0) acid.

For the 8% PCO diet, the level of C18:2 in the tailhead subcutaneous fat increased ($P < .05$) progressively with time. A five-fold increase in C18:2 was noted and this increase was nearly linear between initiation and termination of the trial. Simultaneously, the proportion of C16:1 decreased to a level which was significantly ($P < .05$) lower by the end of the trial. Similar research by Hernandez (1976)

Table 4. Mean Weight Percent of Major Fatty Acids of Tailhead Biopsies by Period within Diet[a].

Period[b]	Fatty Acids 14:0	14:1	15:0	I16:0	16:0	16:1	17:0	I18:0	18:0	18:1	18:2	18:3	TU[c]
						Control							
1	5.7	.9	.9[d]	.5[d]	25.2	4.0	1.9[d]	1.3	12.6	42.6[de]	2.8[d]	1.7[d]	51.9
2	5.1	.9	1.0[de]	.5[de]	25.5	3.7	2.4[d]	1.3	14.2	41.9[de]	2.6[de]	1.1[de]	50.1
3	4.4	.9	.8[d]	.2[e]	25.5	3.4	2.8[de]	1.5	13.9	43.8[d]	2.3[e]	.7[e]	51.0
4	4.2	1.1	1.1[e]	.5[d]	22.9	3.8	3.8[e]	1.7	17.7	39.7[e]	2.6[de]	1.1[de]	48.2
						8% PCO							
1	5.4[d]	.8	.9	.3	25.4	3.5[d]	1.9	1.2	15.6	41.7	2.5[d]	1.1	49.5
2	4.6[de]	.9	.9	.4	24.3	3.3[d]	2.0	1.2	14.1	41.3	6.1[e]	1.1	52.7
3	2.9[e]	.7	.8	.2	23.2	3.1[de]	2.3	1.1	14.2	41.9	8.8[f]	.8	55.3
4	3.2[de]	.7	.8	.2	20.5	2.5[e]	2.0	.7	17.4	39.3	12.1[g]	.8	55.4
						8% POO							
1	6.0[d]	.7	1.0[d]	.4	26.6[d]	3.3[d]	2.0	1.1	15.7[d]	38.7[d]	3.2[d]	1.3[d]	47.2[d]
2	4.4[e]	.7	.7[e]	.5	25.5[d]	2.8[e]	1.5	1.1	12.9[e]	46.5[e]	2.6[d]	1.0[de]	53.4[e]
3	3.4[f]	.6	.6[e]	.2	22.4[e]	2.7[e]	1.8	.8	14.4[de]	49.3[e]	3.2[d]	.7[e]	56.5[e]
4	2.8[f]	.6	.6[e]	.2	20.3[e]	2.5[e]	2.2	.8	17.7[f]	45.6[e]	5.8[e]	.8[e]	55.2[e]

Table 4, Continued

Period[b]	Fatty Acids 14:0	14:1	15:0	I16:0	16:0	16:1	17:0	I18:0	18:0	18:1	18:2	18:3	TU[c]
							8% PLO						
1	4.6	.8	.8	.3	25.8	2.9[d]	2.0[d]	.9[de]	18.1	40.2[de]	2.6[d]	1.1[d]	47.6
2	3.0	.6	.7	.4	24.3	2.6[d]	1.7[de]	1.6[d]	16.7	42.4[de]	3.0[de]	2.8[de]	51.4
3	3.3	.9	.8	.4	24.5	3.0[d]	1.7[de]	.9[de]	15.1	42.9[d]	3.7[e]	3.0[e]	53.4
4	2.9	.6	.6	.4	21.7	1.7[e]	1.4[e]	.8[e]	16.7	38.2[e]	5.7[f]	8.3[f]	54.5

[a] PCO = protected cottonseed oil, POO = protected olive oil, PLO = protected linseed oil (percentages refer to oil content of diet).

[b] Period 1 = start of experiment, Period 2 = 14 days, Period 3 = 28 days, Period 4 = 46 days.

[c] Total Unsaturated fatty acids.

[defg] Values within the same fatty acid and diet having unlike superscripts differ significantly ($P < .05$).

has demonstrated that the level of C18:2 increased ($P < .05$) for four weeks then tapered off while lambs were maintained on a diet containing protected cottonseed oil. For steers, decreases in the level of C16:1 in subcutaneous fat biopsies, due to supplementation with protein protected safflower oil, have been reported (Dinius, Oltien et al. 1974) with linear increases ($P < .05$) in the proportion of C18:2.

Lambs fed the protein protected olive oil diet had an increased ($P < .05$) level of C18:1, from 38.7 to 46.5 percent, in subcutaneous fat from the tailhead area within the first two week period. No consistent increase ($P < .05$) was noted in the proportion of C18:1 after this initial change, but increases ($P < .05$) over those noted for Period 2 were observed in the percent stearic and linoleic acids at the end of the 46 day trial. The level of total unsaturated fatty acids had increased ($P < .05$) from 47 to 53 percent by Period 2 due to the supplementation of the protected olive oil. However, after this time, increases in the level of total unsaturates in the tailhead biopsies were minor ($P > .05$). This was due to either the specificity of the enzymes in incorporation of fatty acids into tissue triglycerides or the hydrogenation of oleic acid to stearic acid at the tissue level or in the rumen because of incomplete protection. Since an increase ($P < .05$) in the levels of C18:0 and C18:2 occurred during the last two weeks of the

trial, it is reasonable that hydrogenation and desaturation of C18:1 occurred at the tissue level. Furthermore, the effect that the increase ($P < .05$) in the level of C18:2 in Period 4 may have had on the level of total unsaturated fatty acids was offset by the corresponding increase ($P < .05$) in the level of C18:0 just noted. Because there is no literature on feeding protected olive oil, or oils high in C18:1, explicit conclusions are not possible without further research.

Along with the increases in C18:0 and C18:1 noted above for lambs supplemented with olive oil, decreases ($P < .05$) in the proportion of C14:0, C16:0, C16:1 and C18:3 were observed in the tailhead biopsies. The level of C14:0 progressively decreased ($P < .05$) from the initiation of the trial until Period 3 (Day 28). Changes in the levels of C16:0 and C18:3 were not significant ($P > .05$) until the third period, at which point they remained constant until termination of the trial. The level of C16:1 decreased ($P < .05$) by 15 percent within the first two week period of the trial, after which decreases were minor ($P > .05$). A 46 percent decrease ($P < .05$) in the proportion of C18:3 occurred between Periods 1 and 3. These changes were probably a dilution effect caused by the increased ($P < .05$) amounts of C18:0, C18:1 and C18:3 being incorporated in the subcutaneous tissue as a result of the olive oil supplementation.

Lambs which consumed the 8% PLO diet had no apparent changes ($P > .05$) in the proportions of C18:2 and C18:3 until Period 3. At this time the levels of C18:2 and C18:3 were raised 173 and 42 percent over initial levels, respectively, in the fat biopsies. Between Periods 3 and 4 the proportion of linolenic acid increased ($P < .05$) nearly threefold while the level of linoleic acid increased ($P < .05$) by a factor of 1.5. The increase in proportions of C18:2 and C18:3 during this part of the trial were similar to the increases in the level of C18:2 noted in the 8% PCO lambs. The increase of C18:2 and C18:3 in the 8% PLO lambs was linear with time and no apparent maximum was reached by the end of the 46 day trial. This linear increase is contrary to the findings in most studies where the incorporation of C18:2 into subcutaneous fat tissues of lambs (Cook et al. 1970, Ford et al. 1975, Park et al. 1975 and Park et al. 1976) and steers (Faichney et al. 1972 and Faichney et al. 1973) has been described by a curve of diminishing increments. The incorporation of C18:1 for olive oil supplemented lambs may have been observed to follow a curve of diminishing increments as Park et al. (1975) described C18:2 to do in lambs supplemented with protected sunflower oil, if samples of subcutaneous fat had been collected within the first 14 days.

Accompanying the increases just described for the lambs fed linseed oil, the levels of C16:1 and C18:1 were observed to decrease ($P < .05$) between the third and fourth periods in the biopsy samples. Scott et al. (1971) have made similar observations on the C16:1 and C18:1 content of subcutaneous fat from lambs supplemented with formaldehyde-treated casein:safflower oil. The decreased levels were thought to be partially due to dilution, which is supported by the relatively small decrease (from 2.9 to 1.7 percent) in the level of C16:1, and partially due to increased competition (at the tissue level) between the unsaturated 18 carbon fatty acids for incorporation into tissue triglycerides (Scott et al. 1971). The latter situation explains the larger decrease (from 40.2 to 38.2 percent) in the proportion of C18:1 in the biopsy samples.

Further comparisons were made by analyzing the means of the fatty acids from the subcutaneous tailhead fat biopsies by experimental diet within each sample period (Table 5). At the initiation of the trial (Period 1) variations ($P < .05$) were noted in the levels of palmitoleic and linolenic acids between the experimental groups. The level of C16:1 in the tailhead adipose tissue of control lambs was higher ($P < .05$) than the level of C16:1 in the group to receive the 8% PLO diet. Also, the proportion of C18:3 was higher ($P < .05$) in the control, than in lambs alloted to receive the protected

Table 5. Mean Percent of Major Fatty Acids of Tailhead Biopsies by Diet within Period[a].

Diet[b]	Fatty Acids 14:0	14:1	15:0	I16:0	16:0	16:1	17:0	I18:0	18:0	18:1	18:2	18:3	TU[c]
						Period 1							
Control	5.7	.9	.9	.5	25.2	4.0^{d}	1.9	1.3^{d}	12.6	42.6	2.8	1.7^{d}	51.9
8% PCO	5.4	.8	.9	.3	25.4	3.5^{de}	1.9	1.2^{de}	15.6	41.7	2.5	1.1^{e}	49.5
8% POO	6.0	.7	1.0	.4	26.6	3.3^{de}	2.0	1.1^{de}	15.7	38.7	3.2	1.3^{de}	47.2
8% PLO	4.6	.8	.8	.3	25.8	2.9^{e}	2.0	.9^{e}	18.1	40.2	2.6	1.1^{e}	47.6
						Period 2							
Control	5.1	.9	1.0	.5	25.5	3.7^{d}	2.4^{d}	1.3	14.2	41.9^{de}	2.6^{d}	1.1^{d}	50.1
8% PCO	4.6	.9	.9	.4	24.3	3.3^{de}	2.0^{de}	1.2	14.1	41.3^{d}	6.1^{e}	1.1^{d}	52.7
8% POO	4.4	.7	.7	.5	25.5	2.8^{e}	1.5^{e}	1.1	12.9	46.5^{e}	2.6^{d}	1.0^{d}	53.4
8% PLO	3.0	.6	.7	.4	24.3	2.6^{e}	1.7^{de}	1.6	16.7	42.4^{de}	3.0^{d}	2.8^{e}	51.4
						Period 3							
Control	4.4^{d}	.9	.8	.2de	25.5	3.4	2.8^{d}	1.5	13.9	43.8^{d}	2.3^{d}	.7^{d}	51.0
8% PCO	2.9^{e}	.7	.8	.2de	23.2	3.1	2.3^{de}	1.1	14.2	41.9^{d}	8.8^{e}	.8^{d}	55.3
8% POO	3.4^{de}	.6	.6	.2^{d}	22.4	2.7	1.8^{e}	.8	14.4	49.3^{e}	3.2^{df}	.7^{d}	56.5
8% PLO	3.3^{de}	.9	.8	.4^{e}	24.5	3.0	1.7^{e}	.9	15.1	42.9^{d}	3.7^{f}	3.0^{e}	53.4

Table 5, Continued

Diet[b]	Fatty Acids 14:0	14:1	15:0	I16:0	16:0	16:1	17:0	I18:0	18:0	18:1	18:2	18:3	TU[c]
						Period 4							
Control	4.2	1.1[d]	1.1[d]	.5[d]	22.9	3.8[d]	3.8[d]	1.7[d]	17.7	39.7[d]	2.6[d]	1.1[d]	48.2[d]
8% PCO	3.2	.7[e]	.8[e]	.2[e]	20.5	2.5[e]	2.0[e]	.7[e]	17.4	39.3[d]	12.1[e]	.8[d]	55.4[e]
8% POO	2.8	.6[e]	.6[e]	.2[e]	20.3	2.5[e]	2.2[e]	.8[e]	17.7	45.6[e]	5.8[f]	.8[d]	55.2[e]
8% PLO	2.9	.6[e]	.6[e]	.4[de]	21.7	1.7[f]	1.4[e]	.8[e]	17.8	38.2[d]	5.7[f]	8.3[e]	54.5[e]

[a] Period 1 = start of experiment; Periods 2, 3 and 4 = days 14, 28 and 46, respectively.

[b] PCO = protected cottonseed oil, POO = protected olive oil, PLO = protected linseed oil (percentages refer to oil content of diet).

[c] Total Unsaturated fatty acids.

[def] Values within the same fatty acid and period having unlike superscripts differ significantly ($P < .05$).

cottonseed and linseed oil diets. These differences were relatively small (.6 to 1.1 percent) and probably represented chance differences which could occur in any experimental trial.

After only 14 days, the effect of the various oil treatments started to become apparent. Lambs receiving the 8% PCO diet were higher ($P < .05$) in the proportion of C18:2 in biopsy samples while the 8% PLO lambs had an elevated ($P < .05$) level of C18:3. Although not significant ($P > .05$), the level of C18:1 was 11 percent higher in the tailhead biopsies of the 8% POO lambs than in the control group. By Period 3 all of the above mentioned differences had become more apparent ($P < .05$) with an increase ($P < .05$) in the proportion of C18:2 in biopsy samples from lambs receiving the protected linseed oil diet. The differences in the levels of C18:1, C18:2 and C18:3 were more marked ($P < .05$) by the termination of the trial (Period 4).

Furthermore, at the final sampling period all lambs receiving diets containing protein protected oils had a higher ($P < .05$) proportion of total unsaturated fatty acids in the subcutaneous tailhead adipose tissue than lambs receiving the diet without added oil. Hernandez (1976) reported increases ($P < .05$) in the level of C18:2 in subcutaneous fat from lambs fed two different levels of protected cottonseed oil. Accompanying these increases, corresponding

decreases ($P < .05$) were reported in the proportions of C14:1 and C16:1 due to the supplementation of the protected oil product. The increases ($P < .05$) in C18:1, C18:2 and C18:3 as well as the decreases ($P < .05$) in the proportion of C14:1 and C16:1 were assumed to be directly related to the increased ($P < .05$) availability of the unsaturated 18 carbon fatty acids in the circulating serum (Hernandez 1976). The decreased ($P < .05$) percents of C14:1 and C16:1 were mainly due to a dilution effect by the increased amounts of unsaturated 18 carbon fatty acids.

Carcass Fatty Acids

The means for the major fatty acids from certain carcass fats are presented in Table 6 by fat depot within each experimental diet. The adipose tissues studied include surface (TB and LD subcutaneous), intermuscular (TB and SM seam) and internal (kidney, mesentary and heart) depots.

Internal adipose tissues of control lambs were observed to be more ($P < .05$) saturated than either surface or intermuscular fats. The internal fats possessed a higher ($P < .05$) proportion of stearic acid and lower ($P < .05$) level of oleic acid. This result was consistent with the findings of Faichney et al. (1972) where kidney and mesentary fat of lambs on feedlot diets were determined to be more ($P < .05$) saturated than adipose depots nearer the body surface.

Table 6. Mean Percent of Major Fatty Acids of Depot Fats by Fat Depot within Diet[a].

Fat Depot[b]	Fatty Acids 14:0	14:1	15:0	I16:0	16:0	16:1	17:0	I18:0	18:0	18:1	18:2	18:3	TU[c]
						Control							
Kidney	2.8^{d}	.6de	.7de	.3de	23.8^{de}	2.1^{de}	3.0^{def}	.9de	30.1^{d}	32.8^{d}	2.3	.6	38.4^{d}
Mesen	3.4^{de}	.6de	.8^{d}	.5^{d}	25.8^{de}	2.3^{d}	3.2^{de}	1.0^{de}	26.9^{d}	31.7^{d}	2.6	1.2	38.4^{d}
Heart	4.4^{ef}	.3^{d}	.6^{e}	.2^{e}	23.2^{d}	1.5^{e}	2.2^{ef}	.6^{d}	29.4^{d}	33.8^{d}	2.4	1.2	39.3^{d}
TB Sm	4.8^{f}	.4^{d}	.7de	.2^{e}	27.8^{e}	2.6^{d}	2.2^{e}	1.0^{de}	16.5^{e}	41.0^{e}	2.1	.8	46.9^{e}
SM Sm	4.5^{ef}	.4^{d}	.7de	.2^{e}	26.1^{de}	2.2^{d}	2.4^{ef}	.9^{d}	19.4^{e}	39.8^{e}	2.4	1.0	45.8^{e}
TB Sb	4.0^{def}	.8^{e}	.8de	.4de	25.1^{de}	3.6^{f}	2.8^{def}	1.0^{de}	17.3^{e}	41.4^{e}	2.2	.7	48.8^{e}
LD Sb	2.9^{d}	1.0^{e}	.8de	.5de	24.4^{de}	3.6^{f}	3.8^{d}	1.4^{e}	17.2^{e}	41.4^{e}	2.1	.9	49.0^{e}
						8% PCO							
Kidney	2.5	.5^{df}	.6	.4de	21.6	1.4^{d}	2.0^{de}	.6^{d}	27.7^{d}	30.4^{d}	11.4^{d}	.8	44.4^{d}
Mesen	3.0	.4^{def}	.5	.3de	23.0	1.6^{d}	1.6^{de}	.4^{d}	25.3^{d}	33.4^{de}	9.7^{d}	.4	46.0^{d}
Heart	3.6	.2^{e}	.4	.2^{d}	23.0	1.5^{d}	1.4^{de}	.4^{d}	27.8^{d}	35.2^{de}	6.0^{e}	.6	43.5^{d}
TB Sm	4.1	.3de	.5	.2^{d}	25.4	2.0^{de}	1.3^{d}	.4^{d}	18.1^{e}	38.9^{ef}	8.5^{de}	.6	50.2^{de}
SM Sm	3.9	.3de	.6	.2de	23.6	2.2^{de}	1.8^{de}	.6de	18.0^{e}	39.6^{fg}	8.4^{de}	.8	51.3^{de}
TB Sb	3.5	.6^{fg}	.5	.2^{d}	22.6	2.5^{e}	1.7^{de}	.7de	15.4^{e}	41.1^{g}	10.9^{d}	.5	55.7^{e}
LD Sb	2.5	.8^{g}	.7	.4^{e}	22.1	2.8^{e}	2.2^{e}	.9^{e}	15.6^{e}	40.5^{g}	10.4^{d}	1.0	55.5^{e}
						8% POO							
Kidney	2.0^{d}	.4^{def}	.4	.3	19.8^{d}	1.4^{de}	1.6	.6	27.2^{d}	39.8^{de}	5.9^{d}	.8de	48.3^{d}
Mesen	2.8^{de}	.5^{ef}	.5	.3	21.9^{de}	1.9^{ef}	1.6	.6	23.2^{e}	41.8^{def}	4.2^{ef}	.8de	49.1^{d}
Heart	3.3^{e}	.3de	.5	.3	21.6^{de}	1.3^{d}	1.6	.7	27.8^{d}	38.2^{d}	3.6^{f}	1.2^{d}	44.5^{e}
TB Sm	3.8^{e}	.5^{ef}	.6	.3	24.8^{e}	2.4^{f}	1.4	.6	16.4^{f}	43.6^{efg}	4.3^{ef}	1.2^{d}	52.0^{d}
SM Sm	3.4^{e}	.2^{d}	.5	.2	24.6^{e}	1.9^{ef}	1.4	.6	17.5^{f}	44.6^{fgh}	4.2^{ef}	.8de	51.7^{d}
TB Sb	3.0^{de}	.5^{ef}	.4	.2	22.4^{de}	2.4^{f}	1.6	.7	15.2^{f}	48.2^{h}	4.7^{de}	.5^{e}	56.4^{f}
LD Sb	2.2^{d}	.6^{f}	.6	.6	20.8^{de}	2.4^{f}	1.8	.9	17.2^{f}	46.4^{gh}	5.4^{de}	1.0^{de}	55.9^{f}

Table 6, Continued

Depot[b]	Fatty Acids 14:0	14:1	15:0	I16:0	16:0	16:1	17:0	I18:0	18:0	18:1	18:2	18:3	TU[c]
						8% PLO							
Kidney	1.9	.2^{d}	.4	.2	18.4	1.0^{d}	1.2	.4	28.9^{d}	31.9^{d}	6.2^{d}	9.2^{d}	48.5^{de}
Mesen	2.6	.5^{def}	.6	.3	21.1	1.4^{de}	1.6	.4	27.2^{d}	32.4^{d}	5.4^{d}	6.6^{d}	46.2^{de}
Heart	3.2	.2^{d}	.6	.2	23.3	1.0^{d}	1.6	.4	30.9^{d}	32.6^{d}	2.9^{e}	2.9^{e}	39.7^{d}
TB Sm	3.2	.4de	.5	.2	22.8	1.7^{ef}	1.4	.4	19.4^{ef}	37.2^{e}	5.0^{d}	6.6^{d}	50.9^{de}
SM Sm	3.2	.3de	.4	.3	23.0	1.6^{e}	1.3	.6	20.5^{e}	35.9^{de}	5.4^{d}	7.2^{d}	50.5^{de}
TB Sb	3.5	.7^{f}	.6	.3	21.0	2.2^{f}	1.6	.6	16.1^{f}	38.9^{e}	6.0^{d}	8.5^{d}	56.2^{e}
LD Sb	3.5	.6^{ef}	.6	.3	21.3	1.8^{ef}	1.4	.6	18.6^{f}	37.5^{e}	6.2^{d}	8.7^{d}	54.7^{de}

[a] PCO = protected cottonseed oil, POO = protected olive oil, PLO = protected linseed oil (percentages refer to oil content of diet).

[b] Mesen = mesentary, TB = Triceps brachii, SM = Semimembranosus, LD = Longissimus dorsi, Sm = seam, Sb = subcutaneous.

[c] Total Unsaturated fatty acids.

defgh Means within the same fatty acid and diet with different superscripts are significantly different ($P < .05$).

Furthermore, for the control lambs, heart fat was lower ($P < .05$) in the proportion of C14:1 than were surface fat samples and the C16:1 content of heart fat was lower ($P < .05$) than that observed for surface or intermuscular adipose samples. Although differences in the level of total unsaturated fatty acids between surface and intermuscular fat samples were minor ($P > .05$), surface fats tended to have higher ($P < .05$) proportions of C14:1 and C16:1 than intermuscular fat samples.

The control demonstrated the deposition of fatty acids within the adipose tissues of lambs fed a milo-alfalfa diet without added fats. When a deviation of this pattern occurred in lambs supplemented protected oils in addition to the milo-alfalfa diet and all other factors being equal, a cause and effect relationship was indicated. Changes which occurred in the fatty acid composition of lambs fed protein protected oils, when conpared to the control, were assumed to be a direct result of the protected oil products.

Lambs fed the protected cottonseed oil diet were similar to the control lambs in the overall pattern of incorporation of unsaturated fatty acids into the various tissues. Although the level of various fatty acids were sometimes different ($P < .05$) between the control and 8% PCO lambs, the order in which unsaturation occurred between the various fat samples was approximately the same regardless of

the dietary treatment. However, heart fat was lower ($P < .05$), by nearly 50 percent, in the level of C18:2 than other samples from the 8% PCO lambs and this was not observed to occur ($P > .05$) in the control group. As a possible explanation for the lower ($P < .05$) linoleic acid content of fat from the heart surface, Hernandez (1976) has reported that the percent of C18:2 in cardiac muscle was lower ($P < .05$) than in skeletal muscle. Assuming that intramuscular and surface fat from the heart are similar, the specificity of fatty acid incorporation in the tissue as well as the cardiac muscle's metabolism of different fatty acids may be reasonable explanations for this unique deposition pattern. Dvorakova and Bass (1970a,b) have indicated that heart muscle (mammals in general) upon increased exercise tend to metabolize more ($P < .05$) quantities of saturated fatty acids (C18:0). With this in mind, the specificity of fatty acid incorporation in cardiac triglycerides (intramuscular and surface fats) is more plausible.

In lambs supplemented with protected olive oil it appeared that surface adipose tissues discriminated against the incorporation of C18:1 to a greater extent than did internal fat tissues (except heart fat). This was demonstrated by the fact that mesentary fat from the 8% POO lambs increased from 31.7 to 41.8 percent, while LD subcutaneous fat only increased from 41.4 to 48.2 percent as

compared to the control. In contrast, linoleic acid was deposited in all tissues with no apparent ($P > .05$) differences in tissue specificity. This would not be an expected result when supplementing an oil containing 72 percent oleic acid.

The inhanced deposition of linoleic acid for lambs supplemented with olive oil suggests a higher specificity for C18:2 by lamb tissues than would be expected when one considers the relatively low level of C18:2 (11 percent) deposited in the carcass fats of lambs fed the protected cottonseed oil which was 58 percent linoleic acid. Faichney et al. (1972) has reported that incorporation of C18:2 in internal lamb adipose tissues, as a result of protected safflower oil (high in C18:2) supplementation, occurred to a greater ($P < .05$) extent than in adipose tissues nearer the body surface. Although only minor ($P > .05$) differences existed in the level of C18:2 between tissues in the current trial, C18:1 was observed to be distributed as Faichney et al. (1972) reported linoleic acid to be deposited for lamb.

Lambs supplemented with protected olive oil had a total unsaturated fatty acid deposition pattern similar to the 8% PCO lambs with internal fat samples being more ($P < .05$) saturated than surface fats (Table 6). Heart fat was again more ($P < .05$) saturated than any other adipose sample. This dietary treatment further demonstrates the inability of

heart fat to incorporate higher ($P < .05$) levels of unsaturated fatty acids, especially C18:2, into triglycerides as has been observed for other internal fat tissues such as kidney and mesentary adipose tissues.

Lambs fed the 8% PLO diet had a deposition pattern similar to the 8% PCO group in that C18:2 and C18:3 tended to be distributed evenly ($P > .05$) in all tissues except heart fat, which was lower ($P < .05$) in the levels of linoleic and linolenic acids than were other adipose samples. Internal adipose tissues tended to contain less ($P < .05$) C14:1 and C16:1 than those tissues nearer the body surface. However, only minor differences ($P > .05$) occurred in the total unsaturate content of all fat samples with the exception of heart fat being more ($P < .05$) saturated. Differences between samples which occurred in the control lambs were not as apparent ($P > .05$) in the 8% PLO group. This evidently was due to a larger decrease in the amount of C18:1 incorporated into surface as opposed to internal fat samples.

The subcutaneous tailhead fat biopsies were in general found to exemplify the changes which occurred in the carcass fats as a result of the protected oil supplementation. Biopsies from the tailhead region of lambs (Hernandez 1976) and steers (Dinius, Oltien and Sattle 1974) have been used to monitor fatty acid changes within body tissues due to the feeding of protected oils with favorable results. Hernandez (1976) reported that although the subcutaneous biopsies did

not indicate the smaller increase of C18:2 in heart fat and muscle samples as compared to other tissues, the changes in fatty acid composition that did occur were specific to the biopsies obtained from each treatment group. A similar result was apparent in the current trial where heart fat did not demonstrate the magnitude of change found in the fatty acid composition of other samples. However, the changes that did occur in the fatty acid composition of heart fat were also noted to occur, only to a greater extent, in the subcutaneous biopsies.

Table 7 lists the mean percents of fatty acids from carcass fat samples by experimental diet within each fat depot. The supplementation of the protected cottonseed, olive and linseed oils provided lambs with increased ($P < .05$) proportions of unsaturated 18 carbon fatty acids which were characteristic of the particular oil (see Table 3 for the fatty acid profile of oils). All carcass tissues studied responded to some degree to the oil supplementation with heart fat (the least responsive) revealing an increase in C18:2 and C18:3 from 2.4 and 1.2 to 6.0 and 2.9 percent, respectively.

The levels of oleic, linoleic and linolenic acids were affected to different extents within the various adipose tissues due to the feeding of the experimental diets. Decreases ($P < .05$) were noted in the level of C16:1 in some,

Table 7. Mean Percent of Major Fatty Acids of Depot Fats by Diet within Fat Depot.

Diet[a]	Fatty Acids 14:0	14:1	15:0	I16:0	16:0	16:1	17:0	I18:0	18:0	18:1	18:2	18:3	TU[b]
Kidney Fat													
Control	2.8	.6^{c}	.7	.3	23.8^{c}	2.1^{c}	3.0^{c}	.9^{c}	30.1	32.8^{c}	2.3^{c}	.6^{c}	38.4
8% PCO	2.5	.5^{cd}	.6	.4	21.6^{cd}	1.4^{d}	2.0^{d}	.6^{cd}	27.7	30.4^{c}	11.4^{d}	.8^{c}	44.5
8% POO	2.0	.4^{cd}	.4	.3	19.8^{cd}	1.4^{d}	1.6^{de}	.6^{cd}	27.2	39.8^{d}	5.9^{e}	.8^{c}	48.3
8% PLO	1.9	.2^{d}	.4	.2	18.4^{d}	1.0^{d}	1.2^{e}	.4^{d}	28.9	31.9^{c}	6.2^{e}	9.2^{d}	48.5
Mesentary Fat													
Control	3.4	.6	.8	.5	25.8^{c}	2.3^{c}	3.2^{c}	1.0^{c}	26.9	31.7^{c}	2.6^{c}	1.2^{c}	38.4^{c}
8% PCO	3.0	.4	.5	.3	23.0^{cd}	1.6^{d}	1.6^{d}	.4^{d}	25.3	33.9^{c}	9.7^{d}	.4^{c}	46.0^{d}
8% POO	2.8	.5	.5	.3	21.9^{cd}	1.9^{cd}	1.6^{d}	.6^{d}	23.2	41.8^{d}	4.2^{e}	.8^{c}	49.2^{d}
8% PLO	2.6	.5	.6	.3	21.1^{d}	1.4^{d}	1.6^{d}	.6^{d}	27.2	32.4^{c}	5.4^{e}	6.6^{d}	46.3^{d}
Heart Fat													
Control	4.9^{c}	.3	.6	.2^{cd}	23.2	1.5^{c}	2.2^{c}	.6^{ce}	29.4	33.8^{c}	2.4^{c}	1.2^{c}	39.3^{c}
8% PCO	3.6^{d}	.2	.4	.2^{c}	23.0	1.5^{c}	1.4^{d}	.4^{d}	27.8	35.2^{cd}	6.0^{d}	.6^{c}	43.5^{de}
8% POO	3.4^{d}	.3	.5	.3^{d}	21.6	1.3^{cd}	1.6^{d}	.7^{c}	27.8	38.2^{d}	3.6^{e}	1.2^{c}	44.5^{d}
8% PLO	3.2^{d}	.2	.6	.2^{c}	23.3	1.0^{d}	1.6^{d}	.4de	30.9	32.6^{c}	2.9^{cd}	2.9^{d}	39.7^{ce}
Triceps brachii Seam Fat													
Control	4.8^{c}	.4	.7	.2	27.8^{c}	2.6^{c}	2.2^{c}	1.0^{c}	16.5	41.0^{cd}	2.1^{c}	.8^{c}	46.9
8% PCO	4.1^{cd}	.3	.5	.2	25.4^{cd}	2.0^{cd}	1.3^{d}	.4^{d}	18.1	38.9^{c}	8.5^{d}	.6^{c}	50.2
8% POO	3.8^{cd}	.5	.6	.3	24.8^{cd}	2.4^{cd}	1.4^{d}	.6^{d}	16.4	43.6^{d}	4.3^{e}	1.2^{c}	52.0
8% PLO	3.2^{d}	.4	.5	.2	22.8^{d}	1.7^{d}	1.4^{d}	.4^{d}	19.4	37.2^{c}	5.0^{e}	6.6^{d}	50.1
Semimembranosus Seam Fat													
Control	4.5	.4	.7^{c}	.2	26.1	2.2	2.4^{c}	.9	19.4	39.8^{c}	2.4^{c}	1.0^{c}	45.8^{c}
8% PCO	3.4	.3	.6^{cd}	.2	23.6	2.2	1.8^{d}	.6	18.0	39.6^{c}	8.4^{d}	.8^{c}	51.3^{d}
8% POO	3.4	.2	.5^{cd}	.2	24.6	1.9	1.4^{d}	.6	17.5	44.6^{d}	4.2^{e}	.8^{c}	51.7^{d}
8% PLO	3.2	.3	.4^{d}	.2	23.0	1.6	1.3^{d}	.6	20.5	35.9^{e}	5.4^{e}	7.2^{d}	50.5^{d}

Table 7, Continued

Diet[a]	14:0	14:1	15:0	I16:0	16:0	16:1	17:0	I18:0	18:0	18:1	18:2	18:3	TU[b]
					Triceps brachii Subcutaneous Fat								
Control	4.0	.8	.8^{c}	.4	25.1	3.6^{c}	2.8^{c}	1.0	17.3	41.4^{c}	2.2^{c}	.7^{c}	48.8^{d}
8% PCO	3.5	.6	.5de	.2	22.6	2.5^{d}	1.7^{d}	.7	15.4	41.1^{c}	10.9^{d}	.5^{c}	55.7^{d}
8% POO	3.0	.5	.4^{e}	.2	22.4	2.4^{d}	1.6^{d}	.7	15.2	48.2^{d}	4.7^{ce}	.5^{c}	56.4^{d}
8% PLO	3.5	.7	.6^{cd}	.3	21.0	2.2^{d}	1.6^{d}	.6	16.1	38.9^{c}	6.0^{e}	8.5^{d}	56.2^{d}
					Longissimus dorsi Subcutaneous Fat								
Control	2.9	1.0	.8	.5	24.4	3.6^{c}	3.8^{c}	1.4^{c}	17.2	41.4^{c}	2.1^{c}	.9^{c}	49.0
8% PCO	2.5	.8	.7	.4	22.1	2.2^{d}	2.2^{d}	.9^{cd}	15.6	40.5^{c}	10.4^{d}	1.0^{c}	55.5
8% POO	2.2	.6	.6	.6	20.8	1.8^{d}	1.8^{d}	.9^{cd}	17.2	46.4^{d}	5.4^{e}	1.0^{c}	55.9
8% PLO	2.5	.6	.6	.3	21.3	1.4^{d}	1.4^{d}	.6^{d}	18.6	37.5^{c}	6.2^{e}	8.7^{d}	54.7

[a] PCO = protected cottonseed oil, POO = protected olive oil, PLO = protected linseed oil (percentages refer to oil content of diet).

[b] Total Unsaturated fatty acids.

[cde] Means within the same fatty acid and fat depot with unlike superscripts differ significantly ($P < .05$).

but not all, tissues (kidney, mesentary and TB and LD subcutaneous fats), along with similar decreases ($P < .05$) in the proportions of C14:1 and C18:1. This tended to suggest that some lamb carcass tissues are more specific in the ratio in which saturated and unsaturated acids are deposited than others. This is supported by some adipose samples (mesentary, heart, SM seam and TB subcutaneous) having increased ($P < .05$) levels of total unsaturated fatty acids as a result of protected oil supplementation while the kidney, TB seam and LD subcutaneous tissues had only minor ($P > .05$) changes. Based on the observation that different ($P < .05$) levels of total unsaturates were present in adipose tissues of lambs fed protected cottonseed oil, Hernandez (1976) has indicated that qualitative lipogenic differences exist between subcutaneous, perineal and seam adipose tissues. Results of the current trial suggest that Hernandez (1976) was correct in his conclusion that lipogenic differences may exist between adipose tissues of lambs.

Since supplementation of the protected oils produced lambs which varied in fatty acid composition, the rather unique composition of each dietary group made possible the investigation into the influence that fatty acid composition may have exerted on the flavor and aroma of meat produced by these lambs. If fatty acid composition had a measurable influence on flavor and/or aroma, sensory evaluation of

roasts and loin chop samples from these lambs should indicate the value or desirability of producing such changes dietarily.

Intramuscular Lipid and Major Fatty Acids

The fatty acid composition and percent total lipid and moisture determined for the Triceps brachii (TB) and Longissimus dorsi (LD) are reported in Table 8 by experimental diet within each muscle. The variations in percent lipid of the TB and LD as a result of diet were negligible ($P > .05$). However, lambs supplemented with protected olive and linseed oils possessed elevated ($P < .05$) moisture levels in both the TB and LD. The importance of such changes are hard to evaluate since the change in level was relatively small (.7 to 2.8 gm per 100 gm muscle).

Supplementation of the protected cottonseed oil resulted in at least a two-fold increase ($P < .05$) of linoleic acid in both muscles while no decreases ($P > .05$) were observed in other unsaturated fatty acids. Increased ($P < .05$) levels of C18:2 in the M. psoas major have been reported as a result of feeding protein protected safflower oil to cattle (Cook, Scott et al. 1972). Decreases ($P < .05$) in the proportion of C16:0 and C18:1 accompanied the increase in C18:2 content reported by these workers. Hernandez (1976) also reported similar (i. e., increases in C18:2 and decreases in C16:0 and C18:1) results in lambs supplemented with protein protected cottonseed oil. In steers supplemented

Table 8. Mean Percent of Lipid, Moisture and Fatty Acids of Muscles by Diet within Muscle.

Item	Longissimus dorsi Experimental Diets[a]				Triceps brachii Experimental Diets			
	Control	8% PCO	8% POO	8% PLO	Control	8% PCO	8% POO	8% PLO
Lipid	4.7	---	5.0	5.1	4.2	4.4	3.8	4.2
Moisture	77.0^{b}	---	78.6^{c}	79.8^{c}	79.1^{b}	78.6^{b}	79.8^{c}	80.2^{c}
Fatty Acids								
C14:0	2.9	2.5	2.1	1.8	2.9	3.1	2.7	2.4
C14:1	.5	.4	.2	.2	.6	.5	.5	.4
C15:0	$.5^{b}$	$.4^{bc}$	$.3^{bc}$	$.3^{c}$	.7	.5	.7	.6
CI16:0	.5	.3	.4	.5	1.1^{b}	$.6^{c}$	1.1^{b}	$.9^{bc}$
C16:0	26.2	24.9	25.1	24.3	24.0	23.9	22.8	20.7
C16:1	3.4^{b}	2.4^{bc}	2.1^{bc}	1.7^{c}	2.8^{b}	2.3^{bc}	2.2^{c}	1.9^{c}
C17:0	1.5^{b}	1.2^{bc}	1.1^{c}	$.9^{c}$	1.8^{b}	1.4^{c}	1.3^{c}	1.2^{c}
CI18:0	1.0^{b}	$.7^{bc}$	$.7^{c}$	$.5^{c}$	1.5^{b}	1.0^{c}	$.8^{c}$	$.7^{c}$
C18:0	14.4	14.7	14.9	14.8	13.4	13.2	13.6	15.0
C18:1	43.4^{bc}	40.8^{b}	46.4^{c}	42.2^{bc}	44.2^{b}	40.7^{bc}	43.8^{bc}	39.4^{c}
C18:2	4.4^{b}	10.8^{c}	5.9^{b}	6.6^{b}	5.5^{b}	11.7^{c}	9.8^{c}	9.2^{c}
C18:3	1.2^{b}	1.1^{b}	$.8^{b}$	6.3^{c}	1.6^{b}	1.2^{b}	1.0^{b}	7.8^{c}
Total Unsaturates	52.9	55.3	55.4	57.0	54.7	56.4	57.2	58.7

[a] PCO = protected cottonseed oil, POO = protected olive oil, PLO = protected linseed oil (percentages refer to oil content of diet).

[bc] Means within the same line and muscle having unlike superscripts are significantly different ($P < .05$).

with protein protected safflower and sunflower oil, the changes in fatty acid composition were not unlike those observed in lambs (Faichney et al. 1972, Hogan and Hogan 1976).

Subcutaneous fat samples collected during slaughter best exemplified the fatty acid composition of the intramuscular lipids from the 8% PCO and control lambs. However, this was not the case for lambs fed the olive oil diet.

Lambs fed the 8% POO diet had an increased ($P < .05$) level of C18:2 in both muscle samples. However, no significant ($P > .05$) increase was observed in the level of C18:1 in the TB as a result of supplementing lambs with protected olive oil. Both tailhead biopsies and subcutaneous carcass fats were good indicators of the composition of the LD while fatty acids in the TB were more similar to the TB and SM seam fats.

Supplementation of protected linseed oil resulted in the production of intramuscular lipids higher ($P < .05$) in C18:2 and C18:3 with a lower ($P < .05$) level of C18:1 in the TB as compared to the control. This lower level of C18:1 was also noted in the TB of the 8% POO lambs. These results tend to indicate a difference in enzyme activity between the TB and other lipid depot sites studied.

Subcutaneous fats served as good indicators of the changes which occurred in the intramuscular lipids of the 8% PLO lambs, with the exception of the lower level of C18:1

in the TB. The SM seam fat was the only other tissue which demonstrated the decrease content of oleic acid. Hernandez (1976) reported that TB and SM lipids were very similar ($P > .05$). Therefore, one might assume that the TB intramuscular and SM seam fatty acids would be approximately the same.

Although no statistical analysis was conducted comparing fatty acid proflies of intramuscular to carcass and tailhead fat samples, differences existing between the samples for any diet appear to be minor. However, heart fat (from all oil supplemented lambs) and the TB intramuscular lipids from the 8% POO and 8% PLO lambs demonstrated unique deposition patterns. This pattern suggests that lipogenic differences between deposition sites (subcutaneous, internal, intermuscular and intramuscular) are limited for the tissues studied with the exception of heart and TB lipids.

The inhanced incorporation of C18:2 into the TB intramuscular lipids along with the apparent discrimination against C18:1 suggest the possibility of greater enzyme specificity in the TB and LD. The differences in preference of fatty acid incorporation between these two muscles implies that differences may exist between other muscles. Hernandez (1976) observed similar differences between the TB and LD of lambs fed protected cottonseed oil. However, he noted that the TB and SM were very similar in fatty acid

composition. This suggests that more than one muscle may be required for sensory evaluation if the effects of fatty acid composition on lamb flavor and aroma are to be accurately determined.

Table 9 lists the fatty acid composition and percent lipid and moisture of the TB and LD within each experimental diet. Differences which occurred in the lipid content between muscles were minor ($P > .05$) for all diets. This is consistent with the findings of Hernandez (1976) where lipid content of muscles was not effected ($P > .05$) by feeding protected cottonseed oil to lambs. However, the TB from the control and 8% POO lambs had a higher ($P < .05$) moisture content.

The level of C18:2 was higher ($P < .05$) in the TB of lambs fed the 8% POO and 8% PLO diets than in the LD of the same lambs. The proportion of C18:2 which occurred in the TB from the lambs fed protected linseed and olive oils (which were 15 and 7 percent C18:2, respectively) was as high as the level found in lambs fed the protected cottonseed oil (which was 58 percent C18:2). These results indicate that there may be a maximum obtainable level of incorporation of C18:2 in the TB. The TB also possessed a unique ability to incorporate this maximum level from a relatively low source of dietary linoleic acid.

Table 9. Mean Percent Lipid, Moisture and Fatty Acids by Muscle within Diet[a].

Item	Control Muscle[b]		8% PCO Muscle		8% POO Muscle		8% PLO Muscle	
	TB	LD	TB	LD	TB	LD	TB	LD
Lipid	4.2	4.7	4.4	---	3.8	5.0	4.2	5.1
Moisture	79.1[c]	77.0[d]	78.6	---	79.8[c]	78.6[d]	80.2	79.8
Fatty Acids								
C14:0	2.9	2.9	3.1	2.5	2.7	2.1	2.4	1.2
C14:1	.6	.5	.5	.4	.5	.2	.4[c]	.2[d]
C15:0	.7	.5	.5	.4	.7	.3	.6[c]	.3[d]
CI16:0	1.1[c]	.5[d]	.6	.3	1.1[c]	.4[d]	.9	.5
C16:0	24.0	26.2	23.9	24.9	22.8	25.1	20.7	24.3
C16:1	2.8	3.4	2.3	2.4	2.2	2.1	1.9	1.7
C17:0	1.8[c]	1.5[d]	1.4	1.2	1.3	1.1	1.2	.9
CI18:0	1.5[c]	1.0[d]	1.0	.7	.8	.7	.7	.5
C18:0	13.4	14.4	13.2	14.7	13.6	14.9	15.0	14.8
C18:1	44.2	43.4	40.7	40.8	43.8	46.4	39.4	42.2
C18:2	5.5	4.4	10.2	11.7	9.8[c]	5.9[d]	9.2[c]	6.6[d]
C18:3	1.6	1.2	1.2	1.1	1.0	.8	7.8	6.3
Total Unsaturates	54.7	52.9	56.4	55.3	57.2	55.4	58.7	57.0

[a] PCO = protected cottonseed oil, POO = protected olive oil, PLO = protected linseed oil (percentages refer to oil content of diet.

[b] TB = Triceps brachii, LD = Longissimus dorsi.

[cd] Means within the same line and diet having unlike superscripts are significantly different ($P < .05$).

Hernandez (1976) reported results similar to those just described; however, differences ($P \leq .05$) in the level of total unsaturates were also reported for lambs supplemented with 8% cottonseed oil protected from rumen fermentation. Changes in total unsaturated fatty acids were not observed in the current trial because oleic acid was deposited in lower concentrations when the deposition rate of linoleic acid was elevated ($P \leq .05$). Furthermore, the results of both Tables 8 and 9 indicate the possible existance of a homeostatic system which maintains the saturated:unsaturated ratio of fatty acids within the intramuscular lipids studied. Data (Tables 6 and 7) for adipose tissue depots do not suggest that such a system is as active in the carcass adipose tissues studied.

Sensory Evaluation

The University of Arizona Panel

The mean scores for aroma, juiciness, tenderness, flavor and overall acceptability evaluation for leg roasts as determined by the sensory panel at The University of Arizona (UA) are presented in Table 10. Lambs fed the 8% PCO and 8% PLO diets were scored lower ($P < .05$) for aroma, flavor and overall acceptability. Although there is no literature on the effects on the palatability of meat due to feeding protected linseed oil, several studies have involved feeding protected oils high in linoleic acid

Table 10. Means of Sensory Panel Evaluation for Lamb Leg Roasts by Treatments over All Judges.

Characteristics	Diet[a] Control	8% PCO	8% POO	8% PLO
Aroma	5.8[b]	4.4[c]	6.2[b]	4.7[c]
Juiciness	6.0	5.9	5.9	6.2
Tenderness	6.3[b]	5.5[bc]	5.1[c]	5.8[bc]
Flavor	5.5[b]	3.4[c]	5.7[b]	4.3[d]
Overall Eval.	5.7[b]	3.9[c]	5.6[b]	4.7[d]

[a] PCO = protected cottonseed oil, POO = protected olive oil, PLO = protected linseed oil (percentages refer to oil content of diet.

[bcd] Means on the same line with different superscripts are significantly different ($P < .05$).

(sunflower, safflower and cottonseed) to lambs (Ford et al. 1975; Park et al. 1975; and Dryden, Marchello and Hernandez personal communications 1977) or steers (Mills et al. 1972; Dinius, Oltien and Sattle 1974; Dinius, Lyon and Walker 1974; and Ford et al. 1976). Samples from these animals were subsequently subjected to sensory panel evaluation. The general consensus of these sensory evaluations has been that elevated ($P < .05$) levels of C18:2 and C18:3 in the meat led to less ($P < .05$) acceptable flavors and aromas.

The UA sensory panel data revealed that the samples from lambs fed the 8% PCO and 8% PLO diets had an oily aroma with some samples from the 8% PLO group having a rancid, musty aroma. The flavors of these meats were characterized as being oily and strong. Park et al. (1974) reported that oily flavor and aroma of lambs supplemented with formaldehyde-treated casein:sunflower and safflower oils were due to abnormally high ($P < .05$) levels of trans, trans-2,4-decadienal, a prominent oxidation product of linoleic acid. These workers also isolated, from the same lamb meat samples, 4-hydroxydodec-cis-6-enoic acid lactone which was thought to contribute a sweet aroma and flavor to the meat. However, the origin of this compound was unclear because it was not present in the oils or fresh meats. Although the compounds identified by Park and associates (1974) were not analyzed in this trial, it seems reasonable that they may have contributed to the off

flavors noted by the sensory panel. According to Park et al. (1974), trans, trans-2,4-dienal can be formed upon the autooxidation of linoleic and/or linolenic acids, which were present in relatively high levels (Tables 6, 7, 8 and 9) in the intramuscular, intermuscular and subcutaneous lipids of lambs fed the 8% PCO and 8% PLO diets.

Aroma and flavor of leg roasts from the olive oil supplemented lambs scored higher ($P \leq .05$) than those from control lambs, but roasts from these lambs were considered less ($P < .05$) tender. Panelists characterized the lambs of the 8% PCO group as being bland with a "beefy" flavor and less strong aroma. Although the lambs fed the olive oil had almost as high a level of C18:2 in their intramuscular lipids (approximately 9.8 percent) as did the cottonseed and linseed oil supplemented lambs, the oily aroma and flavor were not present. This suggests that the subcutaneous and seam fats may have exerted some influence on flavor and aroma of the samples in that subcutaneous fat from the 8% PCO lambs had approximately twice the level of C18:2 that was present in the 8% POO lambs, while the 8% PLO group were observed to be seven to eight times higher in the level of C18:3 (Tables 6 and 7). This may have resulted in a reduced amount of the oxidation compounds found by Park et al. (1974) being produced in the 8% POO lambs.

It has also been reported (Douglas et al. 1973) that milk high in linoleic acid (12.1 percent C18:2) from cows fed a diet containing protected soyflour and soybean oil had an oxidized flavor after four days. However, milk produced by cows supplemented with protected animal tallow (MacLeod et al. 1976) was not different ($P > .05$), as far as oxidized flavor was concerned, after 48 hours. Since animal tallow contains less ($P < .05$) quantities of C18:2 and C18:3 than oils of soybean, safflower, cottonseed or sunflower seeds and resembles olive oil in C18:1 content, these two sources of fatty acids might be expected to produce a similar result in terms of altering the flavor of a product. If the oxidation of unsaturated fatty acids in meat is similar to milk, this data suggest higher ($P < .05$) proportions of C18:2 and C18:3 result in more prevalent oxidized flavors than does an increased level of oleic acid.

Armour Food Company Panel

The mean scores for the sensory evaluation of loin chop samples conducted by the Armour Food Company (AFC) are presented in Table 11 for aroma and flavor. The aroma of loin chops from the 8% PLO lambs was less ($P < .05$) desirable than the control, while no detectable difference ($P > .05$) between the aromas of the other groups was apparent. Flavor, on the other hand, for lambs fed the 8% PCO and 8% PLO diets was considered inferior ($P < .05$) to the control group

Table 11. Mean Scores of Armour Food Company Evaluation.

Characteristic	Control	Diet[a] 8% PCO	8% POO	8% PLO
Aroma	5.44[b]	5.21[b]	5.65[b]	4.42[c]
Flavor	5.98[b]	3.90[c]	5.46[b]	3.75[c]

[a] PCO = protected cottonseed oil, POO - protected olive oil, PLO = protected linseed oil (percentages refer to oil content of diet).

[bc] Means on same line with different superscripts are significantly different ($P < .05$).

while lambs fed the 8% POO diet were as well liked ($P > .05$) as the control. These results are consistent with the findings of the UA sensory panel on roasts from the same lambs.

The AFC panelists characterized the 8% PCO and 8% PLO lambs as having an oily and fishy-oily aroma and an old, musty, oxidized flavor. As discussed earlier, these samples had higher levels of intramuscular C18:2 and C18:3 (Tables 8 and 9) with their respective subcutaneous adipose tissues also being high in these particular fatty acids (Tables 4, 5, 6 and 7). This may have led to the autooxidation and formation of trans, trans-2,4-dienal which was linked (Park et al. 1974) to the oily aroma and flavor of meat high in linoleic acid.

Lambs supplemented with crude cottonseed oil protected from rumen fermentation were less ($P < .05$) desirable than lambs fed a milo-alfalfa diet without added oils (Dryden, Marchello and Hernandez, personal communications 1977). It is possible that impurities in the oil may have been incorporated into the lamb tissue resulting in the less ($P < .05$) desirable flavor. The results of the current study, where lambs were fed food quality cottonseed oil protected from rumen fermentation, suggested that the less ($P < .05$) desirable flavor and aroma were the result of higher ($P < .05$) levels of C18:2 and C18:3 along with the possible oxidation products of these fatty acids.

Bremner et al. (1976) reported that meat with a higher ($P < .05$) level of linoleic acid developed rancid flavors and odors two to three times faster than meat from conventionally fed animals stored in the same manner. This could have been a factor influencing the acceptability of the 8% PCO and 8% PLO lambs since the samples were stored for two months prior to sensory evaluation.

The results of the two sensory panel evaluations, each involving a muscle from different locations in the carcass, were in rather close agreement. This suggests that accurate evaluations can be accomplished using only one muscle, even if some differences ($P < .05$) in fatty acid composition of the muscle and surrounding adipose tissue do exist.

Performance Data

The mean performance and carcass data of the lambs fed the experimental diets are listed in Table 12. The average daily gain of lambs fed the diets containing protected oils were 54 to 70 percent higher ($P < .05$) than lambs fed the milo-alfalfa diet. Increased ($P < .05$) gains of lambs (Faichney et al. 1973, Hernandez 1976) and steers (Garret and Yang 1975) as a result of feeding protected safflower and cottonseed oils have been reported. Faichney (1971) has also reported increased ($P < .05$) gains in lambs supplemented formaldehyde-treated casein. The higher ($P < .05$)

Table 12. Means of Performance and Carcass Data of Lambs by Diet.

Item	Experimental Diet[a] Control	8% PLO	8% POO	8% PLO
Number of lambs	4	4	4	4
Days on treatment	46	46	46	46
Initial weight, kg	34.2	34.6	34.8	34.0
Average daily gain, gm	210[d]	324[e]	341[e]	358[e]
Feed intake per day, kg	1.4	1.6	1.6	1.6
Feed required per kg gain, kg	6.8	5.1	4.8	4.6
Cold carcass weight, kg	22.4	25.7	25.2	25.8
Dressing percent[b]	53.3	53.9	54.1	53.3
Fat thickness, cm/30 kg cold weight[c]	1.2	1.0	.9	.9
Kidney and pelvic fat, %	4.3	4.1	4.8	3.8

[a] PCO = protected cottonseed oil, POO = protected olive oil, PLO = protected linseed oil (percentages refer to oil content of diet).

[b] Calculated from cold carcass weight as a percent of shrunk weight.

[c] Longissimus region over the 12th rib.

[de] Means on the same line with different superscripts differ significantly ($P < .05$).

gains noted for the oil supplemented lambs in the current trial are assumed to be the result of increased caloric density (due to the added oil), increased protein quality (casein was the protein used for lipid protection in this study) and increased feed intake (1.6 kg per day in oil supplemented lambs vs. 1.4 kg per day in control lambs).

Lambs supplemented with the protected oils (cottonseed, olive and linseed) converted feed to animal tissue 25 to 30 percent more effeciently than did lambs consuming the control diet. This is a reflection of the higher energy content of the diets which contained protected oils. No significant changes ($P > .05$) were caused in carcass weight, dressing percent, fat thickness or kidney and pelvic fat. This agrees with the findings of Hernandez (1976) in lambs and Garret and Yang (1975) in steers supplemented with protected polyunsaturated fats.

Serum Lipid, Insulin and Glucagon Level

Table 13 contains the mean levels of serum lipid, insulin and glucagon of the lambs by period within each experimental diet. The level of serum lipid varied between periods within each treatment group with an increase ($P < .05$) in all lambs fed diets containing protected oils, over the 46 day trial. Previous studies involving the supplementation of protected oils to steers (Dryden et al. 1975) and lambs

Table 13. Means of Total Serum Lipid, Insulin and Glucagon Level by Sample Period within Diet.

Diet[a]	Period[b] 1	2	3	4	5	6	7
				mg lipid/100 ml serum			
Control	231^{c}	109^{d}	353^{e}	503^{f}	221^{c}	246^{c}	174^{cd}
8% PCO	195^{c}	165^{c}	293^{d}	382^{e}	315^{de}	319^{de}	315^{de}
8% POO	191^{c}	187^{c}	283^{d}	409^{e}	348^{e}	280^{c}	289^{c}
8% PLO	177^{c}	172^{c}	210^{d}	135^{c}	274^{d}	237^{d}	206^{d}
				ng insulin/ml plasma			
Control	$.54^{c}$	1.19^{d}	1.00^{d}	$.72^{cd}$	1.02^{d}	$.77^{d}$	1.06^{d}
8% PCO	$.41^{c}$	$.71^{cd}$	$.45^{c}$	$.55^{cd}$	$.55^{cd}$	$.84^{d}$	$.80^{d}$
8% POO	$.48^{c}$	$.95^{d}$	$.76^{cd}$	$.72^{cd}$	$.88^{d}$	$.69^{cd}$	1.02^{d}
8% PLO	$.54^{cd}$	$.88^{c}$	$.57^{cd}$	$.44^{d}$	$.44^{d}$	$.48^{cd}$	$.59^{cd}$
				ng glucagon/ml serum			
Control	$.12^{c}$	$.36^{d}$	$.26^{cd}$	$.24^{cd}$	$.21^{cd}$	$.30^{d}$	$.25^{cd}$
8% PCO	$.16^{c}$	$.32^{d}$	$.37^{d}$	$.20^{cd}$	$.29^{cd}$	$.27^{cd}$	$.36^{d}$
8% POO	$.16^{c}$	$.29^{cd}$	$.40^{d}$	$.20^{c}$	$.29^{cd}$	$.24^{c}$	$.24^{c}$
8% PLO	$.17^{c}$	$.34^{d}$	$.39^{d}$	$.30^{d}$	$.44^{de}$	$.30^{d}$	$.54^{e}$

[a] PCO = protected cottonseed oil, POO = protected olive oil, PLO = protected linseed oil (percentages refer to oil content of diet.

[b] Period 1 = day 0, Periods 2, 3, 4, 5, 6 and 7 = days 7, 14, 21, 28, 35 and 46, respectively.

[cde] Means within the same line with unlike superscripts differ significantly ($P < .05$).

(Hernandez 1976) have indicated that serum lipid levels increased ($P < .05$) proportionally with time.

Increases ($P < .05$) in the insulin concentrations of all treatment groups (except the 8% PLO group) occurred from the first to the final period, even though levels were not always different ($P > .05$) between consecutive periods. Hernandez (1976) reported increases ($P < .05$) in the level of plasma insulin in lambs which were supplemented with protected and unprotected cottonseed oil as well as lambs not being fed oil supplements.

McDonald and Warner (1975) reported that insulin has a definite effect on lipid metabolism by stimulating lipogenesis and inhibiting lipolysis. These workers also reported that insulin stimulated the uptake and incorporation of amino acids into protein and inhibits proteolysis. This may explain the increase ($P < .05$) in insulin levels for the 8% PCO and 8% POO lambs since casein was the protein used to protect these oils. The relatively constant level of insulin noted for the 8% PLO lambs may be a reflection of the smaller changes in serum lipid levels for this group as compared to other groups. The large fluctuation (noted in Periods 3 and 4) of serum lipid levels of the control lambs was not reflected in the plasma insulin levels in the same periods.

Glucagon increased in the 8% PCO and 8% PLO lambs upon supplementation of the oils, but the control and 8% POO lambs were not different ($P > .05$) at the termination of the trial as compared to the beginning. Bottger et al. (1973) reported that fat absorption in dogs is accompanied by a substantial ($P < .05$) rise in glucagon level while Muller, Faloona and Unger (1971) reported increases ($P < .05$) in glucagon level due to higher ($P < .05$) levels of amino acids (especially alanine) being absorbed. Similar findings have been reported by Lefebvre and Unger (1972). Assuming glucagon responds similarly in most mammals, the supplementation of lambs with protein protected oils explains the initial increases ($P < .05$) in glucagon levels for the 8% PCO, 8% POO and 8% PLO lambs. However, the increases ($P < .05$) in the glucagon level of control lambs can not be accounted for in this manner, with the only explanation being that control lambs had higher ($P < .05$) levels of serum lipid at various times throughout the trial.

It has been proposed by Lefebvre and Unger (1972) that increased levels of glucagon stimulate the secretion of insulin which has a negative effect of glucagon secretion. This theory offers a more plausible explanation for the insulin and glucagon data observed.

The means of total serum lipid, insulin and glucagon levels by experimental diet within each sample period are listed in Table 14. At the initiation of the trial lambs to

Table 14. Means of Total Serum Lipid, Insulin and Glucagon Level by Diet within Sample Period.

Diet[a]	Period[b] 1	2	3	4	5	6	7
				mg lipid/100 ml serum			
Control	231^{c}	109^{c}	353^{c}	503^{c}	221^{c}	246^{c}	174^{c}
8% PCO	195^{d}	165^{d}	293^{d}	382^{d}	315^{d}	319^{d}	315^{d}
8% POO	191^{d}	187^{d}	283^{d}	409^{d}	348^{d}	280^{d}	289^{d}
8% PLO	177^{d}	172^{d}	210^{e}	135^{e}	274^{d}	237^{c}	206^{e}
				ng insulin/ml plasma			
Control	.54	1.19	1.00^{c}	.72	1.02^{c}	.77^{c}	1.06^{c}
8% PCO	.41	.71	.45^{d}	.55	.55^{cd}	.84^{c}	.80^{cd}
8% POO	.48	.95	.76^{c}	.72	.88^{c}	.69^{cd}	1.02^{c}
8% PLO	.54	.88	.57^{cd}	.44	.44^{d}	.48^{d}	.59^{d}
				ng glucagon/ml serum			
Control	.12	.36	.26^{c}	.24^{c}	.21^{c}	.30	.25^{c}
8% PCO	.16	.32	.37^{cd}	.20^{c}	.29^{cd}	.27	.36^{c}
8% POO	.16	.29	.40^{d}	.20^{c}	.29^{cd}	.24	.24^{c}
8% PLO	.17	.34	.39^{d}	.30^{d}	.44^{d}	.30	.54^{d}

[a] PCO = protected cottonseed oil, POO = protected olive oil, PLO = protected linseed oil (percentages refer to oil content of diet).
[b] Period 1 = day 0, Periods 2, 3, 4, 5, 6 and 7 = days 7, 14, 21, 28, 35 and 46, respectively.
cde Means within the same column and sample type with unlike superscripts are significantly different ($P < .05$).

receive the protected oil diets had lower ($P < .05$) serum lipid levels than those which would receive the control diet. This was assumed to be a chance variation which may happen when sampling any population. Again, all lambs which received the protected oils had higher ($P < .05$) serum lipid levels by the termination of the trial. However, no definite pattern could be established from which one could predict which groups might have the higher serum lipid levels from one period to the next. Insulin and glucagon levels also varied from one period to the next without an established pattern of change. The results of Dryden et al. (1975) and Hernandez (1976) where protected cottonseed oil was fed to steers and lambs, respectively, indicate that increased levels of dietary oils result in increased ($P < .05$) serum lipid levels. In the current trial, periods where serum levels were higher ($P < .05$) for lambs which consumed protected oils, the findings of these workers are consistent. However, when control lambs had higher ($P < .05$) serum lipid levels (Periods 3 and 4) other factors appeared to have an overiding influence. The higher levels of serum lipid in the control group may have been due to increased synthesis of lipids within the liver or increased activity of mobilizing lipase in the adipose tissues.

CONCLUSIONS

From the results of feeding formaldehyde-treated casein:oil (cottonseed, olive and linseed) supplements to lambs combined with the results from previous investigations, the following conclusions have been developed:

1. The supplementation of protected oils caused elevated ($P < .05$) levels of unsaturated 18 carbon fatty acids, characteristic of each oil, to be incorporated in all tissues studied. Linoleic and linolenic acids were incorporated into subcutaneous adipose tissue at a nearly linear rate with time. However, oleic acid was incorporated rapidly within the first 14 days and increased only slightly ($P > .05$) after that time.
2. Subcutaneous tailhead fat biopsies demonstrated the change in fatty acid composition which occurred in most of the body adipose tissues during the trial. However, biopsy samples tended to overestimate the magnitude of change in the composition of heart fat.
3. Lipogenic differences were observed between intramuscular, intermuscular, internal and subcutaneous adipose depots as demonstrated by the extent to

which the unsaturated 18 carbon fatty acids were incorporated into each tissue.

4. Unsaturation of fatty acids was observed to increase ($P < .05$) as the adipose site location was nearer the body surface.
5. Adipose tissues of lambs supplemented with olive oil exhibited a unique ability to incorporate linoleic acid from a relatively low dietary source of this acid.
6. The existence of a homeostatic system for maintaining the ratio of saturates:unsaturates was indicated for intramuscular lipids but not for other tissues.
7. Flavor and aroma were unfavorably altered ($P < .05$) by the protected cottonseed and linseed oil diets. The polyunsaturated 18 carbon fatty acids were assumed to undergo oxidation with the possible formation of trans, trans-2,4-decadien-1-al.
8. A blander, more beef-like flavor was produced in lambs by the olive oil diet.
9. It was indicated that intermuscular and subcutaneous fat, as well as intramuscular fat, influenced the flavor and aroma of leg roasts and loin chops from the experimental lambs.

10. The need for sensory evaluation of more than one muscle from a carcass was not indicated by the results of the two separate sensory panels.
11. Average daily gain and feed efficiency of the lambs were greatly ($P < .05$) inhanced by the protected oil supplements apparently as a result of increased caloric density and more efficient utilization of the protein and lipid.
12. Carcass weight, dressing percent, fat thickness, amount of kidney and pelvic fat or fat content of muscles were not effected ($P > .05$) by the protected oil supplementation during the 46 day trial.
13. Supplementation of all protected oils investigated caused total serum lipid levels to increase ($P < .05$).
14. Insulin and glucagon levels increased ($P < .05$) with time in all lambs with some noted increases ($P < .05$) due to oil supplementation.

SUMMARY

The purpose of this study was to determine if the flavor and/or aroma of lambs could be inhanced by the alteration of the fatty acid composition of body tissues through the supplementation of formaldehyde-treated casein: oil (cottonseed, olive or linseed) products. The dietary treatments for the 46 day trial involving four groups of four lambs each included a basal milo-alfalfa control and the three experimental diets each containing eight percent of one of the different protected oils. In addition, the effect these treatments had on serum lipid, insulin and glucagon levels were studied.

Consumption of the protein protected oils increased ($P < .05$) the levels of unsaturated 18 carbon fatty acids in all carcass depot fats. The olive oil product (8% POO) resulted in higher ($P < .05$) levels of C18:1 in most tissues, while the level of C18:2 was increased ($P < .05$) in all tissues by the protected cottonseed oil product (8% PCO) and the 8% POO diet. The protected linseed oil (8% PLO) diet resulted in elevated ($P < .05$) levels of linoleic and linolenic acid in all tissues studied. Total unsaturated fatty acids was increased ($P < .05$) by the dietary oils.

Acceptability of meat from the control and 8% POO lambs were not different ($P > .05$); however, the 8% PCO and 8% PLO lambs were considered inferior ($P < .05$) by both sensory evaluation panels. One panel evaluated leg roasts while the second sensory group evaluated loin chops.

Lamb performance (weight gain and efficiency) was inhanced ($P < .05$) by the dietary oil supplements. The protected oil products had no apparent ($P > .05$) effect on carcass data (dressing percent and cold carcass weights) or muscle lipid content.

Serum lipid levels were higher ($P < .05$) in oil supplemented lambs. Circulating serum glucagon and insulin increased ($P < .05$) in all lambs with time and in some cases as a result of the protected oil supplementation.

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