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FAT UTILIZATION BY THE YOUNG PIG

by

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## INTRODUCTION

Lipid, or more commonly known as fat, is an important dietary component because of its high fuel value, the palatability it imparts to food, the essential fatty acids it contains which are needed for various processes within the body and because it functions as a carrier of the fat soluble vitamins. It is an important storage form of energy in the animal body because of its high caloric value and the quality and convenience of storage with a minimum amount of weight and water content. Fats, along with carbohydrates, also have the power to reduce the extent of protein catabolism by providing energy for the normal growing animal.

A small amount of fat is required by the animal for supply of certain polyunsaturated acids frequently termed essential fatty acids. Holman (1958) suggested the term essential fatty acids should be reserved for those substances which are active for both maintenance of dermal integrity and growth thus limiting the term to linoleic and arachidonic acids and to such other acids which may be derived metabolically from them. This would eliminate linolenic acid which has been shown active only as a growth factor. Fat deficiency symptoms in swine have been described by Witz and Beeson (1951). Typical symptoms were: scaly dandruff, loss of hair starting at the lower extremities and gradually spreading along the belly, sides and back, brown gummy exudate on the belly and

sides of pigs and necrotic areas on the shoulders and neck. A dietary level of 0.03 percent linoleic acid has been shown to satisfy the essential fatty acid requirement for normal growth but is marginal for normal skin development (Leat, 1959).

With the introduction of solvent extracted protein concentrates in the late 1950's, a smaller amount of fat is being provided by the protein concentrates incorporated into livestock rations. Protein concentrates prepared by the expeller process contain 4 to 5 percent fat, whereas solvent extracted concentrates usually contain less than 1 percent fat. At first commercial feed manufacturers incorporated fat into rations primarily for its physical effect in improving the appearance of the ration, reducing the dustiness and aiding in pelleting of rations. However, more recently fat is used for the nutritive value it imparts to feeds. The main value of fat in animal feeding lies in the contribution it makes towards the energy requirement of the animal.

On the basis of metabolizable energy value of feeds as reported by Diggs et al. (1965), the incorporation of 10 percent fat for an equivalent amount of carbohydrate would increase the energy content of a corn-soybean meal ration approximately 15 percent. This increase in energy should produce at least a 10 percent improvement in feed efficiency. With the older pig, such an improvement is observed. Wagner et al. (1963) observed that pigs averaging 54 days of age and fed a diet containing 10 percent fat required less feed per

unit of gain than did pigs on a diet without added fat. With the increase in energy level there also was an increase in rate of gain. This same trend of improved feed efficiency and increased rate of daily gain resulting from fat additions to the diet has been reported by others (Barrick et al., 1953; Day et al., 1953; Heitman, 1956; Kennington et al., 1958; Lowery et al., 1962; Clawson et al., 1962; and Bayley and Lewis, 1963a). However, work by Peo et al. (1957) and Eusebio et al. (1965) has not consistently shown an improvement from adding fat to the diet of young pigs (14 days old). Sewell and Miller (1965) also observed no difference in growth rate of pigs fed diets containing 0 to 8 percent added fat; however, they did observe an improvement in feed efficiency on the high fat diets. Although no difference was observed in economy of food conversion, Manners and McCrea (1963) reported that from two days to 28 days of age pigs on a low fat diet gained more than did pigs on a high fat diet.

The results obtained from feeding weanling pigs a high fat diet are quite variable. In general, weaning a pig at an early age and feeding it a high fat diet results in retarded growth and an increase in energy required per unit of gain. Just why the baby pig cannot utilize fat as efficiently as the older pig has not been determined. Undoubtedly a host of factors, including (1) the physical form of the diet, (2) inadequate bile secretion or emulsification, (3) degree of saturation of fat, (4) molecular weight of fat, (5) fatty acid chain

length and combinations in fat, (6) lipase activity - both quantity and specificity, act alone or in combination with each other resulting in the inefficient utilization of fat as an energy source.

The objective of the research reported herein was to investigate the utilization of fats and oils by young pigs from two to six weeks of age. Digestibility coefficients were determined for the various fats and oils and were related to the growth data. Fatty acid analyses were conducted on plasma, fecal and feed lipids to establish a fatty acid pattern for determining the relative utilization of individual acids. Both quantity and specificity of porcine pancreatic lipase in two age groups were measured to investigate the relationship of age and substrate on lipase activity.

## REVIEW OF LITERATURE

## Physical Form of the Diet

The form of diet has been implicated as a possible factor in the poor utilization of fat by baby pigs. It has been postulated that addition of fat to a dry diet results in a reduction in food intake. It has further been postulated that feeding a liquid diet would increase food intake and result in efficient conversion of the energy from the fat to more rapid and efficient gains.

The composition of sow milk at different stages of lactation has been determined by many investigators (Braude et al., 1947; Bowland et al., 1949a, 1949b; Heidebrecht et al., 1951; Sheffy et al., 1952; Barnhart et al., 1954; Allen and Lasley, 1960; and Pond et al., 1962). Perrin (1954) observed that from the seventh to the fifty-sixth day of lactation the fat content of sow milk on a dry matter basis decreased from 48 to 39 percent. Dividing the milk sample withdrawn from a gland into fractions based on withdrawal time revealed no difference in fat content during milking in the gland as observed in the cow. Jylling and Sorensen (1960) reported no regular variations occurred either in fat or protein content between three portions of milk obtained from the same gland. They observed that immediately after farrowing the protein content on a dry matter basis is approximately 50 percent and remains relatively high for the first twenty-four hours. This



initial high protein content is a result of the high gamma globulin content of colostrum milk. During the first week of the lactation period, the protein content decreases until it plateaus at approximately 30 to 35 percent and remains at this level for the duration of lactation. The fat content, however, is low at birth (15 percent) and increases during lactation. After the first week of lactation the fat content plateaus at approximately 38 percent and remains at this level for the duration of lactation. Paralleling the increase of fat in milk is the increase in lactose content. At birth milk contains approximately 6.5 percent lactose which increases to approximately 26 percent within twenty-four hours post-partum where it plateaus for the remainder of lactation. Also, it has been estimated that a lactating sow secretes approximately 9,900 kilocalories of energy daily in the milk.

Johnson et al. (1948) observed that pigs weaned at one-day of age and fed a synthetic milk diet gained more than did pigs reared on the sow. They concluded the improved growth rate was probably a reflection of the limited milk-producing capacity of the sow.

Catron et al. (1953) demonstrated a need for fat in synthetic milk diets. They reported the survival rate to seventeen days of age of baby pigs removed immediately from their dam after parturition was 17.2 percent on a low fat diet (0.5 percent) as compared with 50 percent survival on diets which contained lard (29.7 percent). Among the three levels of fat

tested, 10, 20 and 30 percent, the lowest level resulted in the most rapid growth rate. Decreasing the fat content in the synthetic milk did not significantly affect feed efficiency.

Weaning of pigs and feeding a synthetic ration results in a lag in growth (Hartman et al., 1961) lasting for one to two weeks as compared to the rapid growth of pigs nursing their dam (Forshaw et al., 1953). However, at three to four weeks of age the pig becomes adjusted to the change and his growth rate then exceeds that of pigs nursing their dam. By eight weeks of age the growth rate of pigs on a synthetic diet has doubled that observed for suckling pigs. This large difference at eight weeks of age cannot all be attributed to the diet. Pigs employed on the synthetic diets are a somewhat select group of animals and would be expected to perform well, whereas those remaining on the sow are a more representative sample of a population. Also, milk production of the sow reaches a maximum approximately four weeks post-partum and then decreases. With the decrease in milk production, the growth rate of pigs nursing their dam may be reduced since the quantity of milk available becomes a limiting factor. Hartman et al. (1961) have also demonstrated that the growth rate of nursing pigs is rapid until the quantity of milk becomes the limiting factor.

In general, the data illustrates pigs weaned and fed a liquid diet will grow faster than pigs fed a dry diet. Even though a growth lag is present after weaning, the growth lag

in pigs fed a liquid diet will not be as severe nor as long in duration as that of pigs weaned to a dry diet. If intake of a high fat diet is the limiting factor in fat utilization, feeding a liquid diet should increase food intake and result in more efficient and rapid gains.

#### Bile Secretion and Emulsification

Pancreatic lipase exerts its physiological function in the lumen of the upper small intestine, i.e. duodenum and first part of jejunum in the presence of bile and at a slightly acid pH (Borgstrom et al., 1957). Bile is needed for digestion since it supplies bile acids which (1) help emulsify fat globules for digestion by the enzyme lipase, (2) help render the end-products of fat digestion soluble for absorption through the intestinal mucosa and (3) contribute in shifting the pH optimum of pancreatic lipase from pH 8 to 9 in their absence to the slightly acid conditions (pH of about 6) prevailing in the upper small intestine (Borgstrom, 1954). It has been postulated that the secretion of bile acids is low at birth and increases with age and that the low amount secreted early in life could partially account for the poor digestion of fat.

Borgstrom (1964) studied the effect of bile salt concentration and pH on lipase hydrolysis of triolein. In the absence of bile salt a profound change in the glyceride composition was obtained with a change in pH toward neutrality. The

relative proportion of monoglycerides increased and became the dominating glyceride fraction at pH 7.0 and above, whereas at a lower pH, triglyceride was the dominating glyceride species. Addition of bile salt resulted in an increase in the monoglyceride content at the lower pH at the expense of triglyceride and an increase of triglyceride at the expense of monoglyceride at the higher pH values. Incorporating different bile salts, sodium taurodeoxycholate, sodium glycocholate, sodium deoxycholate and sodium cholate, had the same effect of increasing the proportion of monoglyceride present at the expense of triglyceride at the lower pH values. It was concluded that bile salts function in a series of interactions involving the substrate and split products (fatty acids) rather than having any direct effect on the enzyme lipase.

Hofmann and Borgstrom (1962) observed that bile salts present in the duodenum and jejunum form complexes or micelles with fatty acids and monoglycerides, the end products of enzyme hydrolysis, and aid in their absorption from the proximal small intestine. Although bile salts are essential for micelle formation, they are not absorbed in the proximal small intestine where the major portion of fat is absorbed (Senior, 1964). They remain in the lumen of the proximal small intestine during fat absorption and then pass into the ileum where they are reabsorbed, recirculated via the portal blood to the liver where bile is again formed and eventually enter the duodenum where they can again aid in fat absorption.

Phospholipids of foods are principally lecithins and are involved in emulsifying fat (Phillips, 1960). The phospholipid content of sow milk has been estimated to be between 1 and 2 percent of the fat content and apparently is involved in the emulsification of fat present (Sheffy et al., 1952). Sheffy et al. (1951) investigated the effect of homogenization and addition of phospholipids on growth and fat absorption in baby pigs and reported that homogenization of lard, addition of soya lecithin, or particle size of the fat had little effect on subsequent growth, efficiency of feed conversion or fat digestion by two-day old pigs. Manners and McCrea (1963) have also observed no difference in rate of gain or efficiency of feed conversion from the addition of fat as melted or homogenized lard. With rats, Augur et al. (1947) reported a stimulating effect from addition of lecithin on the rate of absorption and coefficient of digestibility of fats. However, Shoshkes et al. (1950) reported that the absorption of orally fed corn oil by the rat was not affected by the presence of soybean phosphatide or Tween 80.

Bayley and Lewis (1963b) working with chicks concluded that emulsification normally limits the digestibility of beef tallow in chick rations. Addition of a non-ionic surface-active agent improved the digestibility of fat by chicks. However, addition of either 10 percent beef tallow or 10 percent free fatty acids derived from beef tallow by catalytic hydrolysis to swine rations revealed that the free fatty acids were

utilized less efficiently than the triglycerides. This was especially true of palmitic, 62 vs. 28 percent digestibility and stearic, 23 vs. 0 percent digestibility, for tallow and the free fatty acids from tallow, respectively. Addition of a detergent resulted in an improvement in the overall utilization of free fatty acids, but had no effect on the utilization of triglycerides. Since the addition of a surface-active agent resulted in an increased utilization of the free acids, they concluded that incomplete emulsification of the free acids resulted in their lowered digestibilities.

March and Biely (1957) reported no improvement in growth rate, feed efficiency or fat digestibility by chicks from addition of a surface-active agent to the diet. Fedde et al. (1960) observed that added levels of ox bile (0 to 8 percent) to diets containing 20 percent beef tallow resulted in significant increasing growth depression in chicks with increasing levels of ox bile. Feed efficiencies paralleled the growth response. The greatest growth depression occurred at the 4 to 8 percent level of added ox bile, whereas only slight depressions were observed in levels of 0.05 to 2 percent. In this study bile was removed from the gallbladders of chicks and was measured with a calibrated syringe. It was assumed that the amount of bile present was indicative of the gallbladder size since visual observations indicated gallbladders of birds receiving high levels of ox bile were greatly enlarged. The results showed that gallbladders of birds fed the 8 percent

ox bile diet were relatively larger than those of birds fed any other diet and that ox bile levels over 1 percent resulted in a significant increase in bile storage.

Hopkins et al. (1959) observed that supplementing a milk replacer for dairy calves with tallow, cocoanut fat, grease or butter resulted in poor digestion of the fat. Inclusion of crude soybean lecithin greatly improved the utilization of the fat sources, more so for cocoanut fat than for the other fat sources.

In vitro studies with sheep pancreatic lipase revealed that fatty acids were liberated from triglycerides quite rapidly in the absence of bile (Heath and Morris, 1963). However the percentage of fatty acids liberated were more than doubled with the addition of bile. Diversion of bile from the small intestine resulted in a rapid decrease in the concentration of total esterified fatty acids in intestinal lymph illustrating the importance of bile in fat absorption. In the absence of pancreatic juice some absorption of fat did occur in the presence of bile.

#### Molecular Weight of Fat Source

The difference in fatty acid composition of the various fat sources produces fat products with varying degrees of molecular weight and melting points. Glyceride structure and fatty acid composition of vegetable, animal and marine fats and oils have been determined and verify the large difference

in molecular weight (Mattson and Volpenhein, 1961, 1963; Mattson et al., 1964; Subbaram and Youngs, 1964; and Hilditch and Williams, 1964). The difference in molecular weight of fat sources has been postulated as one of the factors affecting fat utilization in baby pigs.

Research on fat utilization at the turn of the century suggested that an inverse relationship existed between melting point, especially those melting at a temperature above 50°C, and digestibility of fats. McCay and Paul (1938), using guinea pigs, fed various fat sources and observed an increase in fecal lipid with an increase in melting point of the fat source fed. Substituting fat for an oil source resulted in a marked reduction in digestion of the fat as compared to the oil. In rats fed synthetic triglycerides, Deuel and Hallman (1940) observed an increase in the percent fat recovered in the fecal material as the chain length of the fatty acids in the triglycerides increased (triacetin to trilaurin). With the increase in fat excretion there was also a corresponding decrease in absorption of the triglycerides. Crockett and Deuel (1947), Cheng et al. (1949) and Karvinen et al. (1957) have also reported a decrease in digestibility of fat sources as their melting point increased. On the other hand, Hoagland and Snider (1943a) believed some factor other than melting point determined the relative digestibility of fats since they observed a higher digestibility coefficient for fats containing long chain fatty acids. In subsequent trials Hoagland and



Snider (1943b) reported that incorporating lauric, myristic, palmitic or stearic acids into diets of rats resulted in a decrease in digestibility of the acids as chain length increased. The same trend was also observed with addition of trilaurin, trimyristin, tripalmitin or tristearin. Since both stearic acid and tristearin were poorly absorbed they concluded that the stearic acid content of a fat limits its utilization. Experiments by Mattil and Higgins (1945) indicated rather clearly that stearic acid was very poorly utilized whether fed as a mixed glyceride or a simple triglyceride.

Mattson (1959) reported that it is impossible to differentiate between the effect of melting point and saturated fatty acid content and their subsequent effect on fat utilization. Although the melting point of a fat increases with an increase in saturated long-chain fatty acids, it is not proportional to the content of these acids. If the long-chain acids are present as saturated glycerides, the fat will have a higher melting point than would a fat with the same amount of saturated acids distributed randomly among the glycerides. A typical fat may contain triglycerides with melting points ranging from  $-55^{\circ}\text{C}$  to  $70^{\circ}\text{C}$  thus at any intermediate temperature there would be both solid and liquid fat present. Mattson (1959) concluded that the coefficient of absorbability of a fat is inversely proportional to its content of simple triglycerides made up of saturated fatty acids having a chain length of 18 carbons or greater. The coefficient of

absorbability is influenced by the level of such saturated acids only insofar as they are present as saturated triglycerides.

Gullickson and Fountaine (1939) fed calves butter oil, lard, corn oil, cottonseed oil and soybean oil homogenized into skim milk and observed that butter oil was superior to all other fats and oils tested. Calves fed lard made nearly as rapid gain in weight but were inferior in appearance to those receiving butterfat. In another trial (Gullickson et al., 1942) cocoanut oil, peanut oil and beef tallow were employed along with the previous mentioned fats and oils. Also to determine whether calves required any fat, a low fat diet was included as one of the experimental diets. Calves fed fats of animal origin, butterfat, beef tallow and lard, gained significantly more than did calves fed the vegetable oils. Again butterfat was superior to all other fats and oils tested as a food for young calves. Excellent gains were made by calves on the low-fat diet suggesting that calves have need for no more than the extremely limited amount of fat provided in the low-fat diet.

The results of feeding trials with dairy calves, indicated that butterfat had some properties which made it nutritionally superior to other fats. A series of studies comparing butter with other fats and oils were subsequently conducted with rats. Boutwell et al. (1943) studied the effect of level and type of fat on the growth of rats of varying ages. The

growth promoting value of butterfat was superior to that of corn oil in all age groups with the greatest difference occurring in the 14 day-old group. Increasing the fat levels from 25 to 35 percent of the diet resulted in a corresponding increase in gain with butterfat but a decrease in weight with corn oil. In a subsequent trial (Boutwell et al., 1945) no difference was observed in growth rate of rats fed butter or corn oil with glucose or a galactose-glucose mixture as the carbohydrate portion of the diet. Rats receiving either of the two fats with lactose grew at a slower rate than did rats fed similar diets containing other carbohydrate sources. Deuel et al. (1944a, 1944b) and Deuel and Movitt (1945) fed various sources of fat, including butter, corn oil, hydrogenated cottonseed oil, cottonseed oil, olive oil, peanut oil or soybean oil, and observed no difference in the growth rate of rats. However, Deuel and Movitt (1944) reported that if butter and another fat source were offered simultaneously, rats consumed more of the butter diet than of the other diets irrespective of the fat source. Addition of commercial butter flavors to diets containing hydrogenated cottonseed oil or peanut oil resulted in a greater consumption of the flavored diets as compared to the same fat sources without the butter flavor. Thomasson (1955) has observed that with increasing levels of butterfat in the diet, the rate of growth of rats remains unchanged. With other fats, olive oil, cottonseed oil, beef fat, maize oil, soybean oil, groundnut oil, palm fat, sunflowerseed

oil, poppyseed oil, cocoanut fat, sesame oil, whale oil, herring oil or rapeseed oil, there was a decrease in rate of growth with increasing fat levels. Two theories were postulated why certain fats and oils did not equal butter; (1) the growth promoting substances present in butter were absent in other fats and (2) growth retardation substances were present in other fats and not in butter. Fats, ranked according to their effect on growth rate, were used to determine the rate of intestinal absorption of fat (Thomasson, 1956). The mean amounts of fat recovered in the gastro-intestinal tract after three hours varied from 63 to 86 percent of the dose administered and after 11 hours they ranked as follows in decreasing rate of absorption: butterfat, cottonseed oil, beef tallow, cocoanut fat, soybean oil, and lard. However, this was quite different than ranked according to their effect on growth: lard, butter, cottonseed oil, beef tallow, soybean oil, and cocoanut fat.

The chick has the ability to utilize fat for a high proportion of its energy requirement. Varying results however, have been obtained with the various fat sources employed. Fedde et al. (1960) reported no difference in the growth rate of chicks fed beef tallow, hog grease, safflower oil or refined corn oil. There was an improvement in feed efficiency from added fat regardless of the type of fat fed. A difference in the digestibility of fat was observed at four and eight weeks of age (70 vs. 89 percent). Renner and Hill (1960) reported

an age difference in the chicks ability to utilize beef tallow. In early life utilization of beef tallow was quite low; however, by eight weeks of age the chick was able to utilize it more efficiently. No age difference was observed in the utilization of corn oil or lard. The addition of soybean oil, corn oil, lard, beef tallow, yellow grease or hydrolyzed animal and vegetable fat produced no significant differences in the growth rate of chicks at four and eight weeks of age (Young, 1961). Feed conversion was improved on the added fat diet over the basal diet for all age groups of chicks. From these data it is evident that the chick can use fat as an energy source regardless of the type fat fed and this efficient conversion to energy results in an improvement in feed efficiency with little or no effect on rate of gain.

Work with young pigs on fat utilization has not given the consistent results observed with chicks, rats or calves. Crampton and Ness (1954) reported that pigs reared on a dry diet gained more than did pigs reared on the sow. Addition of 5 percent corn oil to the ration resulted in a small increase in gain, whereas feed efficiency was increased by 18 percent.

Peo et al. (1957) studied the effect of different levels of fat on gain and feed efficiency of pigs averaging 7.9 days of age. With increasing fat levels (0 to 10 percent) during the first two weeks there was a depression in growth rate and an increase in the feed required per unit of gain. Results after the four week test period again revealed a depressing

effect on gain and no improvement in feed efficiency from added fat. These data clearly illustrate a depressing effect of fat on gain and feed efficiency in young pigs.

Lloyd and Crampton (1957) and Lloyd et al. (1957) studied the effect of various fat sources and the influence of age on the apparent digestibility of fat by early-weaned pigs. The fats and oils tested were divided into three categories using saponification values as a means of differentiation (Table 1). Fats and oils having a saponification value under 200 were considered to contain mostly short chain fatty acids, those with saponification values between 185 and 200 were classed as average chain length and those with a saponification value under 185 were considered to contain mostly long chain fatty acids. A highly significant inverse relationship between mean molecular weight (length of chain) of fatty acids of the various fats and oils and their apparent digestibility by early-weaned pigs was observed. The same fats and oils were divided into three new categories using iodine numbers as a measure of the degree of saturation. No differences were observed in the apparent digestibility of saturated, medium saturated or highly unsaturated fats and oils. These workers observed however, that 7-week-old pigs digested a higher percentage of the fat than did 3-week-old pigs and the difference with age was greater with the higher molecular weight fats (Table 2a).

Asplund et al. (1960) observed that pigs fed diets containing added fat (grease or corn oil) gained less and required

Table 1. Relationship of molecular weight and apparent digestibility of fat by early-weaned pigs<sup>a</sup>

Fatty acid chain length	Av. mol. wt.	Av. apparent digestibility
Short	Less than 260 (Sap. value over 200)	94.4
Medium	Between 260 and 285 (Sap. value between 185 and 200)	91.9
Long	More than 285 (Sap. value under 185)	78.2

<sup>a</sup>Adapted from Lloyd and Crampton (1957).

Table 2a. Influence of age on the digestibility of fats and oils by early-weaned pigs<sup>a</sup>

Fatty acid chain length	Average percent digestibility of fat	
	3 weeks	7 weeks
Short chain	86	96
Medium chain	70	90
Long chain	37	78

<sup>a</sup>Adapted from Lloyd et al. (1957).

slightly more feed per unit of gain than did pigs on a basal diet. The results of a digestibility study showed that added fat increased the apparent digestibility of fat, however, there were no differences between fat levels of 10 and 20 percent.

Crampton et al. (1960) reported that pigs 14 days old accepted diets containing 20 percent added fat more readily than control diets. Although no initial preference was shown for any one fat over another, a significant depression in growth was observed in the 42 day trial with pigs fed fish, rapeseed or cocoanut oil gaining less than the group fed butter.

Blair (1963) postulated some source of fat was needed in the baby pigs' diet as a source of fatty acids. However, no advantage was observed in substituting cocoanut oil for lard in the diet during the period from 10 to 25 days of age.

In work with older pigs (three-weeks old) Sewell and Miller (1965) reported an improvement in feed efficiency with addition of corn oil, tallow, or lard. Pigs fed the lard diet required less feed per unit of gain than did pigs fed the other sources. The digestibility of corn oil was significantly greater than that observed for lard or beef tallow.

Eusebio et al. (1965) demonstrated a marked improvement in digestion of fat with an increase in age. In diets containing 10 percent added fat, digestibility of fat increased from an average of 62.1 percent at three weeks to 87.5 percent



at six weeks of age. No consistent improvement in gains or efficiency of feed conversion was observed from adding fat to the diet. Increasing the fat level of the diet did not improve feed efficiency, and in general, had a depressing effect on rate of gain. Cocoanut oil, which has a lower molecular weight (short chain fatty acids) than tallow, lard or soybean oil, was more readily digested and supported more rapid and efficient gains than did the other fat sources. However, cocoanut oil which is composed of glycerides lower in molecular weight than sow milk fat, is not as efficiently utilized as sow milk fat. Thus the results of this work demonstrate that molecular weight of the fat is not the only factor limiting efficient utilization of the fat.

It has been postulated that the degree of saturation of fatty acids in the triglyceride molecule affects the apparent digestibility of the fat source. Bayley and Lewis (1965b) observed an increase in apparent digestibility of fat with the substitution of soybean oil for tallow in the rations of young pigs. Substitution of a partially hydrolyzed mixture of animal and vegetable fats (HEF, 60 percent triglycerides and 40 percent free fatty acids) did not improve the apparent digestibility of fat over that observed for tallow or soybean oil. Renner and Hill (1961a) reported the absorbability of saturated fatty acids varied directly with the level of unsaturated fatty acids in the fat source. The increase in utilization of soybean oil reported by Bayley and Lewis (1965b) may have resulted

from the increased level of unsaturated fatty acids in the soybean oil; however, Eusebio et al. (1965) observed a lower digestibility of soybean oil than of tallow.

The results of experiments summarized herein illustrate the species difference in utilization of fats. Calves, chicks and rats at a young age can apparently utilize various sources of fat which have a wide range in molecular weight. However, the baby pig does not appear capable of efficiently utilizing fat at an early age. It is realized however, that the infant pig can utilize certain types of fat as illustrated by his performance on sow milk.

#### Fatty Acid Composition

The fatty acid composition of triglycerides in the various fat sources not only affects digestion of the fat, but also affects the absorption of the fatty acids. Working with chicks in which the small intestine had been divided into five equal segments, Renner (1965) reported little fat was absorbed until the third segment of the small intestine was reached. At this point there was a preferential rate of absorption with soybean oil being removed at a faster rate than tallow or lard. Vodovar (1966) observed that absorption of fat commenced below the pylorus and continued fairly uniformly along most of the intestine of pigs. Fatty acid molecules with chain lengths of ten carbons or less are known to be transported unesterified in the portal rather than the lymphatic system (Bhalerao et al., 1965; and Isselbacher, 1965). Preferential transport of these

lipids via the blood stream may be a result of their high water solubility, their passive absorption or their poor incorporation into mucosal triglycerides. Long-chain fatty acids are converted to triglycerides in the mucosal cell and secreted into the lymph in the form of lipoproteins.

The distribution of fatty acids in natural oils and fats has been studied quite thoroughly (Mattson and Volpenhein, 1961, 1963; Mattson et al., 1964; Subbaram and Youngs, 1964; and Hilditch and Williams, 1964). Vegetable oils are, in general, rich in dienoic and/or trienoic acids which are predominately linoleic and linolenic acids, whereas fatty acids with more than three double bonds are very rare or nonexistent in these oils (Aaes-Jorgensen, 1961). Animal fats contain a wide variety of fatty acids differing in chain length, degree of unsaturation, position and configuration of double bonds and branching of the carbon chain. Lard is a rather unique animal fat in that palmitic acid is esterified at the 2-position, whereas in other animal fats, the fatty acid at the 2-position is primarily of eighteen carbons in length. Marine oils are very rich in highly unsaturated fatty acids. From the chemical composition of the various fats and oils it is not difficult to see why a difference in digestibility and absorption of fat sources could exist. This does not include the effect of positional attachments of the fatty acids in the triglyceride molecule which is not a randomized process (Mattson and Volpenhein, 1961, 1963; and Mattson et al., 1964).

If hydrolysis of fat by the enzyme lipase is the limiting factor in fat utilization, the incorporation of free fatty acids of neutral fat in the diet should increase fat utilization. Carroll and Richards (1958) compared the utilization of triglycerides (triolein, trilinolein, tristearin and tripalmitin) versus the non-esterified fatty acids of these triglycerides in rats and observed triolein and trilinolein were almost completely digested and absorbed in contrast to the rather low absorption of oleic and linoleic acids. Triglycerides of saturated fatty acids appeared to be utilized to a lesser extent than the unsaturated triglycerides and free fatty acids. In a subsequent trial, Carroll (1958) reported short chain fatty acids up to ten carbons long were completely utilized, whereas a further increase in chain length resulted in a progressive decline in utilization so that relatively little stearic acid was absorbed. Of the 18 carbon fatty acids investigated, the coefficient of absorption for oleic acid was higher than that observed for stearic acid and approached the absorption coefficient observed for short chain fatty acids (100 percent).

Work with  $C^{14}$  carboxyl-labeled saturated fatty acids revealed that absorption of short chain fatty acids (butyric and caprylic) approached 100 percent, whereas that of longer chain fatty acids (lauric and palmitic) was lowered to 86 percent (Kuschnier and Harris, 1961). Absorption of these fatty acids occurred mostly within four to eight hours.

Factors affecting the absorbability of saturated fatty acids in the chick have been studied by Renner and Hill (1961a, 1961b). Previous experiments indicated palmitic and stearic acids to be virtually unutilized by the chick. In each case, the absorption of palmitic, stearic or unsaturated acids was greater if they were fed as mixed triglycerides instead of the free fatty acids obtained from their respective fat sources by hydrolysis. Of the fat sources compared, tallow, lard and soybean oil, the latter resulted in the greatest absorption of total lipids, saturated and unsaturated fatty acids. Young (1961) reported that the absorption of saturated acids varies directly with the level of unsaturated fatty acids in the mixture. The feeding of soybean oil, which contains a larger amount of unsaturated fatty acids, resulted in a greater absorption of saturated fatty acids than did the other fat sources used. Feeding fatty acids varying in chain length revealed that as the chain length increased utilization of fatty acids decreased for both chicks and laying hens. Young et al. (1963) also observed that fatty acids of lard were absorbed more readily than fatty acids of tallow.

In work with pigs, Bayley and Lewis (1962) did not observe the same trend in absorption of saturated fatty acids as reported for chicks and rats. Feeding of triolein and oleic acid or tristearin and stearic acid revealed no difference between the acid and triglyceride, however, both oleic acid and triolein were more readily absorbed than tristearin or

stearic acid. Fatty acids of beef tallow were more readily absorbed than fatty acids of hydrolyzed animal and vegetable fats, thus illustrating that hydrolysis of fat prior to feeding is not the sole limiting factor in fat utilization. Sewell and Miller (1965) reported oleic and linoleic acids were absorbed from corn oil, tallow or lard diets whereas, the absorption of stearic acid was markedly lower. However, their absorption coefficients are quite high compared to the values observed in chicks and rats. More recent work by Bayley and Lewis (1965a) has shown that the absorbability of fatty acids as measured by fatty acid intake and fatty acid composition of feces is not a reliable measure of fatty acid absorption. The most striking difference between the food and fecal lipids was in the degree of unsaturation. A high ratio of saturated to unsaturated (6:1) fatty acids was found in the feces, whereas in the feed the ratio was equal (1:1). This high degree of saturation was attributed to the high level of stearic acid and moderate amounts of palmitic acid in the feces as compared with that in the feed. All pigs voided more pentadecanoic and heptadecanoic acid in the feces than ingested in the food. This is significant in relation to the origin of non-dietary fecal fat since MacFarlane (1962) found these acids formed a major part of the lipids synthesized by bacteria. Hydrogenation of unsaturated acids in the digestive tract has also been observed by Wollaeger et al. (1953). The high amount of stearic acid in the feces may result partially from the saturation by

bacteria of unsaturated fatty acids which would contribute to a lower absorption coefficient for it. Howard et al. (1965) fed rations containing either tallow or maize oil and observed that of the fecal fatty acids 55 to 80 percent consisted of palmitic and stearic acids. Welsch et al. (1966), working with infants 3 days of age, estimated that the total fatty acids present in the diet was 85 percent digestible. As the chain length of the fatty acids increased, the apparent digestibility decreased. Stearic acid had a relatively high digestibility coefficient (75 percent) as compared to the coefficients established in rats, chicks and pigs.

The position of a fatty acid within the glyceride molecule may influence the extent to which it is absorbed according to Davis and Lewis (1964). Fats used in their study were: lard, which has palmitic acid esterified at the 2-position, interesterified lard with completely random distribution of fatty acids and beef tallow, which has saturated acids esterified at the 1-position. The results indicated lard to be more readily digested than interesterified lard and both were more readily digested than tallow.

Friend et al. (1964) studied the utilization of volatile fatty acids in the blood of pigs. On the basis of a maintenance energy requirement of 40 kcal./kg. body weight daily, they calculated that for a 30 kg. pig, the volatile fatty acid contribution from alimentary sources would be between 15 and 28 percent of the maintenance energy requirement.

The influence of saturated fat upon essential fatty acid (EFA) metabolism has been studied recently by Peifer and Holman (1959). Calorie efficiency decreased as the content of hydrogenated coconut oil increased in the presence or absence of EFA in the diet and was most drastic in the absence of EFA. With increasing levels of saturated fat in the diet, growth rate of rats was depressed and high ratios of saturated fat: EFA promoted the onset of EFA-deficiency symptoms. Alfin-Slater et al. (1965) reported that of the methyl esters of fatty acids ( $C_4$ - $C_{18}$ ) given orally to rats, only those on oleate and linoleate supplements had a gain in weight over that exhibited by rats given unsupplemented diets. Although most groups had the typical "scaly skin" syndrome, rats receiving capric, myristic, palmitic and stearic acids had more severe dermal symptoms than rats in the other groups. They concluded that saturated fatty acids increase the susceptibility to EFA deficiency. The dietary effect of saturated triglycerides of medium - ( $C_6$ - $C_{12}$ ) and long-chain ( $C_{14}$ - $C_{18}$ ) fatty acids has been studied by Kaunitz et al. (1958a, 1958b; 1959). Rats fed a diet containing fatty acids of medium-chain length grew faster than did those fed the long-chain fatty acids. It was suggested that the medium-chain fatty acids decrease and the long-chain fatty acids increase the demand for EFA.

Bayley and Lewis (1965b) reported that the absorption of a particular acid is influenced by the other acids in the fat. Palmitic acid was 64 percent digestible in semipurified



tripalmitin, 72 percent in beef tallow diets, 68 percent in HEF diets and 91 percent in soybean oil diets. They concluded the high digestibility of unsaturated acids and the low digestibility of saturated acids in diets indicates the absorption of unsaturated fatty acids is largely independent of the absorption of saturated acids.

Any given fat or fatty acid mixture that contains a high proportion of saturated acids is less well utilized by all species than are the more unsaturated fats. Young and Garrett (1963) studied the effect of oleic and linoleic acids on the absorption of saturated fatty acids by chicks. The absorbability of oleic acid whether fed alone or in a mixture of fatty acids averaged 94.6 percent and absorbability of linoleic acid averaged 97.5 percent. Absorbability of palmitic acid regardless of the level fed was 25 percent. Increasing the ratio of oleic to palmitic in the diet resulted in an increase in absorbability of a total fatty acid mixture and also a proportional improvement in absorbability of palmitic acid. A significant increase in absorbability of palmitic acid was observed in the presence of mixtures of oleic and linoleic acid; however, the improvement was believed to be due to oleic with linoleic acid having little or no effect. Results also showed that the absorbability of palmitic and stearic acid from any mixture of fatty acids is influenced not only by ratio of these saturated fatty acids to oleic or linoleic or both, but also to the ratio of palmitic to stearic

acid within the mixture. These researchers (Young and Garrett, 1963) postulated at least two phenomena may be involved in the mechanism of fatty acid absorption:

- (1) Transformation of the fatty acid in the lumen to a physical-chemical form which is more readily solubilized and made available for absorption.
- (2) Esterification of fatty acids within the intestinal mucosa to form triglycerides which appear in lymphatic chyle.

#### Enzyme Activity and Specificity

In general esterases comprise a broad and ill-defined family of enzymes hydrolyzing ester bonds in various substrates. Within this family it is necessary to distinguish between lipases and esterases. The differentiation is sometimes based on the chemical nature of the substrate it hydrolyzes, lipases being more associated with the degradation of triglycerides. Also differentiation has been based upon the length of the acyl chain of the ester substrate, lipases preferentially splitting esters of long-chain fatty acids and esterases preferentially splitting esters of short-chain fatty acids.

Lipase has been found in gastric secretions; however, any biological significance is doubtful. The presence of lipase in the stomach could result from two possible sources: (1) the enzyme is formed and secreted by gastric glands or (2) it could enter the stomach via regurgitation from the small

intestine. Lipase activity in the small intestine arises from two sources - pancreatic secretion and intestinal secretion. Pancreatic acinar cells synthesize a lipase which flows with pancreatic juice into the duodenum where it promotes hydrolysis of dietary fat. Paneth cells located at the base of small tubular glands called crypts of Lieberkuhn secrete an intestinal lipase for splitting of neutral fats. At first the biological significance of intestinal lipase was doubtful; however, DiNella et al. (1960) reported that because of the relatively large mass of the mucosa, the total lipase activity of the small intestine may approach that of the pancreas. In terms of quantity of enzyme available, intestinal lipase could play a significant role in the hydrolysis and absorption of fats.

It has been postulated that lipase activity of a baby pig is low at birth and increases with age. This increase in activity would account for the increase in fat digestion with an increase in age. However, Kitts et al. (1956) reported that the lipolytic activity of the digestive system in the young pig is relatively abundant at birth and remains high with advancing age. Hartman et al. (1961) observed that the tributyrinase activity of pancreatic tissue of unweaned pigs was high at birth and gradually increased with age. Weaning the pigs and placing them on a synthetic diet resulted in a decrease in tributyrinase activity. Recovery of activity began at four weeks of age and by seven weeks approached the activity

observed in unweaned pigs. The low activity occurring after weaning may be insufficient to hydrolyze the supplemented fat; however, Mattson\* (1966) has indicated that even at this low level of activity, enough enzyme is present to hydrolyze the amount of fat added to most diets. Cunningham and Brisson (1957) added the enzyme pancreatin to diets of two-day-old pigs and reported that fat digestibility was not improved by enzyme supplementation.

The sequence involved in the digestion of fats has been established by Mattson and Beck (1955). Hydrolysis of triglycerides in vivo follows a series of directed stepwise reactions from triglyceride to 1, 2-diglyceride to 2-monoglyceride. The 2-monoglyceride is hydrolyzed to glycerol and free fatty acid; however, it first goes through isomerization to 1-monoglyceride and which is then hydrolyzed to glycerol plus free fatty acid.

Substrate specificity undoubtedly plays an important role in lipase activity. Sobotka and Glick (1934), Weinstein and Wynne (1935), Balls et al. (1937), Wills (1965) and Desnuelle and Savary (1963) have demonstrated that short-chain fatty acids are hydrolyzed more rapidly from a triglyceride molecule than are the longer chain fatty acids. Also it has been shown that emulsification of fat is necessary for lipase to hydrolyze fat at a rapid rate. These and many other factors

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\*Mattson, F. H., Miami Valley Laboratories, Proctor and Gamble, Cincinnati, Ohio. Information on lipase activity and specificity. Private communication. 1966.

interact with lipase thus determining the rate of hydrolysis and substrate specificity.

## EXPERIMENTAL PROCEDURE

## General Procedure

The data from the experiments which comprise this dissertation are on file in the Animal Science Department of the Iowa Agricultural and Home Economics Experiment Station as Swine Nutrition Experiments 6436, 6507, 6514, 6521, 6528, 6617, 6626, 6701, and 6710. The common features of these experiments will be described to avoid unnecessary repetition in the discussion of each individual experiment.

All experimental animals were crossbred pigs of Landrace, Yorkshire and Poland China breeding and were obtained from the swine nutrition farm breeding herd. Within 24 hours after birth, each pig was individually weighed and ear marked, needle teeth clipped and was injected intraperitoneally with 100 milligrams of iron as iron dextran. The male pigs were castrated at approximately seven days of age. All experimental pigs were weaned between 14 and 20 days of age and placed on their respective experimental diets. The animals were sprayed periodically with Toxaphene to control mange.

Pigs in Experiments 6521 and 6626 were group-fed a starter ration for a two-day pre-experimental period. During this time they adjusted to eating a dry feed. After the two-day pre-experimental period the pigs were then placed on their respective experimental diets.

Experiments 6436, 6507, 6514, 6528 and 6617 were conducted

in units with concrete-floored pens. The experimental units were maintained at a relatively constant temperature by a thermostatically controlled heating system. The pigs had access to self-feeders and automatic self-flushing water fountains at all time. In Experiments 6528 and 6617, vacuum type chick water founts were used for the liquid diets. The pens were cleaned daily and wood shavings were provided as bedding.

Experiments 6521, 6626 and 6710 were conducted in a temperature-controlled unit equipped with germicidal (ultraviolet) lamps at different locations in the unit. The concrete floor under the individual metal pens was heated by thermostatically controlled circulating water. The temperature of the room and floor was adjusted to 29°C initially and gradually lowered after the first week until a temperature of 21°C was reached and maintained by the third week of the experiment. Each individual pen was furnished with a self-feeder and a continuous-flow water fountain. The pens were cleaned daily with water.

The experiments were 28 days in length. Pigs and feeders were weighed at weekly intervals. The data collected from each experiment were statistically analyzed and any missing data calculated by the randomized block methods of Snedecor (1956). Any reference to statistical significance pertains to the probability level of 5 percent or less.

The composition and calculated analysis of the basal diets are presented in Tables 3 through 8 in the Appendix.

## Analytical Methods

Fatty acids

Fatty acids were determined by gas-liquid chromatography. Fat was isolated from blood plasma, diet and fecal samples according to a modification of the procedure described by Folch et al. (1957). Approximately 10 grams of tissue, diet or feces were placed in a Waring Blendor along with 190 ml. of a chloroform-methanol mixture (70/30) and allowed to mix for 3 minutes. After blending, the pH of the mixture was adjusted to a pH of 3 with concentrated hydrochloric acid. The solution was filtered, centrifuged for 10 minutes at 7000 r.p.m. and then transferred to a separatory funnel and allowed to stand for 30 to 45 minutes. After separation, the bottom layer was removed into an Erlenmeyer flask and reduced to dryness under vacuum in a nitrogen atmosphere. The residue was redissolved in 10 ml. of Skelly B, centrifuged at 7000 r.p.m. for 10 minutes and then reduced to dryness. The sample was then ready for saponification and methylation.

The saponification and methylation procedures employed were modifications of the methods described by Schmit and Wynne (1964) and Wynne et al. (1965). Ten ml. of a 10 percent alcoholic potassium hydroxide solution was added to the residue obtained in the final step of extraction. The flasks were then placed in a 55°C water bath for 30 minutes for saponification of the fat. Upon removal from the water bath, a 50 percent hydrochloric acid solution was used to adjust the pH



of the solution to pH 3. Skelly B was added and the flask was shaken. The solution was transferred to a separatory funnel and the bottom layer was withdrawn and discarded. Distilled water was added to the separatory funnel, the solution mixed and the water layer withdrawn. The Skelly B solution was dried over anhydrous sodium sulfate, filtered and reduced in volume to dryness under vacuum in a nitrogen atmosphere. Ten ml. of methanol containing 5 percent perchloric acid was added to the flask, a rubber stopper was placed lightly on the flask and the flask was then placed in a 55°C water bath for 5 minutes. Immediately upon removal from the water bath, the methyl esters of fatty acids were extracted with a Skelly B-ether solution (1:1) and washed with distilled water in a separatory funnel. The Skelly B layer was removed, dried over anhydrous sodium sulfate, filtered and reduced to dryness under vacuum and in a nitrogen atmosphere. The residue was dissolved in 4 ml. of hexane and the solution was stored in pyrex culture tubes with teflon caps until analyzed.

The hexane solution of methyl esters was injected directly on to the columns of a Packard gas chromatograph equipped with dual hydrogen flame detectors for measurement of the fatty acids. The glass coiled columns, 2 m long with a 4 mm I.D., were packed with a 15 percent ethylene glycol succinate on a stationary phase of acid-washed Chromosorb W (60 to 80 mesh). Temperature and nitrogen flow rate were maintained at 88°C and 30 ml/minute for separation of long-chain acids

and at 63°C and 50 ml/minute for separation of short-chain fatty acids. A standard solution was injected to obtain the integrator counts/ug. of acid present and the integrator counts obtained for each acid were divided by its corresponding standard acid. The fatty acid values are expressed on a weight-percent basis.

#### Lipase activity

Lipase activity of pancreatic tissue was determined by a modification of the method described by Marchis-Mouren et al. (1959) using tributyrin, butter, cocoanut oil and lard as substrates. Ten ml. of an emulsion, prepared by mixing in a blender for 10 minutes 165 ml. of 10 percent arabic gum solution, 15 gm. crushed ice and 20 ml. of the substrates employed, were placed in a beaker along with 0.3 ml. of a 20 percent sodium taurocholate solution and enough water to bring the final volume to 30 ml. The beaker was placed in a 37°C water bath and electrodes of a direct-reading pH meter were placed in the mixture along with a small agitator and a capillary tube allowing for a slow stream of carbon dioxide free nitrogen to bubble through the mixture. The pH of the solution was adjusted to 7.1 with 0.01 N carbonate free sodium hydroxide (NaOH) solution. The enzyme homogenate was prepared by a modification of the method of Balls et al. (1937). To prepare a sample for analysis, 0.2 gm. of wet pancreatic tissue was homogenized in a Potter-Elvehjem tissue grinder for 3 minutes with 20 ml. of a 0.2 percent sodium chloride solution. The

tissue grinder was kept in an ice bath at all times. With tributyrin as the substrate, 0.2 ml. of enzyme homogenate was used, whereas with butter, cocoanut oil and lard, 2 ml. of the homogenate was used. Upon addition of the enzyme, the pH of the solution was held at pH 7 by addition of 0.01 N NaOH for 5 minutes. Lipase activity was expressed as microequivalents of acid liberated per minute per gm. of wet tissue.

#### Fat analysis

For the fat digestibility studies, both diet and fecal samples were extracted for 4 hours in a Goldfish Fat Extractor at 34 to 35°C. Diet and fecal samples were analyzed in duplicate.

#### Chromic oxide

Chromic oxide content of the feed and fecal samples were analyzed by the simplified method of Kimura and Miller (1957). Apparent digestibilities of the diet nutrients were calculated by the formula:

$$\text{Apparent Digestibility (\%)} = 100 - \left( 100 \frac{\% \text{ indicator in diet}}{\% \text{ indicator in feces}} \times \frac{\% \text{ nutrient in feces}}{\% \text{ nutrient in diet}} \right)$$

The above calculations for apparent digestibility of nutrients were described by Maynard and Loosli (1956) and Young (1961).

Blood samples used for fatty acid analysis were obtained from the anterior vena cava after the pigs had been on the experimental treatment for 10 or 28 days. A 10 percent sodium citrate solution (Hewitt, 1932) was used as an anticoagulant.

Blood samples were immediately placed in centrifuge tubes which contained 0.1 ml. of the sodium citrate solution and centrifuged immediately at 2500 r.p.m. for 10 minutes. The plasma was transferred to disposable plastic culture tubes and stored at  $-17^{\circ}\text{C}$  until processed.

#### Experiment 6436 - Effect of Fat Source on Baby Pig Performance

##### Objectives

In work with rats Augur et al. (1947) reported an increase in rate of absorption and digestion of fats resulting from the addition of lecithin to the fat. Bayley and Lewis (1963b) concluded that addition of a non-ionic surface active agent to chick rations improved the digestibility of beef tallow.

This experiment was designed to study the effect of homogenization of lard and the addition of lecithin, emulsifier (polyoxyethylene glycol mono- and dioleates) or a combination of both to homogenized lard oil on the growth, feed efficiency and fat digestibility of young pigs.

##### Experimental procedure

Seventy-two crossbred pigs averaging 5.0 kg. body weight and 15 days of age were allotted to a randomized block design of six experimental treatments. Pigs were assigned at random from outcome groups of initial weight to the six treatments with three replications of four pigs per pen for each treatment. Composition of the basal diet is presented in Table 3 in the Appendix. Dried skim milk (20 percent) was added to

the basal diet to provide a source of milk protein and to insure that protein would not be a limiting factor in the experiments. Lard, lard oil, lard oil plus lecithin, lard oil plus emulsifier and lard oil plus lecithin and emulsifier were substituted for an equal quantity (10 percent) of starch in the basal diet. Addition of the fat sources increased the caloric density of the rations approximately 16 percent. All fat samples were liquified by heating before mixing them into the diet. Chromic oxide was included in each of the diets at the level of 0.25 percent for the purpose of estimating the digestibility of fat.

Fecal samples were collected individually from each animal after 10 and 28 days on the experimental diets. During collection time, the pigs were placed in metabolism cages until they defecated. The fecal samples were dried in a forced-air oven at 60 to 65°C for 48 hours. A representative fecal sample for a pen of four pigs was obtained by weighing out an equal quantity of fecal dry material from each pig within a pen and mixed thoroughly. This sample represented a pooled sample of the four pigs for that diet treatment. The pooled samples were then dried in an oven for 24 hours at 90 to 95°C. After drying, the fecal samples were stored in small glass vials for determination of chromic oxide and fat.

### Results

Summaries of the results, analysis of variance plans and observed mean squares are presented in Table 9 through 14 in

the Appendix. Addition of fat resulted in a decrease in average total gain (5.9 vs. 4.9 kg.) however, the difference was not significant (Figure 1). Pigs fed the diet containing lard gained significantly more than did pigs fed lard oil (5.9 vs. 5.1 kg.). No significant differences were observed in average total gain from addition of lecithin (4.8 vs. 4.6 kg.). Pigs fed the basal or lard diet gained more than did pigs fed the other diets (5.9 vs. 4.7 kg.).

No significant differences in feed efficiency were observed between the treatments, however, pigs fed the lard diet were the most efficient (1.7 vs. 2.0). Addition of lecithin, emulsifier or a combination of both did not improve feed efficiency over that observed for pigs fed lard or lard oil.

Although pigs fed lard were the most efficient, the metabolizable calories required per kg. of gain (Table 10) were higher than that observed for pigs fed the basal diet (5943 vs. 5742). Addition of 10 percent fat increased the caloric value of the diet 16 percent. On the basis of metabolizable calories required per kg. of gain, pigs fed the basal diet were 17 percent more efficient than pigs fed diets with added fat. Of the fat diets, pigs fed lard were more efficient than pigs fed lard oil alone or with lecithin and an emulsifier. The presence of the emulsifier tended to increase the energy needed per kg. of gain more than that observed for lecithin.

Digestion of fat was significantly higher for pigs fed diets with added fat as compared with those fed the basal diet

Figure 1. Experiment 6436 - Summary of average total gain and feed required per unit of gain

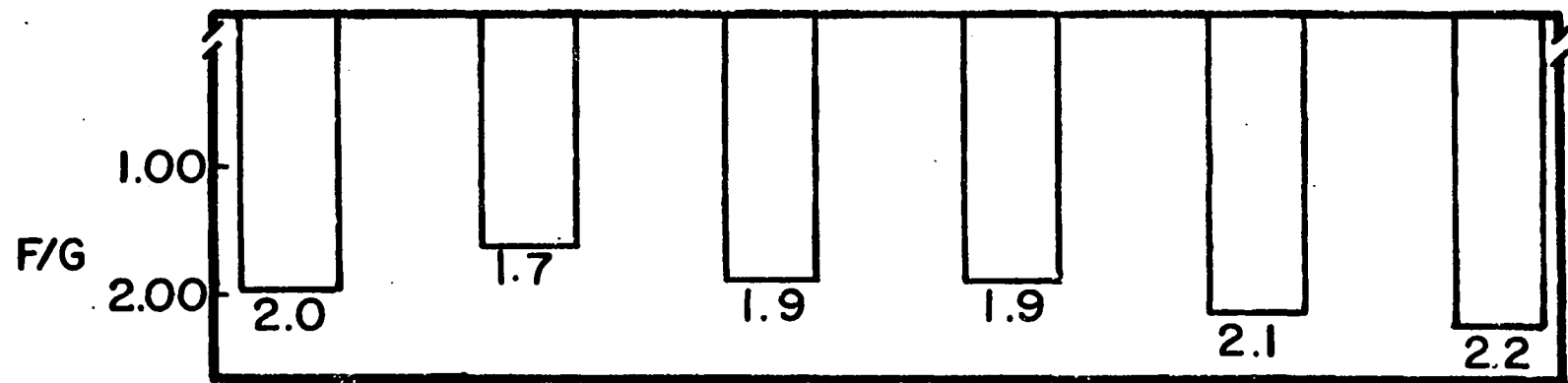
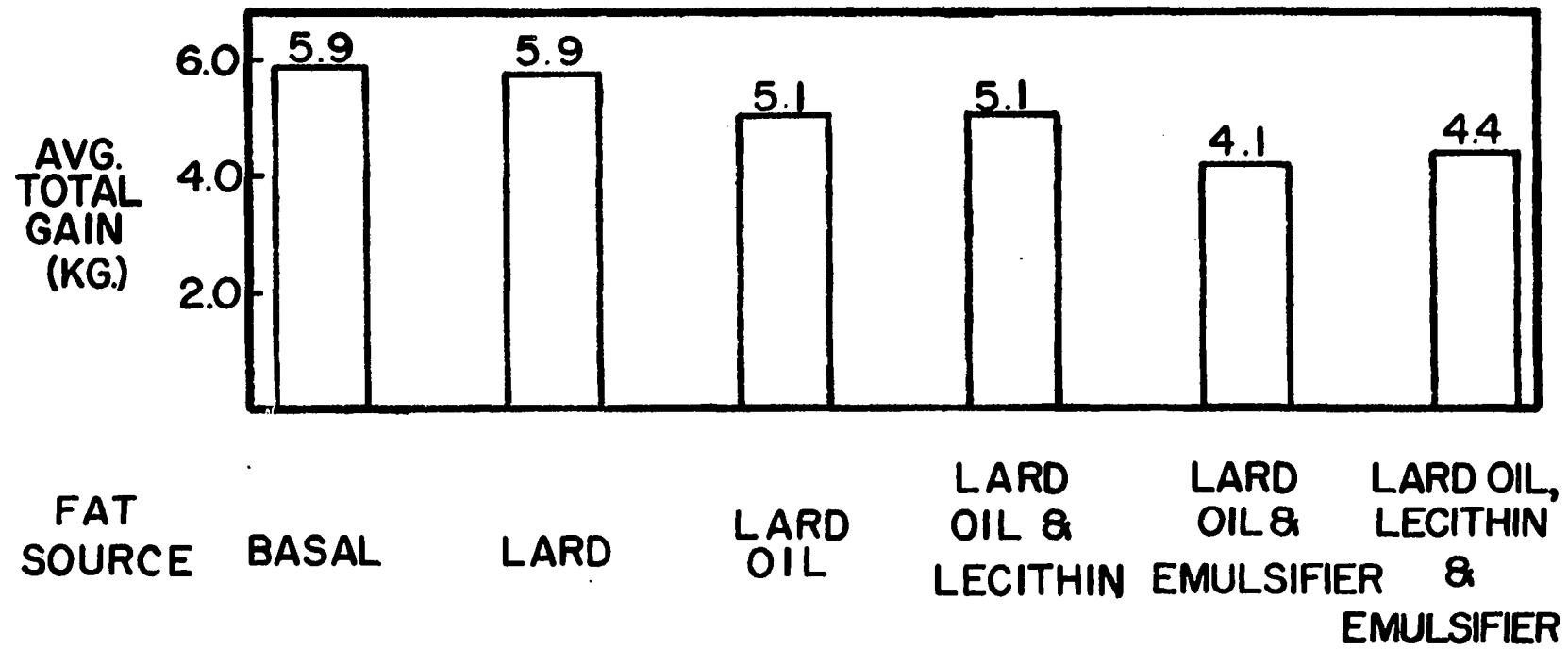
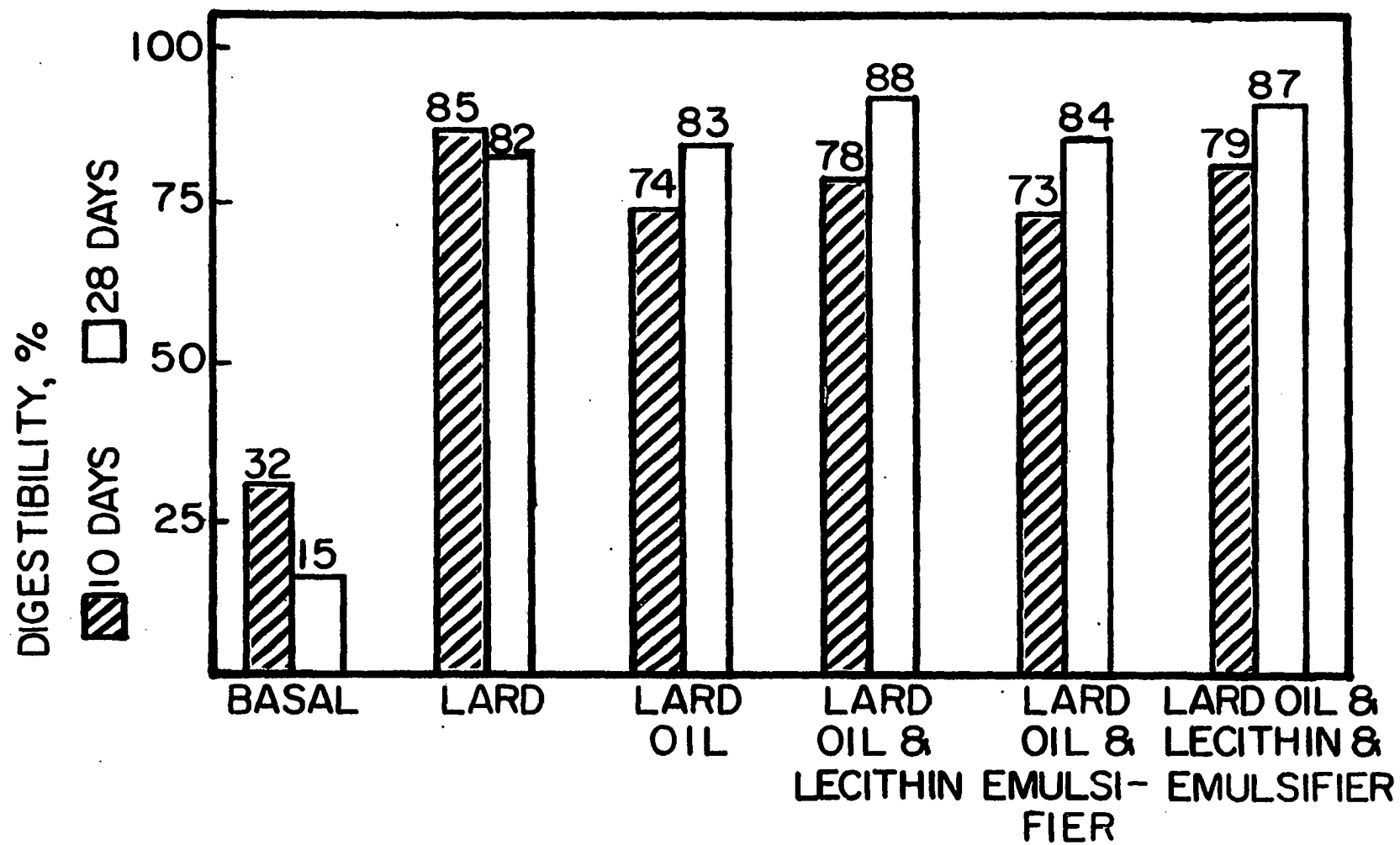




Figure 2. Experiment 6436 - Summary of average apparent digestibility of fat after 10 and 28 days on experiment



(Figure 2). No significant differences in digestibility were observed among the fat sources; however, the digestibility of lard averaged slightly higher than the other sources. Although not statistically significant, there was an age difference in digestibility with the older pigs having a higher digestion coefficient than the young pig (85 vs. 78 percent). This would parallel the improvement in growth and feed efficiency observed for the older pig.

#### Experiment 6507 - Effect of Fat Source on Baby Pig Performance

##### Objectives

Early work suggested an inverse relationship between melting point and digestibility of fat (McCay and Paul, 1938; Deuel and Hallman, 1940; Crockett and Deuel, 1947; Cheng et al., 1949; and Karvinen et al., 1957). However, Hoagland and Snider (1943a, 1943b) postulated that factors other than melting point determined the relative digestibility of fats. They concluded that stearic acid content of a fat limited its digestibility. Gullickson et al. (1942) reported calves gained faster if butter fat was the supplemental fat source. On the other hand, gain and feed efficiency of chicks were improved on added fat diets irrespective of the fat source (Fedde et al., 1960). Lloyd and Crampton (1957) and Lloyd et al. (1957) observed a highly significant inverse relationship between mean molecular weight (length of chain) of fatty acids of various fats and oils and their apparent digestibility by early-weaned

pigs.

This experiment was designed to study the effects of fats differing in mean molecular weight on gain, feed efficiency and fat digestibility by the young pig. The fat sources, butter, cocoanut oil, lard and soybean oil, provided low, medium and high molecular weight saturated and unsaturated fat sources.

#### Experimental procedure

Eighty crossbred pigs averaging 4.9 kg. body weight and 15 days of age were allotted to a randomized block design of five experimental treatments. Pigs were assigned at random from outcome groups of initial weight to the five treatments with four replications of four pigs per pen for each treatment. Composition of the basal diet is presented in Table 3 in the Appendix. Butter, cocoanut oil, lard and soybean oil were substituted for an equal quantity (10 percent) of starch in the basal diet. Addition of the fat sources increased the caloric value of the rations approximately 16 percent. All fat samples were liquified by heating before mixing them into the feed. Chromic oxide was included in each of the diets at the level of 0.25 percent.

Fecal samples were collected and processed according to the procedure outlined in Experiment 6436.

#### Results

Summaries of the results, analysis of variance plans and observed mean squares are presented in Tables 15 through 20 in the Appendix. Although the difference was not significant,

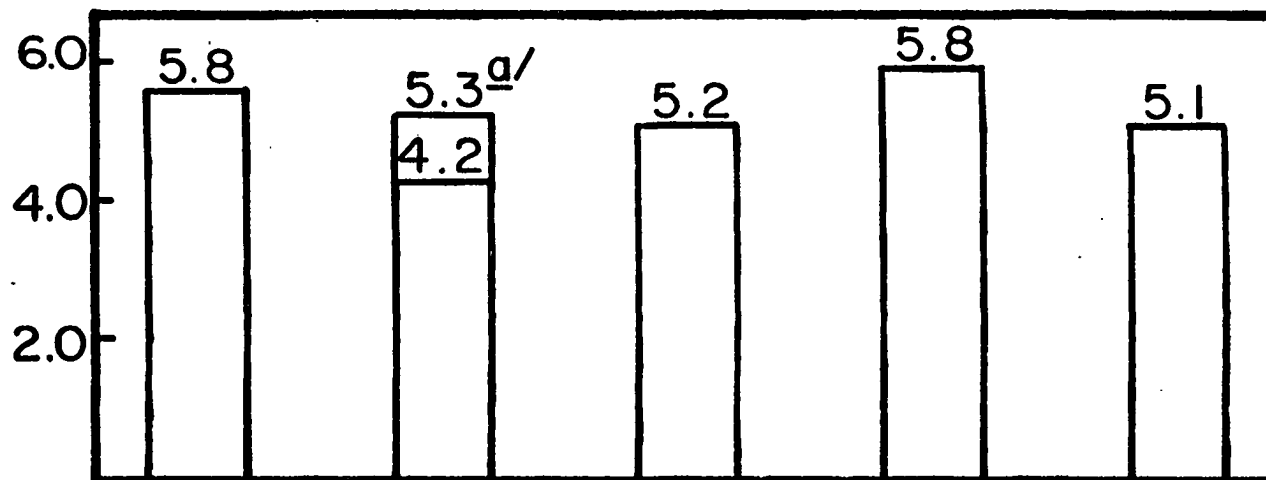
pigs fed the basal diet gained more (Figure 3) than did pigs fed the added fat diets (5.8 vs. 5.1 kg.). No significant differences in gain were observed among the fat sources (5.8 vs. 4.8 kg.). As the molecular weight of the fat source increased there was an improvement in gain. Lard and soybean oil (higher molecular weight) promoted faster gains than did butter or cocoanut oil (5.4 vs. 4.7 kg.).

Pigs fed the butter diet required more feed per unit of gain than did pigs fed the other fat sources (3.3 vs. 1.8) however, the difference was not significant. Both the feed/gain ratio and gain are exaggerated to a certain extent by the poor performance observed for pigs fed butter in the first replication. The pigs consumed feed for several days and then suddenly stopped eating and ate very little for the next few days. Instead of eating the butter diet the bedding material was consumed. Withholding of the bedding and mixing of a diet-water slurry finally helped the pigs to start consuming feed again. Consequently the reduced food intake depressed growth and increased the feed requirement per unit of gain. Pigs fed the basal diet were more efficient than pigs fed added fat diets (1.8 vs. 2.2) irrespective of the butter diet (1.8 vs. 1.8).

Metabolizable calories required per kg. of gain paralleled the feed efficiency data (Table 16). Although the feed/gain ratio was approximately equal for the basal, lard and soybean oil diets, pigs fed the basal diet were more efficient

Figure 3. Experiment 6507 - Summary of average total gain and feed required per unit of gain

AVG. TOTAL  
GAIN (KG.)



FAT SOURCE

BASAL

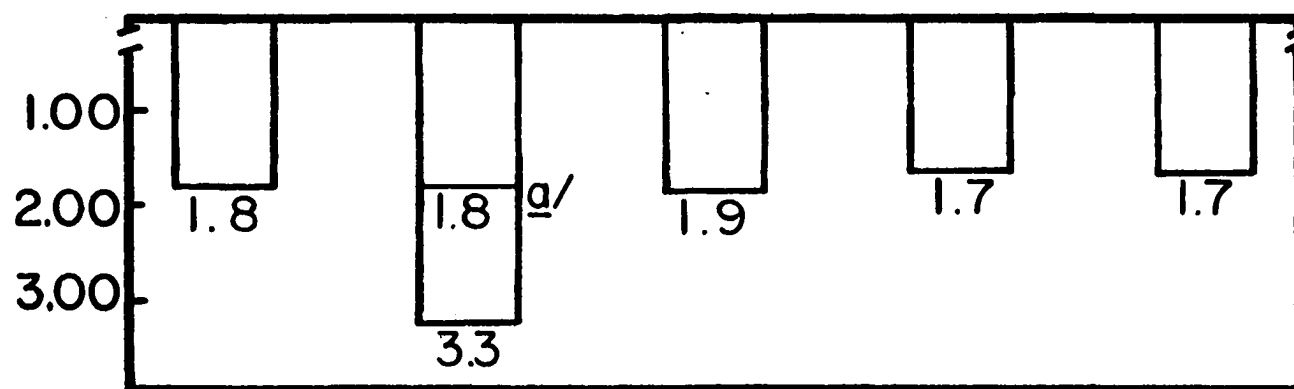
BUTTER

COCOANUT  
OIL

LARD

SOYBEAN  
OIL

F/G



<sup>a/</sup> EXCLUDING THE VALUE FOR REPLICATION 1.

on an energy basis than were pigs fed lard or soybean oil (5344 vs. 5697 vs. 5720 calories, respectively). The energy value reported for butter (11,186 calories) is out of proportion due to the large amount of energy required per kg. of gain for pigs in the first replicate.

No inverse relationship was observed between molecular weight of fat source and digestibility (Figure 4, Table 17). The low digestibility coefficient for fat in the basal ration would be expected since the lipid present would consist of steroids, carotenoids and waxes which are not readily digested and also endogenous fat would be high relative to the low dietary level. Among the fat sources no differences were observed in digestion. With an increase in age there was a significant improvement in fat digestibility (70 vs. 86 percent). The low digestion of butter at 10 days reflects the low intake of feed by one replication during this period. By the end of the experiment, pigs were able to digest butter as readily as the other fat sources.

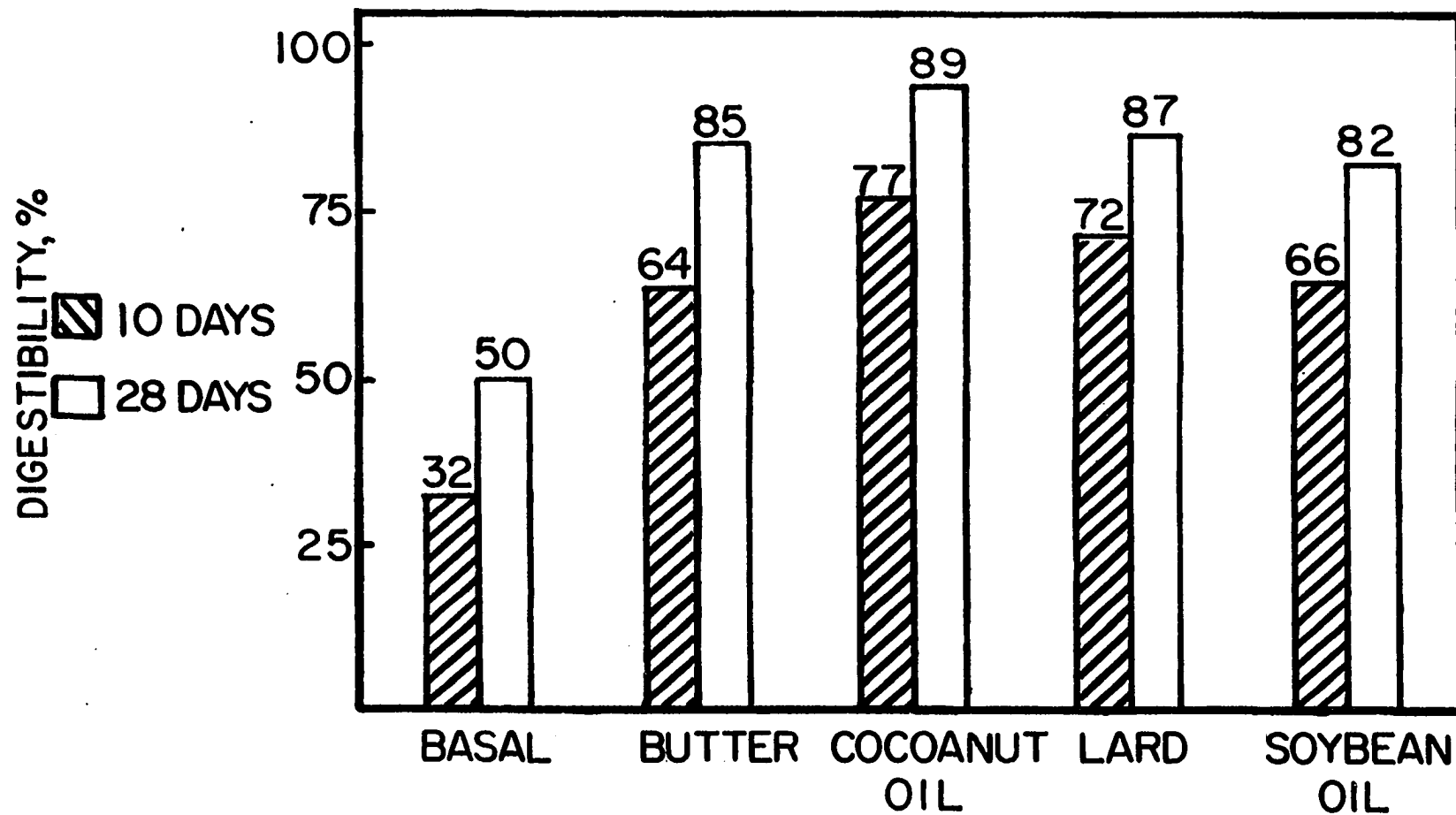
#### Experiment 6514 - Effect of Fat Sources and Methyl Ester Fatty Acids from Corn Oil on Baby Pig Performance

##### Objectives

Results of Experiment 6507 suggested no definite relationship between molecular weight of the fat source and its utilization. A second experiment was conducted to further study



Figure 4. Experiment 6507 - Summary of average apparent digestibility of fat after 10 and 28 days on experiment



the effect of molecular weight and effect of adding free fatty acids of corn oil in the methyl ester form on fat utilization as measured by gain, feed efficiency and fat digestibility.

#### Experimental procedure

Seventy-two pigs averaging 4.4 kg. body weight and 16 days of age were allotted to six experimental diets containing either 10 percent starch, methyl esters of the fatty acids from corn oil, corn oil, butter, coconut oil or lard in a randomized block design. Pigs were assigned at random from outcome groups of initial weight to three replications of four pigs per pen for each experimental treatment. Composition of the basal diet is presented in Table 3 in the Appendix. All fat samples were liquified by heating before mixing them into the basal diet. Chromic oxide (0.25 percent) was included as a marker in the diets.

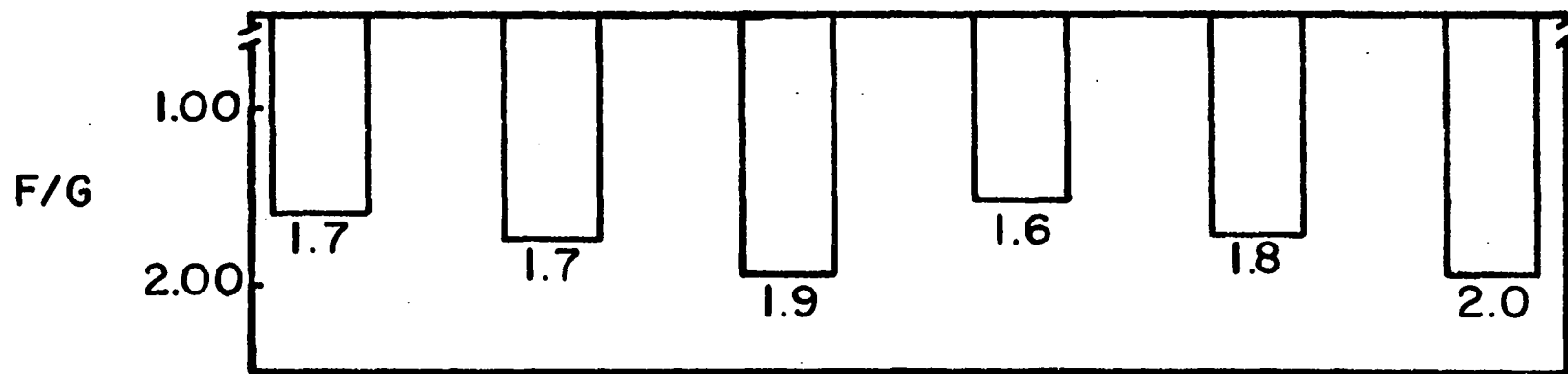
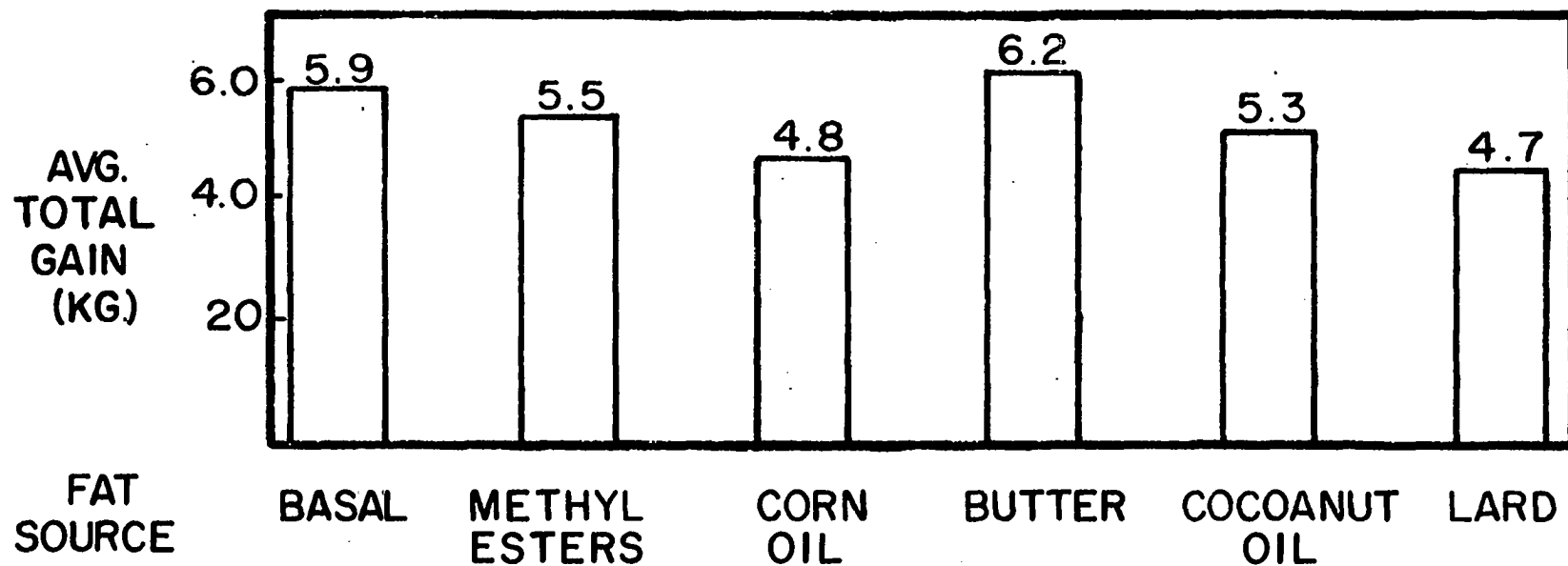
Fecal samples were collected from each pig after 10 and 28 days on their respective diets. The samples were processed according to the procedure outlined in Experiment 6436.

#### Results

Summaries of the results, analysis of variance plans and observed mean squares are presented in Tables 21 through 26 in the Appendix.

Although no statistically significant differences in gain were observed between the fat sources, pigs fed the butter diet gained more than did pigs fed the other fat sources (Figure 5). This is contrary to the results of the previous

Figure 5. Experiment 6514 - Summary of average total gain and feed required per unit of gain



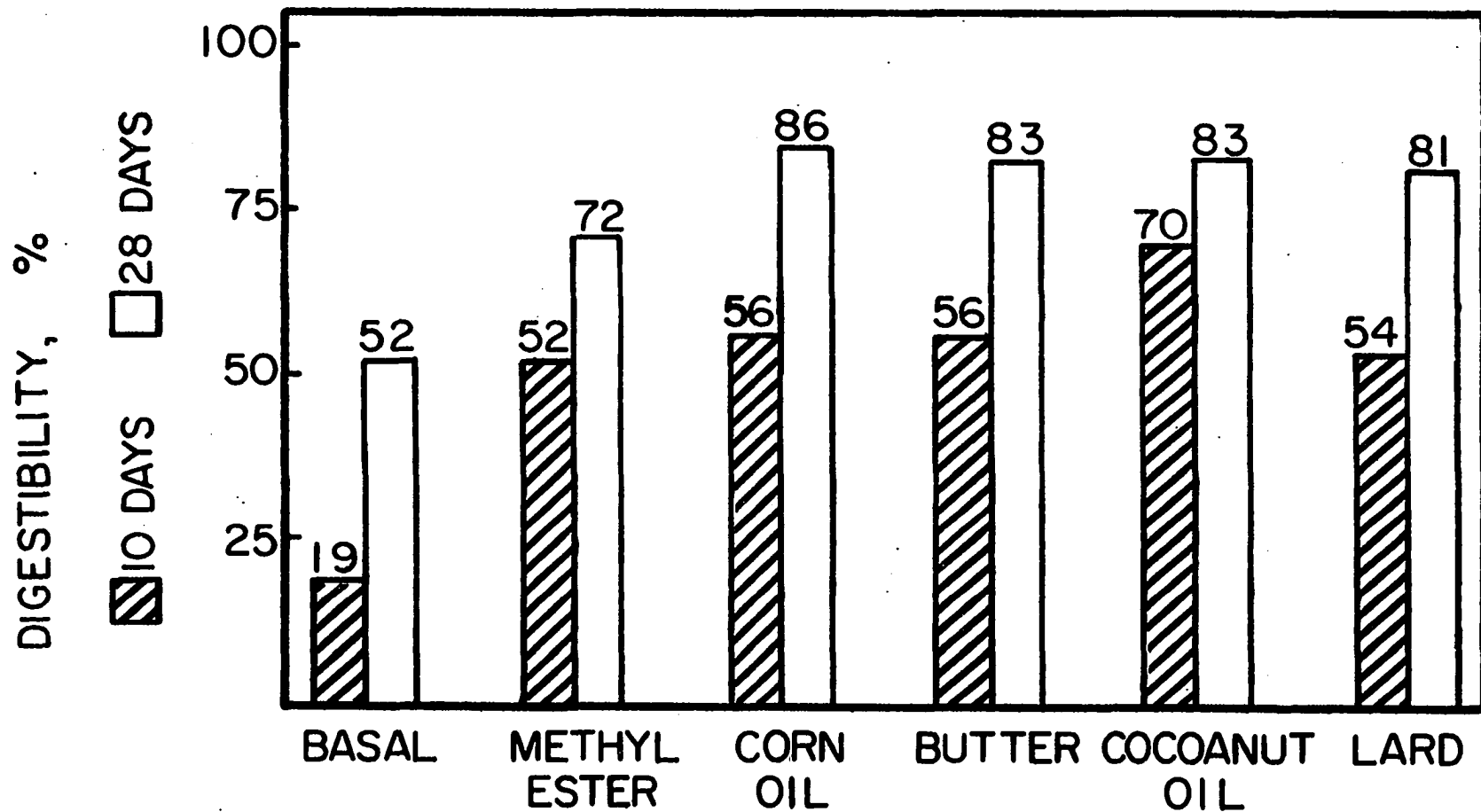
experiment but likely reflects more clearly the nutritive value of butter. On the average, addition of fat depressed the growth rate of pigs compared to that of pigs receiving the basal diet (5.3 vs. 5.9 kg.). Methyl esters of the fatty acids from corn oil promoted a greater gain than did corn oil (5.5 vs. 4.8 kg.), however, the difference was not significant.

Pigs fed the butter diet required significantly less feed per unit of gain than did pigs fed the corn oil or lard diets; whereas, no significant differences were observed among the other fat sources. On the average, addition of fat did not improve feed efficiency over that observed for pigs fed the basal diet (1.8 vs. 1.7).

Even though pigs fed the butter diet were more efficient in terms of feed/gain than pigs fed the basal diet (1.6 vs. 1.7) they required 8.8 percent more calories per kg. of gain than did pigs fed the diet with no added fat (Table 22). On the basis of metabolizable energy values, pigs converted the basal diet more efficiently than they did the diets with added fat. Similar to the improvement in feed/gain, the energy from the methyl ester fatty acids from corn oil was more efficiently utilized than the energy from their counterpart, corn oil.

A significant age difference (Figure 6) was observed for fat digestibility with the older pigs having a higher digestion coefficient than younger pigs (58 vs. 74 percent). No significant differences in digestibility were observed among the fat sources; however, corn oil was more readily digested

Figure 6. Experiment 6514 - Summary of apparent digestibility of fat after 10 and 28 days on experiment





than the other sources. Pigs fed the basal diet had a significantly lower digestibility coefficient for fat than did pigs fed the diets with added fat.

#### Experiment 6521 - Effect of Fat Source on Fat Utilization and Fatty Acid Content of Blood Plasma and Feces

##### Objectives

Natural fats, both vegetable and animal, differ markedly in their fatty acid composition. The presence in large quantity or absence of one or more fatty acids may influence the utilization of the remaining fatty acids. Carroll and Richards (1958) and Carroll (1958) observed that saturated triglycerides were utilized to a lesser extent than unsaturated triglycerides and as the chain length of the saturated fatty acids increased, the digestibility coefficient decreased. Renner and Hill (1961a, 1961b) reported that palmitic and stearic acid are virtually unutilized by the chick. Also it has been shown that the absorption of saturated acids varies directly with the level of unsaturated acids in the diet (Young, 1961).

This experiment was conducted to study the effect of fat source on growth, feed efficiency, fat digestibility and fatty acid patterns in the plasma and feces. Natural fat sources containing short, medium or long-chain fatty acids and a fat source consisting of a mixture of free fatty acids and triglycerides were employed in this experiment.

### Experimental procedure

Thirty-six pigs averaging 4.7 kg. body weight and 17 days of age were randomly allotted from littermate outcome groups to a randomized block design consisting of six replications of six experimental treatments. Butter, cocoanut oil, corn oil, hydrolyzed animal and vegetable fat (HEF) and lard were substituted for an equivalent amount of starch (20 percent) in the basal diet. HEF contains 40 percent free fatty acids and 60 percent triglycerides. Composition of the experimental diet is presented in Table 3 in the Appendix. All fat samples were liquified by heating before mixing them into the feed. Chromic oxide (0.25 percent) was included as a marker in each of the diets.

Fecal samples were collected from each animal after 10 and 28 days on the experimental diets. Plasma samples were obtained at the same time fecal samples were collected. All samples were processed individually for determination of fat digestibility, fecal fatty acids or plasma fatty acids.

### Results

Summaries of the results, analysis of variance plans and observed mean squares are presented in Table 27 through 34 in the Appendix and graphically in Figures 7 through 8.

Pigs fed the basal ration gained significantly more (11.2 vs. 8.3 kg.) than did pigs fed the diets containing added fat. Within the fat sources pigs gained faster on the hydrolyzed fat diet than on the lard diet. No significant differences in

Figure 7. Experiment 6521 - Summary of average total gain and feed required per unit of gain

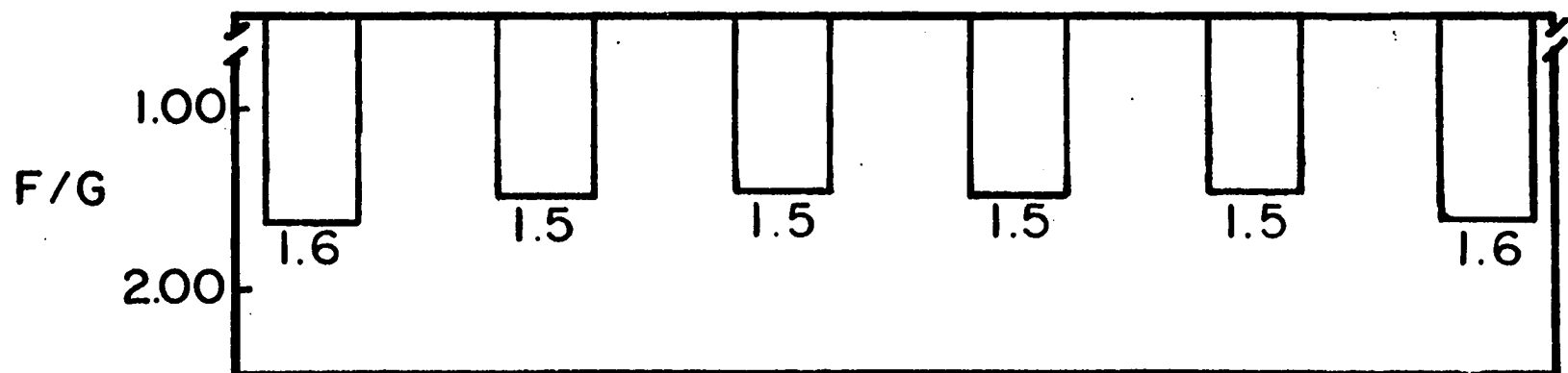
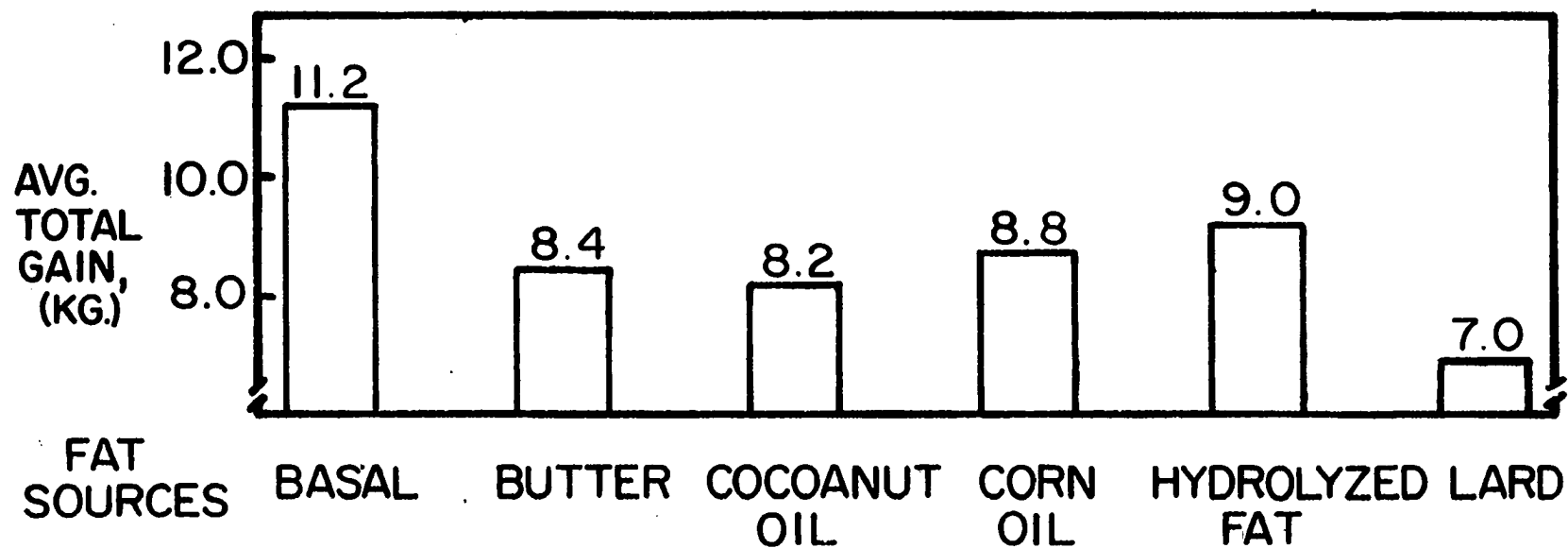
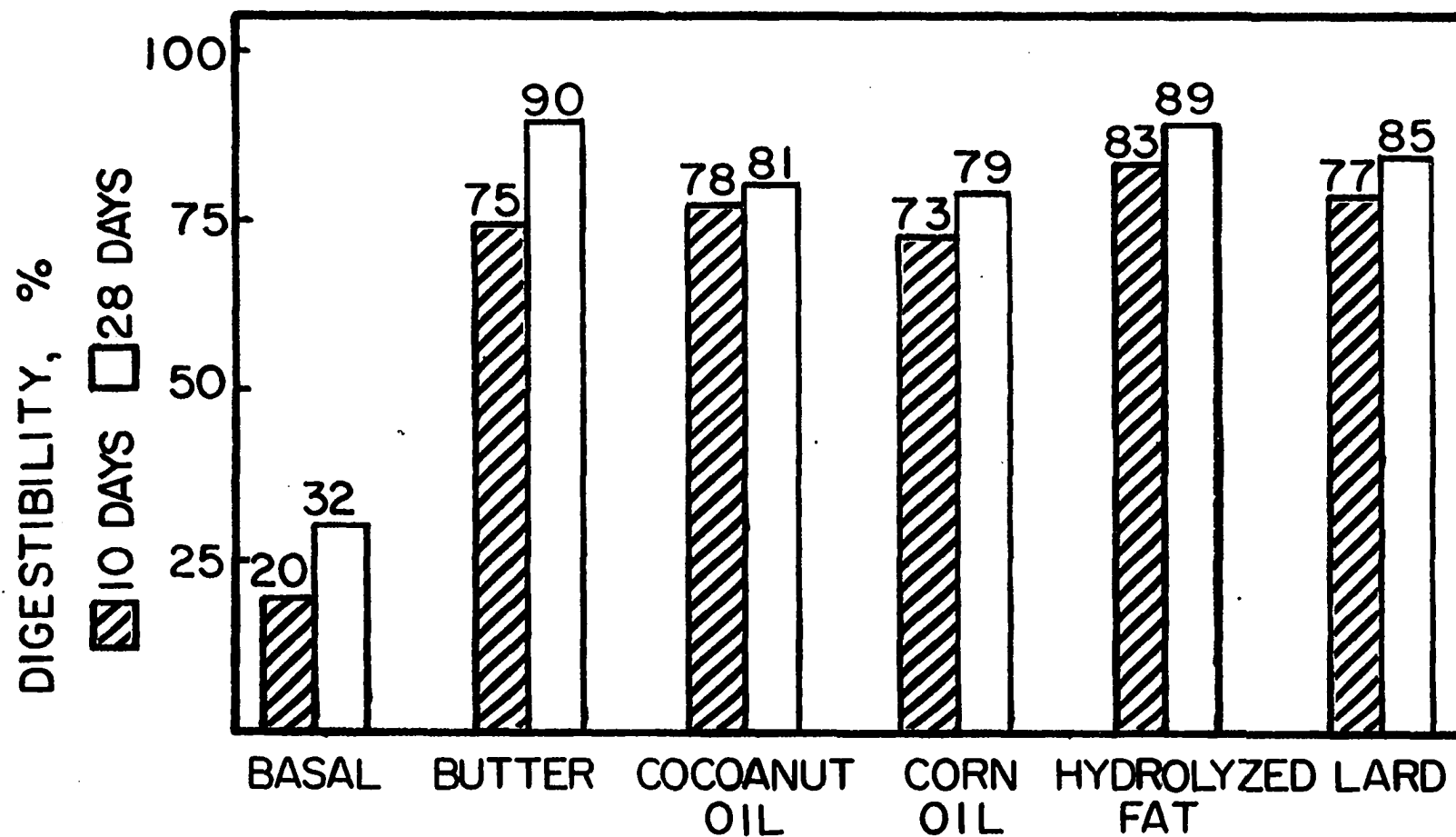


Figure 8. Experiment 6521 - Summary of apparent digestibility of fat



gain were observed between the other fat sources.

No significant differences in feed efficiency were observed among the experimental treatments. However, the metabolizable calories required per kg. of gain revealed that pigs fed the basal diet required 21 percent fewer calories per kg. of gain than did pigs fed the diets containing added fat. Pigs fed the diet containing HEF required 6 percent fewer calories per kg. of gain than did pigs fed the other fat sources.

Analysis of the digestibility data revealed a significant age difference with the older pigs having a higher digestibility coefficient than the younger pigs (Figure 8). Although the digestibility of butter averaged higher than the digestibility of other fat sources, the differences among the fat sources were not significant. Pigs fed the basal diet had a significantly lower digestibility coefficient of fat than did pigs fed the diets with added fat.

No significant relationship between the fatty acids present in the diet and the plasma samples could be established (Table 30). With the exception of pigs fed cocoanut oil, blood contained relatively small amounts of lauric ( $C_{12}$ ), myristic ( $C_{14}$ ) and palmitoleic ( $C_{16:1}$ ) acids. Pigs fed cocoanut oil had a high amount of lauric and myristic acids which was a reflection of the large amount of these acids present in the diet. Although a wide variation in stearic acid ( $C_{18}$ ) was present in the feed, the blood plasma contained a rather constant amount irrespective of the fat source; though, there

was a trend toward a decrease in stearic acid in the blood with an increase in age. Oleic acid ( $C_{18:1}$ ) concentration remained relatively stable with an increase in age. With the decrease in stearic acid concentration with age, there was a corresponding increase in linoleic acid ( $_{18:2}$ ) in the blood. Lauric and myristic acid concentrations increased with age; whereas, palmitic acid concentration was similar for the two ages. The diet contained a relatively small amount of palmitoleic acid, whereas the concentration of this acid in the blood was somewhat higher with a greater concentration at 10 days than at 28 days on experiment.

In general, a greater amount of saturated fatty acids was present in the fecal material than in the feed. After 10 days on experiment the ratio of saturated to unsaturated acids in the feces was 1.6:1 and increased to 2.1:1 after 28 days on experiment; whereas in the diet, the ratio was 1:1. No significant correlations existed between the individual fatty acids in the diet and fecal material though there was a tendency for the fecal and plasma level to reflect the dietary levels of certain fatty acids. The increase in saturation of the feces was due to an increase in stearic acid content at the expense of oleic, linoleic and linolenic acids. Pigs fed cocoanut oil had a greater amount of lauric and myristic acids in the feces which was a reflection of the large amount of these acids present in the diet. The high amount of oleic acid in corn oil resulted in a corresponding increase in oleic acid in the



feces for the two ages.

## Experiment 6528 - Effect of Fat and Form of Diet on Pig Performance

### Objectives

On the basis of sow milk analyses and the performance of suckling pigs, it is rather obvious that the baby pig can efficiently utilize the high level of fat present in sow milk. Johnson et al. (1948) have shown that pigs weaned at one-day of age and fed a synthetic milk diet gained more than did pigs reared on the sow. However, Hartman et al. (1961) observed a growth lag in pigs weaned and fed a dry meal as compared to the normal growth of suckling pigs. It was the purpose of this experiment to study the effect of adding fat to a dried skim milk diet fed in dry or liquid form on baby pig performance as measured by growth and feed efficiency. In previous experiments a corn-soybean meal diet containing dried skim milk (20 percent) and fortified with vitamins and minerals was used. To insure that protein intake or quality were not limiting fat utilization, a milk protein diet (dried skim milk) nutritionally adequate in minerals and vitamins was employed in this experiment.

### Experimental procedure

Eighty pigs averaging 4.7 kg. initial weight and 16 days of age were allotted to a randomized block design of five experimental rations. The pigs were assigned at random from

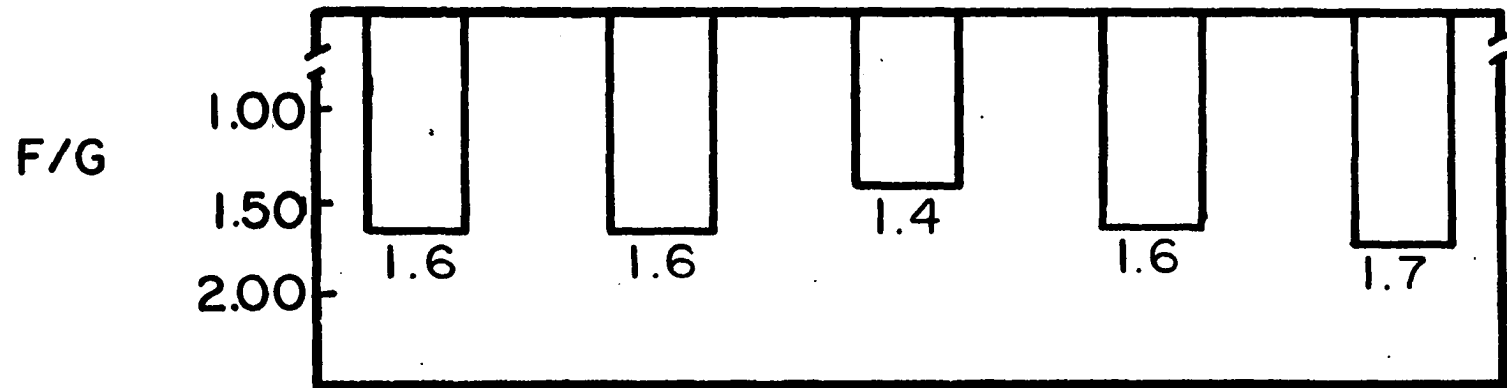
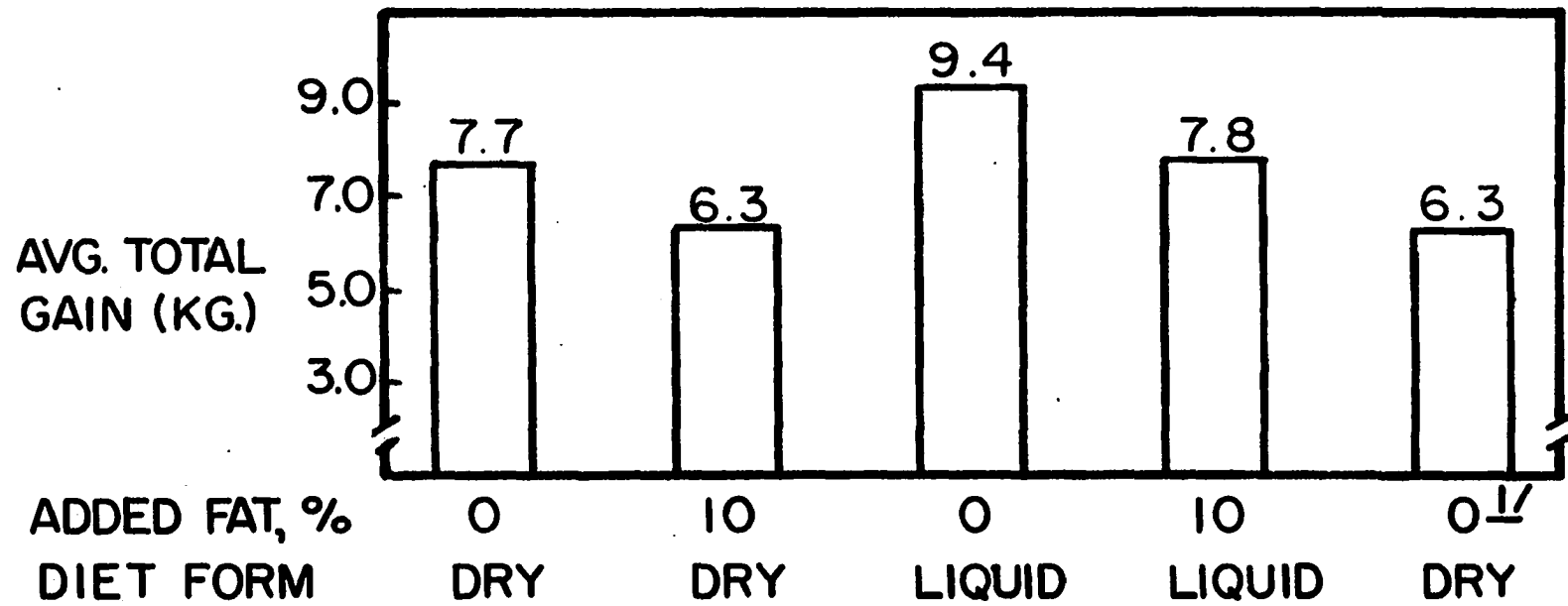
outcome groups of littermates to the five treatments with four replications of four pigs per pen for each treatment. Four of the experimental treatments consisted of a basal diet containing dried skim milk and glucose fed either in a dry or liquid form or the basal diet supplemented with 10 percent fat and fed either in dry or liquid form. The diets containing fat were prepared by replacing an equivalent amount of glucose (10 percent) with a lard oil-lecithin-emulsifier mixture. In previous experiments it was observed that pigs on the basal rations consumed more feed than did pigs on the added fat diets; however, they were 15 percent more efficient in the amount of metabolizable calories required per kg. of gain. Thus the fifth experimental treatment consisted of pair-feeding pigs the basal diet containing no added fat in dry form to the feed intake of the group receiving the dry diet containing 10 percent fat. Liquid diets containing 15 percent solids were prepared fresh twice daily in a 3.8 liter Waring Blender operated at 14,000 r.p.m.

### Results

Summaries of the results, analysis of variance plans and observed mean squares are presented in Table 35 through 38 in the Appendix.

Although the difference was not significant, gains were greater for those pigs fed a liquid diet as compared with the gains of pigs fed dry diets (8.6 vs. 7.0 kg.). Figure 9 illustrates the gain and feed efficiency responses observed.

Figure 9. Experiment 6528 - Summary of average total gain and feed required per unit of gain



<sup>1/2</sup> PAIR FED TO GROUP RECEIVING DRY DIET CONTAINING 10% ADDED FAT.

Addition of fat, either in the dry or liquid diets, depressed growth (7.0 vs. 8.6 kg.); however, the difference was not significant. Limiting the feed intake of pigs fed the basal dry diet did not significantly affect their gain as compared to pigs fed the 10 percent fat dry diet (6.3 vs. 7.8 kg.).

No significant differences in feed efficiency were observed among the treatments. In general, pigs receiving the liquid diets required less feed per unit of gain than did pigs fed the dry diets. Addition of fat did not improve feed efficiency over that observed for pigs on the basal diet. Limit-feeding the basal diet did not increase the feed required per unit of gain as compared to the group fed the dry diet with added fat. On the basis of metabolizable calories required per kg. of gain, pigs fed the basal liquid diet were more efficient than pigs fed the added fat diets in either dry or liquid form. In general, pigs receiving the liquid diets required less energy per kg. of gain than did pigs fed dry diets. Although the gains for the limited fed pigs and the added fat pigs were similar, the limited fed pigs were more efficient on an energy basis than pigs on the added fat diets.

#### Experiment 6617 - Effect of Fat and Form of Diet on Pig Performance

##### Objectives

Experiment 6528 showed that addition of fat to either a dry or liquid diet did not improve the gain or feed efficiency

of pigs over that observed for pigs fed the basal diet. The purpose of this experiment was to further study the effect of diet form and addition of fat on the young pigs ability to utilize fat as measured by gain and feed efficiency.

#### Experimental procedure

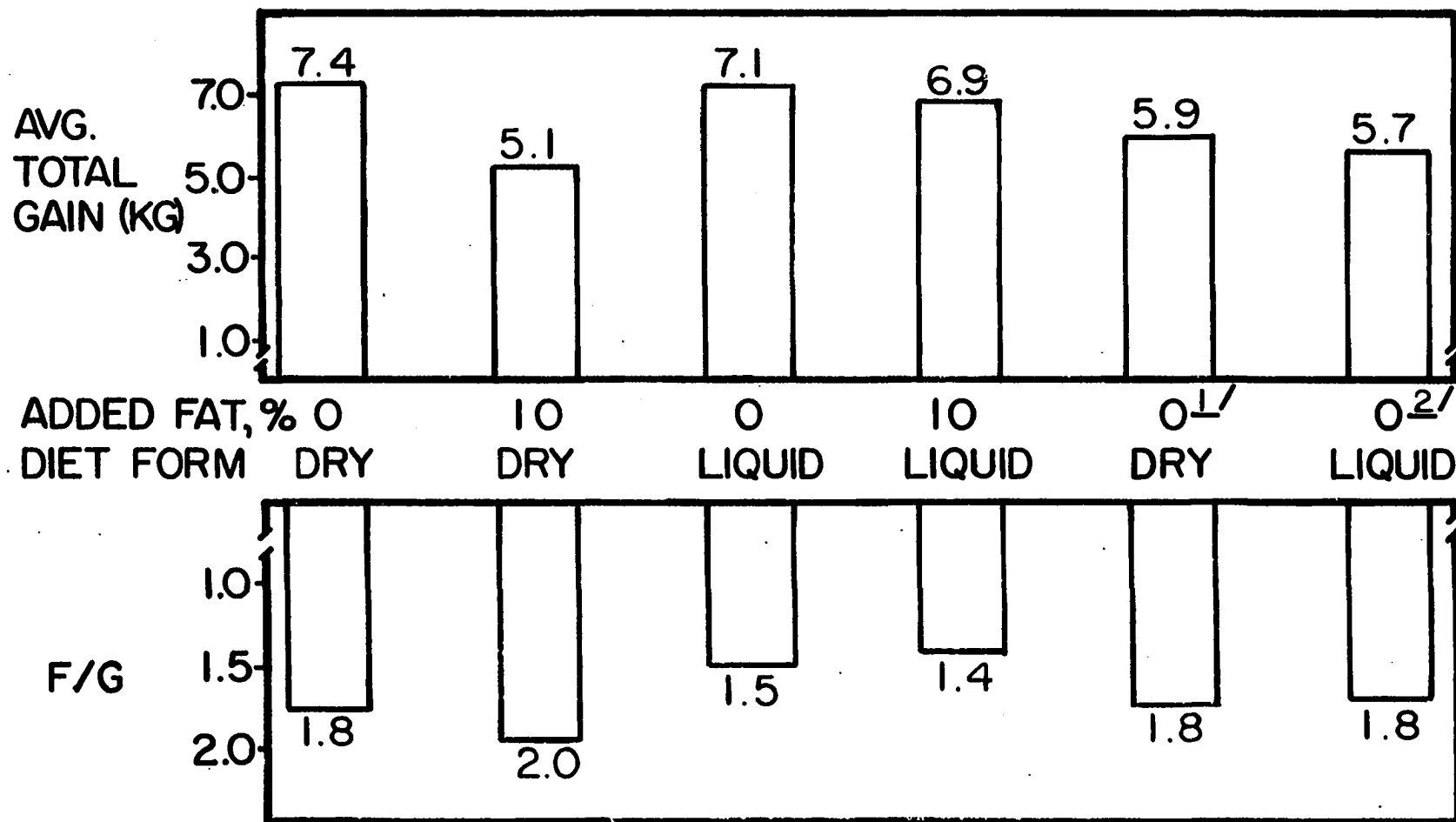
Sixty pigs averaging 4.8 kg. body weight and 16 days of age were allotted to a randomized block of six experimental rations. The pigs were assigned at random from outcome groups of littermates to the six treatments with one replication of four pigs per pen and two replications of three pigs per pen for each treatment. Five of the experimental treatments were the same as those described in Experiment 6528. A sixth treatment consisted of pair-feeding a group of pigs the basal liquid diet to the amount consumed ad libitum by pigs on a 10 percent fat, liquid diet.

Composition of the diets are the same as described in Experiment 6528. All liquid diets contained 15 percent solids and were mixed fresh twice daily.

#### Results

Within ad libitum fed groups      Although not statistically significant, addition of fat depressed the growth rate of pigs (Figure 10) over that observed for pigs fed the basal diet (6.0 vs. 7.2 kg.). Pigs fed the liquid diets gained more than did pigs fed dry diets (7.0 vs. 6.2 kg.); however, the difference was not significant. A significant difference in feed efficiency was observed with pigs receiving the liquid

Figure 10. Experiment 6617 - Summary of average total gain and feed required per unit of gain



<sup>1/</sup> PAIR FED TO GROUP RECEIVING DRY DIET CONTAINING 10% ADDED FAT.

<sup>2/</sup> PAIR FED TO GROUP RECEIVING LIQUID DIET CONTAINING 10% ADDED FAT.



diets requiring less feed per unit of gain than pigs receiving the dry diets (1.4 vs. 1.9). Addition of fat to the diet did not significantly improve feed efficiency over that observed for pigs fed the basal diets (1.7 vs. 1.6). Pigs fed the liquid diets required fewer metabolizable calories per kg. of gain than did pigs fed dry diets (5103 vs. 6473 metabolizable calories). Addition of fat to the diet increased the energy required per unit of gain approximately 22 percent (6320 vs. 5256 metabolizable calories).

Within pair-fed groups Restricting the feed intake did not significantly affect the growth rate of pigs compared to that observed for pigs allowed the diets with added fat ad libitum (5.8 vs. 6.0 kg.). Pigs pair-fed the basal liquid diet to the amount consumed ad libitum by pigs on the liquid diet with added fat gained less (5.7 vs. 6.9 kg.); however, pigs pair-fed the basal diet dry gained more (5.9 vs. 5.1 kg.) than did pigs consuming the dry diet with added fat ad libitum. A significant difference in feed efficiency was observed with pigs receiving the liquid diets more efficient than pigs receiving the dry diets (1.6 vs. 1.9). Also a significant fat x diet form interaction was observed resulting from an improvement in feed efficiency from addition of fat to the liquid diet; whereas, with the dry diet addition of fat increased the feed required per unit of gain. Pigs on the restricted diets required 12 percent fewer calories per kg. of gain than did pigs consuming the diets with added fat ad libitum (6320

vs. 6550 calories).

Experiment 6626 - Effect of Protein Source and Fat Levels on  
Fat Utilization, Fatty Acid Content of Blood  
Plasma and Feces

Objectives

Reber et al. (1953) fed synthetic milk diets of varying protein and fat levels to baby pigs and observed that at an early age, maximum growth and feed efficiency were obtained from pigs fed 41 percent protein and 37.5 percent fat. These levels are similar to the levels in sow milk as reported by Jylling and Sorensen (1960). However, Eusebio et al. (1965) observed that with increasing protein levels (19 to 35 percent) there was a slight reduction in gain at the higher level; whereas, feed efficiency was improved with the increase in protein content of the diet. Peo et al. (1957) reported that maximum gains were obtained from pigs fed a 20 percent protein diet. Also it has been shown with baby pigs that as the fat level in the diet increases there is a corresponding decrease in gain and an increase in feed required per unit of gain (Catron et al., 1953; Peo et al., 1957; and Eusebio et al., 1965).

Lewis et al. (1955) and Peo (1956) have demonstrated that the performance of baby pigs on all plant protein diets does not approach that of pigs fed milk protein.

Though previous studies have involved both milk and

soybean meal as sources of protein, the response to fat was similar with either. This experiment was conducted to further study the effect of protein source and level of fat on fat digestibility, growth, feed efficiency and plasma and fecal fatty acids.

#### Experimental procedure

Thirty-six pigs averaging 4.7 kg. body weight and 18 days of age were allotted to a randomized block design of six experimental treatments. The pigs were allotted at random from outcome groups of littermates to six replicates of six experimental treatments. Levels of 0, 5 and 10 percent lard were incorporated into diets containing casein (fat free) or soybean protein (C-1 Assay). Composition of the basal diets are presented in Table 4 in the Appendix. Chromic oxide (0.25 percent) was included as a marker in the diets for the purpose of estimating the digestibility of fat.

Fecal samples were collected from each animal after 10 and 28 days on the experimental diets. Plasma samples were obtained at the same time of fecal collection. All samples were processed individually for the determination of fat digestibility, fecal fatty acids or plasma fatty acids.

#### Results

Summaries of the results, analysis of variance plans and observed mean squares are presented in Tables 43 through 53 in the Appendix.

A significant protein effect on gain and feed efficiency

was present with pigs fed the casein diets gaining more (8.2 vs. 6.5 kg.) and requiring less feed per unit of gain (1.9 vs. 2.1) than pigs fed the isolated soya protein diets (Figure 11). A significant quadratic regression of gain on fat levels was observed which resulted from an increase in gains from the 0 to 5 percent added fat level and then a decrease in gain from the 5 to 10 percent fat level. With increasing fat levels there was a significant linear regression of feed required per unit of gain on fat levels; however, the greatest response was observed between the 0 and 5 percent level with a negligible response from the 5 to 10 percent fat level.

The metabolizable energy required per kg. of gain paralleled the gain and feed efficiency results. At the 5 percent added fat level, less calories were required per kg. of gain than at 0 or 10 percent added fat. Pigs fed the casein diets were more efficient in converting the energy to gain than were pigs fed the isolated soya protein diet (5847 vs. 6528 metabolizable calories).

Although not significant there was a trend for improved fat digestibility with age (Figure 12). The rather high digestibility coefficient observed after 10 days on experiment as compared with that of previous experiments may be a reflection of employing older pigs in this experiment or using semi-purified diets. No significant differences in fat digestibility were present between the protein sources; however, the coefficients of digestibility were higher for pigs fed casein

Figure 11. Experiment 6626 - Summary of average total gain and feed required per unit of gain

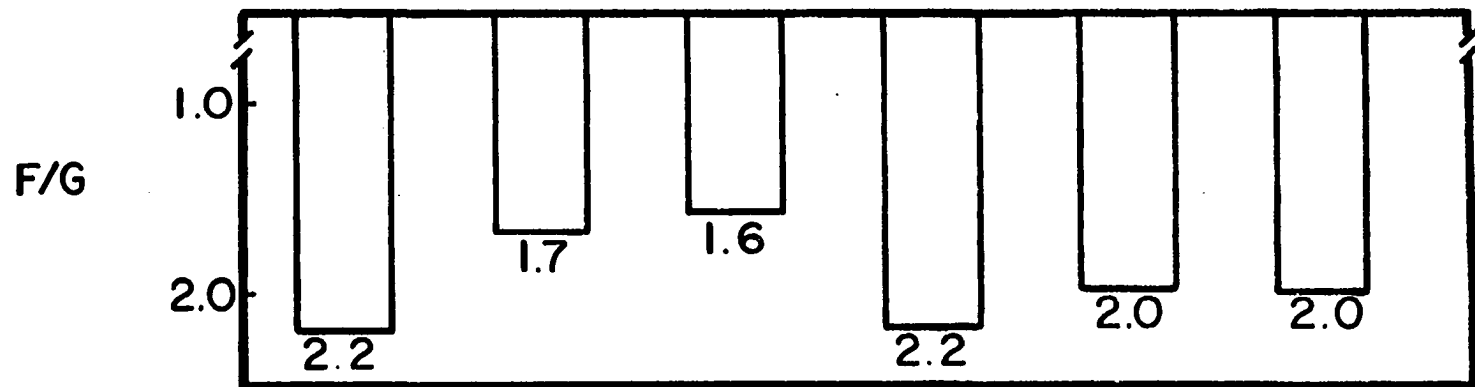
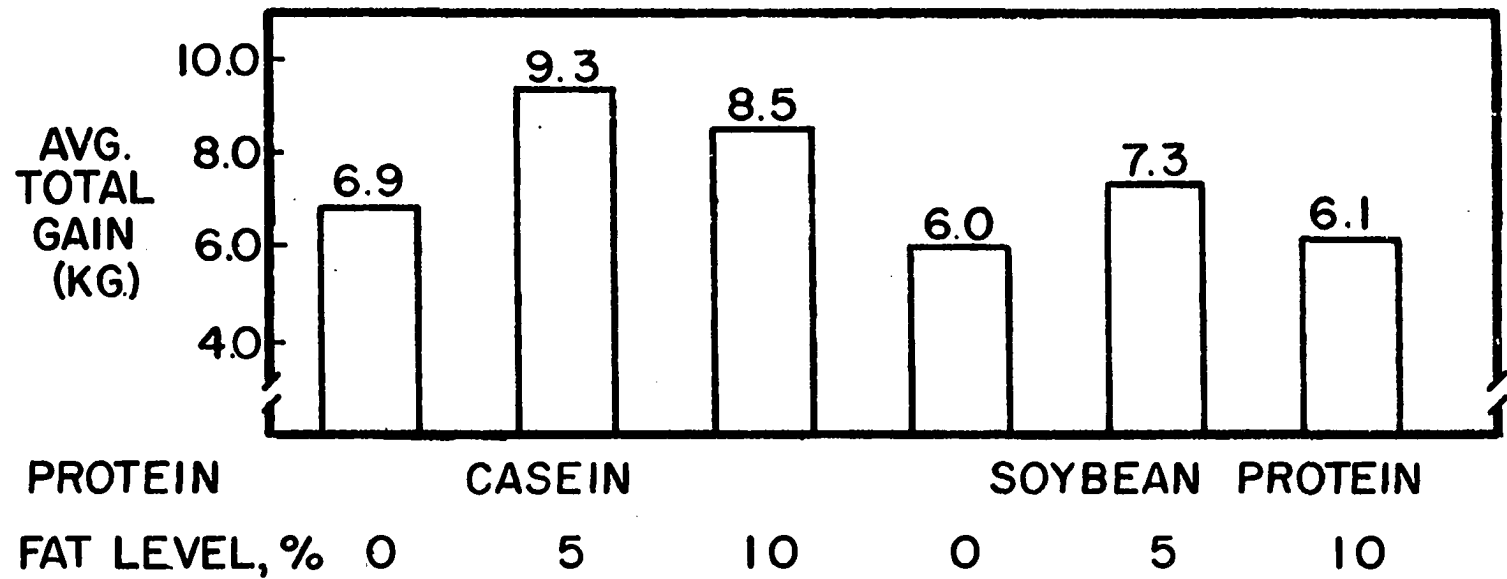
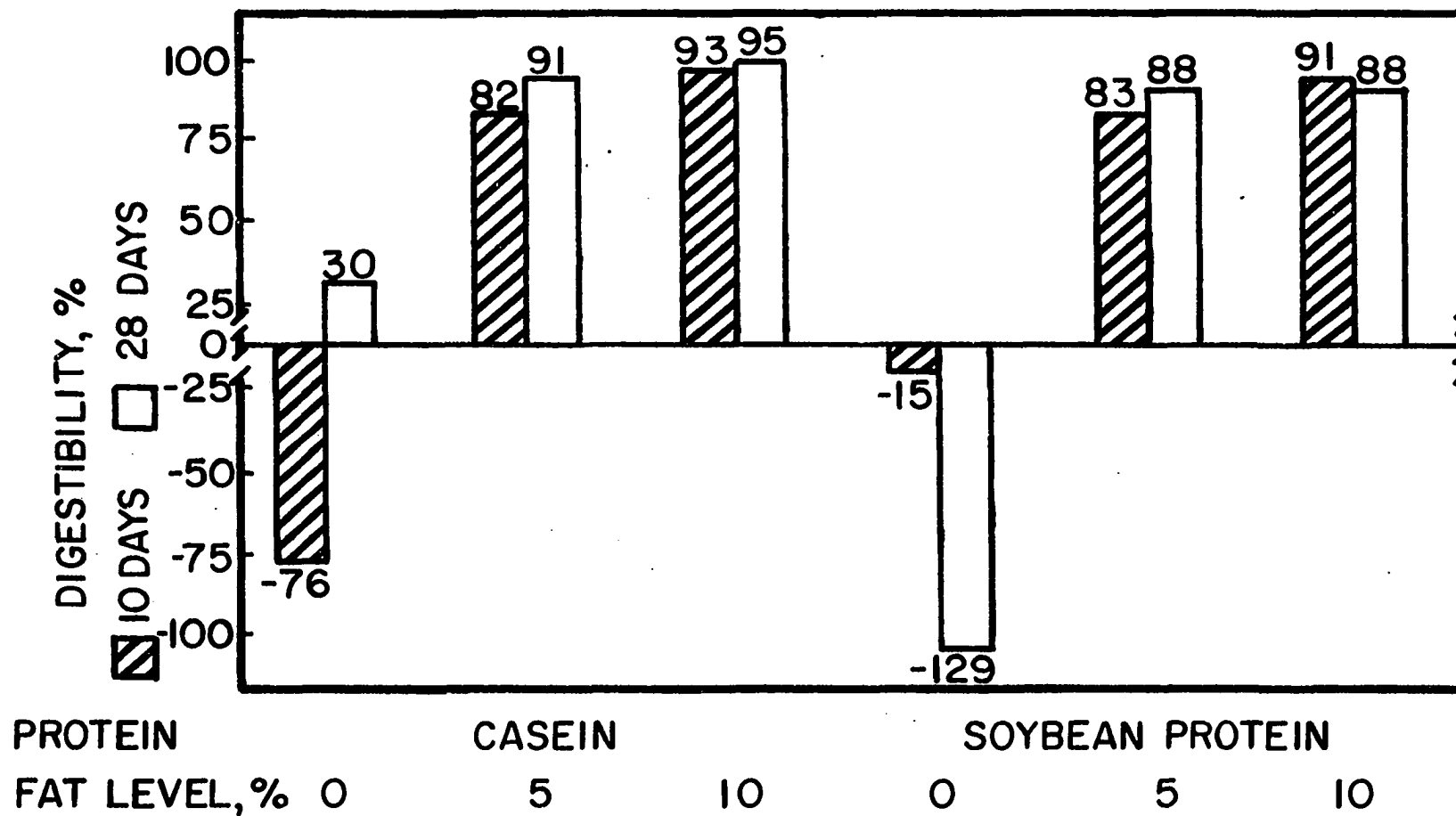


Figure 12. Experiment 6626- Summary of average apparent digestibility of fat after 10 and 28 days on experiment





diets than isolated soya diets. With increasing fat levels, a significant linear and quadratic regression of fat digestibility on added fat levels was present. This was a result of the large improvement in digestibility from the basal to the 5 percent level with little improvement in digestibility from the 5 to 10 percent fat level. Analysis of the data omitting the basal diet revealed no significant difference in fat digestion between the 5 and 10 percent added fat levels. The negative digestibility coefficients on the 0 fat levels indicates more fat which is largely of endogenous origin is being excreted in the feces than consumed. Also the negative coefficients for the basal diet may be due in part to the type of lipid material present. The basal diets contained 0.4 percent fat which would be of very low digestibility, thus contributing to the low digestibility coefficients.

The concentration of lauric ( $C_{12}$ ) and myristic ( $C_{14}$ ) acids were low in the blood at both time periods (Table 46). Of the saturated acids present, palmitic acid ( $C_{16}$ ) concentration was the highest. With regard to the unsaturated acids, oleic acid ( $C_{18:1}$ ) concentration was approximately 12 times greater than palmitoleic ( $C_{16:1}$ ) and 3 times as large as linoleic acid ( $C_{18:2}$ ). No linolenic acid ( $C_{18:3}$ ) was detected in the blood at either time period. Little change in concentration of the individual acids was observed with age. The concentration of lauric, myristic, palmitic and linoleic acids was higher in the plasma of pigs fed isolated soya protein

than those fed casein (Table 47). Palmitoleic acid concentration was similar in both protein groups. As the fat level in the diet increased, there was a corresponding decrease in lauric acid in the plasma. Myristic, palmitic, palmitoleic and stearic acid concentrations were similar at the 0 and 5 percent fat level; whereas, addition of 10 percent fat resulted in a reduction in myristic, palmitic and palmitoleic acids content and increased the stearic acid content. Oleic acid decreased from the 0 to 5 percent level where it then plateaued. The linoleic concentration increased with increasing fat levels in the diet.

After 10 days on experiment the major fatty acid present in the fecal material (Table 48) was stearic acid (53.9 percent) followed by palmitic acid (26.7 percent). After 28 days on experiment stearic acid concentration had increased slightly with palmitic remaining the same; however, both of these constituted the major acids present in fecal material. The ratio of saturated to unsaturated fatty acids in the diet was 0.72:1 which increased to approximately 5.3:1 in the feces. No tridecanoic ( $C_{13}$ ), myristoleic ( $C_{14:1}$ ), pentadecanoic ( $C_{15}$ ) or heptadecanoic ( $C_{17}$ ) acids were present in the diet; whereas in the feces, these acids were present.

No major differences in the fatty acid patterns in the feces were observed between the protein sources (Table 49). Stearic and palmitic acid were the main saturated acids; whereas, oleic was the main unsaturated acid. With increasing fat

levels there was a decrease in lauric, tridecanoic, myristic, myristoleic, pentadecanoic, palmitoleic, heptadecanoic and linoleic acids. Palmitic acid decreased between the 0 and 5 percent level; whereas, stearic acid increased. However, both acids plateaued between the 5 and 10 percent fat level. A small increase in oleic acid was observed with increasing fat levels. Linolenic decreased at the 5 percent fat level and then plateaued.

Experiment 6701 - Determination of Relative Activity and Specificity of Lipase in Pancreatic Tissue

Objectives

It has been postulated that lipase activity is low at birth and increases with age. If this were so, the low lipase activity at birth would account for the low digestibility of fat in the young pig and the increase in fat digestion with age. Kitts et al. (1956) have observed a relatively high lipolytic activity in the digestive system of the young pig and remaining high with advancing age. Hartman et al. (1961) reported that upon weaning there was a drop in lipase activity of pigs as compared to the relatively high lipolytic activity of pigs nursing their dam.

Substrate specificity is involved in determining the amount of lipase activity. Short chain fatty acids are hydrolyzed more readily from a triglyceride molecule than are long chain fatty acids. Also the position of the fatty acid within

the triglyceride molecule affects the rate at which they will be hydrolyzed.

#### Experimental procedure

The whole pancreas was removed from 14 and 56-day-old pigs, frozen in dry ice and acetone and stored at  $-17^{\circ}\text{C}$  until lipase activity could be determined. A modification of the procedure outlined by Marchis-Mouren et al. (1959) for measuring lipase activity was used. In their procedure they measured the lipase activity at a pH of 9. Preliminary experiments conducted in this laboratory revealed that maximum lipase activity was observed at a pH of 7. Figure 13 presents a plot of lipase activity versus pH using tributyrin as the substrate. From this graph it can be seen that maximum activity occurred at pH 7. There was a decrease of titratable 1000 micro-equivalents of acid in going from a pH 7 to the recommended level of pH 9. In this experiment all lipase measurements were conducted at pH 7.

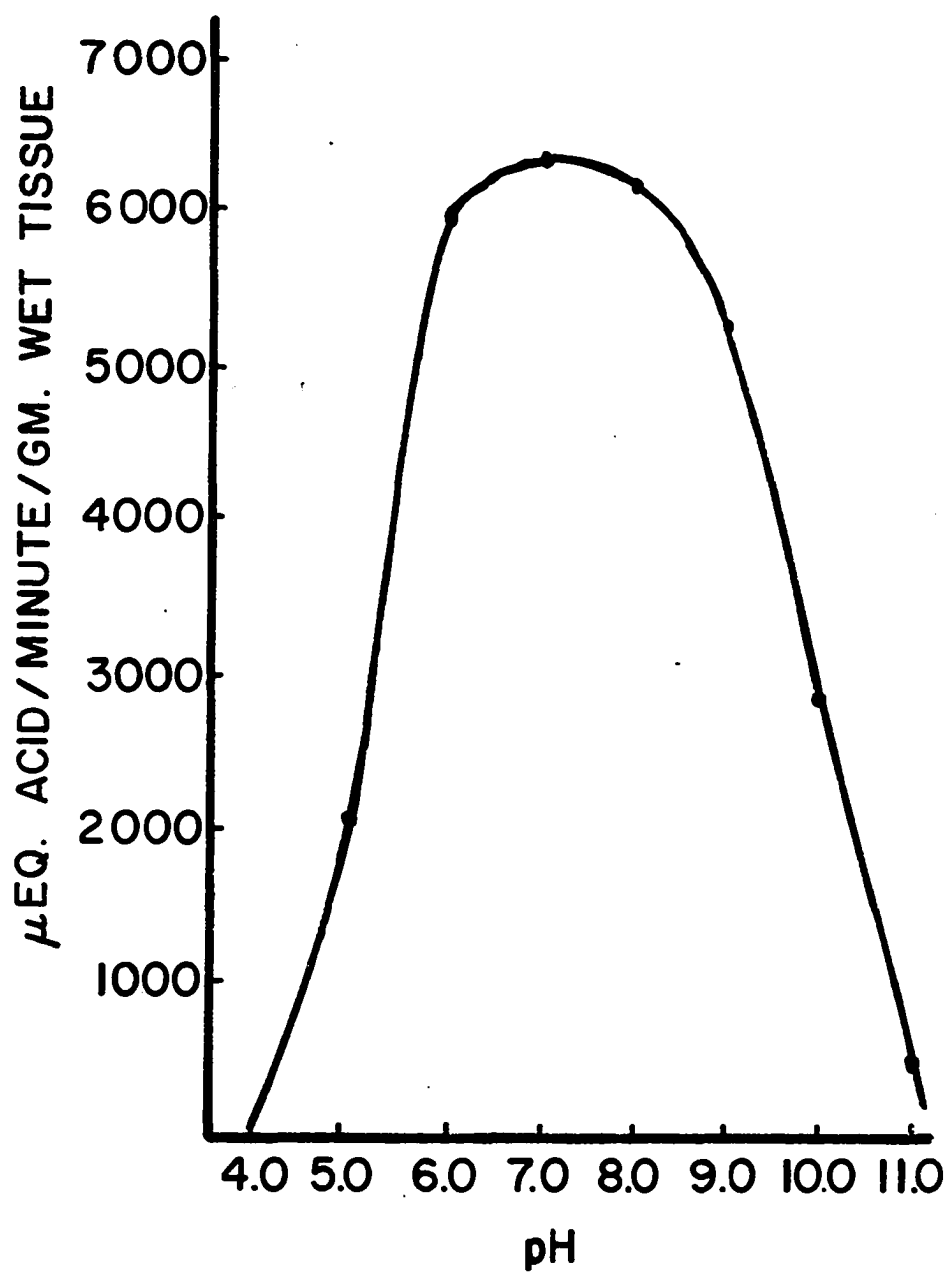
Preparation of substrate and enzyme homogenate have been presented in the Analytical Methods section of General Experimental Procedures.

#### Results

Summaries of lipase activity and specificity, analysis of variance plans and observed mean squares are presented in Table 54 through 57 in the Appendix.

Results of the experiment showed tributyrin to be hydrolyzed approximately 10 times faster than the other substrates

Figure 13. Experiment 6701 - Effect of pH on lipase activity  
using tributyrin as the substrate



resulting in a significant difference (Figure 14). No significant differences in activity were observed between butter and coconut oil or butter and lard. Coconut oil, however, was hydrolyzed significantly faster than lard. In a statistical analysis using just the three substrates, butter, coconut oil and lard, a significantly greater amount of fatty acids were liberated from coconut oil than butter or lard and butter was hydrolyzed significantly faster than lard.

Although the difference was not significant, there was an increase in lipase activity with age. This difference was more prevalent for tributyrin than for any of the other substrates.

A significant substrate x age and substrate x run interactions were observed. The substrate x age interaction resulted from a rather large increase in activity with age for tributyrin; whereas, for butter, coconut oil and lard the increase in activity with age was relatively small. The substrate x run interaction resulted from a large change in activity with tributyrin as the substrate compared to the small change in activity with butter, coconut oil or lard from one run to the next.

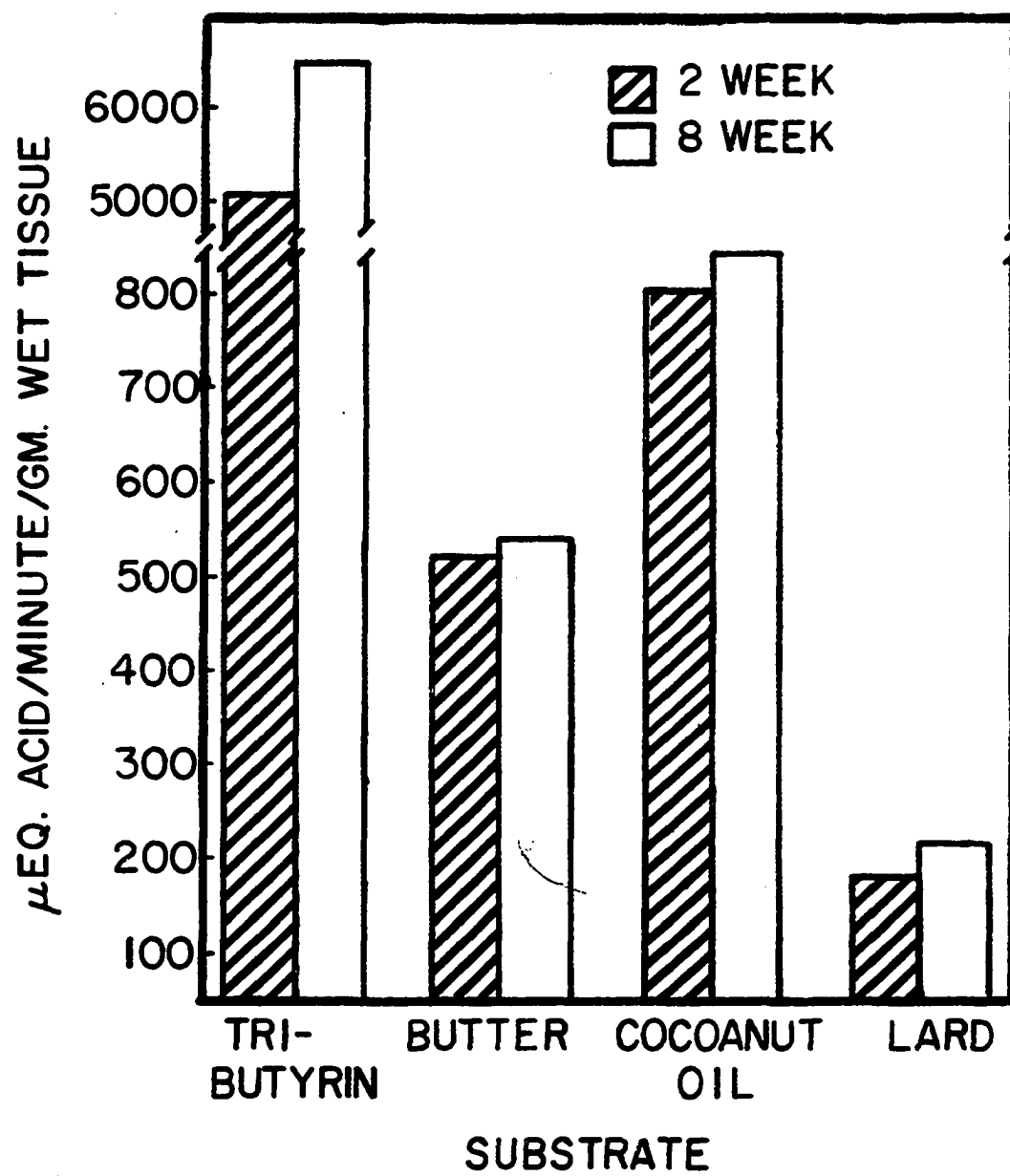
#### Experiment 6710 - Fat Digestibility of Sow Milk

##### Objectives

From the performance of suckling pigs, it may be assumed that the fat in sow milk is relatively efficiently utilized.

Figure 14. Experiment 6701 - Summary of lipase activity and specificity





However, the results thus far obtained have with the exception of Experiment 6701 consistently shown that addition of fat, irrespective of the source to the diet of young pigs depresses growth and increases the feed required per unit of gain. From this general observation the question was then raised, is the fat in milk well utilized by the nursing pig?

#### Experimental procedure

One crossbred Yorkshire x Landrace sow was placed in a farrowing crate on approximately the 110th day of gestation and remained there until she farrowed. After parturition the pigs were allowed to nurse for 48 hours and were then removed and placed in cages modified to allow for collection of fecal material. Each pig was considered a replicate. Immediately prior to and after nursing each pig was weighed to determine the intake of milk. Fecal samples were collected twice daily, stored at  $-17^{\circ}\text{C}$  until termination of the experiment and were then analyzed for fat content. Equal volume samples of milk were taken on day one, three and five of the five-day experimental period and were pooled and analyzed for solids and fat content.

#### Results

A summary of the fat digestibility of sow milk is presented in Table 58 in the Appendix.

The average digestibility coefficient for fat in sow milk was 95 percent. These results substantiate the assumption that fat in sow milk is readily digested. No attempts were

made however, to estimate the efficiency of converting milk solids or calories to gains.

The digestibility coefficients obtained for sow milk fat are subject to errors. Errors in estimating milk intake are likely to be biased downward because of any urinating or defecating which may have occurred and were not measured. Estimates of fecal recovery are likely also to be biased downward due to the inability to recover all the material from the cages.

## GENERAL DISCUSSION

## Physical Form of Diet

A young pig nursing the dam has been shown to suckle about once every 50 minutes for a period of 3 to 4 minutes (Weybrew et al., 1949). During this period a relatively small amount of solids, ranging from approximately 3.5 to 8.8 gm., is ingested. Generally a piglet will double its weight during the first week of life. During this period of rapid growth the conversion efficiency of milk nutrients to body tissue is very high. On the basis of sow milk analyses and the performance of suckling pigs, it is rather obvious that the baby pig can efficiently utilize the high level of fat present in sow milk. The digestibility coefficient for sow milk fat has been estimated to be 95 percent, thus verifying that the fat present is digested and absorbed. Weaning the pig at two weeks of age and placing him on a synthetic diet results in a lag in growth lasting for one to two weeks (Hartman et al., 1961). Additions of fat to these synthetic diets results in a further depression of growth and feed efficiency.

Diaz et al. (1959) observed that baby pigs fed liquid milk diets gained more and required less feed per unit of gain than did pigs fed dry diets. The objectives of Experiments 6528 and 6617 were to determine whether liquid diets with or without added fat would reduce post-weaning growth lag and/or increase nutrient intake. Dried skim milk was used as the

protein source in these diets to insure insofar as possible that quality and quantity of protein were not limiting the efficient utilization of fat.

The results of the experiments showed that the feeding of the liquid diets ad libitum resulted in more rapid and more efficient gains than did feeding of dry diets. The feed intake per pig for the 28 day experimental period was less for the pigs fed liquid diets than pigs fed the dry diets (Table 2b). Addition of fat to either dry or liquid diets reduced

Table 2b. Average ad libitum consumption of feed (kg.) per pig

Added fat, % Diet form	Treatment			
	0 Dry	10 Dry	0 Liquid	10 Liquid
Experiment 6528	7.70	6.11	8.12	5.55
Experiment 6617	12.91	10.25	10.79	9.81
Avg.	10.30	8.18	9.46	7.68

growth and feed efficiency. However, the addition of fat to the liquid diet did not result in as large a reduction in gain and feed efficiency as observed with addition of fat to the dry diet. The results of experiments reported by Peo et al. (1957), Manners and McCrea (1963) and Eusebio et al. (1965) have also shown reduced gain and feed efficiency from addition

of fat to dry diets. Sewell and Miller (1965) reported no difference in the growth rate of pigs fed diets with added fat, but they did observe an improvement in feed efficiency.

In Experiment 6521 pigs fed the basal diet without added fat consumed approximately 12 percent more calories per day and required less feed per unit of gain than did pigs fed diets with added fat. With the addition of fat to the diet there was a decrease in food intake resulting in a corresponding decrease in the intake of protein and other nutrients. Since it appeared possible that the reduced feed efficiency on the diets with added fat could be attributed to level of intake of protein or other nutrients it was decided to conduct a series of experiments in which nutrient intake, other than calories, was restricted to the level of intake on the diets with added fat (Experiments 6528 and 6617). The results showed that the growth rate of pigs on the equal fed dry diet without added fat was equal to or superior to that observed for pigs fed the dry diet with added fat. However, this same trend was not observed for pigs fed equal amounts of the liquid diets. The addition of fat to the liquid diet resulted in an improvement in growth and feed efficiency.

In summary, neither the physical form of the diet nor level of nutrient intake limits the efficient utilization of fat. Addition of fat to the diet results in reduced growth rate and feed efficiency. The metabolizable energy values established with the older pig (Diggs et al., 1965) may not

present the true value of fats for the baby pig. Even if the fat was absorbed and all deposited as depot fat it would still appear as metabolizable calories. Some method must be developed for determining what happens to the fat after it is absorbed -- whether it is used for energy purposes or deposited as fat. Eusebio et al. (1965) have shown that the latter situation may prevail since they observed a decrease in specific gravity of pigs fed diets with added fat indicating that pigs fed diets high in fat did deposit more of the fat as body fat.

#### Emulsification of Fat

Emulsification of fats with water can be easily achieved but the resultant emulsion is transitory. In plant and animal fats the fat is present and is maintained in an emulsified form, mainly due to the presence of phospholipids. Oser (1965) reported milk fats to be the most complex of the food fats and that this complex lipid material, which includes phospholipids, is present as a natural emulsion. Sheffy et al. (1952) estimated the phospholipid content of sow milk to be between 1 to 2 percent of the fat content. The efficiency of utilization of sow milk fat may be in part due to its presence as a stable emulsion. In Experiment 6436 it was decided to determine whether the addition of emulsifying agents to fats would promote greater digestion and more efficient utilization of the fat. A natural emulsifying agent, lecithin, and a synthetic agent, polyoxyethylene glycol mono- and

dioleates, were incorporated into lard oil for this purpose.

The results showed that the incorporation of lecithin and/or the emulsifier into lard oil did not improve the utilization of fat as measured by growth, feed efficiency or digestibility of fat. This is in agreement with the results of experiments conducted with pigs (Sheffy et al., 1951; Manners and McCrea, 1963; and Bayley and Lewis, 1963b), chicks (March and Biely, 1957; and Fedde et al., 1960) and rats (Shoshkes et al., 1950). However, in other reports with chicks (Bayley and Lewis, 1963b), rats (Augur et al., 1947) and dairy calves (Hopkins et al., 1959) addition of lecithin or an emulsifier to the diet improved fat digestibility.

The results of this experiment indicate that emulsification of fat is not necessarily a factor in the efficient utilization of fat. Though Borgstrom (1954) and Heath and Morris (1963) have clearly demonstrated that the emulsification by bile salts is necessary for hydrolysis and absorption of fat, it is possible that the emulsification of fat by lecithin or synthetic agents is not the same as that obtained by bile salts in vivo or through the phospholipids in sow milk.

The importance of bile salts in the utilization of fat has been demonstrated by Knoebel and Ryan (1963). These authors found more fat present in the ileum of bile-deficient dogs than normal dogs suggesting a defective absorption of the fat. Poley et al. (1963) observed a change in the



proportion of total bile acids and conjugated bile acids with age in humans. No conclusion was reached regarding the effect of these changes on fat digestion and absorption. The change in efficiency of fat utilization with age observed in swine (Eusebio et al., 1965) may be related to a change in both type of bile acids and total quantity of acids secreted. The inclusion of fats in the diet may also affect changes in bile acid synthesis and secretion. Hellstrom et al. (1962) reported that replacement of cocoanut oil with corn oil resulted in an increase in daily synthesis of deoxycholic acid in the rabbit.

#### Effect of Molecular Weight of Fat or Fat Source on Gain and Feed Efficiency

Natural fats contain fatty acids of varying chain length and degree of saturation resulting in a wide range in molecular weight of the fat sources. The glyceride structure and fatty acid composition of animal, vegetable and marine oils and fats have been determined and verify this large difference in molecular weight (Mattson and Volpenhein, 1961, 1963; Mattson et al., 1964; Subbaram and Youngs, 1964; and Hilditch and Williams, 1964). Results of experiments conducted by Lloyd and Crampton (1957) and Lloyd et al. (1957) revealed there was an inverse relationship between molecular weight of the fat source and digestibility of fat. With the variation in composition of fats, baby pigs may be able to utilize the

lower molecular weight fats more efficiently than the higher molecular weight fats. The objectives of Experiments 6507, 6514 and 6521 were to determine the effect of molecular weight of fat sources on growth and feed efficiency.

Pigs fed the basal diets without added fat gained more and required less feed per unit of gain than did pigs fed diets with added fat. This is in agreement with the results of experiments conducted with pigs (Peo et al., 1957; Asplund et al., 1960; and Eusebio et al., 1965); whereas other work with chicks (Fedde et al., 1960) and pigs (Sewell and Miller, 1965) showed an improvement in feed efficiency with addition of fat to the diet.

In the present experiments pigs fed diets with added butter and cocoanut oil gained more and were more efficient than pigs fed diets with added corn oil, lard or soybean oil. Results of experiments with dairy calves (Gullickson and Fountaine, 1939; Gullickson et al., 1942; and Thomasson, 1955) and rats (Boutwell et al., 1943) have also shown that butter contains properties which make it nutritionally superior to the other fats. Eusebio et al. (1965) also reported that cocoanut oil supported more rapid and efficient gains than did tallow, lard or soybean oil. However, Deuel et al. (1944a, 1944b, and 1945) showed no difference in the growth rate of rats fed butter or other fat sources. Blair (1963) also reported no advantage in substituting cocoanut oil for lard in the diet of baby pigs as measured by growth rate and

feed efficiency.

Lard is very similar in chemical composition to sow milk fat (deMan and Bowland, 1963) and since sow milk is efficiently utilized, lard should possibly promote rapid and efficient gains. In the present experiments addition of lard to the diet depressed the growth of pigs more than did the other fat sources. Eusebio et al. (1965) have also shown that the growth rate of pigs was significantly less on diets with added lard than that observed on diets with added tallow or soybean oil. However, Thomasson et al. (1956) reported that addition of lard to the diet increased the growth rate of rats more than did addition of butter, cottonseed oil, beef tallow, soybean oil or cocoanut fat. Even though lard is similar in chemical composition to sow milk fat, the fat in milk is present as a complex material containing milk proteins, fats and sugar, which may facilitate its utilization; whereas, addition of lard to the diet is not conducive for formation of this complex.

The poor utilization of the high molecular weight fat sources may be due to inefficient hydrolysis of the triglycerides containing long-chain fatty acids. Desnulle and Savary (1963) observed that triglycerides of short-chain fatty acids were hydrolyzed faster than triglycerides of long-chain fatty acids. Since it appeared possible that hydrolysis of fat may limit its utilization, several experiments were conducted to determine the effect of addition of free

fatty acids or a partially hydrolyzed fat source to the diet on fat utilization (Experiments 6514 and 6521). Addition of fatty acids from corn oil as the methyl esters to the diet improved the growth rate and feed efficiency of pigs over that observed with diets containing corn oil or lard. The improved gain and feed efficiency was still inferior to the performance observed on the butter diet but was equal to that obtained from addition of cocoanut oil. Including a partially hydrolyzed fat in the diet promoted faster gains than did the other fat sources. No difference in feed efficiency was observed among the fat sources. The results of these experiments suggest that hydrolysis of the high molecular weight fat sources (corn oil and lard) does limit their efficient utilization by baby pigs. These results are in disagreement with those reported by Carroll and Richards (1958) and Renner and Hill (1961a, 1961b) in which triglyceride fatty acids were more readily absorbed than free fatty acids added to the diet. On the other hand Bayley and Lewis (1962) showed no difference in utilization of free fatty acids or the triglycerides from which they were obtained.

Bayley and Lewis (1965b) postulated that as the level of unsaturated fatty acids in the fat increased, there was an improvement in fat utilization. Young (1961) also reported that the absorption of saturated acids varies directly with the level of unsaturated fatty acids in the mixture. In the present experiments, soybean oil which contains a high

proportion of unsaturated fatty acids, was less efficiently utilized as measured by gain and feed efficiency than the more saturated fats, butter, coconut oil or lard. The same trend was also observed for lard oil which differs from lard in that products termed stearins are removed during the manufacturing process. This would give rise to a product containing a higher proportion of unsaturated acids than saturated acids. Eusebio et al. (1965) have also shown that the saturated coconut oil is utilized more readily than the unsaturated soybean oil. Thus it appears factors other than level of unsaturated fatty acids are involved in regulating utilization of fat.

Although a trend was present for pigs fed butter and coconut oil to have more rapid and efficient gains than those fed the other fat sources the data would suggest that molecular weight of the fat source is not the only factor hindering efficient utilization of fat. Dividing the fat sources into animal or vegetable origin revealed no difference in performance as reported by Gullickson et al. (1942) in which calves fed fats of animal origin gained more than did those fed vegetable fats.

#### Effect of Molecular Weight of Fat Source on Fat Digestibility

Researchers have suggested that melting point and stearic acid content of a fat affects its digestion and absorption.

However Mattson (1959) noted since fats are composed of triglycerides with fatty acids of varying chain length and degree of saturation, which allow them to melt over a relative wide temperature range, melting point is not a reliable parameter for differentiating fat digestibility. Lloyd and Crampton (1957) and Lloyd et al. (1957) reported a highly significant inverse relationship between mean molecular weight (length of chain) of fatty acids of various fats and oils and their apparent digestibility by early-weaned pigs. In the present experiments the effect of molecular weight of fat source on fat digestibility was investigated.

Of the fat sources investigated no significant differences in fat digestibility which could be associated with molecular weight (Table 2c) were observed. This is in disagreement with the results reported by Lloyd and Crampton (1957) and Lloyd et al. (1957). Sewell and Miller (1965) have shown a difference in digestibility of fat sources with a higher digestibility coefficient observed for corn oil than lard or beef tallow. Eusebio et al. (1965) reported that coconut oil was more readily digested than the other fat sources employed. Pigs 3 weeks old had higher digestibility coefficients for coconut oil, lard and lard oil than for the other fat sources; whereas, at 7 weeks of age the digestion of all fat sources was similar, except for the methyl ester fatty acids from corn oil. The relatively high digestibility coefficient observed for HEF at 3 weeks of age is not out of

proportion if consideration is given to the digestibility of the other fat sources. In Experiment 6521 the digestibility of all fat sources averaged 72 to 83 percent with no significant differences observed among the sources. However the values cited for butter, cocoanut oil, corn oil and lard in Table 2c are the average digestibility values for several experiments in which these fat sources were employed; whereas, the value for HEF is taken from one experiment in which the coefficients were high for all fat sources at 3 weeks of age.

Table 2c. Apparent digestibility of fat by early-weaned pigs

Fat or oil	Fatty acid chain length	Age	
		3 weeks	7 weeks
		Digestibility, %	
Butter	Short	65.0	86.3
Cocoanut oil	Medium	75.1	84.4
Corn oil	(unsaturated)	64.4	82.8
Methyl ester fatty acids from corn oil		52.3	72.1
Lard	Long	78.8	86.1
Soybean oil	(unsaturated)	66.0	81.7
Lard oil	(unsaturated)	74.4	83.6
Hydrolyzed animal and vegetable fat (HEF)		82.9	89.0

Hoagland and Snider (1943b) and Mattil and Higgins (1945) postulated that the stearic acid content of a fat limited its

digestion. Soybean oil, lard oil and corn oil contain relatively small amounts of stearic acid and should therefore be digested more readily than other fat sources. However, lard was digested more efficiently than lard oil and both lard and cocoanut oil were digested more efficiently than soybean oil or corn oil. These results clearly demonstrate that stearic acid content is not the only limiting factor in digestion of fat by young pigs. Mattson (1959) concluded that the coefficient of absorbability of a fat is inversely proportional to its content of simple triglycerides made up of saturated fatty acids having a chain length of eighteen carbons or greater and that the level of saturated fatty acids affects the coefficient of absorbability only insofar as they are present as saturated triglycerides.

In all the experiments the digestibility coefficient for fat was significantly higher in the diets with added fat than in the basal diet. This would be expected since the fat present in the basal diet is low and a higher percentage of the total would consist of waxes, sterols and other lipid products unavailable to the pig; whereas in the diets with added fat, the fat was readily available for digestion. Also the relative amount of endogenous fat to dietary fat excretion is higher for pigs fed the basal diet than diets with added fat. This would bias the digestibility coefficient for fat in the basal diet downward.

The main difference in digestion observed among the fat



sources was an age difference. The average digestibility coefficient for pigs 3-weeks old, considering all fat sources, was 69.2 percent; whereas by 7-weeks of age the digestibility coefficient had increased to 83.5 percent. This improvement in digestibility with age has previously been reported in pigs (Lloyd and Crampton, 1957; Lloyd et al., 1957; and Eusebio et al., 1965) and chicks (Fedde et al., 1960; and Renner and Hill, 1960). It was observed that, after initiation of the experiment, pigs fed the diets with added fat lost or gained very little weight during the first week and maintained their weight or gained slightly during the second week. However by the third week on experiment the pigs started to gain quite rapidly and at the termination of the experiment were growing at the same rate as pigs fed the basal diet. Eusebio et al. (1965) have shown a large improvement in digestibility of fat by baby pigs between 4 and 7 weeks of age with little improvement between 7 and 10 weeks of age. This improved digestibility of fat would parallel the observed change in growth rate.

#### Effect of Protein Source on Fat Utilization

Lewis et al. (1955) and Peo (1956) have demonstrated that the growth and feed efficiency of baby pigs on all plant protein diets does not approach that of pigs fed milk protein. Since plant proteins do not support the performance that milk proteins do, addition of fat to diets containing plant protein may result in a protein deficiency thus limiting efficient

utilization of fat.

In Experiments 6507, 6514 and 6521 a corn-soybean meal diet containing dried skim milk (20 percent) was used. The results of the experiment revealed that addition of fat to the diet depressed growth rate and feed efficiency. In two subsequent trials (Experiments 6528 and 6617) all of the protein was supplied by dried skim milk. Again substitution of fat for starch in the diet resulted in a decrease in growth rate and an increase in feed required per unit of gain.

Since these experiments were conducted at different times and did not include plant or milk protein diets simultaneously no direct comparisons can be made between the two protein sources. However, in Experiment 6626 two protein sources, casein and isolated soya protein, were employed to further study the effect of protein source on fat utilization. A significant improvement in gain and feed efficiency was observed resulting from substituting casein as the protein source for soybean protein. Addition of fat to the diets, irrespective of protein source, resulted in significant improvements in gain and feed efficiency. This is contrary to the results in previously cited work and previous experiments reported herein in which addition of fat to the diet depressed growth rate and feed efficiency. However, the difference in results may partially be accounted for by the fact that the diets used in Experiment 6626 were semi-synthetic diets, whereas in the other experiments natural diets were used.

though the natural diets employed in Experiments 6507, 6514 and 6521 were calculated to be adequate in all nutrients, it is possible that limited availability of some of the nutrients may have affected energy or fat utilization.

The fat digestibility coefficients paralleled the growth data with higher digestibility coefficients and faster rate of gain on the casein diets than on the soybean diets. Akabane and Fujiwara (1966) also suggested a relationship exists between protein source and fat utilization from their observations that infants fed soya bean milk had 3 times as much triglycerides in their feces than did infants fed cow's milk.

These results (Experiment 6626) would verify the available data demonstrating milk proteins are superior to plant proteins in baby pig diets; however, they add to the confusion regarding relationships of protein and fat utilization.

#### Effect of Fat Levels on Fat Utilization

The corn-soybean meal diets employed for baby pigs usually provide 1 to 2 percent fat, which contains a relatively high proportion of lipid material unavailable to the pig. Addition of fat to a corn-soybean meal diet for the older pig results in an improvement in feed efficiency, whereas, with the baby pig it decreases growth rate and increases the feed required per unit of gain. The level of fat incorporated into the diet may limit the efficient utilization of fat by young pigs.

In Experiments 6507 and 6514 a 10 percent level of fat was used; whereas, in Experiment 6521 a 20 percent level was employed. Irrespective of the level, growth rate and feed efficiency were depressed with the addition of fat to the diet. In Experiment 6626 three levels of fat, 0, 5 and 10 percent lard, were added to essentially fat-free (0.4 percent fat) diets. As the level of added fat was increased there was a significant improvement in both gain and feed efficiency. This is contradictory to the results of experiments conducted by Peo et al. (1957) and Eusebio et al. (1965) who reported that increasing the levels of fat in the diet depressed growth rate and did not improve feed efficiency. The results of the present experiment may be partially accounted for by the age of pigs used. Although the pigs were weaned at 18 days of age, they were group-fed for several days prior to allotment to the experiment diets. At the time of allotment the average age of the pigs was 21 days. From results of previous studies the growth lag is neither as severe nor as long in duration at this age as compared with younger pigs.

Since 10 and 20 percent fat levels were not used in the same experiments no direct comparisons of fat digestion can be made between them; however there was a trend for higher digestibility coefficients at the 20 percent added fat level than at the 10 percent level. Asplund et al. (1960) noted no difference in the apparent digestibility of fat with

increasing levels from 10 to 20 percent. In Experiment 6626, an improvement in fat digestibility with increasing fat levels was observed. The difference, however, is largely attributable to the low digestibility coefficient for fat in the control low fat diets. Analysis of the data showed no significant difference in fat digestibility between 5 and 10 percent added fat.

#### Effect of Fatty Acid Composition of Diet on Plasma and Fecal Fatty Acid Patterns

The total amount of fatty acids in the blood stream is considerably less than the amount of fat that might be ingested in a single feeding. Therefore, during the period of alimentary lipemia some of the lipids in the blood would acquire the composition of the dietary fat. Dole et al. (1959) noted that ingestion of a large amount of fat increased the fatty acids present in the blood to as much as six times the normal level (50 meq. to 300 meq.) within several hours postprandial. However, this increase was transitory and within 6 hours after ingestion of the test meal, plasma fatty acids had returned to the normal level (50 meq.). They concluded that the degree of alimentary lipemia depends on the type of fat fed and the level. To obtain a substantial rise in concentration of plasma fatty acids a large amount of fat must be fed.

In the present experiments (Experiments 6521 and 6626)

the total amount of lipid material in the plasma was not measured. Therefore, changes in the concentration of the fatty acids with the type of fat fed or with age relate only to the changes in the fatty acid patterns and not to the total amount of an acid present.

In general, there was little correlation between the fatty acid patterns of the plasma and the diet. The plasma levels of each fatty acid remained relatively constant irrespective of the type of fat fed with the exception of coconut oil. In Experiment 6521 addition of coconut oil, which contains high amounts of lauric and myristic acids, to the diet resulted in a corresponding increase of these acids in the plasma. Dole et al. (1959) also observed little change in the over-all plasma fatty acid patterns from inclusion of corn oil or butter in the diet; whereas after ingestion of coconut oil there was an increase in lauric and myristic acids. Excluding coconut oil, the major saturated acids present in the plasma were palmitic and stearic acids; whereas, the pattern of unsaturated acids was equally divided between oleic and linoleic acids. No marked changes in the plasma fatty acid patterns were observed with age though the concentration of lauric and myristic acids increased slightly and the concentration of stearic acid decreased.

Increasing levels of fat in the diet (5 to 10 percent) did not appreciably change the plasma fatty acid patterns. There was a slight reduction in lauric and myristic acid

concentrations depending on the type of fat employed. Lard which contains relatively insignificant amounts of these acids was used as the fat source in the studies comparing levels of fat and consequently there would not be a large amount of these acids present in the plasma. The level of lauric and myristic acids in the plasma on the 0 added fat level would reflect the plasma or tissue pools of these acids.

The low amount of short-chain fatty acids present in the plasma may reflect the low amount in the diet or, on the other hand, these short-chain acids are absorbed via the blood thus they are more readily metabolized than the long-chain fatty acids which are absorbed via the lymphatic system. Friend et al. (1964) reported that between 15 and 28 percent of the maintenance energy requirement of the pig could be supplied by the volatile fatty acids contributed from alimentary sources. Dole et al. (1959) have postulated that the relative stability of plasma fatty acid patterns may result from a conversion of fatty acids during digestion or the patterns may be held constant by rapid recycling of fatty acids between the blood and tissue pools.

No significant correlations were observed between the fatty acids present in the diet and the fecal material. In general the fecal material contained a larger amount of saturated acids, mainly stearic acid, than did the diet. Bayley and Lewis (1965a, 1965b) have also demonstrated an increase in saturation of fecal lipids and also observed that it was

largely stearic acid. Howard et al. (1965) reported that 55 to 80 percent of the fatty acids present in the feces were palmitic and stearic acids. The high amount of stearic acid in the feces may arise from several sources. First, Carroll (1958) estimated the absorption coefficient for stearic acid to be 12 percent, thus very little is absorbed and the rest is excreted via the feces. Secondly, hydrogenation of unsaturated fatty acids by bacteria may occur in the lower digestive tract. Wollaeger et al. (1953) have shown that such a process does occur. Wollaeger et al. (1953) also reported that the continued presence and patterns of fatty acids in feces of subjects fed a fat-free diet is indicative that a portion of the fecal fatty acids are derived from sources other than food lipid. In Experiment 6626, pigs fed essentially a low fat diet had similar fecal fatty acid patterns to that observed for pigs fed diets with added fat with the exception of stearic acid. Addition of fat to the diet increased the stearic acid content of the fecal material approximately 20 percent.

In Experiment 6626 the fecal material contained more pentadecanoic and heptadecanoic acids than food lipid which contains an insignificant amount of these acids. Bayley and Lewis (1965a and 1965b) have also observed this same trend. The significance of the odd-carbon acids in the feces is illustrated by the work of MacFarlane (1962) who found these acids formed a major part of the lipids synthesized by



bacteria. Thus the fatty acids present in fecal material may be a reflection of bacterial degradation and synthesis of fatty acids rather than the poor absorption of such acids from the food lipid. The small amount of linoleic and linolenic acids found in the feces may have originated from bacterial synthesis or hydrogenation of unsaturated acids by bacteria to saturated acids and does not necessarily reflect these acids were not utilized from the diet.

Bayley and Lewis (1965b) reported that even though the composition of dietary fat covered a wide range, the fatty acid composition of fecal fat was not affected by alterations in food lipids. In Experiment 6521 the same trend was observed in that the composition of fecal fat was similar for pigs fed corn oil, HEF and lard. However, incorporation of butter or cocoanut oil into the diet resulted in an increase in lauric and myristic acid content of the feces. This is a reflection of the high concentration of these acids in the food lipids rather than hydrogenation of unsaturated acids and degradation by bacteria which may occur.

In summary, the data from Experiments 6521 and 6626 reveal that plasma and fecal fatty acid patterns are not indicative of the absorption of fatty acids from the digestive tract unless there is a wide variation in the fatty acid content of the fat employed. The fatty acids in fecal material may arise from sources other than food lipids thus resulting in biased absorption coefficients. Canulation of the thoracic

lymph duct and portal blood vessel would give more reliable information on absorption of fatty acids as affected by type of fat used and the influence of one fatty acid on the absorption of another.

#### Lipase Activity and Specificity

Kitts et al. (1956) and Hartman et al. (1961) reported a high lipolytic activity in young pigs which gradually increases with age. Hartman et al. (1961) also reported that the weaning of pigs resulted in a decrease in tributyrinease activity of pancreatic tissue. The activity remained low for several weeks and returned to normal levels by 6 to 7 weeks of age.

In Experiment 6701, the estimated hydrolysis using tributyrin as a substrate was significantly higher than that observed with the other substrates, butter, cocoanut oil and lard. Sobotka and Glick (1934), Weinstein and Wynne (1935), Balls et al. (1937), Wills (1965) and Desnuelle and Savary (1963) observed that triglycerides containing short-chain fatty acids are hydrolyzed more rapidly than triglycerides containing long-chain acids which would partially account for the rapid hydrolysis of tributyrin. Also Desnuelle and Savary (1963) reported that the general term lipase represents a host of enzymes including an esterase which hydrolyzes short-chain water-soluble acids. Tributyrin is more water-soluble than the other fat sources and, therefore, is more

readily hydrolyzed by an esterase.

Since the hydrolysis of tributyrin was approximately 10 times higher than that observed for the other fat sources, the significant differences in hydrolysis rate between the substrates is largely accounted for by the hydrolysis of tributyrin. An analysis was conducted omitting the tributyrin data and showed that cocoanut oil was hydrolyzed more rapidly than butter or lard and butter was hydrolyzed faster than lard.

With increasing age (2 to 8 weeks) there was a small increase in the hydrolysis of the substrates. This is in agreement with the results of experiments conducted by Hartman et al. (1961). The increase was more evident for tributyrin than the other substrates however, there was no evidence of any change in specificity occurring.

The high digestibility coefficient (95 percent) observed for sow milk fat indicates that lipase apparently hydrolyzes this type of fat quite rapidly. However, lard which has been shown to be quite similar in composition to sow milk fat (deMan and Bowland, 1963) is hydrolyzed to a lesser extent than are the other fat sources. The hydrolysis of sow milk fat may be attributed to an enzyme present in the milk. Herrington (1954) reported that cow's milk contains a fat-splitting enzyme. A milk lipase has also been reported in human milk (Tarassuk et al., 1964) and guinea pig (McBride and Korn, 1963).

In conclusion, there are some indications of lipase specificity in that tributyrin was hydrolyzed more rapidly than were the other substrates. There was no evidence of any changes in specificity or adaptive processes occurring with which could account for the improvement in digestibility and utilization of fat with increased age (2 to 8 weeks).

## SUMMARY

Nine experiments involving 454 pigs were conducted to study factors influencing the utilization of fat by young pigs.

Growth rate and feed efficiency were improved with liquid diets over the performance observed for pigs fed dry diets. However, the use of liquid diets did not improve the utilization of fat. Restricting the feed intake of pigs fed the basal diet to the amount pigs consumed of the diet with added fat fed either in liquid or dry form indicated that food intake was not the factor limiting utilization of fat.

Incorporation of an emulsifier, lecithin or a combination of the two into lard oil, did not improve utilization of fat as measured by growth rate, feed efficiency, or fat digestion as compared with pigs fed diets containing lard oil alone.

Although pigs fed diets containing butter and cocoanut oil gained more and were more efficient than pigs fed diets containing either corn oil, soybean oil, or lard, molecular weight of the fat source is not the only factor hindering efficient utilization of fat as pigs fed the basal diet gained more and were more efficient than pigs fed diets with added fat. Incorporation of free fatty acids or a partially hydrolyzed fat source improved fat utilization a little as measured by growth rate and feed efficiency.

Utilization of fat as measured by apparent fat digestion was improved with increasing age. At three weeks of age the digestibility coefficient averaged 69 percent; whereas, at seven weeks of age the digestibility coefficient averaged 84 percent. No significant differences in fat digestibility were observed among the fat sources.

No definite patterns existed as to the effect of protein source on utilization of fat. Addition of fat to a corn-soybean meal diet or a dried skim milk diet depressed growth rate and feed efficiency; whereas, in one experiment addition of fat to casein diets improved growth rate and feed efficiency as compared to diets with isolated soybean protein as the protein source.

There was some indication of lipase specificity in that tributyrin was hydrolyzed more rapidly than were the other substrates, butter, coconut oil and lard. However, there was no evidence of any changes in specificity or adaptive processes occurring which could account for the commonly observed improvement in digestion and utilization of fat as the pigs progress from birth to 7 or 8 weeks of age.

Plasma and fecal fatty acid patterns reflected to a limited extent the fatty acids present in food lipids, however they are not reliable parameters for determining utilization of fat. There was little correlation between plasma, fecal and diet fatty acids.

The young pig can utilize certain types of fat as

evident by the ability to utilize sow milk fat. Digestibility studies with suckling baby pigs revealed that the digestibility coefficient for sow milk fat averaged 95 percent.

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APPENDIX

Table 3. Composition of basal diets

Ingredient	Experiment		
	6436-6507 6514	6521	6528 6617
Ground yellow corn	41.3	29.4	--
Solvent soybean meal (50% protein)	19.6	21.4	--
Dried skim milk	20.0	20.0	59.0
Starch	10.0	20.0	--
Sucrose	5.0	5.0	--
Dextrose	--	--	38.6
Calcium carbonate	0.3	0.3	--
Dicalcium phosphate	1.1	1.2	--
Vitamin-antibiotic premix <sup>a</sup>	2.0	2.0	2.0
Iodized salt	0.5	0.5	0.2
Trace mineral mix <sup>b</sup>	<u>0.2</u>	<u>0.2</u>	<u>0.2</u>
Total <sup>c</sup>	100.0	100.0	100.0

<sup>a</sup>Composition presented in Table 5.

<sup>b</sup>Composition presented in Table 7.

<sup>c</sup>Calculated analysis presented in Table 5.

Table 4. Composition of basal diets

Ingredient	Protein Source	
	Casein	Soybean
Casein (fat free)	24.40	--
C-1 Assay protein <sup>a</sup>	--	24.40
Sucrose	5.00	5.00
Dextrose	30.00	30.00
Starch	32.65	33.05
Methionine	0.15	0.10
Calcium carbonate	--	0.55
Dicalcium phosphate	3.30	2.40
Iodized salt	0.50	0.50
Vitamin-antibiotic premix <sup>b</sup>	2.00	2.00
Trace mineral mix <sup>c</sup>	<u>2.00</u>	<u>2.00</u>
Total <sup>d</sup>	100.00	100.00

<sup>a</sup>Skidmore Enterprises, Cincinnati, Ohio.

<sup>b</sup>Composition presented in Table 6.

<sup>c</sup>Composition presented in Table 8.

<sup>d</sup>Calculated analysis presented in Table 6.



Table 5: Calculated analysis and amounts of vitamins and antibiotics added per kilogram of complete diet

Constituent	Experiment					
	6436-6507 6514		6521		6528 6617	
Protein, %	20.00		20.00		20.00	
Energy, Met. Cal./kg.	2913		2937		3208	
Calcium, %	0.71		0.72		0.77	
Phosphorous, %	0.62		0.63		0.61	
Vitamins and Antibiotics: units/kg.	Added	Total	Added	Total	Added	Total
Vitamin A, I.U.	5500	6409	5500	6147	5500	5500
Vitamin D <sub>2</sub> , I.U.	1093	1093	1093	1093	1093	1093
Riboflavin, mg.	10.6	15.5	10.6	15.4	3.5	15.5
Pantothenic acid, mg.	21.1	32.4	23.8	34.7	7.0	26.6
Niacin, mg.	42.2	57.2	47.5	60.6	64.2	68.6
Choline, mg.	--	970	--	968	327	992
Vitamin B <sub>12</sub> , mcg.	44	44	44	44	44	44
Chlortetracycline, mg.	110	110	110	110	110	110
Sulfamethazine, mg.	110	110	110	110	110	110
Penicillin, mg.	55	55	55	55	55	55
Ethoxyquin, mg.	150	150	150	150	150	150

Table 6. Calculated analysis and amounts of vitamins and antibiotics added per kilogram of complete ration

Constituent	Protein Source			
	Casein		Soybean	
Protein, %		20.00		20.00
Energy, Met. Cal./kg.		2961		2939
Calcium, %		0.79		0.79
Phosphorous, %		0.61		0.61
Vitamins & Antibiotics:				
units/kg.	Added	Total	Added	Total
Vitamin A, I.U.	5500	5500	5500	5500
Vitamin D <sub>2</sub> , I.U.	1093	1093	1093	1093
Vitamin B <sub>12</sub> , mcg.	44	44	44	44
Vitamin E, mg.	110	110	110	110
Vitamin C, mg.	33	33	33	33
Vitamin K, mg.	4.4	4.4	4.4	4.4
Thiamine, mg.	1.3	1.3	1.3	1.3
Riboflavin, mg.	11	11	10.8	11
Niacin, mg.	66	66	65	66
Pantothenic acid, mg.	22	22	21	22
Choline, mg.	1100	1100	1100	1100
Biotin, mcg.	198	198	198	198
Folic acid, mcg.	990	990	990	990
Inositol, mg.	198	198	138	138
Pyridoxine, mg.	1.1	1.1	--	1.1
Chlortetracycline, mg.	110	110	110	110
Sulfamethazine, mg.	110	110	110	110
Penicillin, mg.	55	55	55	55
Ethoxyquin, mg.	150	150	150	150

Table 7. Composition of trace mineral mix

Element <sup>a</sup>	Percent of element in premix	Levels in feed when added at 0.20%
		Mg./kg. or P.P.M.
Manganese	5.68	113.6
Zinc	8.10	162.0
Iron	7.00	140.0
Copper	0.48	9.5
Cobalt	0.17	3.3
Potassium	0.75	15.0

<sup>a</sup>Elements as the sulfate form. Calcium carbonate was used as the carrier.

Table 8. Composition of trace mineral mix (Experiment 6626)

Element	Mg./kg. or P.P.M.	
	Casein	C-1 Assay
Potassium Acetate	2500	2100
Zinc Oxide	50.4	45.5
Cobalt Carbonate	1.9	1.9
Manganese Carbonate	39.6	28.6
Copper Sulfate	9.9	8.1
Iron Sulfate	98.8	70.1
Magnesium Carbonate	396	366

Table 9. Experiment 6436 - Summary of average total gain and feed required per gain

	Treatment <sup>a</sup>					
	Basal	Lard	Lard Oil	Lard Oil + Lecithin	Lard Oil + Emulsifier	Lard Oil + Lecithin + Emulsifier
Replication	<u>Total Gain, kg.</u>					
1	3.3	5.4	4.6	4.5	3.4	3.9
2	7.5	6.5	5.7	5.6	4.9	4.3
3	7.0	5.7	5.0	5.2	4.1	4.9
Average	5.9	5.9	5.1	5.1	4.1	4.4
	<u>Feed/Gain</u>					
1	2.3	1.7	1.9	1.8	2.1	2.4
2	1.7	1.6	2.2	1.9	2.0	2.2
3	2.0	1.9	1.7	2.1	2.2	2.0
Average	2.0	1.7	1.9	1.9	2.1	2.2

<sup>a</sup>Fats added to the diet at a level of 10%.

Table 10. Experiment 6436 - Summary of metabolizable calories per kg. of gain

	Treatment <sup>a</sup>					
	Basal	Lard	Lard Oil	Lard Oil Lecithin	Lard Oil Emulsifier	Lard Oil Lecithin Emulsifier
Replication						
1	6650	5828	6401	6213	7132	7998
2	4880	5482	7540	6428	6666	7288
3	5697	6520	5735	7116	7544	6928
Average	5742	5943	6559	6586	7114	7405

<sup>a</sup>Fats added to the diet at a level of 10%.

Table 11. Experiment 6436 - Average apparent digestibility of fat after 10 and 28 days on experiment

	Treatment <sup>a</sup>					
	Basal	Lard	Lard Oil	Lard Oil + Lecithin	Lard Oil + Emulsifier	Lard Oil + Lecithin + Emulsifier
Replication						
1	39.8 <sup>b</sup> 30.6 <sup>c</sup>	82.7 83.3	79.3 84.8	83.5 85.1	76.7 81.4	69.6 80.2
2	45.7 8.7	88.0 82.1	74.6 85.9	84.3 88.8	68.4 86.6	81.4 93.2
3	11.4 7.9	84.2 79.1	69.3 80.0	65.9 93.0	73.9 84.2	85.9 87.5
Average	32.3 15.7	84.9 81.5	74.4 83.6	77.9 88.9	73.0 84.1	78.9 86.9

<sup>a</sup>Fats added to the diet at a level of 10%.

<sup>b</sup>Apparent digestibility after 10 days on trial.

<sup>c</sup>Apparent digestibility after 28 days on trial.

Table 12. Experiment 6436 - Analysis of variance of average total gains<sup>a</sup>

Source	d.f.	Mean squares
Total	71	2.9702
Outcome Groups (O.G.)	11	6.3295**
Replication (Rep.)	2	15.7145**
O.G./Rep.	9	4.2440*
Treatment (Trt.)	5	6.8808
Basal versus added fat	1	10.6984
Lard versus lard oil	1	14.2155*
Lecithin versus no lecithin	1	0.1355
Emulsifier versus no emulsifier	1	9.2488
Emulsifier-lecithin interaction	1	0.1056
O.G. x Trt.	55	1.9428
Rep. x Trt. (Error)	10	2.4410
O.G./Rep. x Trt.	45	1.8321

\*Indicates significant difference at  $P = 0.05$  or less.

\*\*Indicates significant difference at  $P = 0.01$  or less.

<sup>a</sup>Coefficient of variation = 15.37%.

Table 13. Experiment 6436 - Analysis of variance of feed required per unit of gain<sup>a</sup>

Source	d.f.	Mean squares
Total	17	0.0500
Replication (Rep.)	2	0.0200
Treatment (Trt.)	5	0.0691
Basal versus added fat	1	0.0003
Lard versus lard oil	1	0.2124
Lecithin versus no lecithin	1	0.0061
Emulsifier versus no emulsifier	1	0.1220
Emulsifier-lecithin interaction	1	0.0045
Rep. x Trt. (Error)	10	0.0464

<sup>a</sup>Coefficient of variation = 10.86%.



Table 14. Experiment 6436 - Analysis of variance of fat digestibility<sup>a</sup>

Source	d.f.	Mean squares
Total	35	550.3341
Age	1	92.3841
Replication (Rep.)	2	102.4449
Age x Rep.	2	32.2119
Treatment (Trt.)	5	3324.8565**
Basal versus added fat	1	16480.4973**
Lard versus lard oil	1	24.3450
Lecithin versus no lecithin	1	118.2372
Emulsifier versus no emulsifier	1	1.2015
Emulsifier-lecithin interaction	1	0.0013
Rep. x Trt.	10	79.8954
Age x Trt.	5	185.6763
Age x Rep. x Trt.	10	54.8379

\*\*Indicates significant difference at  $P = 0.01$  or less.

<sup>a</sup>Coefficient of variation = 12.44%.

Table 15. Experiment 6507 - Summary of average total gain and feed required per gain

	Treatment <sup>a</sup>				
	Basal	Butter	Cocoanut Oil	Lard	Soybean Oil
Replication	<u>Total Gain, kg.</u>				
1	4.9	0.4	5.1	4.6	4.5
2	5.8	5.8	3.2	5.4	4.2
3	5.9	6.1	5.3	6.5	6.2
4	6.4	4.5	7.1	6.7	5.5
Average	5.8	5.3 <sup>b</sup>	5.2	5.8	5.1
	<u>Feed/Gain</u>				
1	1.9	7.8	2.0	1.8	1.8
2	1.8	2.2	2.5	1.8	1.9
3	2.0	1.7	1.5	1.7	1.6
4	1.7	1.6	1.6	1.5	1.5
Average	1.8	1.8 <sup>b</sup>	1.9	1.7	1.7

<sup>a</sup>Fats added to the diet at a level of 10%.

<sup>b</sup>Excluding the value for replication 1. Total gain was 4.2 kg. and feed/gain was 3.3 if replication 1 is included.

Table 16. Experiment 6507 - Summary of metabolizable calories per kg. of gain

	Treatment <sup>a</sup>				
	Basal	Butter	Cocoanut Oil	Lard	Soybean Oil
Replication					
1	5474	26,358	6642	6618	5972
2	5214	7265	8582	5917	6458
3	5761	5745	5210	5615	5510
4	4925	5377	5298	5139	4939
Average	5344	6129 <sup>b</sup>	6433	5697	5720

<sup>a</sup>Fat substituted for starch at the 10% level.

<sup>b</sup>Excluding the value for replication 1.

Table 17. Experiment 6507 - Average apparent digestibility of fat after 10 and 28 days on experiment

	Treatment <sup>a</sup>				
	Basal	Butter	Cocoanut Oil	Lard	Soybean Oil
Replication					
1	40.3 <sup>b</sup> 36.1 <sup>c</sup>	29.4 77.7	86.9 85.9	57.6 86.5	77.1 70.6
2	11.9 51.3	66.4 91.5	68.5 89.2	76.9 88.0	34.3 74.7
3	5.6 51.6	74.4 83.6	79.3 87.0	78.4 90.1	73.0 88.4
4	70.6 62.1	86.3 90.0	74.7 95.7	76.3 81.8	79.8 93.2
Average	32.1 50.3	64.1 85.7	77.4 89.4	72.3 86.6	66.0 81.7

<sup>a</sup>Fats added to the diet at a level of 10%.

<sup>b</sup>Apparent digestibility after 10 days on trial.

<sup>c</sup>Apparent digestibility after 28 days on trial.

Table 18. Experiment 6507 - Analysis of variance of average total gain<sup>a</sup>

Source	d.f.	Mean squares
Total	79	4.9489
Outcome Groups (O.G.)	15	11.4021
Replication (Rep.)	3	21.0085
O.G./Rep.	12	9.0005
Treatment (Trt.)	4	6.8969
Basal versus added fat	1	6.1772
Butter versus cocoanut oil	1	7.2676
Lard versus soybean oil	1	4.1256
Butter and cocoanut oil versus lard and soybean oil	1	10.0172
O.G. x Trt.	60	3.2058
Rep. x Trt. (Error)	12	6.3387
O.G./Rep. x Trt.	48	2.4225

<sup>a</sup>Coefficient of variation = 24.21%.

Table 19. Experiment 6507 - Analysis of variance of feed required per unit of gain

Source	d.f.	Mean squares
Total	19	1.8656
Replication (Rep.)	3	2.2189
Treatment (Trt.)	4	1.9063
Basal versus added fat	1	0.3100
Butter versus cocoanut oil	1	3.9480
Lard versus soybean oil	1	0.0050
Butter and cocoanut oil versus lard and soybean oil	1	3.3672
Rep. x Trt. (Error)	12	1.7638

Table 20. Experiment 6507 - Analysis of variance of fat digestibility<sup>a</sup>

Source	d.f.	Mean squares
Total	39	489.6662
Age	1	2681.8975*
Replication (Rep.)	3	571.2371
Rep. x Age	3	183.9156
Treatment (Trt.)	4	2272.9022**
Basal versus added fat	1	8629.4938**
Butter versus cocoanut oil	1	288.4902
Lard versus soybean oil	1	124.3225
Butter and cocoanut oil versus lard and soybean oil	1	49.3024
Rep. x Trt.	12	233.6855
Age x Trt.	4	26.4379
Age x Rep. x Trt.	15	143.2028

\*Indicates significant difference at  $P = 0.05$  or less.

\*\*Indicates significant difference at  $P = 0.01$  or less.

<sup>a</sup> Coefficient of variation = 21.66%.

Table 21. Experiment 6514 - Summary of average total gain and feed required per gain

	Treatments <sup>a</sup>					
	Basal	Methyl Esters	Corn Oil	Butter	Cocoanut Oil	Lard
Replication	<u>Total Gain, kg.</u>					
1	5.2	5.6	2.9	6.9	3.7	4.2
2	6.8	5.3	5.3	5.7	5.8	4.1
3	5.8	5.5	6.1	6.0	6.3	5.9
Average	5.9	5.5	4.8	6.2	5.3	4.7
	<u>Feed/Gain</u>					
1	1.7	1.8	2.3	1.5	2.0	2.0
2	1.6	1.7	1.6	1.6	1.7	2.0
3	1.8	1.7	1.9	1.6	1.6	1.9
Average	1.7	1.7	1.9	1.6	1.8	2.0

<sup>a</sup>The fat sources were fed at a level of 10% of the diet.



Table 22. Experiment 6514 - Summary of metabolizable calories per kg. of gain

	Treatment <sup>a</sup>					
	Basal	Methyl Esters	Corn Oil	Butter	Cocoanut Oil	Lard
Replication						
1	4840	6167	7920	4988	6661	6672
2	4542	5832	5567	5400	5658	6796
3	5126	5763	6411	5395	5318	6362
Average	4836	5921	6633	5261	5879	6610

<sup>a</sup>Fat substituted for starch at the 10% level.

Table 23. Experiment 6514 - Average apparent digestibility of fat after 10 and 28 days on experiment

	Treatment <sup>a</sup>					
	Basal	Methyl Esters	Corn Oil	Butter	Cocoanut Oil	Lard
Replication						
1	20.4 <sup>b</sup> 78.1 <sup>c</sup>	40.6 71.0	40.0 80.4	28.3 86.3	51.2 76.2	51.9 83.6
2	4.7 55.2	79.5 78.2	73.0 90.9	74.7 85.6	75.0 85.1	74.0 89.8
3	32.5 21.8	36.8 67.1	55.2 88.4	65.4 77.6	84.7 87.4	36.1 68.4
Average	19.2 51.7	52.3 72.1	56.1 86.6	56.1 83.2	70.3 82.9	54.0 80.6

<sup>a</sup>Fats added to the diet at a level of 10%.

<sup>b</sup>Apparent digestibility after 10 days on trial.

<sup>c</sup>Apparent digestibility after 28 days on trial.

Table 24. Experiment 6514 - Analysis of variance of average total gain<sup>a</sup>

Source	d.f.	Mean squares
Total	69	3.7793
Outcome Groups {O.G.}	11	4.6765
Replication {Rep.}	2	8.1138
O.G./Rep.	9	3.9127
Treatments (Trt.)*	5	4.2568
O.G. x Trt.	53	3.5480
Rep. x Trt. (Error)	10	3.6119
O.G./Rep. x Trt.	43	3.5332

<sup>a</sup>Coefficient of variation = 17.60%.

\*By Duncan's Multiple Range test no differences were observed among treatment means.

Table 25. Experiment 6514 - Analysis of variance of feed required per unit of gain<sup>a</sup>

Source	d.f.	Mean squares
Total	17	0.0454
Replication	2	0.0500
Treatment (Trt.)*	5	0.7750
Rep. x Trt.	10	0.0286

<sup>a</sup>Coefficient of variation = 9.55%.

\*Duncan's Multiple Range test was used to test the difference between treatment means. Pigs fed butter required significantly less feed per unit of gain than did pigs fed corn oil or lard.

Table 26. Experiment 6514 - Analysis of variance of fat digestibility

Source	d.f.	Mean squares
Total	35	559.1603
Age	1	6019.1736**
Replication (Rep.)	2	578.9840
Rep. x Age	2	486.4168
Treatment (Trt.)*	5	1324.3793
Rep. x Trt.	10	224.1957
Age x Trt.	5	98.3603
Age x Rep. x Trt.	10	215.4999

\*\*Indicates significant difference at  $P = 0.01$  or less.

\*Duncan's Multiple Range test was used to test the difference between treatment means. Pigs fed the added fat diet had significantly higher digestibility coefficients for fat than did pigs fed the basal diet.

Table 27. Experiment 6521 - Summary of average total gain and feed required per gain

	Treatment <sup>a</sup>					
	Basal	Butter	Cocoanut Oil	Corn Oil	Hydrolyzed Fat	Lard
Replication	<u>Total Gain, kg.</u>					
1	10.6	4.4	8.2	8.3	8.7	6.2
2	9.7	9.1	10.2	8.2	6.4	6.8
3	11.1	7.6	6.0	8.6	7.4	7.3
4	14.0	10.0	8.7	8.9	12.8	7.0
5	9.0	6.3	6.0	7.5	7.0	4.4
6	12.6	12.9	10.2	11.4	12.0	10.3
Average	11.2	8.4	8.2	8.8	9.0	7.0
	<u>Feed/Gain</u>					
1	1.7	1.7	1.3	1.3	1.3	1.3
2	1.2	1.4	1.4	1.6	1.7	1.4
3	1.5	1.6	1.8	1.7	1.5	1.6
4	1.7	1.4	1.4	1.4	1.4	2.0
5	1.6	1.5	1.6	1.7	1.6	2.1
6	1.7	1.4	1.3	1.4	1.3	1.4
Average	1.6	1.5	1.5	1.5	1.5	1.6

<sup>a</sup>Fats added to the diet at the 20% level.

Table 28. Experiment 6521 - Summary of metabolizable calories/kg. of gain

	Treatment <sup>a</sup>					
	Basal	Butter	Cocoanut Oil	Corn Oil	Hydrolyzed Fat	Lard
Replication						
1	4883	6753	5147	5092	5145	4915
2	5011	5503	5244	6091	6584	5581
3	4291	6015	7022	6514	5853	6095
4	5061	5382	5277	5482	5413	7718
5	4733	5867	6341	6640	5575	8294
6	5009	5327	5131	5405	4881	5310
Average	4831	5808	5694	5871	5575	6319

<sup>a</sup> Fat added to the diet at the 20% level.

Table 29. Experiment 6521 - Average apparent digestibility of fat after 10 and 28 days on experiment

	Treatment <sup>a</sup>					
	Basal	Butter	Cocoanut Oil	Corn Oil	Hydrolyzed Fat	Lard
Replication						
1	-23.4 <sup>b</sup> 64.4 <sup>c</sup>	86.6 85.8	60.3 94.6	90.7 87.4	76.6 91.9	88.4 93.8
2	35.3 49.8	58.7 92.6	62.0 93.8	89.1 86.4	61.2 80.6	81.8 93.8
3	37.3 27.3	56.6 87.4	85.8 55.7	38.8 50.1	86.1 89.7	48.7 69.5
4	49.0 36.9	77.4 94.0	78.5 74.2	78.0 85.0	91.0 88.2	80.4 86.5
5	36.4 42.4	84.0 92.5	95.3 91.4	54.1 75.9	90.1 93.8	88.4 88.7
6	-13.6 -30.3	85.4 88.0	83.7 76.2	86.0 89.0	92.4 90.0	73.6 79.7
Average	20.2 31.9	74.8 90.0	77.6 81.0	72.8 79.0	82.9 89.0	76.9 85.3

<sup>a</sup>Fats added to the diet at a level of 20%.

<sup>b</sup>Apparent digestibility after 10 days on trial.

<sup>c</sup>Apparent digestibility after 28 days on trial.

Table 30. Experiment 6521 - Fatty acid composition of diet and plasma

Diet	Fatty acid, % of total							
	C <sub>12</sub>	C <sub>14</sub>	C <sub>16</sub>	C <sub>16:1</sub>	C <sub>18</sub>	C <sub>18:1</sub>	C <sub>18:2</sub>	C <sub>18:3</sub>
<u>Plasma, 10 days</u>								
Basal	1.1	2.7	30.0	3.1	14.3	33.4	15.4	--
Butter	1.8	4.4	30.1	5.2	12.3	27.8	18.4	--
Cocoanut Oil	9.6	11.4	21.7	2.9	15.5	21.7	17.2	--
Corn Oil	0.7	2.6	21.0	2.2	12.4	21.3	39.8	--
HEF	0.7	1.6	25.2	4.6	15.7	33.6	18.6	--
Lard	0.4	0.9	26.7	4.0	17.1	32.5	18.4	--
Avg.	2.4	3.9	25.8	3.7	14.6	28.4	21.3	--
<u>Diet</u>								
Basal	12.9	3.9	15.6	--	4.0	22.3	40.2	1.1
Butter	4.1	8.9	26.4	2.0	11.3	33.7	11.6	2.0
Cocoanut Oil	40.9	15.9	13.7	0.1	3.7	13.6	12.1	--
Corn Oil	5.0	1.4	34.1	--	6.7	43.7	8.1 <sup>a</sup>	1.0
HEF	2.8	3.1	36.8	2.4	21.4	30.1	3.3	0.1
Lard	0.9	1.4	26.9	1.4	13.9	38.3	17.2	--
Avg.	11.2	4.2	25.7	1.6	10.3	30.3	15.5	1.1
<u>Plasma, 28 days</u>								
Basal	4.0	8.8	29.0	2.5	9.9	28.3	17.5	--
Butter	1.8	8.4	27.5	2.2	10.3	30.1	19.7	--
Cocoanut Oil	6.4	19.1	22.8	3.2	9.6	20.3	18.6	--
Corn Oil	2.4	4.9	18.9	0.6	8.1	20.5	44.6	--
HEF	1.3	4.4	21.8	3.5	11.7	34.5	22.8	--
Lard	1.1	2.6	27.0	2.5	12.2	34.9	19.7	--
Avg.	4.5	8.0	24.5	2.4	10.3	28.1	23.8	--

<sup>a</sup>The value for C<sub>18:2</sub> (linoleic acid) is lower than values reported in the literature.



Table 31. Experiment 6521 - Fatty acid composition of diet and fecal material.

Diet	Fatty acid, % of total							
	C <sub>12</sub>	C <sub>14</sub>	C <sub>16</sub>	C <sub>16:1</sub>	C <sub>18</sub>	C <sub>18:1</sub>	C <sub>18:2</sub>	C <sub>18:3</sub>
<u>Fecal, 10 days</u>								
Basal	6.6	5.8	25.2	4.0	28.9	20.6	6.8	2.3
Butter	5.4	8.1	23.7	3.8	28.0	23.5	6.0	1.4
Cocoanut Oil	11.5	11.9	22.9	2.1	23.7	20.7	5.7	1.4
Corn Oil	2.0	3.2	23.9	1.9	28.9	31.5	6.5	2.3
HEF	2.1	2.6	25.4	3.0	29.0	22.4	4.4	1.3
Lard	2.2	2.2	24.8	3.6	38.1	21.6	4.9	2.7
Avg.	5.0	5.6	24.3	3.1	31.1	23.4	5.7	1.9
<u>Diet</u>								
Basal	12.9	3.9	15.6	--	4.0	22.2	40.2	1.1
Butter	4.1	8.9	26.4	2.0	11.3	33.7	11.6	2.0
Cocoanut Oil	40.9	5.8	13.6	0.1	3.6	13.5	12.1	--
Corn Oil	5.0	1.4	34.2	--	6.7	43.7	8.1 <sup>a</sup>	1.0
HEF	2.8	3.1	36.8	2.4	21.4	30.1	3.2	0.1
Lard	0.9	1.4	26.9	1.4	13.9	38.3	17.1	--
Avg.	11.2	4.2	25.7	1.6	10.3	30.3	15.5	1.1
<u>Fecal, 28 days</u>								
Basal	2.9	4.0	29.3	4.0	27.1	27.8	3.2	1.7
Butter	3.7	8.7	26.1	5.4	34.5	17.5	2.6	1.9
Cocoanut Oil	10.7	15.7	24.2	2.9	25.3	16.9	2.2	2.0
Corn Oil	2.2	3.2	23.4	3.2	37.6	25.6	3.6	2.2
HEF	1.8	3.2	26.6	3.8	40.2	18.8	2.7	2.6
Lard	1.0	2.4	27.5	3.2	44.0	17.6	2.4	2.2
Avg.	3.7	6.2	26.2	3.8	34.8	20.6	2.8	2.1

<sup>a</sup>The value for C<sub>18:2</sub> (linoleic acid) is lower than values reported in the literature.

Table 32. Experiment 6521 - Analysis of variance of average total gain<sup>a</sup>

Source	d.f.	Mean squares
Total	34	5.9200
Replication (Rep.)	5	19.2346**
Treatment (Trt.)*	5	11.3662**
Rep. x Trt.	24	2.0115

\*\*Indicates significant difference at  $P = 0.01$  or less.

<sup>a</sup>Coefficient of variation = 16.19%.

\*Duncan's Multiple Range test was used to test the difference between treatment means. Pigs fed the basal diet gained significantly more than did pigs fed the diets with added fat. Pigs fed HEF gained significantly more than did pigs fed lard.

Table 33. Experiment 6521 - Analysis of variance of feed required per unit of gain<sup>a</sup>

Source	d.f.	Mean squares
Total	34	0.0429
Replication (Rep.)	5	0.0744
Treatments (Trt.)	5	0.0363
Rep. x Trt.	24	0.0377

<sup>a</sup>Coefficient of variation = 12.60%.

Table 34. Experiment 6521 - Analysis of variance of fat digestibility

Source	d.f.	Mean squares
Total	71	724.3225
Age	1	1296.3384*
Replication (Rep.)	5	508.9049
Rep. x Age	5	297.4081
Treatment (Trt.) <sup>a</sup>	5	6179.4106**
Rep. x Trt.	25	397.1743
Age x Trt.	5	55.0994
Age x Rep. x Trt.	25	199.9376

\*Indicates significant difference at  $P \leq 0.05$  or less.

\*\*Indicates significant difference at  $P \leq 0.01$  or less.

<sup>a</sup>Duncan's Multiple Range test was used to test the difference between treatment means. The digestibility of the fat in the basal diet was significantly lower than the digestibility of fat in the supplemented diets.

Table 35. Experiment 6528 - Summary of average total gain and feed required per gain

Added fat, % Diet form	Treatment <sup>a</sup>				Basal (0%) pair fed to 10% fat dry
	0 Dry	10 Dry	0 Liquid	10 Liquid	
Replication	<u>Total Gain, kg.</u>				
1	9.4	6.1	7.9	9.8	6.2
2	7.4	5.8	10.4	3.9	6.2
3	7.6	7.3	10.1	7.5	7.2
4	6.5	5.9	9.1	9.8	5.6
Average	7.7	6.3	9.4	7.8	6.3
	<u>Feed/Gain</u>				
1	1.5	1.6	1.4	1.5	1.6
2	1.6	1.6	1.4	1.9	1.6
3	1.6	1.6	1.4	1.4	1.7
4	1.8	1.8	1.4	1.4	2.0
Average	1.6	1.6	1.4	1.6	1.7

<sup>a</sup>Fat added to the diet at the 10% level.

Table 36. Experiment 6528 - Summary of metabolizable calories per kg. of gain

Added fat, % Diet form	Treatment <sup>a</sup>				Basal (0%) pair fed to 10% fat dry
	0 Dry	10 Dry	0 Liquid	10 Liquid	
Replication					
1	4816	5852	4571	5520	5194
2	5253	5884	4638	7050	5044
3	5120	5830	4555	5160	5595
4	5928	6716	4617	5158	6300
Average	5279	6070	4595	5722	5533

<sup>a</sup>Fat added at the 10% level.

Table 37. Experiment 6528 - Analysis of variance of average total gain and feed<sup>a</sup>

Source	d.f.	Mean squares
Total	77	6.0906
Outcome Groups (O.G.)	15	6.5435
Replication (Rep.)	3	6.0420
O.G./Rep.	12	6.6689
Treatment (Trt.)	4	25.9477
Dry versus liquid	1	37.9610
Fat versus no fat	1	36.9208
Form x fat interaction	1	0.0791
Pair fed basal versus 10% fat dry ad lib.	1	0.0003
O.G. x Trt.	58	4.6039
Rep. x Trt. (Error)	12	10.1509
O.G./Rep. x Trt.	46	3.1569

<sup>a</sup>Coefficient of variation = 21.32%.

Table 38. Experiment 6528 - Analysis of variance of feed required per unit of gain<sup>a</sup>

Source	d.f.	Mean squares
Total	19	0.0301
Replication (Rep.)	3	0.0303
Treatment (Trt.)	4	0.0498
Dry versus liquid	1	0.0961
Fat versus no fat	1	0.0144
Form x fat interaction	1	0.0144
Pair fed basal versus 10% fat dry ad lib.	1	0.0112
Rep. x Trt.	12	0.0235

<sup>a</sup>Coefficient of variation = 9.56%.

Table 39. Experiment 6617 - Summary of average total gain and feed required per unit of gain

Added fat, % Diet form	Treatment <sup>a</sup>					
	0 Dry	10 Dry	0 Liquid	10 Liquid	0 <sup>b</sup> Dry	0 <sup>c</sup> Liquid
Replication	<u>Total Gain, kg.</u>					
1	6.4	5.8	7.5	6.2	6.6	5.5
2	6.4	4.2	6.6	5.5	4.3	4.4
3	9.4	5.4	7.3	8.9	6.7	7.3
Average	7.4	5.1	7.1	6.9	5.9	5.7
	<u>Feed/Gain</u>					
1	1.9	1.9	1.4	1.4	1.7	1.6
2	1.7	2.1	1.6	1.4	2.0	1.9
3	1.7	2.0	1.5	1.4	1.6	1.8
Average	1.8	2.0	1.5	1.4	1.8	1.8

<sup>a</sup>Fat added at the 10% level.

<sup>b</sup>Pair fed to group receiving dry diet containing 10% added fat.

<sup>c</sup>Pair fed to group receiving liquid diet containing 10% added fat.



Table 40. Experiment 6617 - Summary of metabolizable calories per kg. of gain

Added fat, % Diet form	Treatment <sup>a</sup>					
	0 Dry	10 Dry	0 Liquid	10 Liquid	0 <sup>b</sup> Dry	0 <sup>c</sup> Liquid
Replication						
1	6018	6962	4513	5414	5350	4987
2	5460	7630	5227	5341	6409	6228
3	5410	7358	4908	5215	5249	5679
Average	5629	7317	4883	5323	5669	5631

<sup>a</sup>Fat substituted for dextrose at the 10% level.

<sup>b</sup>Pair fed to group receiving dry diet containing 10% added fat.

<sup>c</sup>Pair fed to group receiving liquid diet containing 10% added fat.

Table 41. Experiment 6617 - Analysis of variance of average total gain<sup>a</sup>

Source	d.f.	Mean squares
Total	57	5.8529
Outcome Group (O.G.)	9	10.5352
Replication (Rep.)	2	23.0910
O.G./Rep.	7	6.9478
Treatment (Trt.)	5	7.9101
Within equal fed groups		
Fat versus no fat	1	15.4754
Liquid versus dry	1	3.6482
Interaction	1	20.4270
Among ad lib. fed groups		
Fat versus no fat	1	15.5252
Liquid versus dry	1	4.9280
Interaction	1	19.0974
O.G. x Trt.	43	4.6336
Rep. x Trt. (Error)	10	10.8467
O.G./Rep. x Trt.	33	2.7509

<sup>a</sup>Coefficient of variation = 28.51%.

Table 42. Experiment 6617 - Analysis of variance of feed required per unit of gain<sup>a</sup>

Source	d.f.	Mean squares
Total	17	0.0440
Replication (Rep.)	2	0.0399
Treatment (Trt.)	5	0.1140
Within equal fed groups		
Fat versus no fat	1	0.0065
Liquid versus dry	1	0.2352**
Interaction	1	0.3284**
Among ad lib. fed groups		
Fat versus no fat	1	0.0169
Liquid versus dry	1	0.4524**
Interaction	1	0.1008
Rep. x Trt.	10	0.0142

\*Indicates significant difference at  $P \leq 0.05$  or less.

\*\*Indicates significant difference at  $P \leq 0.01$  or less.

<sup>a</sup>Coefficient of variation = 6.96%.

Table 43. Experiment 6626 - Summary of average total gain and feed required per unit of gain

Protein source	Casein			Soybean Protein		
	0	5	10	0	5	10
Fat level, %						
Replication	Total gain, kg.					
1	4.9	9.3	9.7	4.5	7.8	3.9
2	7.8	8.9	8.4	7.0	7.9	6.2
3	10.3	10.7	8.8	8.0	10.5	8.9
4	9.2	7.8	9.9	4.8	6.8	6.8
5	6.1	7.4	4.5	5.4	4.0	5.0
6	3.2	11.5	9.5	6.3	7.0	6.0
Average	6.9	9.3	8.5	6.0	7.3	6.1
	Feed/Gain					
1	2.6	1.6	1.6	2.3	1.8	2.3
2	1.7	1.7	1.5	2.1	1.7	1.8
3	2.0	1.8	1.6	2.1	1.7	1.7
4	1.8	1.8	1.6	2.3	1.8	1.9
5	2.2	1.8	2.1	2.1	2.6	2.0
6	3.0	1.3	1.6	2.2	2.2	2.1
Average	2.2	1.7	1.7	2.2	2.0	2.0

Table 44. Experiment 6626 - Summary of metabolizable calories per kg. of gain

Protein source	Casein			Soybean Protein		
	0	5	10	0	5	10
Fat level, %						
Replication						
1	7719	4978	5377	6934	5792	7780
2	5101	5342	5027	6336	5351	6103
3	5953	5702	5457	6265	5288	5831
4	5226	5797	5515	6808	5834	6606
5	6641	5895	7122	6328	8370	6673
6	8862	4176	5353	6657	7188	7348
Average	6584	5315	5642	6555	6304	6724

Table 45. Experiment 6626 - Average apparent digestibility of fat after 10 and 28 days on experiment

Protein source	Casein			Soybean Protein		
Fat level, %	0	5	10	0	5	10
Replication						
1	-76.4 <sup>a</sup> -47.4 <sup>b</sup>	93.8 93.2	89.2 86.9	31.6 -211.5	88.2 85.2	95.1 90.2
2	38.4 35.2	86.4 93.1	96.6 96.5	45.9 -173.7	90.3 88.0	96.0 90.7
3	-357.6 70.6	87.9 96.2	96.1 97.3	-54.6 -75.5	91.1 91.6	86.8 95.3
4	27.4 42.2	94.6 98.1	92.5 98.7	-17.6 -229.4	87.2 86.6	92.6 82.0
5	18.4 65.6	91.0 94.2	87.8 96.8	-19.6 -86.2	61.0 82.3	93.2 76.2
6	-106.1 13.2	38.6 70.4	95.2 93.9	-114.6 31.6	79.4 94.2	85.1 90.4
Average	-76.0 29.9	82.0 90.9	92.9 95.0	-15.0 -124.1	82.9 88.0	91.5 87.5

<sup>a</sup>Apparent digestibility after 10 days on trial.

<sup>b</sup>Apparent digestibility after 28 days on trial.

Table 46. Experiment 6626 - Fatty acid composition of diet and plasma

Protein source	Fat level, %	Fatty acid, % of total							
		C <sub>12</sub>	C <sub>14</sub>	C <sub>16</sub>	C <sub>16:1</sub>	C <sub>18</sub>	C <sub>18:1</sub>	C <sub>18:2</sub>	C <sub>18:3</sub>
<u>Plasma, 10 days</u>									
Casein	0	0.02	0.01	17.6	3.2	17.2	46.4	9.0	---
	5	0.13	0.16	22.6	4.9	13.8	46.4	12.0	---
	10	0.16	0.24	19.1	2.4	20.1	46.3	11.8	---
Soybean	0	0.91	0.66	24.7	4.4	13.4	43.6	12.4	---
	5	0.16	0.22	21.2	3.8	15.4	42.5	16.3	---
	10	0.40	0.20	16.8	2.8	13.1	43.8	23.0	---
Avg.		0.30	0.25	20.3	3.6	15.5	44.8	14.1	---
<u>Diet</u>									
Casein	0	---	---	24.8	4.9	23.7	28.9	16.7	---
	5	0.04	0.85	28.5	4.0	17.3	43.0	9.7	1.6
	10	0.02	0.89	24.8	3.2	17.4	41.8	9.8	2.0
Soybean	0	---	---	21.0	1.7	12.5	31.1	30.4	3.3
	5	---	0.71	24.2	3.1	16.3	44.1	9.9	1.6
	10	0.03	0.64	24.6	3.2	17.2	44.5	9.1	0.8
Avg.		0.02	0.52	24.6	3.4	17.4	38.9	14.3	1.6
<u>Plasma, 28 days</u>									
Casein	0	0.08	0.16	15.8	4.7	16.5	57.1	5.6	---
	5	0.15	0.39	20.0	4.9	14.5	45.3	14.7	---
	10	0.06	0.21	18.1	3.5	15.6	45.6	16.9	---
Soybean	0	0.34	0.44	21.6	4.8	11.5	45.3	16.0	---
	5	0.11	0.53	19.4	3.7	13.0	39.4	23.9	---
	10	0.04	0.16	20.4	3.7	13.1	41.1	21.5	---
Avg.		0.13	0.32	19.2	4.2	14.0	45.6	16.4	---

Table 47. Experiment 6626 - Fatty acid composition of plasma

	Fatty acid, % of total						
	C <sub>12</sub>	C <sub>14</sub>	C <sub>16</sub>	C <sub>16:1</sub>	C <sub>18</sub>	C <sub>18:1</sub>	C <sub>18:2</sub>
Protein source							
Casein	0.10	0.18	18.9	4.0	16.3	47.8	11.7
Soybean	0.32	0.37	20.7	3.9	13.3	42.6	18.8
Fat levels							
0	0.34	0.32	20.0	4.3	14.6	48.1	10.7
5	0.13	0.32	20.8	4.3	14.2	43.2	16.8
10	0.12	0.20	18.6	3.1	15.5	44.2	17.8



Table 48. Experiment 6626 - Fatty acid composition of feces

Protein source	Fat level %	Fatty acid, % of total											
		C <sub>12</sub>	C <sub>13</sub>	C <sub>14</sub>	C <sub>14:1</sub>	C <sub>15</sub>	C <sub>16</sub>	C <sub>16:1</sub>	C <sub>17</sub>	C <sub>18</sub>	C <sub>18:1</sub>	C <sub>18:2</sub>	C <sub>18:3</sub>
10 days													
Casein	0	0.05	0.04	1.3	3.0	3.1	28.4	2.2	2.2	49.3	8.3	0.9	1.2
	5	0.04	0.04	0.9	1.0	0.9	24.0	0.6	1.0	59.3	10.8	0.4	1.1
	10	0.02	--	0.5	0.3	0.3	27.8	0.5	0.6	54.8	13.3	0.8	1.1
Soybean	0	0.04	0.04	1.0	2.0	3.3	27.8	0.9	1.2	45.6	14.8	2.0	1.2
	5	0.04	0.02	0.5	0.8	1.5	25.7	0.6	0.7	56.3	11.3	1.1	1.4
	10	0.02	0.01	0.5	0.4	0.7	26.1	0.4	0.8	58.1	11.9	0.2	0.7
Avg.		0.04	0.02	0.8	1.2	1.6	26.6	0.9	1.1	53.9	11.7	0.9	1.1
28 days													
Casein	0	0.13	0.07	0.6	2.1	2.2	33.0	1.4	1.5	50.4	6.7	0.8	1.3
	5	0.02	0.01	0.5	1.2	1.2	24.4	0.4	0.6	62.2	7.4	0.1	1.0
	10	0.02	0.02	0.5	1.2	0.7	24.0	0.5	0.6	63.1	7.9	0.3	1.3
Soybean	0	0.04	0.04	0.4	3.6	4.0	24.1	1.4	1.3	51.0	10.6	1.7	1.7
	5	--	--	0.3	0.8	1.2	25.3	0.6	0.7	58.3	11.7	0.8	0.4
	10	0.01	0.01	0.3	0.5	0.8	25.6	0.2	0.6	60.0	10.2	0.5	1.4
Avg.		0.04	0.02	0.4	1.6	1.7	26.1	0.8	0.9	57.5	9.1	0.8	1.2

Table 49. Experiment 6626 - Fatty acid composition of feces

	Fatty acid, % of total											
	C <sub>12</sub>	C <sub>13</sub>	C <sub>14</sub>	C <sub>14:1</sub>	C <sub>15</sub>	C <sub>16</sub>	C <sub>16:1</sub>	C <sub>17</sub>	C <sub>18</sub>	C <sub>18:1</sub>	C <sub>18:2</sub>	C <sub>18:3</sub>
Protein source												
Casein	0.05	0.03	0.7	1.5	1.4	26.9	0.9	1.1	56.5	9.1	0.6	1.2
Soybean	0.02	0.02	0.5	1.4	1.9	25.8	0.7	0.8	54.9	11.8	1.0	1.1
Fat levels												
0	0.06	0.05	0.8	2.7	3.2	28.3	1.5	1.6	49.1	10.1	1.4	1.4
5	0.02	0.02	0.6	1.0	1.2	24.8	0.6	0.8	59.0	10.3	0.6	1.0
10	0.02	0.01	0.4	0.6	0.6	25.9	0.4	0.6	59.0	10.8	0.4	1.1

Table 50. Experiment 6626 - Analysis of variance for average total gain<sup>a</sup>

Source	d.f.	Mean square
Total	35	4.7658
Replication (Rep.)	5	11.2158**
Treatment (Trt.)	5	10.1585**
Casein versus Soybean	1	27.1962**
Fat levels	2	10.1530*
Linear	1	4.2504
Quadratic	1	16.0556**
Protein x fat interaction	2	1.6452
Protein x fat linear	1	3.1393
Protein x fat quadratic	1	0.1512
Rep. x Trt.	25	2.3973

\*Indicates significant difference at  $P = 0.05$  or less.

\*\*Indicates significant difference at  $P = 0.01$  or less.

<sup>a</sup>Coefficient of variation = 21.06%.

Table 51. Experiment 6626 - Analysis of variance of feed required per unit of gain<sup>a</sup>

Source	d.f.	Mean squares
Total	35	0.1325
Replication (Rep.)	5	0.1560
Treatment (Trt.)	5	0.3886**
Casein versus Soybean	1	0.3969*
Fat levels	2	0.6689**
Linear	1	1.0375**
Quadratic	1	0.3003
Protein x fat interaction	2	0.1040
Protein x fat linear	1	0.1584
Protein x fat quadratic	1	0.0496
Rep. x Trt.	25	0.0765

\*Indicates significant difference at  $P = 0.05$  or less.

\*\*Indicates significant difference at  $P = 0.01$  or less.

<sup>a</sup>Coefficient of variation = 14.28%.

Table 52. Experiment 6626 - Analysis of variance for fat digestibility<sup>a</sup>

Source	d.f.	Mean squares
Total	70	81358.25
Age	1	38.43
Replication (Rep.)	5	1846.74
Rep. x Age	5	8897.84*
Treatment (Trt.)	5	61118.23**
Casein vs. Soybean	1	5411.47
Fat levels	2	146247.42**
Linear	1	228528.00**
Quadratic	1	63966.84**
Protein x Fat Interaction	2	3842.42
Protein x fat linear	1	5292.00
Protein x fat quadratic	1	2392.84
Rep. x Trt.	25	2415.54
Age x Trt.	5	13944.13
Age x Rep. x Trt.	24	3335.26

\*Indicates significant difference at  $P = 0.05$  or less.

\*\*Indicates significant difference at  $P = 0.01$  or less.

<sup>a</sup>Coefficient of variation = 112.20%.

Table 53. Experiment 6626 - Analysis of variance for fat digestibility<sup>a</sup>

Source	d.f.	Mean squares
Total	46	108.65
Age	1	108.90
Replication (Rep.)	5	178.48
Rep. x Age	5	60.59
Treatment (Trt.)	3	175.69
Casein vs. Soybean	1	91.57
Fat levels	1	399.63
Protein x Fat Interaction	1	35.88
Rep. x Trt.	15	154.64
Age x Trt.	3	88.09
Age x Rep. x Trt.	14	41.60

<sup>a</sup>Coefficient of variation = 14.00%.

Table 54. Experiment 6701 - Summary of relative lipase activity and specificity

	Substrate				Average
	Tributyrin	Butter	Cocoanut Oil	Lard	
Age, weeks					
2	5117	537	811	182	1662
8	6583	542	848	217	2048
Average	5850	540	830	200	

Table 55. Experiment 6701 - Summary of relative lipase activity and specificity

Run	Age Week	Substrate, $\mu$ eq. acid/min./gm. wet tissue			
		Tributyrin	Butter	Cocoanut Oil	Lard
1	2 <sup>a</sup>	7,718	549	1,460	304
	8	10,087	693	1,360	326
2	2	13,636	603	2,056	512
	8	12,719	705	1,594	533
3	2	6,766	872	1,174	283
	8	14,385	1,062	1,757	460
4	2	13,522	1,708	1,978	418
	8	20,246	1,771	2,361	661
5	2	12,053	1,420	1,851	446
	8	13,230	1,217	1,851	434
6	2	9,634	1,192	1,424	354
	8	13,106	1,183	1,727	376
7	2	8,310	1,175	1,416	236
	8	8,387	953	1,221	252

<sup>a</sup> Represents the total of two pigs for each age within a run.



Table 56. Experiment 6701 - Analysis of variance of lipase activity and specificity<sup>a</sup>

Source	d.f.	Mean squares
Total	111	6,703,408
Pigs	27	1,837,246
Age	1	4,160,701
Runs	6	3,167,645
Age x Run	6	882,242
Pigs/Age/Run	14	1,510,401**
Substrates (Sub.)	3	200,494,325**
Tributyrin versus butter, cocoanut oil and lard	1	595,918,172**
Cocoanut oil versus butter	1	1,179,431
Butter versus lard	1	1,614,322
Cocoanut oil versus lard	1	5,553,450*
Sub. x Pig (Error)	81	1,148,021
Sub. x Age	3	3,632,349**
Sub. x Run	18	1,827,498*
Sub. x Age x Run	18	889,212
Sub. x Pigs/Age/Run	42	790,282

\*\*Indicates significant difference at  $P = 0.01$  or less.

\*Indicates significant difference at  $P = 0.05$  or less.

<sup>a</sup>Coefficient of variation = 9.11%.

Table 57. Experiment 6701 - Analysis of variance of lipase specificity

Source	d.f.	Mean squares
Total	83	102,577
Pigs	27	73,223
Age	1	13,528
Runs	6	164,384
Age x Runs	6	22,792
Pigs/Age/Run	14	60,032
Substrates (Sub.)	2	2,782,402**
Butter versus cocoanut oil	1	1,179,431**
Butter versus lard	1	1,614,323**
Cocoanut oil versus lard	1	5,553,450**
Sub. x Pig (Error	54	18,001
Sub. x Age	2	2,262
Sub. x Run	12	44,941
Sub. x Age x Run	12	21,284
Sub. x Pig/Age/Run	28	6,172

\*\*Indicates significant difference at  $P = 0.01$  or less.

Table 58. Experiment 6710 - Summary of fat digestibility of sow milk<sup>a</sup>

	Pig Number									
	1	2	3	4	5	6	7	8	9	10
Milk intake, liquid (gm)	610	1131	1534	986	989	417	709	1239	1011	449
Milk intake, solids (gm)	123.9	229.8	311.7	200.4	201.0	84.7	144.1	251.8	205.4	91.2
Fat intake, gm	5.35	9.93	13.46	8.66	8.68	3.66	6.22	10.88	8.88	3.94
Fecal material, dry (gm)	2.844	3.171	1.612	2.533	2.576	3.856	3.739	4.268	2.970	2.727
Fat content of feces, %	9.45	6.98	10.27	6.75	7.80	10.50	4.94	16.10	23.04	12.36
Fat excretion, gm	0.269	0.221	0.166	0.171	0.201	0.405	0.185	0.687	0.684	0.337
Digestibility, %	94.97	97.77	98.77	98.02	97.68	88.93	97.02	93.68	92.30	91.45

<sup>a</sup>Sow milk contained 20.32 percent solids and 4.32 percent fat.