The influence of the dietary addition of dihydroxyacetone and pyruvate on carcass fat accumulation in growing-finishing swine

by Tamara Lynn Ferguson

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Animal Science
Montana State University

Abstract:
Decreasing the fat content of pork will make it a more attractive meat product to the consumer. Two triose compounds, dihydroxyacetone and pyruvate, were examined for possible positive effects on lowering the fat accumulation in growing-finishing swine. Two experiments were conducted; Experiment no. 1 had 24 pigs weighing 80-85 kg initially, Experiment no. 2 had 44 pigs weighing 73-84 kg initially. In Experiment no. 1, pigs were assigned to one of two diets, a nutritionally adequate basal corn-soybean meal diet plus Polycose , a glucose polymer (control) or a 3:1 mixture of dihydroxyacetone and pyruvate (DHA:PYR). In Experiment no. 2, pigs were assigned to one of four diets, the same basal diet plus PolycoseR, DHA:PYR, dihydroxyacetone (DHA), or pyruvate (PYR). The trioses and the PolycoseR replaced 4% of each diet or 3.85% of the total calories of each diet. Weight gain, average daily gain, and feed intake were the same for all the diets within each trial ($P > .05$). In Experiment no. 1, the DHA:PYR-fed pigs showed reduced back fat measurements at the first (15%) and tenth rib (12%) and average back fat was reduced 12% ($P < .05$). In Experiment no. 2, the pigs showed no reduction in back fat measurements. There were no differences in leaf fat within each experiment. In Experiment no. 1 there were no differences in belly measurements (untrimmed and trimmed weights and percent of cold carcass of each), but in Experiment no. 2, the DHA-fed pigs had the lowest belly measurements. Muscle accumulation as measured by loin eye area and lean cut amounts was not sacrificed. In both experiments loin eye areas were the same. In Experiment no. 1 untrimmed lean cuts were the same and percent trimmed lean cuts were greater in the triose-fed pigs, 57.7% vs. 55.3% ($P < .02$). In Experiment no. 2 trimmed lean cuts of the DHA-fed pigs were the greatest (48.2 kg) vs. PYR-fed pigs (44.0 kg) and control pigs (44.6 kg) and percent trimmed lean cuts were greatest in the DHA-fed pigs (59.2%), followed by the PRY-fed pigs (56.8%), and the least in the control pigs (56.5%; $P < .05$). Laboratory analysis of leg and loin samples taken in Experiment no. 1 showed a decrease ($P < .01$) in percent fat with a corresponding increase in percent protein. Organ weights and blood biochemical profile were unaltered by the feeding of the trioses in Experiment no. 1 and in Trials 1 and 2 of Experiment no. 2. In Experiment no. 1, the triose-fed pigs showed an increased ($P < .05$) serum glutamic pyruvic transaminase (SGPT), but in experiment no. 2, the pigs on the three different triose diets showed no increase in SGPT. In Experiment no. 1, the triose-fed pigs showed an overall decrease in carcass fat accumulation. However, in Experiment no. 2, Trials 1 and 2, the feed containing DHA became heat-damaged by the occurrence of the Maillard reaction, making conclusions difficult. The Maillard reaction is a nonenzymatic browning reaction that occurred between the carbonyl group of the DHA and the free amino groups of the diet's protein, causing some of the amino acids to become unavailable to the animal. Consequently, the DHA- and the DHA:PYR-fed pigs in Trials 1 and 2 showed reduced growth and were not included for comparisons in Experiment no. 2.

THE INFLUENCE OF THE DIETARY ADDITION OF DIHYDROXYACETONE AND PYRUVATE ON CARCASS FAT ACCUMULATION IN GROWING-FINISHING SWINE

by

Tamara Lynn Ferguson

A thesis submitted in partial fulfillment
of the requirements for the degree

of

Master of Science

in

Animal Science

MONTANA STATE UNIVERSITY
Bozeman, Montana

December, 1989

APPROVAL

of a thesis submitted by

Tammy L. Ferguson

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

December 4, 1989 — C W Newman

Date — Chairperson, Graduate Committee

Approval for the Major Department

December 4, 1989 — Arthur C. Linton

Date — Head, Major Department

Approval for the College of Graduate Studies

December 15, 1989 — Henry L Parsons

Date — Graduate Dean

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a master's degree at Montana State University, I agree that the Library shall make it available to borrowers under the rules of the Library. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgement of source is made.

Permission for extensive quotation from or reproduction of this thesis may be granted by my major professor, or in his absence, by the Dean of Libraries when, in the opinion of either, the proposed use of the material is for scholarly purposes. Any copying or use of the material in this thesis for financial gain shall not be allowed without my written permission.

Signature Tammy L. Ferguson

Date Dec. 9th 1989

ACKNOWLEDGMENTS

I would like to express my sincere thanks to Dr. C. W. Newman, my advisor and friend, for his advice and encouragement throughout my graduate program. I would also like to thank Dr. Rosemary Newman, Dr. Kris Havstad and Dr. Mark Petersen for serving on my graduate committee and for their guidance.

Special thanks go to Dr. Nancy Roth and Ms. Petrea Hofer for their many hours of patient and helpful assistance at the MSU Nutrition Center laboratory and to Mr. Delbert Elliott and Mr. Joe Pepper for all their help at the MSU Swine Center. I would also like to thank Dr. Doug Gray and Dr. Wayne Gipp for their help at the MSU Meats laboratory. Appreciation is also expressed to Dr. Ron Stanko at Montefiore Hospital, Pittsburgh, Pennsylvania for his advice with and for his expert assistance in data analysis.

This research was supported in part by a grant from Ross Laboratories, Columbus, Ohio. A special thanks is given to Dr. A. L. Hecker and Dr. Robert Miller of Ross Laboratories for their contributions to the success of this research.

I especially wish to thank my husband and my family for their encouragement and moral support throughout my graduate studies.

TABLE OF CONTENTS

TABLE OF CONTENTS - Continued

LIST OF TABLES

LIST OF TABLES - continued

ABSTRACT

Decreasing the fat content of pork will make it a more attractive meat product to the consumer. Two triose compounds, dihydroxyacetone and pyruvate, were examined for possible positive effects on lowering the fat accumulation in growing-finishing swine. Two experiments were conducted; Experiment no. 1 had 24 pigs weighing 80-85 kg initially, Experiment no. 2 had 44 pigs weighing 73-84 kg initially. In Experiment no. 1, pigs were assigned to one of two diets, a nutritionally adequate basal corn-soybean meal diet plus Polycose^R, a glucose polymer (control) or a 3:1 mixture of dihydroxyacetone and pyruvate (DHA:PYR). In Experiment no. 2, pigs were assigned to one of four diets, the same basal diet plus Polycose^R, DHA:PYR, dihydroxyacetone (DHA), or pyruvate (PYR). The trioses and the Polycose^R replaced 4% of each diet or 3.85% of the total calories of each diet. Weight gain, average daily gain, and feed intake were the same for all the diets within each trial ($P > .05$). In Experiment no. 1, the DHA:PYR-fed pigs showed reduced back fat measurements at the first (15%) and tenth rib (12%) and average back fat was reduced 12% ($P < .05$). In Experiment no. 2, the pigs showed no reduction in back fat measurements. There were no differences in leaf fat within each experiment. In Experiment no. 1 there were no differences in belly measurements (untrimmed and trimmed weights and percent of cold carcass of each), but in Experiment no. 2, the DHA-fed pigs had the lowest belly measurements. Muscle accumulation as measured by loin eye area and lean cut amounts was not sacrificed. In both experiments loin eye areas were the same. In Experiment no. 1 untrimmed lean cuts were the same and percent trimmed lean cuts were greater in the triose-fed pigs, 57.7% vs. 55.3% ($P < .02$). In Experiment no. 2 trimmed lean cuts of the DHA-fed pigs were the greatest (48.2 kg) vs. PYR-fed pigs (44.0 kg) and control pigs (44.6 kg) and percent trimmed lean cuts were greatest in the DHA-fed pigs (59.2%), followed by the PRY-fed pigs (56.8%), and the least in the control pigs (56.5%; $P < .05$). Laboratory analysis of leg and loin samples taken in Experiment no. 1 showed a decrease ($P < .01$) in percent fat with a corresponding increase in percent protein. Organ weights and blood biochemical profile were unaltered by the feeding of the trioses in Experiment no. 1 and in Trials 1 and 2 of Experiment no. 2. In Experiment no. 1, the triose-fed pigs showed an increased ($P < .05$) serum glutamic pyruvic transaminase (SGPT), but in experiment no. 2, the pigs on the three different triose diets showed no increase in SGPT. In Experiment no. 1, the triose-fed pigs showed an overall decrease in carcass fat accumulation. However, in Experiment no. 2, Trials 1 and 2, the feed containing DHA became heat-damaged by the occurrence of the Maillard reaction, making conclusions difficult. The Maillard reaction is a nonenzymatic browning reaction that occurred between the carbonyl group of the DHA and the free amino groups of the diet's protein, causing some of the amino acids to become unavailable to the animal. Consequently, the DHA- and the DHA:PYR-fed pigs in Trials 1 and 2 showed reduced growth and were not included for comparisons in Experiment no. 2.

CHAPTER I

INTRODUCTION

Pigs are produced for a source of income and food for human consumption. Pork possesses many nutrients, including high quality protein, essential fatty acids, water-soluble vitamins, and many trace minerals, making it a desirable food source for humans. Like most animal products, pork is high in total protein, providing an excellent balance of essential amino acids. While many plant proteins are deficient in lysine, tryptophan, methionine, and cystine, pork is abundant in these important amino acids. Pork in the human diet can greatly improve the quality of protein for better growth, maintenance and good health. The water-soluble vitamin content of pork is high compared to that of most foods. Pork is especially high in thiamin and like most meat and dairy products, pork is high in vitamin B_{12}, riboflavin and niacin. Pork and especially pork liver, is a good source of vitamin A. These vitamins are important for good health and proper growth.

Pork is relatively high in fat compared to most plant products. The relationship between dietary fat and heart disease is controversial. It has often been assumed that animal fats are the major cause of atherosclerosis, but numerous studies have failed to incriminate the diet as the sole cause of heart disease (Pagenkopf, 1988). Regardless of this question's outcome, the U.S. pork producers have responded to this probable relationship by reducing the amount of carcass fat dramatically over the past 25 years. An important consideration regarding fat in pork is its fatty acid composition. Consumers desire food products low in saturated fats and cholesterol and high in polyunsaturated fats. Pork is higher in polyunsaturated fatty acids than beef, lamb, or milk and is lower in cholesterol than butter, cheddar cheese, eggs, organ meats, and many seafoods (Watt and Merrill, 1963). Up to 18% of the total fatty acids in pork fat is made up of linoleic acid, linolenic acid, and arachidonic acid, all of which are polyunsaturated (Pond and Maner, 1984). The fatty acid composition of pork can be altered easily by the fatty acids in the pigs diet. Dietary polyunsaturated fat can increase the percentage of polyunsaturated fat in the meat, allowing the producer to meet the consumer demands. Care must be taken not to feed too high a level of unsaturated fats resulting in a soft, watery carcass, which is undesirable and difficult to process and market.

Pork is nutrient dense, providing many essential nutrients, without containing excessive calories. However, pork has a reputation for being high in fat. In order to make this excellent food source a more desirable product, the total fat must be reduced. By making pork a more consumer acceptable product, it is predictable that salability would increase. Today, producers are taking more interest in producing lean, meaty hogs. Lean pigs grow more efficiently and are more economical to produce because they take less feed per pound of gain (Cunha, 1977; Kauffman, 1987). The cost of feed represents approximately 60-80% of the total cost of producing pork and a lean pig requires about two-thirds as much feed per unit of gain as a fat type pig (Cunha, 1977). Excess trimmable fat in pork is undesirable because of its high cost to producers, its low consumer acceptability, and the price paid for separable fat is very low compared to the price paid for lean meat. The producer receives a premium for leaner hogs because the packers are changing their specifications in favor of leaner carcasses. Retailers are showing more concern about marketing lean meat because of consumer demand. As a result of current advertising trends and health awareness media, consumers are buying food products with less fat and reduced cholesterol.

Reduction of fat content in pork still needs to be made. The U.S. consumer demands less fat in meat products and until this decrease is realized, the level of pork consumption will probably continue to decline and most certainly will not increase substantially. Pork producers need to concentrate on breeding and management programs to produce lean, meaty pigs. Pigs and their carcasses vary widely in their composition. Some are trim while others are fat, and some are muscular while others are angular. Muscle content can vary up to 20% in live hogs and up to 30% in their carcasses (Kauffman, 1987). This variation can result from heredity and genetic selection, environmental differences, and/or feeding and management practices.

The research reported herein deals with feeding two triose carbohydrates, dihydroxyacetone and pyurvate to finishing swine in an attempt to reduce body fat accumulation.

The objectives of this research were:

1) To determine if a 3:1 mixture of dihydroxyacetone and pyruvate fed at a 4% level of the diet to finishing swine would inhibit fat

accumulation without reducing muscle protein accretion or feed efficiency.

2) To determine if dihydroxyacetone or pyruvate alone fed at a 4% level of the diet would reduce fat accumulation compared to feeding the 3:1 mixture of these two compounds.

CHAPTER II

LITERATURE REVIEW

The first section of this literature review presents some factors affecting the quantity of carcass fat in swine, such as breed, sex, diet and environmental conditions. This section also explains some of the different methods of influencing fat accumulation in swine, including genetic selection, manipulation of the diet, and the use of nutrient and subcutaneous repartitioning agents.

The second section of this review deals with the triose compounds, dihydroxyacetone and pyruvate, used in the feeding trials reported herein. A description of the trioses and their usefulness as lipotropic agents is included, as well as the possible metabolic aspects that might be involved. Also presented is the use of the triose compounds in clinical nutrition and other areas of human study. Finally, an explanation of how heat-damaged feed caused by the occurrence of the Mailard reaction between one of the trioses and the amino acids in the feed influenced the outcome of some of the research presented herein.

Genetic Selection

Through the use of genetic selection, considerable improvement of the carcass quality of hogs has been made over the past 25 years. Comparing 1950 to the present, there has been an average 21 pound decrease in lard and an average 29 pound increase in lean pork cuts per 240 pound carcass (Cunha, 1977). This accomplishment has been primarily brought about by breeding and genetic selection for leaner, meatier hogs. Carcass quality traits are highly heritable. Cunha (1977) reported estimates of heritability for carcass back fat thickness and yield of lean cuts in swine to be 38% and 29%, respectively and Kennedy et al., (1985) reported heritability for carcass back fat to be as high as 40-61%, depending on the breed and the individual animal.

Fortin and Elliot (1985) attempted to estimate how a reduction in back fat thickness would be expected to influence the distribution and partitioning of protein and fat in the body. A reduction in back fat thickness was accompanied by a decrease in total body fat (126.2 g/mm of back fat for the subcutaneous fat depot and 20.4 g/mm of back fat for the perinephric - retroperitoneal fat depot). These researchers also found that after generations of selecting for pigs with good growth rates and low back fat measurements, there was a decrease in total body fat and an increase in total body protein. The increase in total body protein was most dramatic in the edible meat component of the total carcass, making those carcasses more desirable.

In the effort to produce leaner, meatier pigs, animal breeders should use caution not to sacrifice animal health and reproductive ability. Some pigs have been bred to the point where they are too heavy in the ham and loin area and too light in the shoulder and rib cage. These animals are encountering problems during the latter part of growth due to lack of lung, heart, and digestive tract capacity (Pond and Maner, 1984). Maternal qualities have also suffered because of the selection for meatiness taking precedence over selection for all other desirable qualities. Extremes in leanness and heavy muscling in swine are not compatible with superior maternal performance and producers are shifting back to producing replacement females superior in mothering ability but somewhat lacking in good carcass composition (Kauffman, 1987). Many important characteristics must be selected for and maintained while selecting for a meat-type animal as well as selecting for carcass leanness.

In the past, some heavy muscled pigs have been susceptible to pork stress syndrome (PSS). This is an acute shock-like syndrome, often resulting in death. It is associated with stressing the pigs during moving and handling, especially during warm weather. Approximately 70% of PSS swine produce pale soft exudative pork (PSE) (Cunha, 1977). Soft pork is not a desirable product and should be selected against, even at the expense of producing less muscle. Another concern is that along with reducing back fat some of the intramuscular fat has also been reduced to the point of creating a dry, less tasty pork product (Pond and Maner, 1984). Carcass evaluation needs to be included in selection programs to prevent this problem.

Breed Differences

The breed of a pig can have a major influence on its performance and carcass qualities. One breed may be more suited for reproduction and maternal ability, while another breed may have outstanding carcass qualities. However, there are often more differences in carcass composition within breeds than between breeds. Line differences or within breed differences as well as breed differences in carcass quality are due to the genetic background of the individual animals.

Different strains of pigs grow at different rates, respond differently to dietary ingredients, and reach market weight with different body compositions. In an experiment done by Bayley and Summers (1968) using four strains of pigs, Landrace, Yorkshire, Lacombe, and a Landrace x Hampshire cross, they found that the Landrace strain gained the slowest of the three and that when dietary protein was increased, the Landrace and the crossbreds did not grow faster as did the Yorkshires and Lacombes. The proportion of bone in the carcass is also influenced by breed. For example, the Pietrain and Belgian Landrace types have a more favorable lean:bone ratio as compared with the Large White breed (Whittemore, 1986). There are many different breeds of pigs and each breed possesses certain distinctive qualities. However, the underlying difference is the genetic make-up of the individual.

Sex Differences

There are differences in carcass composition due to sex (Whittemore, 1986). Boars are leaner than barrows (castrated males) and gilts are leaner than barrows. At equal fatness, boars have lower concentrations of lipid and higher concentrations of water in their back fat than castrates. The different sexes show slight differences between their fatty acid composition. Although gilts are usually leaner than barrows, the fatty acid composition of their back fat appears to be similar. These differences in body fat and fatty acid composition do not appear to affect tenderness or tastiness (Pond and

Maner. 1984).

Pigs of different sexes respond differently to nutrients in the diet. Hale and Southwell (1967) and Burris et al. (1987) found that barrows were less demanding in their protein requirements than gilts, indicating collection of experimental data should be done separately for the different sexes. Bayley and Summers (1968) reported that boars grew significantly faster than gilts and that boars responded to increased protein levels by increasing their gain, whereas the gilts did not. In this same experiment, it was found that gilts required less feed per pound of gain than the boars and that an increase in level of dietary protein reduced the amount of feed required per pound of gain by the boars, but not the gilts. Smith et al. (1967) showed that gilts were more responsive to improvements in the level and type of protein than were barrows. The plateau for daily lean tissue growth rate is dependent on the sex as well as the strain of the pig (Whittemore 1986).

Environmental Differences

Environmental conditions may affect the nutrient levels needed in the diet of growing pigs (Mitchell et al., 1950). Seasons appear to have an effect on the level of dietary protein consumed by growing pigs. When diets containing different levels of protein were fed ad libitum to pigs, pigs on a high protein diet consumed more in the winter and less in the summer, but exactly the opposite response occurred with pigs fed a low protein diet (Agarwala and Sundaresan, 1956). Moustgaard (1962) found that during cold weather pigs deposited more back fat and excreted more nitrogen than in warm weather. In this study the pigs were limited in their feed intake, which may have shifted the use of the dietary protein to be used as a source of energy. The increase in nitrogen excretion was probably due to the animals using the amino acid carbon chains for energy and excreting the nitrogen portion of the amino acids as waste.

Temperature can have a positive or negative affect on the growth rate and carcass quality of growing pigs. Seymour et al. (1964) found that pigs housed in 16°C temperatures grew significantly faster than pigs in 32°C temperatures and that pigs housed at 2°C required significantly more feed per unit of gain than those housed at 16°C. Fuller and Boyne (1971) fed the necessary quantity of feed to pigs at 5°C and 13°C to maintain the same rate of gain as those kept at moderate temperatures; the pigs kept at 5°C showed fatter carcasses than those kept at 23°C. But, when the pigs were fed the same quantity of feed growth of the pigs kept in the cooler environment was reduced, however there were no differences in carcass composition. Holmes (1971) found carcass length to be longer in pigs kept at higher temperatures, which was in agreement with the findings of Holme and Coey (1967). Several studies have suggested that at temperatures exceeding approximately 29°C, pig activity is depressed and feed consumption is decreased (Seymour et al., 1964). This depression and lack of appetite might have a negative affect on growth as well as carcass quality.

The number of pigs maintained together interacts with the stress caused by extremely hot or cold temperatures. During hot weather, animal density per group should be decreased and conversely during cold weather, should be increased. Crowding can result in increased incidence of stomach ulcers and fatalities associated with pigs that are genetically susceptible to porcine stress syndrome (Pond and Maner, 1984). Stressed and poor-doing pigs display carcasses of inferior quality.

Poor ventilation resulting in the build-up of noxious gases and contaminants can result in poor health and reduced performance in pigs (Pond and Maner. 1984). Humidity has little effect on pig performance until it exceeds 85% during hot weather when it can depress activity and daily gain, and ultimately reduce carcass quality (Pond and Maner, 1984). Variations in light intensity or exposure appear to have little effect on performance of growing-finishing pigs, except for a trend of improved feed utilization with extended periods of darkness (Pond and Maner, 1984).

Marketing Strategies

Weight at time of slaughter has a major affect on body composition and carcass quality of market hogs. As a pig grows, the percent of body protein declines and the percent of fat increases. The weight of lean cuts are greater from pigs marketed at heavier weights, but the percentage of lean cuts declines because of increasing fatness (Pond and Maner, 1984). However, contemporary market hogs that have been selected for leanness can be fed to heavier market weights without sacrificing the percentage of lean cuts (Kauffman, 1987).

Overall the wholesale value of lean meat from lightweight pigs is greater, but the higher processing costs does not justify slaughtering pigs at a lighter weight (Pond and Maner, 1984).

The Diet

Fatness itself is not related to age and weight, but is a direct function of the level of nutrients supplied in relation to the level of nutrients needed. The level of nutrients needed are the requirements for maintenance plus the requirements for maximizing daily tissue deposition as dictated by the animals genetic composition. Fattening takes place when the protein and/or energy in the diet exceeds the need by the animal to maximize protein accretion. Improving the diet by increasing the proportion of protein in relation to energy will usually reduce fatness. When the protein supply is inadequate, the dietary energy that is not used for lean tissue growth will be deposited as fat (Whittemore, 1986).

The single, most important determinant of variation in the composition of growing pigs is the total quantity of food consumed. Fat deposition occurs in excess only when the food supply exceeds the need for maintenance, maximum potential lean tissue growth, and the minimum balance of fat in normal growth (Whittemore, 1986). Ideally, pigs are fed to reach their plateau for lean tissue accretion without encouraging excessive fat deposition.

Simultaneous fat catabolism and protein anabolism is a sign of growth under nutritional stress and should be avoided. While these nutritionally stressed animals may lose total body fat, but not muscle protein, subsequent gains will be sacrificed for lean growth as well as for fatty tissue growth (Whittemore, 1986). Slow growth is expensive growth and should not be encouraged.

Dietary Protein

Carcass leanness is affected by the level of protein in the diet. Lean deposition increases when higher levels of protein are fed. Although pigs can produce maximum lean meat only if provided adequate protein (with a proper balance of amino acids), this increase in lean deposition cannot exceed the animal's genetic capacity. Pigs fed a higher level of protein (14-20%) not only displayed carcasses with higher percent of lean, but also had less carcass back fat than pigs fed a lower percent protein (10-16%) (Seymour et al., 1964). Pigs fed the higher levels of protein required less feed per pound of gain compared to the pigs on the lower levels of protein. These results agree with other researchers who found that pigs fed a low protein diet throughout the growing-finishing period performed poorer and yielded carcasses that were inferior to those of pigs fed high protein diets (Gilster and Wahlstrom, 1973; Davey, 1976; Hale and Newton,1986). Cunningham et al. (1973) and Gilster and Wahlstrom (1973) found that feeding low protein diets resulted in increased back fat, decreased loin eye areas, and decreased percentage of lean cuts.

Jesse (1982) reported that all protein supplementation could be removed from a corn-based finishing diet for a 9 kg increment in gain without affecting performance or carcass quality, if it is removed after the pigs reach 91 kg body weight. Shields and Mahan (1980) also reported that a temporary moderate protein restriction can be placed on pigs in the finishing phase without adversely affecting gain or carcass quality. Pigs fed an alternating high protein diet and low protein diet for two week intervals during the growing-finishing phase did not show a difference in weight gain, but did show a decrease in feed conversion and an increase in back fat thickness (Hale and Newton, 1986).

Lysine is generally the first limiting amino acid in most swine diets. If lysine is limiting, a portion of the other essential amino acids will be used as a source of energy, possibly causing an increase in fat deposition and a concurrent decrease in muscle protein deposition. Evidence for this theory was shown by Bayley and Summers (1968) when they measured increased fecal nitrogen in swine fed low levels of lysine. This effect would probably be seen when any of the essential amino acids were limiting in the diet, since all must be provided in the proper ratios for maximum utilization. Therefore, it is important to have a proper balance of amino acids as well as an adequate amount of total protein in the diet of growing-finishing swine to ensure good carcass quality. It is also important to maintain a good rate of gain when a high protein diet is used to increase carcass quality.

Dietary Energy

Restriction of feed intake of swine has been a standard practice in some European countries for many years. Restricted feed intake may improve carcass quality by reducing carcass fat. However, pigs on a restricted diet can take longer to reach market weight due to a slower rate of gain. A certain amount of energy is required for normal lean tissue growth (Whittemore, 1986).

A fat-type pig will respond best to limited feeding by showing the greatest improvement in carcass quality vs a lean-type pig. Restriction of the total energy intake can be accomplished either by restricting the total diet offered or by feeding a high-fiber, low-energy diet ad libitum (Greer et al., 1965). These authors discovered that with increasing levels of feed, there was a linear increase in average daily gain and in back fat thickness and a linear decrease in percent of lean cuts. In this same study it was found that as the level of feeding increased, the amount of saturated fatty acid deposition in the back fat increased, and the amount of unsaturated fatty acid deposition decreased, which was consistent with the findings of Ellis and Zeller (1931).

Repartitioning Agents

Repartitioning agents are used to regulate metabolism in meat animals. The effects are desirable, as they partition absorbed nutrients away from adipose lipid deposition and toward muscle protein deposition. This shift in nutrient partitioning to cause a new state of physiological equilibrium has been termed homeorhesis (Bauman et al., 1982). As of yet, little progress has been made toward identifying the mechanisms by which repartitioning agents work.

Somatotropin

One of these agents is somatotropin or growth hormone. Porcine growth hormone is a protein produced by the pituitary gland. It has been shown in several experiments that with repeated subcutaneous injections, porcine somatotropin will increase muscle mass as well as increase the rate and efficiency of gain in growing-finishing pigs (Boyd, 1986). The injections of somatotropin were given once daily, using the total body weight as a guide to the dosage level (mg/kg of body weight). The optimum dosage depended on the ending carcass criteria. A common dosage level used in experiments was between 20 and 120 mg/kg of body weight (Machlin, 1972; Rebhun et al., 1985; Boyd, 1986).

Because of an anticipated improvement in feed efficiency and gain when somatatropin was used, researchers usually increased the dietary amino acids and other nutrients over that recommended by the National Research Council (Boyd, 1986). In most of these studies, researchers report an increase in loin eye area, a decrease in back fat thickness, as well as a decrease in muscle fat (Turman and Andrews, 1953; Machlin, 1972; Chung et al., 1985; Boyd, 1986).

Because somatotropin is a protein, naturally produced in the body and is easily destroyed by heat and digestion, no residue problems are expected and the meat from these injected animals should be safe for human consumption (Rebhun et al., 1985).

Machlin (1972) reported some pig mortality with liver and kidney degeneration, hemorrhage of the stomach, edema, and arthritis being the most common histological observations in the growth hormone treated pigs. In a later study (Chung et al. 1985), pig health was monitored closely by measuring arginase activity, creatinine and blood urea nitrogen (BUN) levels in the blood and at the conclusion of the study, extensive histopathology studies were conducted on tissue samples. No evidence of deleterious effects upon animal health were found in the treated pigs.

To begin addressing the mechanisms by which growth hormone affects growth, Chung et al. (1985) looked at various blood measurements. They found plasma glucose and insulin concentration to be elevated in the treatment pigs, suggesting that the animals had developed a state of insulin resistance. They also observed a reduction in BUN and a reduction in pituitary growth hormone, but presence of growth hormone antibodies. The diabetogenic effect of growth hormone found by Chung et al. (1985) causes some concern as to its long-term consequences on growth performance. This finding along with the adverse health effects found by Machlin (1972) cause some question as to somatotropins usefulness as a lipotropic agent for meat animals.

Beta-adrenergic agonists

Another group of repartitioning agents that has received attention recently are the beta-adrenergic agonists. The most common one of these is clenbuterol, which was first used as a bronchodilator drug. Clenbuterol has a chemical structure similar to that of epinephrine. Unlike somatotropin, clenbuterol is administered orally. Exogenous administration of norepinephrine or epinephrine has been shown to reduce fat deposition in swine (Cunningham et al., 1963). However, the effective dosage level of clenbuterol is much less than that of epinephrine or norepinephrine (Ricks et al., 1984a), indicating that clenbuterol is much more potent.

The two most common beta-adrenergic agonists that have been studied for livestock are clenbuterol and its analogue, cimaterol (Dalrymple et al., 1984; Moser et al., 1984; Ricks et al., 1984a and b; Jones et al., 1985). Following a 7 week feeding trial of cimaterol to swine starting at 65 kg and finishing at 104 kg, Jones et al. (1985) reported depressed feed intake, improved feed efficiency, increased loin eye areas, decreased back fat measurements, and no effect on rate of gain. Dalrymple et al. (1984) and Moser et al. (1984) also noted the favorable change in lean:fat ratio, but no change in feed efficiency. Withdrawal of cimaterol for 7 days caused compensatory fat deposition to the point of equalling the back fat measurements of the control pigs (Jones et al., 1985).

Blood urea nitrogen levels were measured in clenbuterol-fed finishing steers and found to decrease as the level of the drug fed increased, indicating the treatment may have increased nitrogen retention (Ricks et al., 1984b). Jones et al. (1985) reported depressed feed intake in the cimaterol-fed pigs, along with decreased carcass fat measurements. As shown by Ellis and Zeller (1931) and Greer et al. (1965), decreased caloric intake decreased carcass fat deposition.

The femur bones of the cimaterol-fed pigs were shorter and lighter weight than the control pigs (Jones et al., 1985). Postmortem evaluation revealed hoof lesions in the cimaterol-fed pigs (Jones et al., 1985). However, during the short experimental time, no lameness problems were evident. As reported with porcine growth hormone, feeding clenbuterol and cimaterol may not be without its potential health problems for swine.

Dihydroxyacetone and Pyruvate

Dihyhdroxyacetone and pyruvate are three carbon carbohydrates (trioses) which are natural glycolytic metabolites. Potential use of these trioses as feed additives evolved from the discovery of their value as a lipotropic agent in controlling the excessive accumulation of fat in and around the liver of ethanol-fed rats. Clinical research is currently being done to determine the possibility of positive effects of ingestion of dihydroxyacetone and pyruvate by humans.

Controlling Alcohol Induced Fatty Liver

Fat accumulation can be undesirable, especially in certain parts of the body such as in and around the vital organs, where it can be detrimental to the health of man and other animals. Chronic ingestion of alcohol is known to induce steatosis, fat accumulation in the liver (Rubin and Lieber, 1974). Recent studies have suggested that steatosis could be a factor in alcohol-induced hepatic cirrhosis, a very serious disease in human alcoholics marked by excess formation of connective tissue (Rubin and Lieber, 1974). No satisfactory therapy for alcohol-induced fatty liver has yet been found.

In an attempt to find an effective therapy for this condition in humans, a combination of pyruvate, dihydroxyacetone, and riboflavin was added to the diet of ethanol-fed laboratory rats (Stanko et al., 1978). This combination of nutrients prevented the excessive accumulation of fatty acids in the rat liver. Ethanol ingestion increases the concentration of the three major lipid fractions, triglycerides, phospholipids, and cholesterol esters, with its greatest effect on the triglyceride concentration, which is believed the most damaging element in ethanol-induced fatty liver (Mendenhall et al., 1969). Feeding a combination of pyruvate and dihydroxyacetone to ethanol-fed rats inhibited the accumulation of lipids in the liver and had its greatest effect on the triglyceride concentration, making the feeding of these lipotropic agents a very desirable therapy (Stanko et al., 1978).

In the search for a lipotropic agent the effect of chronic alcohol ingestion on the body's metabolism was considered. Oxidation of alcohol appears to increase the production of hydrogen ions in the body (Lieber, 1968) and cause the production of NADH (Rao et al., 1984). Metabolic acidosis is prevented by the increased conversion of the oxidized to reduced forms of the intermediate substrates and cofactors necessary for oxidative metabolism. This conversion is favorable to fatty acid synthesis and unfavorable to fatty acid oxidation (Lieber, 1968). An effective lipotropic agent therefore might be a good hydrogen acceptor or a chemical necessary for efficient oxidative metabolism. Both of the trioses are natural metabolites in the glycolitic pathway. Pyruvate, the end product of glycolysis, is a natural metabolite of glucose and of some amino acids. Dihydroxyacetone, an intermediate in glycolysis, is a natural metabolite of fatty acids, glucose, and some amino acids. Both compounds serve as hydrogen acceptors and oxidize the NADH produced during ethanol oxidation (Rao et al., 1984).

Further studies feeding pyruvate and dihydroxyacetone as a supplement to ethanol-fed rats showed not only did this therapy prevent fatty liver, but also maintained the fatty acid composition levels of the hepatic lipids at that of the control group (Goheen et al., 1981).

This study also found that the liver triglyceride concentration was reduced to the greatest extent in the ethanol-fed rats receiving the trioses. Measurements of both plasma lipid fatty acid composition and liver lipid fatty acid composition of rats fed ethanol without the trioses showed a decrease in the triglyceride concentration of the former and an increase in the latter. While these same measurements taken from rats fed the ethanol diet with the trioses showed an increase in plasma triglyceride concentration and a decrease in liver triglyceride concentration. These results demonstrated that alcohol might inhibit mobilization of triglycerides from the liver, while the trioses might enhance such mobilization (Goheen et al., 1981).

In a later study, dihydroxyacetone and pyruvate were replaced with their reduced counterparts, glycerol and lactate, in an alcohol containing rat diet and were found to abolish fatty liver (Rao et al., 1984). Hence, the theory of dihydroxyacetone and pyruvate working as hydrogen acceptors to oxidize the NADH produced by the oxidation of ethanol might not be correct. Fatty liver was also inhibited when rats were fed the alcohol diet supplemented only with pyruvate or glycerol, however when dihydroxyacetone was fed it had no inhibitory effect (Rao et al., 1984). This data raises some questions because dihydroxyacetone and glycerol are counterparts in the metabolic scheme. Also the addition of glucose or lactate reduced the liver triglyceride concentration by 50% in the ethanol-fed rats. Due to conflicting reports, further investigation is needed to elucidate the mechanisms involved in the prevention of alcohol-induced fatty liver.

Controlling Body Fat Accumulation

It was discovered that not only did the trioses prevent fatty liver in laboratory rats, but they also had an inhibitory effect on lipid synthesis in the entire rat body (Stanko and Adibi, 1986). Following a 112 day feeding period, rats receiving the diet with triose had a 32% smaller body fat content than the rats receiving the control diet. When the body composition results were expressed as a unit of body weight, the rats receiving the triose diet had significantly greater protein, water, and glycogen content than the rats receiving the control diet. Body composition was compared in this manner due to the significantly lower body weights of the triose-fed rats. This reduction of body weight may have been partially due to the dramatic inhibition of lipid accumulation in the body of the rats.

Metabolic Aspects of the trioses

Fat accumulation in the body can be reduced by several mechanisms, two of which are: (a) by increasing loss of calories in the feces or (b) by increasing the oxidation to CO_2 and H_2O in some oxidative pathways. Investigation of these two theories have suggested that the inhibition of lipid deposition in triose-fed rats is due to increased energy expenditure and CO_2 production and not to the fecal loss of calories (Stanko and Adibi, 1986).

Hormones play a major role in energy metabolism of the body. Thyroxine and insulin are two important hormones that regulate the body's metabolism of energy (Frandson, 1981). Thyroxine is responsible for about half of the normal animal's basal metabolic rate as it increases the rate of oxygen consumption in all cellular metabolism and stimulates cytoplasmic protein synthesis. Thyroxine also increases the absorption of glucose and its utilization as well as increasing glycogenolysis. Insulin increases the cell's uptake and utilization of energy and plays a role in regulation of lipid synthesis. The plasma of laboratory rats receiving the triose diet was significantly lower in insulin and slightly higher in thyroxine concentration (Stanko and Adibi, 1986). The lowered lipid synthesis in the adipose tissue of the triose-fed rats correlates with their lowered plasma insulin. The increased energy expenditure of the triose-fed rats correlates with their raised plasma thyroxine. These results may help lead to understanding the actual metabolic mechanisms being changed or regulated by the addition of trioses to the diet.

Energy metabolism and thermogenesis are also dependent on dietary constituents. The addition of pyruvate and dihydroxyacetone, both found in the glycolytic pathway, may alter metabolism by increasing substrate "futile" cycling and thereby increasing energy expenditure at the expense of lipid deposition. One of the possible "futile" cycles occurring here is the phosphorylation of pyruvate to phosphoenolpyruvate and dephosphorylation back to pyruvate (Katz and Rognstad, 1976). Dihydroxyacetone also requires phosphorylation before entering metabolic pathways.

Use of the trioses in Human Clinical Nutrition

Additional research was needed to understand the effect of the trioses on metabolism and many questions arose, such as whether the lipotropic effect of the trioses was species-specific. Recent research with human subjects has demonstrated that their effect is not species-specific and that they are invaluable clinical nutritional tools. It was found that with the addition of a 3:1 mixture of dihydroxyacetone and pyruvate to the diet of obese female patients, following hypocaloric therapy, weight gain and lipid deposition was inhibited (R. T. Stanko, unpublished data). In this study, the trioses had no negative effect on nitrogen retention of the body and no undesirable side effects were noted after extensive physical examination.

It has been shown that with dietary addition of the trioses, hepatic and body glycogen stores are increased in laboratory rats (Stanko and Adibi, 1986). An experiment completed using humans subjects revealed that supplementary trioses increased arm muscle glycogen stores. Also arm exercise endurance capacity was enhanced by 20% by increasing glucose availability to the muscle (R. T. Stanko, unpublished data). In this study, feeding the trioses increased hepatic glucose release and muscle glucose uptake, which is indirect evidence of increased glucose utilization during exercise, resulting in enhanced muscle endurance capacity. Implications for future use of the trioses by athletes to increase endurance exist and may prove fruitful. It has been suggested that other valuable clinical uses of the trioses may also be possible, such as a therapy for patients suffering from chronic pulmonary disease (R. T. Stanko, personal communication). The trioses might enhance the function of fatigued, debilitated pulmonary muscles. Stanko also suggests that the increased glucose release might benefit non-insulin dependent diabetic patients as well. The uses of pyruvate and dihydroxyacetone are many and future research has much to discover about these unique metabolites.

Maillard Reaction

The Maillard reaction was named after its discoverer Louis-Camille Maillard, a French biochemist who published the initial studies on this subject between 1912 and 1916. It is a nonenzymatic chemical reaction induced by heat, involving the condensation of an amino group and a reducing group usually belonging to a sugar (Feeney and Whitaker, 1982). This reaction can reduce the nutritional value of many foodstuffs by changing the nutrients and making them unavailable for absorption.

The Maillard reaction has three major stages, the first of which is the carbonyl-amine reaction. This first stage is simple, easy to understand chemistry, but the following two stages branch out into a wide variety of reactions with many diverse end products. Although the Maillard reaction has been studied extensively, it is these complex secondary reactions that make the chemistry difficult to elucidate. The intermediates of the reaction polymerize to form many brown pigments collectively referred to as melonoidins that cause the browned color of many foods. The browning reaction in food stuffs is responsible for the formation of many flavors, antioxidants, preservatives and coloring materials (Kawashima et al., 1980).

The condensation of carbonyl and amine compounds damage the nutritional quality of proteins by reducing the amount of essential amino acids, especially lysine available for absorption (Feeney and

Whitaker, 1982). The different sugars and amino acids that can undergo the Maillard reaction do so at very different rates and to different extents (Feeney and Whitaker, 1982). Hurrell and Carpenter (1974) reported that the amino acid, lysine was susceptible to the Maillard reaction. Kawashima et al. (1980) tested several sugars with several amino acids and found dihydroxyacetone to be the most reactive sugar and lysine to be the most reactive amino acid. These authors also reported that dihydroxyacetone produced the most extensive reaction and the most intensive color change. Dihydroxyacetone is the active ingredient in some artificial tanning products for the skin. It reacts with the skin's proteins resulting in an orange-brown color that is reversible with time (Kawashima et al., 1980).

CHAPTER III

INHIBITION OF CARCASS FAT ACCUMULATION IN SWINE WITH DIETARY ADDITION OF A 3:1 MIXTURE OF DIHYDROXYACETONE AND PYRUVATE

Introduction

Dihydroxyacetone and pyruvate (trioses) are both three carbon metabolites occurring naturally in the glycolytic pathway. The potential use of these trioses as feed additives evolved from the discovery of their value as a lipotropic agent used to control the excessive accumulation of fatty acids in and around the liver of alcoholics (Stanko et al., 1978). In an attempt to find a therapy for alcohol-induced fatty liver in humans, a combination of pyruvate, dihydroxyacetone, and riboflavin was added to the diet of laboratory rats and prevented accumulation of esterified fatty acids in the liver. (Stanko et al., 1978). Later, these results were confirmed by others (Goheen et al., 1981; Rao et al., 1984) and alcohol-induced fatty liver was also prevented with the addition of pyruvate alone in the diet of rats (Rao et al., 1984).

The addition of pyruvate and dihydroxyacetone for 112 days to a nutritionally balanced diet reduced the total body fat by 32%, but not the body protein content of growing rats (Stanko and Adibi, 1986). Not only did the trioses prevent hepatic lipid deposition, but also reduced adipose tissue lipid accumulation in rats. The inhibiting effect of dihydroxyacetone and pyruvate on total body fat showed that these trioses might have potential use as a lipotropic agent in livestock animals, particularly swine.

Improving carcass quality by decreasing fat accumulation and increasing muscle protein has been a major focus for the swine industry for many years. Consumers demand a leaner meat product. Pork has a reputation for being a product high in fat, but at the same time it is high in protein and many other essential nutrients. In order to improve this high protein meat product and make it a more salable item, the percentage of fat must be decreased.

To evaluate whether the trioses were species-specific and to attempt to decrease carcass fat in meat animals, a 3:1 mixture of dihydroxyacetone and pyruvate was fed to finishing swine at 4% of the diet for 28 days.

Material and Methods

Twenty-four Yorkshire x Duroc x Hampshire swine (12 male castrates and 12 females) weighing 80-85 kg were housed in individual pens, paired littermates by sex were fed either a control diet or a treatment diet for 28 days. The control diet consisted of a basal corn-soybean meal diet plus Polycose, a glucose polymer that replaced 3.85% of the calories in the diet (4% of the diet). The treatment diet consisted of the same corn-soybean meal diet plus a 3:1 mixture of dihydroxyacetone and calcium pyruvate that replaced 3.85% of the calories in the diet (4% of the diet). The diets were isocaloric and isonitrogenous containing 16% protein (Table 1). Water was provided ad libitum throughout the feeding trial.

On the 29th day of the study, 18 hours after feeding, blood samples were taken via vena cava puncture and the pigs were slaughtered. Blood samples were frozen and later analyzed. Hot carcass weight was measured. The heart, liver, kidney, and spleen were removed, rinsed with saline, and weighed. After chilling the carcass (24 h at 1°C) cold carcass weight was measured, leaf fat was removed and weighed, and back fat measurements were taken with a steel rule at the first and last rib and at the last lumbar vertebrae. The carcasses were split between the tenth and eleventh rib for loin eye area and tenth rib back fat measurements. Back fat at the tenth rib was measured off the medial line approximately three-fourths of the distance along the longest axis of the loin eye area toward the belly (USDA, 1981).

Table 1. PERCENTAGE COMPOSITION OF DIET

Item:	Polycose	Triose
Ground corn	67.40	67.40
Soybean meal	16.35	16.35
Extruded soybeans	8.50	8.50
Salt	.40	.40
Dicalcium phosphate	2.25	2.25
Limestone	.40	.40
Trace mineral mix[a]	.10	.10
Vitamin mix[a]	.40	.40
Antibiotic[b]	.10	.10
Flavoring mix[c]	.10	.10
Triose mix[d]	–	4.00
Polycose[e]	4.00	–

[a]Met or exceeded the recommendations of the National Research Council (1979).
[b]Oxytetracycline, 110 g/kg.
[c]Pig Nectar. AgriAmerica, Inc. North Brook, IL 60062.
[d]Three parts of dihydroxyacetone to one part of pyruvate.
[e]A Glucose polymer prepared by Ross Labs, Columbus, OH.

Leg, loin, shoulder, and belly were removed and weighed before and after trimming of fat. The right leg and rear one-third of the right loin were skinned, deboned, ground, and freeze-dried for later laboratory analysis of protein, fat, moisture, and ash. The loin eye area of six carcass pairs was dissected from exterior fat and likewise analyzed.

The blood samples were analyzed by conventional laboratory techniques for hemoglobin concentration, hematocrit, erythrocyte and leukocyte count using a Coulter counter for cell count differential. The blood samples were also analyzed for alkaline phosphatase, serum glutamic oxaloacetic transaminase (SGOT), serum glutamic pyruvic transaminase (SGPT), gamma glutamyl transpeptidase and cholesterol using a Baker Instruments CentrifiChem 500 auto-analyzer and Medical Analysis Systems, Inc. reagents. Triglycerides were determined using CentrifiChem Triglycerides/INT with the ChetrifiChem 500. Moisture content of the ground leg and loin samples was determined by subtracting the weight after freeze-drying for 96 hours from the weight before freeze-drying. Freeze-dried meat samples were analyzed for protein by kjeldahl digestion and for lipid by ether extract (AOAC, 1980). A meat sample was burned at 500°C for twelve hours to determine ash content. The paired t-test was used for statistical analysis of the data (Dixon and Massey, 1969).

Results

None of the animals showed any obvious symptoms of abnormalities or stress during the 28 day feeding period. There were no differences in feed intake (10,475±306 cal/day vs. 10,577±306 cal/day, $P > .05$) or in weight gain (21.3±0.5 kg vs. 20.7±1.1 kg, $P > .05$) between control and treated animals respectively (Table 2). No differences existed in hot carcass weight (74.7±1.2 kg vs. 74.6±1.3 kg, $P > .05$) or in cold carcass weight (72.2±1.3 kg vs. 72.3±1.3 kg, $P > .05$) or in carcass yield between control and treated animals respectively.

Table 2. INITIAL WEIGHT, FINAL WEIGHT, BODY WEIGHT GAIN, AND CALORIC INTAKE OF SWINE FED POLYCOSE OR A 3:1 MIXTURE OF DIHYDROXYACETONE AND PYRUVATE IN FINISHING SWINE

	Polycose		Triose		
Item	Mean	SE[a]	Mean	SE	P[b]
No of pigs	12		12		
Initial wt, kg	79.2 ±	1.3	79.4 ±	1.3	>.05
Final wt, kg	100.5 ±	1.7	100.1 ±	1.7	>.05
Gain, kg	21.3 ±	.05	20.7 ±	1.1	>.05
Intake, kcal/day	10,475.0 ±	306.0	10,577.0 ±	306.0	>.05

[a]Standard error of the mean.
[b]Probability.

Back fat measurements are presented in Table 2. The triose-fed pigs showed a 12 to 15% decrease ($P < .01$) in back fat measurements at the first and last rib compared to the control pigs. There were no differences in back fat at the last lumbar vertebrae, but average back fat was reduced by 12% in the triose fed pigs ($P < .01$). Tenth rib back-fat was similarly reduced in the triose fed pigs ($P < .02$). Leaf fat and trimmable fat were also significantly decreased in treated animals ($P < .05$; Table 3).

Percent untrimmed lean cuts were similar or equal in both groups, but percent trimmed lean cuts were increased in the triose fed pigs

(P < .02). Trimmed and untrimmed bellies were similar in both groups of animals (P=NS). There was a general overall decrease in carcass fat in the treated animals however, muscle protein did not decrease as was shown by no change in the loin eye areas and by an increase in trimmed lean cuts (Table 4).

Lipid, protein, moisture and ash content of the untrimmed loin and leg are presented in Table 5. The laboratory analysis for percent fat showed a significant decrease in the untrimmed loin of the triose fed pigs (P < .01).

Table 3. CARCASS FAT MEASUREMENTS OF SWINE FED POLYCOSE OR A 3:1 MIXTURE OF DIHYDROXYACETONE AND PYRUVATE IN FINISHING DIETS

	Polycose		Triose		
Item	Mean	SE[a]	Mean	SE	P[b]
No of pigs	12		12		
Carcass wt, kg	72.2	± 1.3	72.4	± 1.3	>.05
Back fat, cm					
First rib	4.33	± .02	3.68	± .02	<.01
Last rib	2.35	± .08	2.03	± .09	<.01
Last lumbar	2.15	± .11	2.06	± .10	>.05
Average back fat	2.94	± .11	2.59	± .11	<.01
Adj avg back fat[c]	2.92	± .10	2.58	± .10	<.01
Tenth rib	2.54	± .12	2.23	± .08	<.02
Leaf fat					
Total, g	1260.0	± 95.0	1085.0	± 72.0	<.02
g/kg carcass	17.4	± 1.2	15.0	± .10	<.02
Trimmed fat					
Total, kg	10.3	± 0.8	9.3	± 0.6	<.05
g/kg carcass	14.6	± 0.8	13.1	± 0.8	<.05

[a]Standard error of the mean.
[b]Probability.
[c]Average back fat adjusted to 100 kg live weight.

Table 4. CARCASS MEASUREMENTS OF SWINE FED POLYCOSE OR A 3:1 MIXTURE OF DIHYDROXYACETONE AND PYRUVATE IN FINISHING DIETS

	Polycose			Triose			
Item	Mean		SE[a]	Mean		SE	P[b]
No. of pigs	12			12			
Carcass wt, kg	72.2	±	1.3	72.4	±	1.3	>.05
Lean cuts							
Untrimmed, kg	53.0	±	1.4	53.7	±	1.6	>.05
% of cold carcass	73.5	±	1.5	74.1	±	1.5	>.05
Trimmed, kg	39.9	±	0.6	41.6	±	0.6	<.06
% of cold carcass	55.3	±	0.5	57.7	±	0.9	<.02
Belly							
Untrimmed, kg	12.6	±	0.3	12.1	±	0.3	>.05
% of cold carcass	17.5	±	0.2	16.8	±	0.2	>.05
Trimmed, kg	8.4	±	0.2	8.2	±	0.9	>.05
% of cold carcass	11.7	±	0.1	11.3	±	0.6	>.05
Loin eye area, cm^2							
Unadjusted	31.8	±	0.9	31.5	±	1.0	>.05
Adjusted[c]	31.7	±	0.9	31.3	±	0.9	>.05
Lean pork, %[d]	53.9	±	0.6	55.0	±	0.4	>.05

[a]Standard error of the mean.
[b]Probability.
[c]Adjusted to 100 kg live weight.
[d]Calculated from the hot carcass weight, back fat at the tenth rib and loin eye area, U.S.D.A.- NSIF (1981).

The trend was the same for the percent fat in the untrimmed leg of the treated pigs, but was not significant. As the percent fat decreased, the percent protein increased in the loin and leg of the triose fed pigs (P < .01). Percent ash and percent moisture also increased in the loin of the treated pigs (P < .01). The trend for this increase was also in the leg of the treated animals, but it was nonsignificant.

Blood determinations (Table 6) showed an 11% increase (P < .02) in leukocytes and a 9% increase (P < .04) in serum cholesterol in the triose fed pigs. All other blood components were similar in the two groups of animals. Liver function blood analysis showed only an 18% decrease in SGPT (P < .05). Liver tissue break down is reflected by a high serum SGPT level. The lowered SGPT of the triose-fed pigs might suggest greater liver tissue integrity.

Organ weights for the liver, heart, spleen, and kidney were similar in both groups of animals (Table 7).

Table 5. PROTEIN, FAT, ASH, AND MOISTURE CONTENT OF DEBONED REAR LEGS AND LOINS OF CARCASSES FROM SWINE FED POLYCOSE OR A 3:1 MIXTURE OF DIHYDROXYACETONE AND PYRUVATE IN FINISHING DIETS

	Rear leg			Loin		
Item	Mean		SE[a]	Mean		SE
No of pigs	12			12		
Protein, %						
Polycose	45.3	±	2.0	27.9	±	1.2
Triose	47.4	±	1.8	31.1	±	1.2
P[b]	<.01			<.01		
Fat, %						
Polycose	51.6	±	1.8	70.2	±	1.4
Triose	49.4	±	2.0	66.2	±	1.4
P	>.05			<.01		
Ash, %						
Polycose	2.4	±	0.1	1.4	±	0.1
Triose	2.5	±	0.1	1.6	±	0.1
P	>.05			<.01		
Moisture, %						
Polycose	61.3	±	0.9	48.1	±	1.2
Triose	62.2	±	0.9	50.9	±	1.2
P	>.05			<.01		

[a]Standard error of the mean.
[b]Probability.

Table 6. BLOOD MEASUREMENTS OF SWINE FED POLYCOSE OR A 3:1 MIXTURE OF DIHYDROXYACETONE AND PYRUVATE IN FINISHING DIETS

	Polycose			Triose			
Item	Mean		SE[a]	Mean		SE	P[b]
No of pigs		12			12		
Enzymes, IU/L[c]							
SGOT	22.5	±	4.0	17.8	±	2.0	>.05
SGPT	28.3	±	2.0	23.5	±	5.0	<.05
ALKP	139.5	±	9.0	148.2	±	10.0	>.05
GGTP	22.0	±	1.0	23.6	±	2.0	>.05
Lipids, mg/dl							
Cholesterol	85.0	±	3.0	93.2	±	9.0	<.02
Triglycerides	24.3	±	4.0	25.3	±	4.0	>.05
Cell counts							
Erythrocytes, M/mm^3	7.8	±	0.2	7.8	±	0.2	>.05
Leukocytes, M/mm^3	16.7	±	0.8	17.5	±	0.9	<.05
Hematocrit, %	44.2	±	1.6	44.8	±	1.2	<.05
Hemoglobin, g/dl	14.5	±	0.3	14.7	±	0.3	>.05

[a]Standard error of the mean.
[b]Probability.
[c]Serum glutamic oxalacetic transaminase, Serum glutamic pyruvic transaminase, Alkaline phosphatase, and Gamma glutamyl transpeptidase.

Table 7. ORGAN WEIGHTS OF SWINE AT SLAUGHTER FED POLYCOSE OR A 3:1 MIXTURE OF DIHYDROXYACETONE AND PYRUVATE IN FINISHING DIETS

	Polycose			Triose			
Item	Mean		SE[a]	Mean		SE	P[b]
No of pigs		12			12		
Liver, g	1373	±	59	1424	±	80	>.05
Heart, g	328	±	7	328	±	7	>.05
Spleen, g	152	±	7	150	±	4	>.05
Kidney, g	308	±	12	318	±	13	>.05

[a]Standard error of the mean.
[b]Probability.

Discussion

Reduction of body fat in meat animals is desirable only if weight gain, feed efficiency, and muscle protein yield are uninhibited. The data presented show that feeding the 3:1 mixture of dihydroxyacetone and pyruvate as a portion of an adequate diet to finishing swine reduced body fat deposition without reducing rate or efficiency of gain or muscle mass deposition. Deposition of back fat, leaf fat, and trimmed fat were decreased in the treated pigs. Laboratory analysis showed that along with a decreased fat content of the untrimmed loin and leg there was an increased protein content percent. Muscle yield was not sacrificed by feeding the trioses, as was shown by the increased percent lean cuts of the triose-fed pigs and the identical loin eye areas of the two groups.

In a previous study done with rats the data showed a similar pattern of decreasing body fat deposition without decreasing body protein content (Stanko and Adibi, 1986). After being fed the trioses for 112 days at 20% of their diet these rats displayed a 32% decrease in body fat and no change in protein content when compared to control rats. In the present study with swine fed dihydroxyacetone and pyruvate as 4% of the diet for only 28 days, the changes in body fat were 12 to 15%, with no change in body protein content.

Weight gain in the triose pigs was uninhibited by the feeding of the trioses. This lack of depression in their weight gain might be partially explained by the increase in carcass moisture as shown in the untrimmed loin. With extended periods of feeding the triose mixture to rats as 20% of their total calories, Stanko and Adibi (1986) reported inhibited weight gain. Possibly, with increased dosages of prolonged feeding, swine would also show decreased weight gain.

The metabolic mechanism(s) by which the trioses act to inhibit lipid deposition is unknown. Previous studies with rats showed an increase in energy expenditure and CO_2 production (Stanko and Adibi, 1986) and the inhibition of triglyceride synthesis in adipose and hepatic tissue (Stanko et al., 1978).

The triose fed pigs showed no obvious symptoms of any abnormalities. Long-term toxicity trials are needed to confirm this. External examination of the triose pigs did reveal brown staining of the feet and noses which was reversible with time. This discoloration was probably due to external contact with the dihydroxyacetone during feeding. The cause is known as the Maillard reaction or nonenzymatic browning and is quite harmless to the skin (Kawashima et al., 1980). The reaction takes place between a carbonyl group of a sugar and an amine group of the skin's protein (Feeney and Whitaker, 1982).

Organ weights, blood erythrocyte count, hemoglobin concentration, and liver function tests were unaffected by the feeding of trioses with the exception of a slight decrease in SGPT. It is unknown why this change existed. There was also a significant increase in the blood leukocyte count. The significance of this change is also unknown. There was an increase in serum cholesterol in the triose-fed pigs as well as a trend toward an increase in serum triglycerides, which may have been due to the increased fat mobilization.

Another method of decreasing carcass fat in swine is the use of repartitioning agents. This is a relatively new science and is still in the testing phases. One of these methods is the use of somatotropin (growth hormone), a protein hormone synthesized by the pituitary gland. Repeated subcutaneous injections of porcine growth hormone to growing-finishing swine weighing 45-100 kg resulted in decreased fat accumulation as well as increased muscle deposition, increased feed efficiency, and increased gains (Machlin, 1972; Chung et al., 1985; Rebhun et al., 1985; Boyd, 1986). In the present study feeding dihydroxyacetone and pyruvate to 80-100 kg pigs did not result in increased feed efficiency or muscle size. The pigs were fed the trioses during a time in the life cycle of active lipid deposition and little muscle mass growth. Studies feeding the trioses to younger pigs weighing 45-100 kg, during their growing phase, need to be conducted to see if muscle accumulation could be enhanced. Although the result of chronic injections of growth hormone is a favorable shift in the lean:fat ratio, Machlin (1972) reported some pig mortality caused by tissue degeneration and organ failure. Other studies, with growth hormone have not supported Machlin's findings and have reported no pig mortality or deleterious effects upon animal health (Turman and Andrews, 1953; Chung et al., 1985; Boyd, 1986).

Another method of shifting the lean:fat ratio in swine is the feeding of the B-adrenergic agonist, clenbuterol and its analogue, cimaterol (Ricks et al., 1984_a and $_b$; Dalrymple et al., 1984; Moser et al., 1984; Jones et al., 1985). Following a 7 week feeding trial using cimaterol, Jones et al. (1985) reported improved feed efficiency, decreased back fat measurements, and increased loin eye areas. Dalrymple et al. (1984) and Moser et al. (1984) also noted a similar favorable shift in the lean:fat ratio, but no improved feed efficiency after feeding cimaterol. The triose pigs in the present study showed a favorable shift in the lean:fat ratio, but no change in feed efficiency or loin eye area. Jones et al. (1985) reported hoof lesions and shortened, lighter weight femur bones in the cimaterol- fed pigs.

Beneficial effects on body composition occurred after extended (45-100 kg weight) chronic injections of growth hormone (Machlin, 1972) and after seven weeks of feeding cimaterol (Jones et al., 1985). In the study reported, the pigs were fed the trioses for only 28 days and at a very low percent of their diet (4%), but still a favorable shift in the lean:fat ratio was observed.

The triose compounds used in this study are natural metabolites which are not foreign to the animals body. Human consumption of meat from these animals fed trioses should therefore cause no undesirable side effects. Human subjects fed dihydroxyacetone and pyruvate as 15% of the calories for 21 days have developed no side effects by examination or biochemical evaluation (R. T. Stanko, unpublished data.)

It was concluded that the feeding of the mixture of dihydroxyacetone and pyruvate to swine decreased body fat content without affecting feed efficiency or muscle protein accumulation. This study, along with previous studies done with rats and humans (Stanko and Adibi, 1986) and (R. T. Stanko, unpublished data), establishes that the lipotropic effect of the triose mixture is not species-specific.

Summary

Twenty four finishing pigs (12 male castrates and 12 females) weighing 80-85 kg were pair-fed for 28 days, a nutritionally adequate basal corn-soybean meal diet, plus a 3:1 mixture of dihydroxyacetone and pyruvate (triose) and Polycose[R], a glucose polymer as control. Both triose and Polycose[R] replaced 3.85% of the calories or 4% of the diet. The pigs were paired litter mate by sex. Twelve were fed the triose mixture and twelve were fed the Polycose diet. Weight gain and feed consumption were recorded and carcass measurements were taken to evaluate fat and muscle deposition. The right leg and rear one-third of the right loin were skinned, deboned, ground, and analyzed in the laboratory for protein, fat, moisture, and ash. Weight gain, average daily gain, and feed intake were the same for the triose fed pigs and the control pigs ($P < .05$). In the triose fed pigs, back fat at the first and tenth rib and average back fat was reduced by 15, 12, and 12% ($P < .01$), respectively. Muscle accumulation measured by loin eye area and untrimmed lean cuts, was not altered by diet and percent trimmed lean cuts was higher in the triose fed pigs, 57.6 vs. 55.3% ($P < .02$). Laboratory analysis of leg and loin samples showed a decrease in percent fat with a corresponding increase in percent protein in the triose fed pigs ($P < .01$). Organ weights as well as the blood biochemical profile were unaltered by the diet ($P < .05$). Liver function tests were not affected by the diet, except for an increase in serum glutamic pyruvic transaminase (SGPT) in the triose-fed pigs ($P < .05$). It was concluded that a 3:1 mixture of dihydroxyacetone and

pyruvate added at 4% of an adequate diet reduced body fat accumulation without reducing muscle protein or feed efficiency in finishing swine.

CHAPTER IV

THE EFFECT OF FEEDING DIHYDROXYACETONE, PYRUVATE, OR A 3:1 MIXTURE OF DIHYDROXYACETONE AND PYRUVATE TO FINISHING SWINE

Introduction

For decades the swine industry has focused on improving carcass quality by decreasing fat accumulation while increasing muscle protein. Many substances have been tested to accomplish this goal. Daily injections of porcine growth hormone reduced carcass fat and increased muscle mass in studies reported by Machlin, (1972); Chung et al., (1985); and Rebhun et al., (1985). Feeding B-adrenergic agonists, clenbuteral or cimaterol reduced carcass fat in finishing swine (Ricks et al., 1984; Dalrymple et al., 1984; Moser et al., 1984; Jones et al., 1985). The consumer demands a lean meat product, so in order for pork to be competitive, its fat content must be reduced.

Feeding a 3:1 mixture of dihydroxyacetone and pyruvate to finishing swine at a 4% level in the diet for 28 days resulted in the reduction of body-fat accumulation without a reduction in muscle protein deposition (Chapter III). Earlier work by Stanko and Adibi (1986) showed that the addition of these triose compounds to the diet of rats reduced hepatic lipid deposition and adipose tissue accumulation. Goheen et al., (1981) and Rao et al., (1984) also found that the addition of these glucose metabolites to the diets of rats reduced hepatic lipid deposition despite alcohol ingestion. Because both rats and swine showed these favorable results, the effect of feeding the trioses was assumed not to be species specific. The results of the study conducted on finishing pigs (Chapter III) indicated the potential use of trioses as a metabolic control of carcass fat deposition. In an earlier study concerning fatty liver control, Rao et al., (1984) found that feeding pyruvate alone to rats reduced hepatic lipid deposition, while feeding dihydroxyacetone alone had no inhibitory effect. It is possible that the trioses, when used together have a synergistic effect on lipid metabolism. It is also possible that only one of the trioses caused the change in fat deposition, while the other was inactive.

Additional work was needed to confirm the effect reported in Chapter III and to determine if the trioses fed alone are as effective as the 3:1 mixture of dihydroxyacetone and pyruvate. The objective of the present study was to evaluate the effect of feeding pyruvate alone, dihydroxyacetone alone, and a 3:1 mixture of dihydroxyacetone and pyruvate, all at 4% of the diet.

Materials and Methods

Forty-four Yorkshire x Duroc x Hampshire swine (36 male castrates and 8 females) weighing 73-84 kg were housed in individual pens and fed one of four diets for 28 days. The diets were all based on a nutritionally adequate basal corn-soybean meal mixture and contained 4% of either Polycose^{R}, dihydroxyacetone, pyruvate, or a 3:1 mixture of dihydroxyacetone and pyruvate. The trioses and the Polycose^{R} replaced 3.85% of the total calories in the diets. The diets were isocaloric and isonitrogenous, all containing 16% protein. The basal diet fed is presented in Table 1 of Chapter III. Water was available to the pigs throughout the feeding trials.

The experiment was conducted in three trials during 1987: Trial number 1 was in May-June with 20 pigs, Trial number 2 was in July-August with 12 pigs, and Trial number 3 was in October-November with 12 pigs. In Trials 1 and 2, the feed was mixed prior to the feeding trial and included the Polycose^R or the trioses. This feed was then stored in an area that was not temperature controlled and day time temperatures reached 32°C. In Trial 3, the feed was premixed, but the Polycose^R and the trioses were stored at 4°C and added to the feed just prior to feeding. All the pigs were fed approximately 1.4 kg twice daily at 0830 and 1600 h.

Weight gain and feed consumption were recorded. In Trials 1 and 2, after a 28 day feeding period, blood samples were taken via vena cava puncture 18 hours after the last feeding and the pigs were slaughtered. In Trial number 3 the blood samples were not taken prior to slaughter. The blood samples were frozen for later analysis. Organ weights were taken in Trials 1 and 2 for the heart, liver, kidney, and spleen, but not in Trial 3. Hot carcass weights were measured for all the pigs. The carcasses were chilled for 24 hours at 1°C and the cold carcass weight was recorded. The leaf fat was removed from the carcasses and weighed and the back fat measurements were taken with a steel rule at the first and last rib and at the last lumbar vertebrae. The carcasses were split between the tenth and eleventh rib for loin eye area and tenth rib back fat measurements. The loin eye areas (longissimus dorsi muscle) were measured with a planeminer according to published procedures (USDA, 1981). The tenth rib back fat thickness was measured off the medial line approximately three-fourths of the distance along the longest axis of the loin eye area toward the belly (USDA, 1981). The lean cuts, which includes the leg, loin and shoulder, were separated from the carcasses and weighed before and after trimming of excess fat. The bellies were also separated from the carcass and weighed before and after trimming.

Blood samples were analyzed by conventional laboratory techniques for hemoglobin concentration, hematocrit, erythrocyte and leukocyte counts, using a Coulter counter for cell count differential. Further blood analysis determined serum glutamic oxaloacetic transaminase (SGOT), serum glutamic pyruvic transaminase (SGPT), alkaline phosphatase (ALKP), gamma glutamyl transpeptidase (GGT), and cholesterol using a Baker Instruments CentrifiChem 500 auto-analyzer and Medical Analysis Systems, Inc. reagents. Triglycerides were determined using CentrifiChem Triglycerides/INT with the CentrifiChem 500. The paired t-test was used for statistical analysis of the data (Dixon and Massey, 1969), excluding the 16 dihydroxyacetone-fed pigs in Trials 1 and 2, as it was determined that the feed containing dihydroxyacetone in these two trials was heat damaged by the Maillard reaction, which severely reduced the available amino acids in the diets.

Sixteen pigs were fed either dihydroxyacetone alone or a mixture of three parts dihydroxyacetone and one part pyruvate. Eight pigs were on each diet: in Trial no. 1 (May-July 1987), five were fed dihydroxyacetone alone and five were fed the 3:1 mixture, in Trial no. 2 (July-Aug 1987), three were fed dihydroxyacetone alone and 3 were fed the 3:1 mixture. These diets were mixed prior to the feeding trial and were not refrigerated, but stored in an indoor area where the temperature ranged from 24°C to 35°C. In Trial no. 3 however, the dihydroxyacetone that was mixed in the diets was refrigerated at 4°C prior to feeding. The data from the 16 dihydroxyacetone-fed pigs in Trials 1 and 2 was kept separate from that of the remaining 28 pigs. Dye-binding tests were conducted on samples of all of the diets fed in Trials 1 and 2 in order to confirm the occurrence of the Maillard reaction in the dihydroxyacetone containing feed, as described by Noguchi et al., (1982).

Results

The animals showed no signs of stress nor did they display any symptoms of abnormalities during the 28 day feeding trial.

The results will be presented in two parts; the first of which will be the 28 pigs on the diets that were not affected by the heat-damaging Maillard reaction, which were 10 pigs from Trial 1, 6 pigs from Trial 2, and all of the 12 pigs in Trial 3. The second part of the results will be the remaining 16 pigs on the diets that were heat damaged by the Maillard reaction, which were 10 pigs from Trial 1 and 6 pigs from Trial 2.

Pigs fed diets unaffected by the Maillard reaction

Initial weight of the pigs fed dihydroxyacetone (73.10 ± .7) was less than that of the pigs fed the control diet (83.50 ± .1) and the pyruvate (82.20 ± 1.4; $P < .05$). Final weight, average daily gain, and feed intake were similar between pigs on the three different diets (Table 8).

Table 8. INITIAL WEIGHT, FINAL WEIGHT, BODY WEIGHT GAIN, AND CALORIC INTAKE OF SWINE FED POLYCOSE, PYRUVATE, OR DIHYDROXYACETONE IN FINISHING DIETS

	Polycose		Pyruvate		DHA[a]	
Item	Mean	SE[b]	Mean	SE	Mean	SE
No of pigs	10		10		8	
Initial wt, kg	83.50 ±	.1[d]	82.20 ±	1.4[d]	73.10 ±	.7[c]
Final wt, kg	108.60 ±	1.5	110.70 ±	2.0	107.30 ±	1.0
Avg daily gain, kg	.79 ±	.04	.77 ±	.04	.82 ±	.02
Intake, Kcal/day	11,079 ±	306	11,046 ±	306	11,053 ±	306

[a]Dihydroxyacetone
[b]Standard error of the mean.
[c,d]Values in the same line with different superscripts are different from one another ($P < .05$).

Carcass length at slaughter of the Polycose[R]-fed (control) pigs was less than that of the pyruvate and dihydroxyacetone-fed pigs (81.0 ± .7 cm), (81.9 ± .8 cm), and (83.7± .4 cm), respectively ($P < .05$). Also at slaughter, both the hot and the cold carcass weights differed between the three groups of pigs. The pyruvate-fed pigs had the lowest carcass weights (79.7 ± 2.0 and 77.4 ± 2.0 kg), which differed ($P < .05$) from the control pigs (81.0 ± 1.3 and 78.9 ± 2.0 kg) and the dihydroxyacetone-fed pigs (84.8 ± .8 and 82.3 ± .8 kg), hot and cold carcass weights, respectively (Table 9).

Table 9. CARCASS FAT MEASUREMENTS OF SWINE FED POLYCOSE, PYRUVATE, OR DIHYDROXYACETONE, IN FINISHING DIETS

	Polycose		Pyruvate		DHA[a]	
Item	Mean	SE[b]	Mean	SE	Mean	SE
No of pigs	10		10		8	
Carcass lgth, cm	81.0	± .7[d]	81.9	± .8[de]	83.7	± .4[e]
Hot wt, kg	81.0	± 1.3[de]	79.7	± 2.0[d]	84.8	± .8[e]
Cold wt, kg	78.9	± 1.2[de]	77.4	± 2.0[d]	82.3	± .8[e]
% Yield						
hot	74.6	± .8	73.9	± .7	76.6	± .2
cold	72.6	± .8	71.8	± .7	74.3	± .2
Back fat, cm						
First rib	4.08	± .22	3.95	± .26	4.26	± .13
Last rib	2.45	± .09	2.28	± .19	2.74	± .27
Last lumbar	2.09	± .12	2.07	± .14	2.32	± .08
Average back fat	2.89	± .12	2.75	± .17	3.10	± .12
Adj avg back fat[c]	2.76	± .11	2.66	± .15	2.91	± .12
Tenth rib	2.49	± .14	2.49	± .17	2.56	± .11
Leaf fat						
Total, g	1209.3	± 58.8	1225.5	± 81.3	1399.5	± 106.2
g/kg carcass	15.35	± .7	15.85	± .9	17.03	± 1.3
Trimmed fat						
Total, kg	11.2	± .4	10.8	± .6	14.5	± .5
Percent	14.3	± .5	13.9	± .7	17.7	± .6

[a]Dihydroxyacetone.
[b]Standard error of the mean.
[c]Average back fat adjusted to 100 kg live weight.
[d,e]Values in the same line with different superscripts are different from one another, ($P < .05$).

Back fat measurements are presented in Table 9. Back fat was not different at the first rib, last rib, last lumbar vertebra, or at the tenth rib between diets. There was no difference between diets for average back fat or when the average back fat was adjusted to 100 kg live weight to give adjusted average back fat. There were also no differences between leaf fat weights or trimmed fat weights for the pigs on different diets.

Measurements taken on the specific cuts, untrimmed and trimmed and the percentage of the cold carcass weight for each are presented in Table 10. There was no difference in the untrimmed lean cuts between diets. But when these measurements were calculated as a percent of the cold carcass weight, the pyruvate-fed pigs and the control pigs showed a higher percentage than the dihydroxyacetone-fed pigs (73.9 ± .6%, 73.4 ± .8%, and 70.2 ± 1.2%), respectively. The dihydroxyacetone-fed pigs had the highest amount of trimmed lean cuts, but there was no difference between diets for the control and the pyruvate-fed pigs. The dihydroxyacetone-fed pigs also had the highest ($P < .05$) percentage of trimmed lean cuts which was not different from the pyruvate-fed pigs but was more than the control pigs. Untrimmed and trimmed belly weights were lowest ($P < .05$) for the dihydroxyacetone-fed pigs and there were no differences between these belly measurements for the control and pyruvate-fed pigs. When the untrimmed and trimmed belly weights were calculated as a percentage of the cold carcass weight, the dihydroxyacetone-fed pigs still had the lowest ($P < .05$) percent, with no differences between the control and pyruvate-fed pigs. The loin eye areas and the adjusted loin eye areas were the same for the control, pyruvate-fed, and dihydroxyacetone-fed pigs. The percent lean pork was also the same for the control, pyruvate-fed, and dihydroxyacetone-fed pigs.

Table 10. CARCASS MEASUREMENTS OF SWINE FED POLYCOSE, PYRUVATE, OR DIHYDROXYACETONE IN FINISHING DIETS

	Polycose		Pyruvate		DHA[a]	
Item	Mean	SE[b]	Mean	SE	Mean	SE
No of pigs	10		10		8	
Carcass wt, kg	78.9 ±	1.2	77.4 ±	2.0	82.3 ±	.8
Lean cuts						
Untrimmed, kg	57.8 ±	.8	57.8 ±	1.3	57.1 ±	1.1
% of cold carcass	73.4 ±	.8[f]	73.9 ±	.6[f]	70.2 ±	1.2[e]
Trimmed, kg	44.6 ±	1.3[e]	44.0 ±	1.6[e]	48.7 ±	.7[f]
% of cold carcass	56.5 ±	1.0[e]	56.8 ±	.8[ef]	59.2 ±	.8[f]
Belly						
Untrimmed, kg	13.4 ±	.3[f]	13.2 ±	.4[f]	11.9 ±	.1[e]
% of cold carcass	17.0 ±	.01[f]	17.0 ±	.01[f]	14.0 ±	.01[e]
Trimmed, kg	9.7 ±	.4[f]	9.6 ±	.4[f]	7.9 ±	.1[e]
% of cold carcass	12.0 ±	.01[f]	12.0 ±	.01[f]	10.0 ±	.01[e]
Loin eye area, cm^2						
Unadjusted	33.8 ±	1.5	32.5 ±	1.5	33.4 ±	1.0
Adjusted[c]	33.0 ±	1.4	31.9 ±	1.5	32.2 ±	1.0
Lean pork, %[d]	53.0 ±	1.5	52.5 ±	1.5	54.0 ±	0.5

[a]Dihydroxyacetone.
[b]Standard error of the mean.
[c]Adjusted to 100 kg live weight.
[d]Calculated from the hot carcass weight, back fat at the tenth rib, and loin eye area, NDIF.
[e,f]Values in the same line with different superscripts are different from one another ($P < .05$).

Pigs fed diets affected by the Maillard reaction

Sixteen pigs fed the diets damaged by the Maillard reaction were not included in the statistical analysis, but the data collected from them is reported below. In trials 1 and 2 a stained, browned color that is typical of the Maillard reaction, developed in all the feed containing dihydroxyacetone.

The results of the dye-binding tests showed extensive reduction in the amount of available lysine (approx. 25%) in the diets containing dihydroxyacetone. It was assumed that the Maillard reaction also damaged other amino acids having free amino groups in the feed as well. Dye-binding tests were also performed on the control and pyruvate diets and showed no indication of lysine damage. The two diets containing Polycose[R] and pyruvate displayed none of the brown discoloration that is typical of the Maillard reaction.

The pigs fed the heat-damaged diets showed reduced weight gain and poorer growth when compared to the pigs fed diets not affected by the Maillard reaction. For this reason, these 16 pigs were not included in the data for statistical analysis. It was observed that the snouts and legs of all the pigs in Experiment no. 2 that were fed dihydroxyacetone, in a mixture or alone, were stained an orange-brown color due to the occurrence of the Maillard reaction between the skin's proteins and the dihydroxyacetone. The results for these 16 pigs are presented in Tables 11 and 12.

Table 11. INITIAL AND FINAL WEIGHT, WEIGHT GAIN, INTAKE, AND CARCASS MEASUREMENTS OF PIGS FED DIHYDROXYACETONE OR A 3:1 MIXTURE OF DIHYDROXYACETONE AND PYRUVATE THAT UNDERWENT THE MAILLARD BROWNING REACTION

	Dihydroxyacetone			3:1 DHA/Pyr[a]		
Item	Mean		SE[b]	Mean		SE
No of pigs	8			8		
Initial wt.	83.57	±	1.5	83.24	±	1.5
Final wt.	102.90	±	1.6	106.30	±	2.1
Average daily gain	.63	±	.03	.74	±	.04
Intake, Kcal/day	11,053.0	±	306.0	11,032.0	±	306.0
Carcass lgth, cm	81.6	±	.7	81.1	±	.9
Hot wt, kg	75.8	±	1.3	77.7	±	1.6
Cold wt, kg	73.6	±	1.4	75.5	±	1.6
% Yield						
hot carcass	73.7	±	.6	73.1	±	.6
cold carcass	71.5	±	.6	71.0	±	.7

[a]A 3:1 mixture of dihydroxyacetone and pyruvate.
[b]Standard error of the mean.