EFFECTS OF DIETARY FIBER ON DIGESTION, BLOOD PLASMA LIPIDS AND GASTROINTESTINAL TRACT PARAMETERS IN NONRUMINANTS

By

WILLIAM NESMITH CANNON

Bachelor of Science
Middle Tennessee State University
Murfreesboro, Tennessee
1970

Master of Science in Agriculture
University of Kentucky
Lexington, Kentucky
1973

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
DOCTOR OF PHILOSOPHY
December, 1985

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Thesis approved:

Charles V. Maxwell
Thesis Adviser

Robert Teeter

David S. Buchanan

Eldon C. Nelson

Theodore E. Staley

Norman N. Durham
Dean of the Graduate College

ACKNOWLEDGEMENTS

This thesis represents the work of many individuals at Oklahoma State University. My sincere thanks are extended to the members of my committee, Drs. C. V. Maxwell, chairman and advisor, D. S. Buchanan, E. C. Nelson, F. N. Owens, R. G. Teeter and T. E. Staley.

Major contributions to this work were also made by Drs. C.G. Beams, Jr. and G. L. Morgans. Fellows graduates students, particularly, Dr. D. C. Weakly and J. W. Ward, provided professional and personal support during this study. I wish to express my appreciation to the faculty of the Animal Science Department, laboratory personnel and the support staff during the course of this study.

My greatest appreciation goes to Dr. C. V. Maxwell. As an advisor he always asked, "Why?"; and when the need arose, "How can I help?". Without his warm support and encouragement this study would not have been possible.

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CHAPTER I

INTRODUCTION

Forages and by-products have traditionally been fed to swine and other nonruminants as a means of reducing cost (when these fibrous feedstuffs are cost effective), supplying protein, vitamins, minerals and other nutrients as well as bulk. The use of fiber and fibrous feed resources in nonruminant nutrition declined as the availability of vitamin and mineral supplements increased and reduced the necessity of alfalfa and forage feeding. In addition the almost universal use of low fiber grains and soybean meal diets evolved as the most cost effective means of meeting the nutritional requirements of swine and poultry in this country. Renewed interest in the feeding of forages and fibrous by-products to nonruminants occurred as a result of competition for cereal gains and reports indicating the usefulness of fiber in nonruminant diets. There is an increasing consensus that the ability of the pig to utilize fiber had been underestimated (Baird et al.,1970; Clemens et al., 1975; Argenzio and Southworth, 1974). Recent studies provide evidence that considerable energy can be made available to the pig by fermentation of cell wall constituents in the lower intestinal tract (Kass, et al., 1980; Zoipoulus et al., 1982; Dennis et al., 1983). The addition of fiber to poultry diets usually results in an increased in feed intake to compensate for the effects of energy dilution (Hill and Dansky, 1954; Waldroup, et al., 1976);however, beneficial effects have been observed (Savory and Gentle, 1976; Hegde et al., 1978; Ricke et al., 1982).

The use of forages and by-products at high levels in swine and poultry diets has been proposed for developing countries where a shortage of feed grains exists. The great variability in chemical composition among fiber sources requires an understanding of the effects of fiber components on digestion. Yet, little is known concerning the digestibility of specific fiber components and the effect of dietary fiber components on the digestibility of other nutrients. A more thorough understanding of the basic physiological effects of dietary fiber components on the gastrointestinal tract and on the absorption and excretion of dietary components is essential for development of feeding regimes which maximize the utilization of fibrous feed resources.

Recent developments in the area of animal nutrition have been paralleled by those in the field of human nutrition. The current interests in dietary fiber in human nutrition is a result of the hypothesis that a lack of dietary fiber in the diet may be linked with a wide range of diseases such as diabetes, atherosclerosis, obesity, colon cancer, diverticulosis and other diseases of the large intestine (Burkitt, 1977). It has been demonstrated that certain fiber sources or fiber components alter digesta bulk and rate of passage through the intestinal tract, as well as bind, and thus decrease absorption of minerals and lipids (Keys, 1982). How these factors may affect the incidence of disease, availability of nutrients in fibrous feeds and overall nutritional status is not known.

Experiments involving humans, while providing directly applicable results, are costly, limited in employable techniques and pose ethical questions; therefore, appropriate animal models are needed. While nonhuman primates are probably the most appropriate models, they are difficult to maintain, limited in availability, and expensive. Pigs, however, are readily available, easily maintained and substantial physiological data on the pig is available. Due to the similarity in the digestive tract and circulatory system between man and pigs, the pig may be a suitable model for studies concerning the effects of dietary fiber (Pond, 1980). Additional data on the effects of dietary fiber on physiological parameters in the pig are necessary to verify the usefulness of the pig as a model for human dietary fiber research.

The objective of this study was to investigate the effects of various fiber sources on intake, rate of passage, plasma lipids, site and extent of digestion and absorption in nonruminants.

CHAPTER II

REVIEW OF LITERATURE

Introduction

This review will consist of a general overview of dietary fiber and its effect on digestion. The emphasis of the review will center on dietary fiber in swine and poultry nutrition. A short review of the effect of dietary fiber on blood plasma lipids in humans will be included.

Definition of Dietary Fiber

The definition of "dietary fiber" has been in flux since Burkitt (1973) proposed that a lack of dietary fiber might be responsible for a variety of human diseases. Previously, dietary fiber had been mainly a concern of animal nutritionists who defined fiber as crude fiber, the residue left after acid and base digestion. One of the problems with defining dietary fiber as crude fiber is that the more digestible fiber fractions are greatly underestimated (Cumming, 1976). To correct this, Trowell (1972) proposed that dietary fiber be defined as the plant cell components which resisted digestion by mammalian enzymes. The definition was later broadened to include under the term dietary fiber, the structural polysaccharides of the cell wall, lignin, plant lipids, nitrogen, trace elements and other substances (Trowell, 1974). This is generally the most widely accepted definition; however, the definition is still not standardized. Southgate (1976) suggested that the classification of dietary fiber be simplified to include only cellulose, lignin, and noncellulosic polysaccharides since classical terminology, based on different fractions of the plant cell wall, consists of isolated components which may be artifacts of the extraction procedures and due to the analytical problems of fractionalizing these complex groups.

In this manuscript the classification of Southgate (1976) will be used to define the various fiber fractions. As more research is accumulated and with improved analytical procedures more precise classification of dietary fiber may be beneficial. Currently extensive classification may only lead to undefined complexities which provide little to further our understanding of the effects of dietary fiber on digestion.

Classification of Dietary Fiber

The following review of the composition and classification of dietary fiber was summarized largely from material published by Southgate (1976) and Kay (1982). Dietary fiber is primarily the structural components of plant cell walls and consist of cellulose, noncellulosic polysaccharides and lignin. The noncellulosic polysaccharides include a large number of heteroglycans which include hemicellulose, pectin, gums and mucilages. These components vary in their digestibility, water binding and ion exchange capacities; physical factors which appear to be responsible for many of the differing responses observed between various dietary fibers.

Cellulose

Cellulose is a linear polymer of glucose units connected by 1-4 beta glycosidic linkages. It is the major structural component in the plant cell wall. The cellulose molecules are stabilized by hydrogen bonds between hydroxyl groups which form strong intermolecular bonds (Reese et al., 1950). Due to the beta configuration of the glucose units cellulose is resistant to the action of pancreatic amylase, but can be broken by bacteria cellulases (Yost, 1972).

Noncellulosic Polysaccharides

This group includes all the matrix polysaccharides from the cell wall, together with all the other indigestible polysaccharides other than cellulose. While this group includes a large number of different structural types of polysaccharides and ideally should be subdivided on a structural basis, at this time simplification is necessary due to analytical problems which have not allowed the development of simple repeatable analysis, and a lack of understanding of the relationship between type of structure and physiological properties.

Hemicellulose. Hemicellulose consist of cell wall polysaccharides derived from various pentoses and hexoses. It is a mixture of linear and highly branched polysaccharides which contain various sugar residues: xylose, arabinose, glucose and mannose. Hemicellulose acts as a plasticizer and intertwines with lignin between the cellulose fibers (Aspinall and Greenwood, 1962).

Pectins. Pectins are cell wall galacturonic acid polymers with pentose and hexose side chains. Pectin is found in the primary cell walls and in intracellular layers. Pectins are readily soluble in water with a high degree of methylation of the carboxyl group and upon cooling will form a gel (Southgate, 1976).

Gums and Mucilages. Plant gums are sticky exudates formed at the site of a plant injury. They are a complex group of noncell wall polysaccharides containing glucoronic and galacturonic acids, xylose, arabinose and mannose. Mucilages are non-cell wall polysaccharides, some of which are also storage polysaccharides. Mucilages are found within the endosperm or storage polysaccharides of plant seeds where they protect the seed from desiccation. They resemble hemicellulose structurally but are not biochemically classed with them because of their occurrence in a distinct part of the plant (Cumming, 1976).

Lignin

This summary of lignin was obtained primarily from the published review of Jung and Fahey (1983). Lignin is composed of phenylpropane polymers. It is a highly complex noncarbohydrate structure but not a polysaccharide. It combines with cellulose and hemicellulose to form structural support for the plant and continues to polymerize as the plant ages. Lignin arise from an initiated dehydrogenative polymerization of phenylamines and tyrosine (Sarkanen and Ludwig, 1971). The monomers: p-coumaryl, coniferyl and sinapyl alcohols account for most of the lignin molecule (Harkin, 1973). The moneric alcohols form free radicals under the influence of phenol oxidase and these radicals undergo nonenzymatic reactions to form polyphenols (Brown, 1964). The lack of enzymatic control result in random bonding and forms the complex structure of lignin. The strong carbon-carbon bonds and ether linkages are not susceptible to simple hydrolysis. Digestion of the plant decreases as the cell wall lignin content increases. It was general assumed that encurstation of cellulose by lignin was the major cause for the decrease in digestion, but Harkin (1973) suggested that covalently bonding of lignin to plant polysaccharides is more important.

Fiber Sources Used in this Study

The effects of dietary fiber on digestion are dependent on the composition of the fiber source and most fiber sources are extremely complex. Individual fiber sources contain various cell wall and non-cell wall components. Isolated semi-purified fiber components are subjected to physical and chemical treatments which may alter their biological activities (Van Soest, 1978) and makes interpretation of results difficult (Van Soest and McQueen, 1973); nevertheless, the complexity of fiber requires that an association between structure and function be made to permit an estimation of the effects of dietary fiber on digestion. To accomplish this, fiber components need to be studied individually. Several fiber sources used in this study are reviewed below. They represent fiber sources that are typically found in current feeding practices and which differ in their fiber composition.

Wheat Bran

Wheat bran is the fiber source most often used as a fiber additive in human nutrition. Wheat bran is the by-product of the flour milling process and is not a uniform product. It is comprised of the outer layers of the wheat grain: the pericarp, the seed coat, the hyaline layer and the aleurone layer. Bran amounts to about 11-16% of the whole wheat and usually some endosperm is included. In general bran consist of 21% cellulose, 20-26% pentosan, 7-9% starch, 11-15% protein, 5-10% fat and 5-9% ash (Cummings, 1976). It is highly palatable and has a laxative effect. Using the scanning electron microscope Hargers et al. (1980) described the surface changes occurring in wheat bran during passage through the intestinal tract of the rat. Bacteria begin adhering to the surface of the wheat bran in the ileum. The major digestive action occurred in the large intestine where the aleurone cells were ruptured and the protein and lipid content opened to digestion.

Beet pulp

Dried beet pulp is a by-product of the sugar industry. It is make by drying the residual beet chips from which the sugar has been extracted. It is bulky, very palatable and used predominately in dairy and beef cattle feeding, but is popular in dog and other fur bearing animals due to it's effect on fecal consistency (Smith, 1984). The fiber is highly digestible and contains about 8% crude protein and 25-30% pectic substances.

Guar Gum

Guar gum is isolated from the ground endosperm of the Indian Cluster bean, Cyanopsis tetragonolobas. It consists of 1,4 beta D-galactomannan with single unit side chains of 1,6 alpha D-galactose (Anderson and Chen, 1979). The water soluble protein consist of 35% galactose, 63% mannose and 5 to 7% protein. It is used as a thickening agent in paper production and in dairy products. Guar gum has little cation binding action but does form gels in the small intestines and may slow gastric emptying (Kay,1982).

Psyllium Seed

Psyllium seeds are the seeds of the plantage plant. They contain mixtures of neutral and acidic carbohydrate polymers and have been used as a laxative since early times. The active substance is the plant mucilages of the seed. While by definition they would be mucilages, they closely resemble hemicellulose in composition and structure (Kay and Strasberg, 1978). Psyllium seeds have been incorporated into human food products and proposed as a dietary fiber additive (Kies, 1982).

Solka Floc

Solka floc is the trade name of a purified wood cellulose product manufactured by the Brown Company of Berlin, NH. It contains 85% alpha cellulose and 15% non-alpha cellulose, including hemicellulose and pentosans (Lang and Briggs, 1977). It has been extensively used in animal trials as a bulk filler. Similar products are currently being added to bread as a dietary fiber source.

Metabolic and Nutritional Effects of Dietary Fiber in Poultry

The addition of a nondigestible fiber to poultry diets generally results in an increase in feed intake to compensate for the effects of energy dilution (Hill and Dansky, 1954; Saito et al, 1959; Waldroup, et al., 1976; Savory and Gentle, 1976; Dvorak and Bray, 1978). Less well recognized are the beneficial effects that fiber may provide in poultry diets. Ricke et al. (1982) found improved average daily gain (ADG) in chicks with the addition of 8 percent alfalfa cell walls or lignin to the diet, while Hegde et al. (1978) observed an increase in chick growth rate with the addition of wheat bran. Savory and Gentle (1976) reported an improvement in the digestibility of the other dietary components with the addition of cellulose. A decrease in carcass fat without a reduction in growth rate was noted as increasing levels of oat hulls were added to a growing chick diet (Hill and Dansky, 1954). High fiber diets have been proposed as a means of controlling weight gain in growing broiler breeder pullets (Isaack et al., 1959; Waldroup et al., 1976). This is supported by the work of Piliang et al. (1982) who fed 81.5% rice bran in a pullet diet and obtained satisfactory results. These studies demonstrate the usefulness of fibrous products in poultry diets.

Site of Fermentation

Fermentation in poultry occurs in the cecum (Thornburn and Willcox, 1965) and crop (Bayer et al., 1978). Fermentation in the ceca is similar in nature to fermentation in the large intestine of other species. The crop of the chicken appears to resemble the surface of the bovine rumen (Bayer et al., 1978). There is a bacterial population present and the crop may be a potential fermentation site for high fiber diets. However, Bayer et al., (1978) did not find any pH control and the limited time in the crop suggests that little fermentation is likely to occur.

Negative Effects of Fiber

Not all the effects of fiber have been beneficial. While it is generally true that birds increase intake to compensate for energy dilution, the ability to maintain caloric intake is dependent on the level and source of dietary fiber. Bayer et al. (1978) found a depression in the rate of gain of chicks when 6% cellulose was substituted for corn. In their trial, birds were limit-fed three times daily for only 30 min. at each feeding and therefore, there may not have had sufficient time to increase intake to compensate for the dilution effects of the cellulose. Cherry et al. (1983) fed pullets a corn-soybean meal diet diluted with either 20% cellulose or 20% sand. Birds fed the sand diet overcame the caloric dilution by increasing intake and thereby maintained egg production. Birds fed the 20% cellulose also increase intake, but were unable to maintain caloric intake equal to those fed the controls diet and therefore had a decline in egg production.

Fiber sources high in hemicellulose, pectin or gums have been shown to depress growth rate (Ricke et al., 1982). The substitution of high levels of rye for wheat or corn in growing chicks has resulted in reducing growth rate and feed efficiency due to beak impaction and the excretion of wet and sticky feces. Wagner and Thomas (1977, 1978), while investigating the growth depression in chicks associated with diets containing rye, fed a simulated rye premix containing 8% pectin. Pectin addition decreased the rate of gain in chicks. Penicillin alleviated the depression suggesting that the depression was due to microbial action. However, when 0 to 6% pectin was added to a corn-soybean meal diet, penicillin alleviated only a portion of the reduced gain suggesting that factors other than microbial action are involved in the growth depression associated with pectin.

Guar meal from guar beans is a potential protein source for poultry but is poorly utilized due to the guar gum content. Attempts to improve the growth rate of birds fed guar meal by steam pelleting and methionine supplementation were unsuccessful, while the addition of enzyme preparations, MKC hemicellulase and betaganese M, improved growth rate (Verma and McNab, 1982). Ray (1982) overcame a 2 percent grow depression in chicks fed guar gum with the addition of enzymes and Grammer et al. (1982) demonstrated similar results in chicks fed a rye diet. These results indicate that the non-cellulose polysaccharides are responsible for the depressed growth rate and that growth can be improved by enzymatically breaking down the polysaccharides. This procedure may be useful for utilization of fibrous ingredients in poultry ration.

Effect on Intestinal Tract Size

Fiber and the increased feed intake associated with fiber addition may have an effect on the intestinal tract. Fisher and Weiss (1956) reported that maximum intake is regulated by the extent to which the digestive tract could distend. However, poultry are capable of limited anatomical and physiological adaptation to dietary nutrients. Birds consuming diets containing high levels of cellulose have increased gut dimensions (Savory and Gentle, 1976; Dvorak and Bray, 1978; Adbelsamie, et al., 1983). Kondra et al. (1974) observed an increase in the weight of the digestive tract and the height of the intestinal villi when feeding chicks high fiber diets. These results are not consistent with all fiber sources. Hegde et al. (1978) found that when added at levels of 10% of the diet, wheat bran increased tract weight while coarse wheat straw and bagasse had no effect on intestinal tract weight.

It has been suggested that an increase in bulk fill may increase rate of passage (Bayer et al., 1978; Dvorak and Bray, 1978); however, Savory and Gentle (1976) observed similar times in the appearance of a chromic oxide marker using Japanese Quail fed a diet with or without 20% cellulose.

Metabolic and Nutrition Effect of Dietary Fiber in Swine

Dietary fiber has traditional been thought of as having little effect on digestion in swine other than as a bulk constituent of the diet prior to the large intestines where some microbial digestion occurred (Cranwell, 1968). This is not surprising in light of the fact that until the advent of the NDF and ADF procedures, fiber was usually reported as crude fiber. The ability of fibers to bind water and form gels which could decrease digestibility of feed components or increase passage rate was not fully appreciated. Despite potential problems fibrous feedstuffs will be increasingly utilized in swine production as competition for traditional feedstuffs increase. The following sections will review the evidence for fiber digestion in swine, effects of fiber on nutrient digestibility and intestinal tract parameters.

Site of digestion

Most studies have shown little or no fiber digestion prior to the terminal ileum. The pH in the stomach is unsuitable for growth of cellulosic bacteria and the transit times through the small intestine are too short for major bacterial fermentation. Cranwell (1968) reviewed the earlier work on microbial fermentation in the pig and found little evidence of fiber digestion anterior to the large intestines, but recent studies have indicated that digestion to a limited extent might occur. Favorable conditions and sufficiency time are required for microbial fermentation. Horszczaruk (1962) found that larger particles could be retained in the stomach and small intestine for up to 36 hours and Clemens et al. (1975) reported retention time for large particles of up to 60 hours in the stomach. Times of this magnitude would allow for microbial fermentation of dietary fibers if other conditions were favorable.

Friend et al. (1963) reported considerable microbial fermentation in the stomach of young pigs with the formation of VFA and lactic acid. Key and Debarthe (1964) using ileally cannulated pigs, reported 1-20% digestibility of alfalfa hemicellulose cranial to the deuodenum and 4-48% cranial to the ileum. Sambrook (1979), in a series of studies using single re-entrant cannulas, reported some fiber digestibility in the stomach and small intestines. Kass et al. (1980) found that 38.8% of the cellulose digested in pigs fed a corn-soybean meal diet, was digested in the small intestine. Hansen (1983) reported 38% digestion of the cellulose in a corn-soybean meal diet prior to the cecum in pigs. These studies indicate that dietary fiber is partially fermented prior to entering the large intestine in pigs. It should be noted that the fiber sources used in these studies have not all been pure and various other materials or components of the fiber fraction could have been reduced and thereby provided the indications of fiber digestion. Still, there seems to be sufficient evidence to suggest some digestion of the fiber fraction may occur prior to the cecum.

The major sites of digestion of dietary fiber in swine are the cecum and large intestine. This is due to the longer retention time and suitable conditions for microbial fermentation. Large intestine transit time is 20-35 h (Key and Debarthe, 1974; Heck and Grovum, 1975). Clemens et al.(1975) demonstrated rapid passage through the small intestines and cecum and then prolonged retention of fluids and particlate markers, first in the accending and then descending colon. Cauguilem and Labie (1977) and Kass et al. (1981) found that the addition of fiber to the diet decreased transit time. The magnitude of the affect of fiber on transit time was greatest when fiber was added to a 0% fiber diet and additional increments of fiber decrease transit time at a decreasing rate.

Large intestine microbial fermentation produces VFA, lactic acid, methane and hydrogen which may be absorbed and metabolized by the animal. The VFA produced are absorbed mainly from the cecum and colon (Argenzio and Southworth, 1975). Reports on the amount of available energy produced by microbial fermentation have varied. Partridge et al. (1982) reported that while dietary cellulose was digested by the growing pig and produced VFA, fermentation provided no net energy gain. Farrell and Johnson (1972) concluded, based on the VFA content of the digesta, that microbial fermentation could provide about 2% of the maintenance requirement of sows. Friend et al. (1964) estimated that fiber potentially could provide 15-28% of the maintenance requirement of the sow based on arterial-venous differences of VFA. Using slaughter techniques Kass et al. (1980) estimated that fiber could provide 12-14% of the maintenance energy requirement of sows. The data appears to support the hypothesis that dietary fiber can contribute a significant amount of energy to the diet of swine.

Cecal Enlargement

Various workers have observed an enlargement of the cecum and colon with increased fiber levels (Bohman et al., 1963; Sheared and Dunkie, 1968; Farrell and Johnson, 1972). This enlargement may be due to increased bulk or to microbial fermentation. Cecal enlargement in lactose fed pigs (Shearer and Dunkin, 1968) indicated that increased microbial fermentation is responsible for cecal growth. Enlargement of the gut in pigs fed high fiber diets could be an adaptation mechanisms which decreases the rate of digesta passage and increases retention time allowing for the development of an intestinal flora to improve digestion (Gargallo and Zimmerman, 1981).

Effect on other nutrients

Murray (1976) using ileally cannulated pigs demonstrated the effects of various fiber sources on the apparent digestibility of nitrogen. The addition of gel-forming polysaccharides to the diet caused a decrease in apparent nitrogen digestibility at the terminal ileum. Cellulose addition increased rate of passage but had no effect on nitrogen digestibility. Digestibility of lysine hydrochloride was

100% in all diets suggesting that fiber did not reduce with the digestibility of water soluble dietary components. He concluded that the decrease in nitrogen was due to a reduction in hydrolysis of the protein due to gel formation and not rate of passage or bulk per se.

Dietary fibers can act as cation exchange resins binding mineral elements (McConnell et al., 1974). Partridge (1978) found a reduction in apparent absorption of Ca, P, Mg, K and Zn in pigs fed diets containing 9% cellulose.

There are indications of increased VFA levels at the terminal ileum with increased fiber intake. This may be due to an increase in starch available for fermentation posterior to the terminal ileum because of reduced digestibility of the whole diet or to increased passage rate (Kidder and Manners, 1980).

Effect on Production

Neonatal pig mortality is a major problem with the swine industry. The majority of these loses occur within 3 to 4 days postnatally among the smaller pigs due to their failure to sucessfully compete for milk and the resulting hypogylcemia and death. The inability of the young pig to maintain glucose levels high enough to prevent hypogylcemia is due to the rapid depletion of the limited glycogen reserve and limited gluconeogenic capacity (Mersmann, 1974). In an attempt to overcome these limitations, Boyd et al. (1982) fed sows, beginning at 90 days gestation, diets with 15% of the energy source as either monohydrate (control), 1,3-butanediol or an equimolar mixture of acetate and lactate. Butanediol and the acetate-lactate mixture increased total liver glycogen levels by 32% and 27%, respectively, when compared to sows fed the control diet. This suggests that fiber sources which produce VFA may improve pig survival rates by increasing the neonatal pig liver glycogen stores.

Fiber addition to the ration of lactating sows has been shown to increase milk fat, VFA production and plasma glucose levels (Vankempen and Grimbergen, 1977; Zoiopolus et al., 1982; Bryan et al., 1984). An increase in milk fat could improve pig survival rate. Pollmann et al. (1980) reported pig survival rates were 8 percent higher for pigs on sows fed a gestation ration containing 50% alfalfa. Zoiopolus et al. (1982) reported higher milk fat levels in sows milk when oat hulls or straw was added to the diet and suggested it was due to an increase in acetate formation in the lower gut.

Danielson (1970, 1974) and Poe (1975) reported that high fiber forages may form an economical diet for gestating sows. Sows have shown an adaptation to the addition of 50% alfalfa in the diet by increasing hemicellulose and cellulose digestion over a 90 day period (Dennis et al., 1983). These studies indicate that fibrous diets for gestating and lactating sows may improve production and be economically beneficial.

Average Daily Gain

The addition of high levels of fiber to the diet of growing swine usually results in a reduction in average daily gain (Keys and Debarth 1974; Van Soest and Young 1970; Kuan et al., 1983). When conventional feed ingredients used in swine rations are replaced with lower energy fibrous ingredients, there is a reduction in the caloric content of the ration. The ability of the pig to increase dietary intake to maintain digestible energy intake is a major factor influencing weight gain of pigs fed high fiber diets. The depression in average daily gain seen in pigs fed high fiber diets is usually attributed to a dilution of the energy content of the diet (Baird et al., 1970; Cole et al., 1976). Fiber also affects the digestibility of other nutrients (Cunning et al., 1962; Pond et al., 1962; Key and DeBarth 1974; Kornegay 1978; Kass et al., 1980) as discussed above. Fiber digestibility varies widely with the source and level of the fiber in the diet (Kass et al., 1980; Laplace and Lebas, 1981) and these differences can result in an effect on average daily gain. The degree of digestibility of dietary fiber in the pig depends on a number of factors including: the degree of lignification (Forbes and Hamilton, 1952), the level in the diet (Kass, et al., 1980) and the age of the pig (Friend et al.,1963). High levels of neutral detergent fiber (NDF) significantly decreased the digestibility of both dry matter and NDF. King and Taverner (1975) found that when NDF was used as the independent variable in a regression equation it gave a more accurate estimation of ration digestibility than crude fiber or acid detergent fiber. Fiber may increase digesta passage rate (Kass et al., 1980) and thereby decrease digestibility. The ability to digest fiber varies widely among individual pigs (Key et al., 1970; Farrell, 1973; King and Taaverner, 1975). An understanding of the magnitude and interaction of these factors is necessary to estimate the effects of fiber on average daily gain. Maximum daily gain however, is not always the overriding criterion in swine production and even a reduction in daily gain with high levels of fibrous ingredients may be economically acceptable.

Modification of Bacteria

Efforts to improve utilization of fibrous feeds by modifying the microbial population or providing cellulase enzymes have not been very productive. Improvements in digestibility by inoculation with cellulose fermenting bacteria have been shown (Vartiovaara, 1947); however, there was a limited number of animals (4) in this trial. Bodart (1978) found no improvement in digestibility with the addition of a dietary cellulase enzyme, but the cellulase was not protected from hydrolysis. Recently Ravindran (1984) found that virginimycin decreased passage rate and improved digestibility. Enzymes have been utilized in poultry to improve digestibility of fibrous ingredients (Verma and McNab, 1982; Ray, 1982). These results are encouraging and may offer methods to improve fiber digestibility in nonruminants in the future.

Effect of Dietary Fiber on Plasma Lipids and Cholesterol Metabolism

Numerous epidemiological studies have suggested a relationship between dietary fiber intake and atherosclerosis (Keys, 1982). Several authors have suggested that dietary fiber may prevent or delay the development of atherosclerosis (Burkitt, et al., 1974; Trowell and Burkitt, 1977). This has generated studies to determine the effects of dietary fiber on serum cholesterol and plasma lipid levels. The proposed mechanisms whereby dietary fiber may alter serum cholesterol and triglyceride levels are : (1) altering intestinal absorption, metabolism and release of cholesterol, (2) altering the hepatic metabolism of cholesterol, (3) altering the metabolism of lipoprotein (Anderson and Chen, 1979).

Blood plasma cholesterol is derived from synthesis within the body, dietary cholesterol and the recycling of cholesterol from bile secretions into the intestine. The later source of cholesterol is commonly referred to as enterhepatic circulation (Brown et al., 1981) and results in the reabsorption of most of the cholesterol and bile acids that flow into the intestine. Dietary fiber may decrease enterohepatic circulation since bile acids are strongly bound by lignin and alfalfa (Story and Kritchevsky, 1977). This may result in an increase in fecal excretion of cholesterol from dietary sources and bile acids.

Experiments on the effects of dietary fiber on plasma cholesterol have produced varied results. These studies are extensively reviewed elsewhere (Spiller and Amen, 1976; Falkehay, 1979; Kay, 1982). Truswell and Kay (1975) found that plasma cholesterol levels were not affected when rats were fed wheat bran, but were decreased when rats were fed citrus pectin. Heaton et al. (1976) found no change in blood plasma levels in human males fed whole wheat bread compared to males fed a non-bran control. Jenkins et al. (1979) fed human subjects one of three fiber sources: guar gum, pectin or wheat bran. Guar gum and pectin lowered plasma cholesterol levels while wheat bran produced no response. Other fiber sources which have been reported to lower plasma cholesterol levels in rats are psyllium seed and sugar beet pulp (Forsythe, 1978). Forsythe et al. (1978) found an increase in plasma cholesterol levels in rats fed wheat bran when compared to those fed a non-fiber control diet. Aspet al et. (1981) reported that rats fed wheat bran had increased plasma cholesterol levels while those fed guar gum had decreased plasma cholesterol levels when compared to those fed a control diet.

Lignin has been shown to have a lowering effect on plasma cholesterol in rats (Judd et al., 1976). Leifzmann et al. (1979) reported that lignin formed an unabsorbable complex with cholesterol in the intestinal lumen. Muelle et al. (1978) found no effect of lignin on plasma cholesterol levels.

In general these result indicate that wheat bran has little effect on plasma cholesterol levels while the noncellulosic polysaccharides usually lower plasma cholesterol levels. Cellulose and lignin have produced varied effects which can be explained, in part, by differences in the fiber source studied. Based on the available data it cannot be determined if dietary fiber can be used to reduce plasma cholesterol levels in man. Therefore, continuing efforts to determine the effects of fiber on plasma lipids are required.

CHAPTER III

INFLUENCE OF DIETARY FIBER LEVEL AND SOURCE ON CHICK GROWTH AND GASTROINTESTINAL TRACT

W.N. Cannon, R. Teeter and C.V. Maxwell

Oklahoma State University, Stillwater 74078

Abstract

Two chick digestion trials were conducted to evaluate the impact of fiber composition and level on feed intake, weight gain, digestibility, intestinal tract size and digesta passage rate. In the first trial, two semi-purified fiber sources, psyllium seed and Solka floc, as sources of noncellulosic polysaccharides and cellulose, respectively and one inert source of bulk (polyethylene) were added to a corn-soybean meal basal diet to examine fiber effects. Chicks consuming diets containing polyethylene increased feed intake ($P<.05$) and maintained weight gain up to a level of 50% added polyethylene. Chicks fed increasing levels of Solka floc increased feed consumption only slightly and consequently energy consumption and body weight gain declined ($P<.05$). Birds fed increasing levels of psyllium seed decreased ($P<.05$) feed intake and markedly reduced weight gains. Digesta retention time did not differ between fiber sources. Percent digesta dry matter was lower in chicks fed the two fiber sources compared to polyethylene. In the second trial, eight natural fiber sources which varied in their

digestibility and water binding were added by weight (30% of basal) to the basal diet. Fiber sources differed in their effect on weight gain, feed intake and gain to feed ratio. The digestibility of the diets varied, however starch digestion was not significantly reduced by the addition of fiber. These results indicate that fiber sources differ in digestibility and in their effect on feed intake and weight gain.
Key Words: (Dietary Fiber, Chicks, Digesta Fill, Digesta Passage Rate, Digestibility)

Introduction

Economical nutrient sources are needed by the poultry industry to reduce production costs. One potential method to reduce feed cost is to increase the use of by-product feeds in poultry diets. By-products frequently contain useful energy, protein, minerals and vitamins at nominal cost but can exceed 20% crude fiber content. High dietary fiber content is associated with reduced caloric density and growth rate if birds are not able to consume more feed and maintain energy intake. Dietary fiber has been reported to depress growth (Wagner and Thomas, 1977, 1978; Bayer et al., 1978) and decrease utilization of nonfibrous nutrients (Dvorak and Bray, 1977). However, Hegde et al. (1978) and Rick et al. (1982) reported increased average daily gains, and Savory and Gentle (1976) observed increased digestibility of other dietary components with the addition of fiber to the diet. These conflicting observations may be due to differences in fiber source, composition and dietary level. The objective of this study was to evaluate the effects of specific semi-purified fiber components and level on feed intake, body weight gain, digestibility, digesta passage rate and the physiological impact of fiber on gastrointestinal tract capacity.

Materials and Methods

Trial 1: Two hundred and four 14 day old New Hampshire x Columbian Plymouth Rock chicks were randomly allotted to seventeen treatment groups. Treatments were replicated with two pens of six birds each and consisted of the following semi-purified fiber sources added to the basal diet at various levels: psyllium seed[a] (PS), a noncellulosic polysaccharide (5, 10, 15, 20%); Solka floc[b] (SF), a source of cellulose (10, 20, 30, 40, 50, 60%); and ground polyethylene[c] (PO), an inert source of dietary bulk (10, 20, 30, 40, 50, 60%). All fiber sources were added to the basal diet by weight (table 1). Preliminary trials indicated reasonable chick survival with all dietary fiber sources at high levels, except psyllium seed; therefore, PS was not evaluated above the 20% level. Birds were housed in wire floor batteries and received their respective diet for an 8 d feeding period. Weight gain and feed intake were determined for the 8 d feeding period.
Digestibility was estimated using chromic oxide as an indigestible marker. Digesta retention time was estimated on day 8 by monitoring feces for first appearance of ferric oxide as described by Smith and

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[a] psyllium seed (Mucilose Flakes, Winthrop Lab, New York, N.Y.)

[b] Solka floc (Brown Co., Berlin, N.H.)

[c] polyethylene (Phillips Petroleum Co., Bartlesville, Okla.)

Teeter (In press). Four birds were chosen at random from each treatment and killed by cervical dislocation. Gastrointestinal tracts were removed and bisected at the crop, proventriculus, gizzard, small intestinal, cecum and colon. Excised segments were weighed with and without contents so that segment and digesta wet weight, dry weight and dry matter could be quantitated. Digesta samples were dried at 55c for 48 h and the percent digesta dry matter determined. Fiber water binding capacity was estimated using procedures described by Robertson and Eastwood (1981).

Trial 2: Trial two was conducted the same as trial one, except that the treatments consisted of eight readily available high fiber feedstuffs which varied in quantity and composition of available nutrients and dietary fiber. The fiber sources consisted of alfalfa, amaranth, bagasse, beet pulp, corn bran, rice bran, wheat straw and wheat bran. Fiber was added at a constant level of 30% to the basal diet.

The data for both experiments were analyzed with least square analysis of variance. The model included diet and pen. If the treatment effect was significant a Duncan's multiple range was performed.

Results and Discussion

The effect of bulk and dietary fiber on chick performance in experiment 1 are shown in table 2 and figures 1-4. Daily feed intake of birds fed 10 to 60% added PO averaged 44.1 g/d which was significantly higher ($P<.01$) than birds fed SF (33.6 g/d), PS (28.3 g/d) or the control (27.1 g/d) diet. Average daily feed intake of birds fed 10 to

60% SF was increased ($P<.01$) when compared to birds fed the control diet, while the average feed intake of chicks fed 5 to 20% PS did not differ ($P>.05$) from birds fed the control diet. The effect of increasing levels of bulk or fiber on feed intake is shown in figure 1. Birds fed PO increased feed intake quadratically. Feed intake increased with levels of PO up to 50% and declined with 60% addition of PO. Birds fed SF increased feed consumption over control but feed consumption did not differ ($P<.05$) among the levels of SF addition. Feed intake for birds fed PS was did not differ from basal except at the 20% level of PS addition where feed intake was reduced ($P<.05$). These results with increasing levels of PO are consistent with the early work of Hill and Dansky (1954) and Scott and Forbes (1958) that chicks increase feed intake to maintain a constant level of energy intake. The initial increase in intake and then leveling of intake with SF is similar to the results of Dvorak and Bray (1978) who reported a plateau in intake at 10% cellulose fiber addition.

Average basal intake (table 2) was significantly higher for chicks fed the PO diet (32.7 g/d) compared to birds fed the control diet (27.1 g/d). Average basal intake did not differ between birds fed control, SF (25.4 g/d) and PS (25.4 g/d) diets. After an initial increase with fiber addition, basal intake declined in chicks fed SF and PS but not those fed PO (figure 2).

Average weight gain of chicks fed 10 to 60% PO was 24.4 g/d and did not differ ($P<.01$) from those fed the control, 24.1 g/d. Birds fed SF and PS gained 18.0 and 12.5 g/d, respectively, which was lower ($P>.05$) than the 24.4 g/d gain of the birds fed the control diet. A linear reduction in average weight gain with increasing fiber levels was observed in birds fed SF and PS (figure 3).

Birds fed increasing levels of PO were able to adjust feed consumption in response to the reduced caloric density and maintained weight gains with up to 60% PO addition. This vividly demonstrates the broilers capacity to maintain energy consumption. Birds fed increasing levels of SF and PS increased feed intake but did not maintain energy intake with increasing intake of dietary fiber as did chicks fed PO.

Body weight gains followed energy intake and did not differ ($P>.01$) in birds fed increasing levels of PO compared to chicks fed the control diet. In birds fed SF and PS weight gains decreased linearly ($P<.01$) with increasing dietary fiber levels. These differences between PO (inert bulk) and dietary fiber are consistent with the report of Cherry et al., (1983) who found that pullets increased feed intake and maintained caloric intake with up to 20% dilution of the diet with sand; however, with the addition of 20% cellulose, the increase in feed intake was not sufficient to maintain caloric intake and production declined. These results suggest that the amount of fiber that can be tolerated without reducing body weight gain varied markedly and is dependent on the fiber composition.

Digestibility of the basal diet was 82.5%. The average digestibility of birds fed 10 to 60% PO and SF was 62.8% and 63.9% respectively while birds fed 5 to 20% PS had an average diet digestibility of 70.4%. The addition of PO and the two fiber sources reduced ($P<.01$) average digestibility. Percent diet digestibility (figure 4) declined with increasing levels of PO and fiber addition and indication that the fiber sources in this study were not digested as well as the basal diet.

Differences between the two fiber sources, independent of inclusion level, suggest that physical differences, toxic factors or other differences between fiber sources play a role in determining the effect of fiber upon feed intake and body weight gain. Physical differences between SF and PS may have resulted in the differences observed. Birds fed the PS but not the SF diet were observed with feed particles adhering to their beaks. Fowl have a viscous type saliva and feed components such as gluten in wheat and the gums of barley and rye form a paste in the mouth which may adhere to the beak and reduce feed intake. This could have produced a reduction in feed intake in birds fed PS; however, no increase in the number of birds with adhered feed was observed with increasing levels of PS.

These effects on feed intake, basal intake, weight gain and digestibility indicate that dietary fiber does not act as an inert filler. Differences in fiber composition as represented by the two types of fiber in this trial indicated that the effects of dietary fiber on feed intake and weight gain of chicks is dependent on the fiber source.

Digesta contents of each segment of the gastrointestinal tract were collected, however usually less than a gram of dry matter was recovered in the crop, proventriculus, cecum and colon and the amounts collected were highly variable between birds on the same treatment. Therefore, only the data on the digesta collected in the gizzard and small intestines are presented in table 3. The percent dry matter in the gizzard of birds fed PO averaged 52% and was consistently higher than that observed in birds fed SF (36%) or PS (14%). The percent dry matter in the small intestine followed the same trend with birds fed PO consistently having a higher level of dry matter (33.2%) compared to birds receiving SF (24.4%) or PS (15.6%).

The waterbinding capacity of the fibers used in this experiment are presented in table 4. PS had the largest amount of water retained (4.851 g/g dm), compared to basal (.569 g/g dm), SF (1.134 g/g dm) or PO (.155 g/g dm). Relatively little is known regarding the contribution of fiber to gastrointestinal solids, volume and water retention potential. The fiber sources in this experiment differed up to 660% in water binding capacity (table 4). This increase in water retention resulted in an increase in digesta fill in the intestinal tracts of birds fed PS and corresponds to the reduced digesta dry matter content.

Rate of digesta passage was estimated using ferric oxide. First appearance of ferric oxide (table 5) for chicks receiving the basal diet was estimated to be 240 min. and exceeded the time for all fiber treatments although the differences were not significant. Time of first appearance did not differ in birds fed increasing levels of PO and SF. Birds fed increasing levels of PS tended to have a decrease in the time of first appearance from 232 min for those fed 5% to 157 min for those fed 20%. The failure to detect differences in time of first appearance was surprising in light of the increasing level of intake noted with PO and the increased bulk consumption of both polyethene and Solka floc. It was expected that increasing the level of fiber would decrease retention time. A possible explanation is that birds had been held off feed for 4 h to synchronize initial feed intake. This length of time may have resulted in an emptying of the gastrointestinal tract which may have masked any influence of increased dietary consumption or undigested bulk on digesta passage rate.

An alteration in gastrointestinal tract size could have masked any effect of fiber on time of first appearance. Empty tract weight after adjusting for body weight are shown in table 6. Total tract weight when adjusted for body weight gains did not differ ($P<.05$) between treatments. Gizzard weights tended to increase in chicks fed PO compared to those fed SF, PS or control. The gizzard weight of chicks fed increasing levels of PO tended to increase from 12.44 g in birds fed 10% PO to 20.12 g in birds fed 60% PO and indicates that increases in digesta fill result in increased muscle growth.

These results demonstrate that dietary fiber does not act as an inert ingredient. Chicks fed increasing levels of PO increased feed intake and maintained basal intake and weight gain. In contrast, chicks fed increasing levels of SF, maintained feed intake and decreased basal intake and average daily gain; while chicks fed PS had a decreased feed intake, basal intake and average daily gain. Percent digesta dry matter was higher in birds fed PO compared to those fed SF or PS.

The second trial was conducted to compare fiber sources typically found in livestock feeds to the semi-purified fiber sources utilized in experiment 1 and to test the hypothesis that fiber water binding capacity of fibrous feeds is an indicator of the effects of dietary fiber sources on performance. Eight feedstuffs varying in fiber composition and water binding capacity (table 4) were added at 30% by weight, to a nutritional complete basal diet to form rations varying in fiber composition and water binding capacity. The feedstuffs were alfalfa, amaranth , bagasse, beet pulp, corn bran, rice bran, wheat bran and wheat straw.

The effects of natural fiber sources on chick performance are presented in table 7. Feed intake increased with the addition of fiber, although the increase was not significant. Basal intake was 27 g/d for birds fed the basal control diet. Birds fed diets containing alfalfa, amaranth, bagasse and wheat bran increased feed intake moderately from 115-126% of control while birds fed beet pulp, corn bran, rice bran and wheat bran increased feed intake 140-152%. Therefore birds fed alfalfa, amaranth, bagasse and wheat bran had a reduced basal intake compared to control, while birds fed beet pulp, corn bran, rice bran and wheat bran had an increased basal intake compared to birds fed the control diet.

Body weight gain averages 24 g/d for birds fed the control diet. Weight gain did not differ (P>.05) in birds fed diets containing the fiber addition with the exception of birds fed wheat bran. Birds fed wheat bran gained 32 g/d which was a significant increase over the gain of birds fed the control diet. This increased weight gain with the inclusion of wheat bran is in agreement with the report of Hegde et al. (1978) who reported an increase in growth rate of chicks with the substitution of 10% wheat bran for starch.

Overall digestibility for birds fed the control diet was 82% and was not significantly different from birds fed corn bran (82%), amaranth (78%), beet pulp (74%) or wheat bran (73%). Several fiber sources lowered digestibility: alfalfa (70%), rice bran (68%), bagasse (66%), and wheat straw (67%).

There were no differences (P>.05) in overall starch digestibility between treatments. Starch digestibility was almost complete for all treatments and indicates that fiber addition had little effect on starch digestion.

The effect of fiber addition on percent small intestinal digesta dry matter (table 8) was quite variable. The reduced percent dry matter with the more undigestible fibers is in agreement with the report of Bayer et al. (1978) that water intake is increased in birds fed high fiber diets and results in a lower dry matter content in the crop. The lower levels of dry matter in the gizzard of birds fed beet pulp (16.1%) tend to confirm the observed decrease in percent dry matter noted with the noncellulosic polysaccharide (PS) in experiment 1. No differences (P>.05) were noted in the percent dry matter in the small intestine birds fed 30% added fiber; however, as in the small intestine chicks fed beet pulp and alfalfa tend toward wetter digesta.

The effects of fiber source on gastrointestinal tract size are presented in table 9. Total tract weights, after adjusting for body size, were not significantly different between birds fed either the control diet or one of the fiber sources. The gizzard weight of birds fed the control diet (11.11 g) was less (P<.05) than the gizzard weight of birds to which 30% fiber had been added. Other workers have shown that poultry are capable of anatomical and physiological adaptation. Kondra et al. (1974) observed an increase in the weight of the digestive tract and an increase in the height of the intestinal villi, when feeding high fiber diets. Abbelsamie et al. (1983) reported an increase in relative length and weight of the intestine and ceaum with increased fiber levels.

This study demonstrates the need to evaluate fiber sources based on individual composition. Chicks were able to increase feed intake and maintain caloric intake when an inert bulk, polyethelene, was added to the diet; however, when the two semi-purifed fiber sources were addied to the diet the chicks were unable to increase intake and performance decreased. Significant differences in feed intake and weight gain occurred between the two fiber types and the levels of inclusion. The addition of 30% of a wide range of fiber sources however had little effect on weight gain since birds increased intake and maintain energy gain. The addition of 30% wheat bran to the control basal increased feed intake and average gain in growing chicks.

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TABLE 1. COMPOSITION OF BASAL DIET USED IN EXPERIMENTS 1 AND 2

Ingredient	%
Cornstarch	53.35
Casein (5-01-162)	21.00
Dry egg solids	13.00
Arginine	.90
DL Methionine	.50
Glutamic acid	5.26
Glysine	.12
Mineral mix	5.37
Vitamin mix	.40
Chomic oxide	.10
Total	100.00

TABLE 2. EFFECT OF FIBER TYPE AND LEVEL ON FEED INTAKE, BASAL INTAKE, BODY WEIGHT GAIN, AND OVERALL DIGESTIBILITY IN EXPERIMENT 1

Item	Control	Polyethy-ene	Solka floc	Psyllium seed	SE
Feed intake, g/d	27.1[c]	44.1[a]	33.6[b]	28.3[c]	.6
Basal intake, g/d	27.1[b]	32.7[a]	25.4[b]	25.4[b]	.5
Weight gain, g/d	24.1[a]	24.4[a]	18.0[b]	12.5[c]	.6
Digestibility, %	82.5[a]	62.8[c]	63.9[c]	70.4[b]	1.4

[abc]Significant at (P<.01)

Polyethyene and Solka floc were added at 10,20,30,40,50 and 60% levels, psyllium seed was added at 5,10,15 and 20% levels.

TABLE 3. PRECENT DIGESTA DRY MATTER IN THE GIZZARD AND SMALL INTESTINE OF CHICKS FED POLYETHYLENE, SOLKA FLOC AND PSYLLIUM SEED

Treatment		Gizzard	Small Intestine
		% dry matter	
Basal		0.0	20.5
Polyethylene			
	10	47.2	28.1
	20	51.8	29.8
	30	55.6	29.6
	40	50.8	31.7
	50	51.3	39.0
	60	54.6	41.3
Solka floc			
	10	22.0	24.8
	20	32.5	19.4
	30		24.9
	40		28.5
	50	55.5	23.5
	60		25.7
Psyllium seed			
	5	9.6	13.4
	10	13.5	12.8
	15	9.9	11.6
	20	22.0	24.8

TABLE 4. WATER BINDING CAPACITY OF DIETARY FIBER SOURCES

Fiber source	Grams water retained/ g sample
Exp. 1	
Basal	.569
Polyethylene	.155
Psyllium seed	4.851
Solka floc	1.134
Exp. 2	
Bagasse	1.502
Alfalfa	1.448
Amaranth	.767
Beet pulp	2.867
Corn bran	1.280
Rice bran	.734
Wheat bran	1.358
Wheat straw	2.458

TABLE 5. INFLUENCE OF FIBER AND BULK ON RATE OF DIGESTA PASSAGE IN CHICKS

Treatment	Level[a] %	Time[b] min
Basal	0	240
Polyethylene		
	10	172
	20	172
	30	180
	40	157
	50	182
	60	195
Solfa floc		
	10	202
	20	202
	30	187
	40	210
	50	172
	60	210
Psyllium seed		
	5	232
	10	172
	15	165
	20	157

[a]Percent added by weight to basal diet

[b]Average time to first appearance for 6 dropping /pen

TABLE 6. EFFECT OF DIETARY FIBER ON GASTROINTESTINAL TRACT WEIGHT IN EXPERIMENT 1

Treatment	Level	Total tract	Gizzard	Proven-triculus	SI	CECA	LI
Control		41.40	11.11^{c}	3.37	25.92^{c}	3.00^{b}	.84^{b}
Polyethylene							
	10%	45.03	12.44^{bc}	3.02	31.02^{b}	3.72^{b}	1.80^{a}
	20%	42.47	13.70^{bc}	2.74	28.70^{bc}	3.83^{b}	1.62^{b}
	30%	42.21	16.57^{ab}	3.19	28.95^{bc}	3.80^{b}	1.42^{b}
	40%	42.20	16.58^{ab}	2.80	29.84^{bc}	3.45^{b}	1.45^{b}
	50%	41.22	17.27^{ab}	3.07	25.22^{c}	2.87^{b}	1.04^{b}
	60%	42.51	20.12^{a}	2.77	27.47^{c}	3.39^{b}	1.74^{ab}
Solfa floc							
	10%	39.15	11.28^{c}	2.74	28.31^{c}	2.89^{b}	1.25^{b}
	20%	49.71	12.08^{bc}	3.11	36.60^{ab}	4.57^{ab}	1.91^{a}
	30%	41.74	10.44^{c}	2.80	27.58^{c}	3.01^{b}	.95^{b}
	40%	41.92	9.34^{c}	2.67	29.37^{bc}	4.26^{ab}	.86^{b}
	50%	41.92	14.24^{bc}	3.13	25.81^{c}	3.10^{b}	1.70^{ab}
	60%	45.42	10.25^{c}	2.59	38.11^{a}	3.92^{b}	2.27^{a}
Psyllium							
	5%	45.97	12.00^{bc}	3.18	31.33^{b}	3.36^{b}	1.60^{b}
	10%	42.62	9.90^{c}	2.96	41.21^{a}	3.59^{b}	2.22^{a}
	15%	47.02	12.27^{bc}	3.34	42.43^{a}	5.16^{a}	1.65^{b}
	20%	42.34	11.03^{c}	2.35	40.46^{a}	3.45^{b}	3.30^{a}

^{abc} Means within columns with different superscripts differ ($P<.05$)

TABLE 7. EFFECT OF FIBER ON CHICK PERFORMANCE IN EXPERIMENT 2

Fiber	Feed intake g/d	Basal intake g/d	Gain g/d	Digest-ibility %	Starch digestion %
Control	27	27	24^{bc}	82^{a}	96
Alfalfa	32	25	27^{ab}	70^{bc}	99
Amananth	32	25	24^{bc}	78^{ab}	95
Bagasse	31	23	20^{c}	66^{c}	99
Beet pulp	41	32	24^{bc}	74^{abc}	99
Corn bran	38	29	27^{ab}	82^{a}	98
Rice bran	38	29	23^{bc}	68^{bc}	98
Wheat bran	39	30	32^{a}	73^{abc}	98
Wheat straw	34	26	20^{c}	67^{c}	99

[abc] Means within columns with different superscript differ ($P<.05$)

TABLE 8. EFFECT OF FIBER SOURCE ON DIGESTA DRY MATTER IN THE GIZZARD AND SMALL INTESTINE OF CHICKS

Treatment	Gizzard	Small Intestine
	% dry matter	
Basal	0.0	20.5
Alfalfa	26.7	16.4
Amaranth	41.6	24.3
Bassage	25.0	19.2
Beet pulp	16.1	13.0
Corn bran	31.4	25.7
Rice bran	41.5	26.5
Wheat bran	28.9	22.9
Wheat straw	26.6	22.0

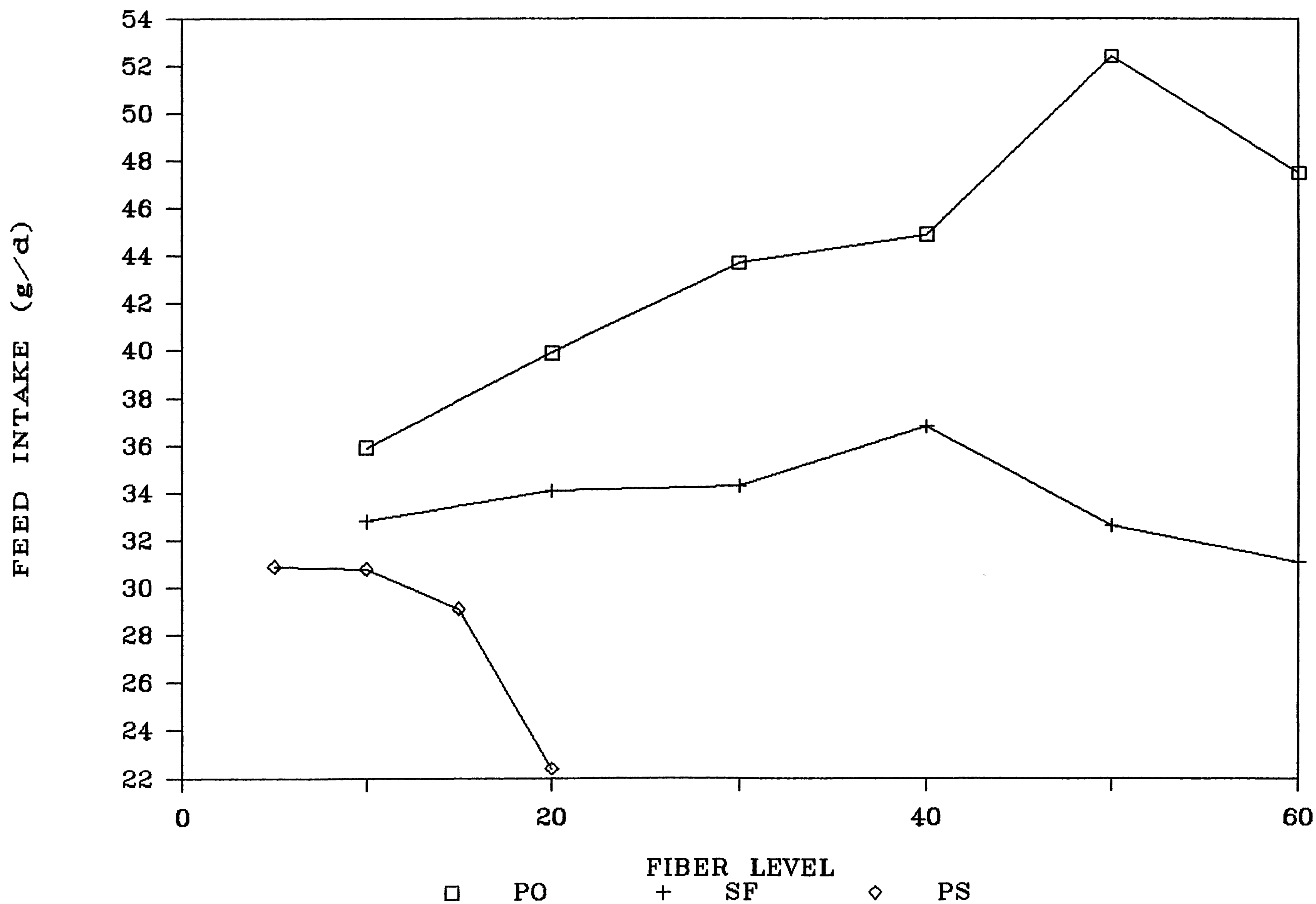
TABLE 9 . EFFECT OF NATURAL FIBER SOURCE ON GASTRONITESTINAL TRACT SIZE

Treatment	Total tract	Gizzard	Proven-triculus	SI	CECA	LI
			Grams^{A}			
Control	41.40	11.11^{e}	3.37	25.92^{d}	3.00^{c}	$.84^{d}$
Alfalfa 30%	46.32	17.06^{bc}	2.75	34.12^{a}	4.00^{abc}	1.15^{cd}
Amaranth 30%	41.87	16.09^{c}	2.75	25.87^{d}	3.50^{bc}	$.61^{d}$
Bagasse 30%	46.12	28.83^{a}	2.95	32.41^{abc}	2.89^{c}	2.37^{ab}
Beet pulp 30%	43.24	17.88^{bc}	2.47	33.34^{ab}	4.86^{ab}	2.56^{a}
Corn bran 30%	44.87	19.34^{bc}	2.68	29.13^{abcd}	4.33^{abc}	1.62^{abcd}
Rice bran 30%	45.79	20.74^{b}	2.69	30.45^{abcd}	4.16^{abc}	1.37^{bcd}
Wheat straw 30%	40.60	20.02^{bc}	2.93	28.70^{bcd}	3.05^{c}	2.15^{abc}
Wheat bran 30%	38.65	16.27^{c}	2.72	26.53^{cd}	5.12^{a}	1.15^{cd}

^{A}Empty tract weights (average of 4 birds per treatment)

^{abcde} Means within columns with different superscripts differ (P<.05)

Legend for Figures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FIBER LEVEL
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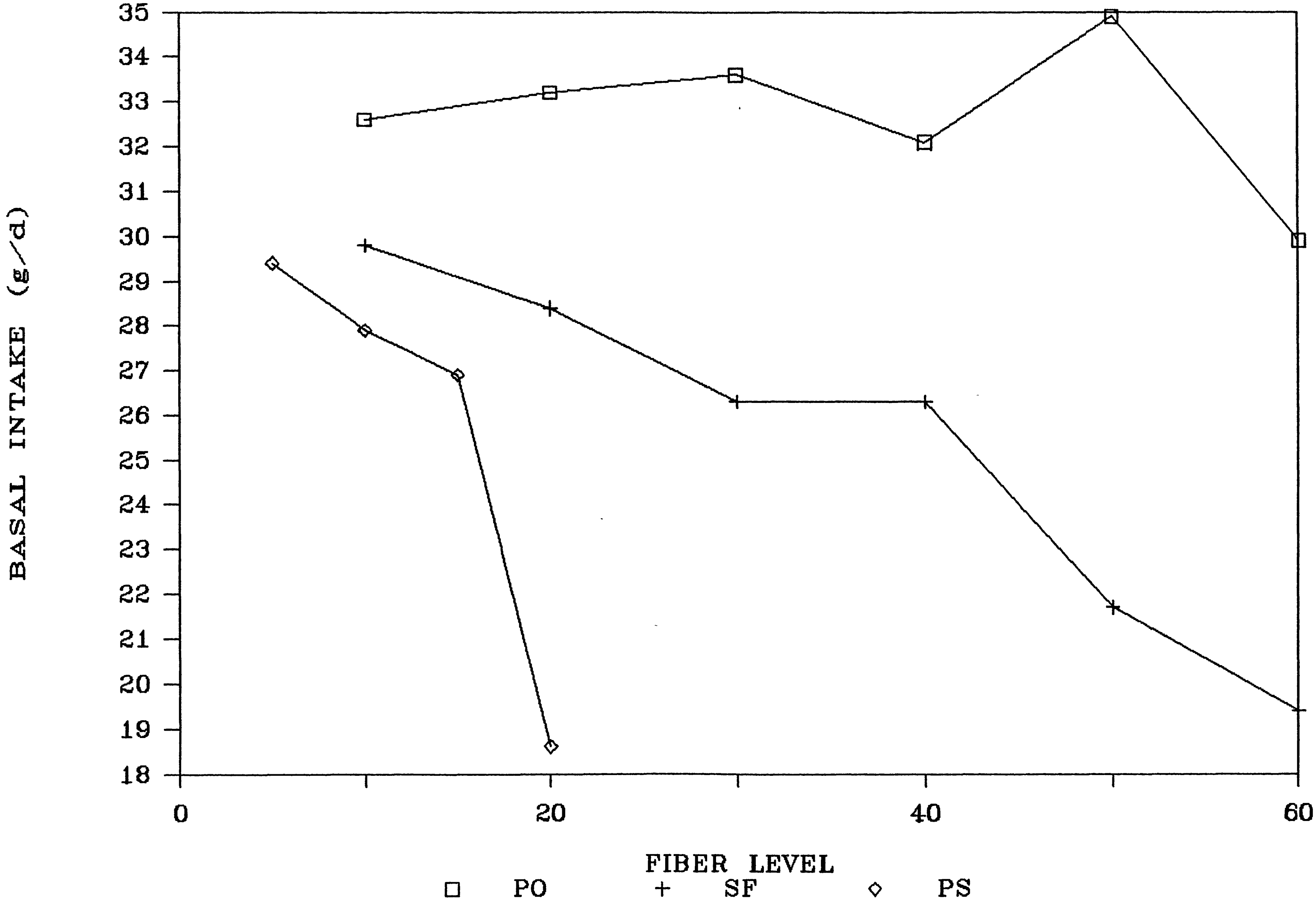
BASAL INTAKE (g/d)
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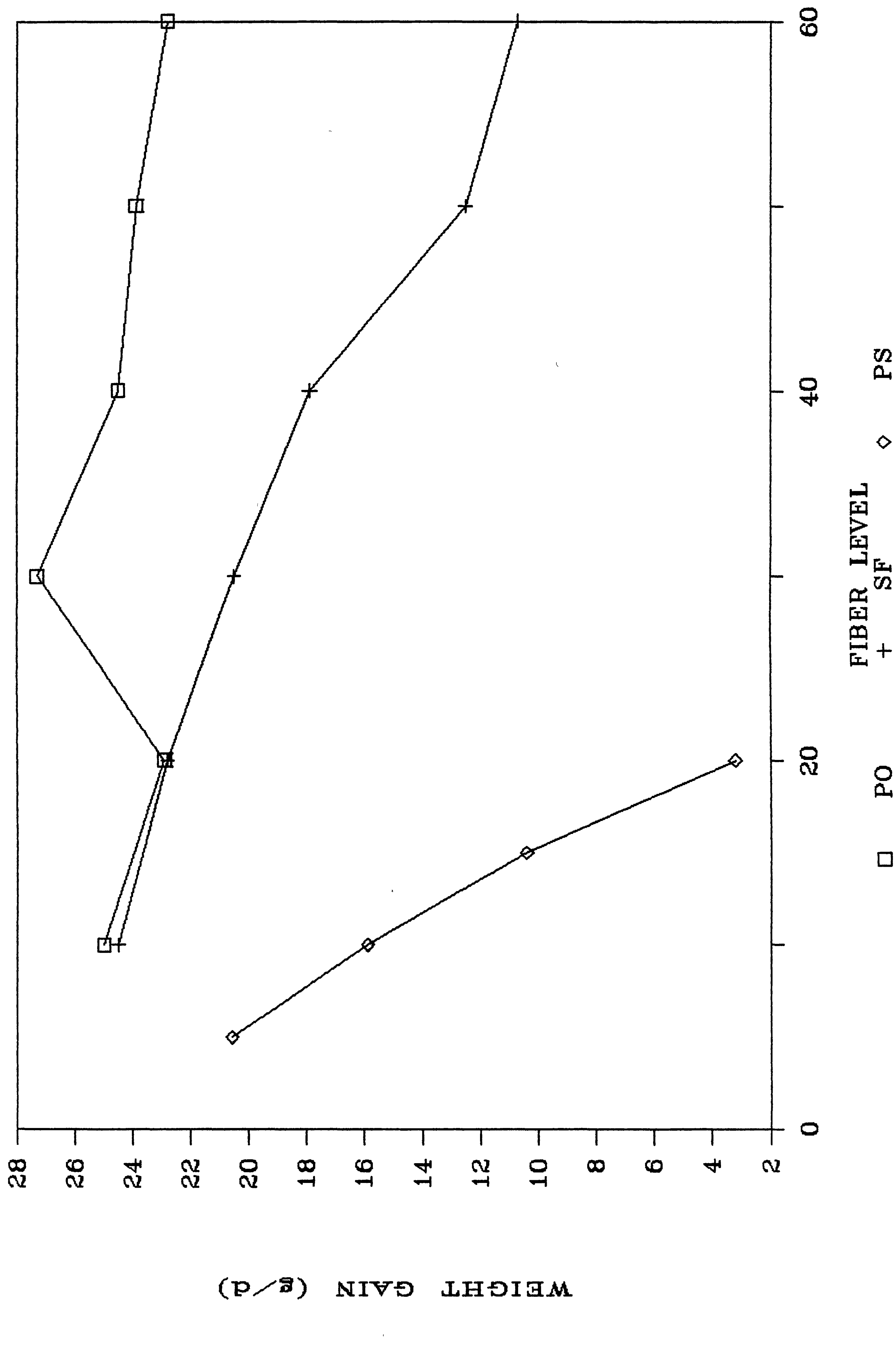

WEIGHT GAIN (g/d)
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FIBER LEVEL
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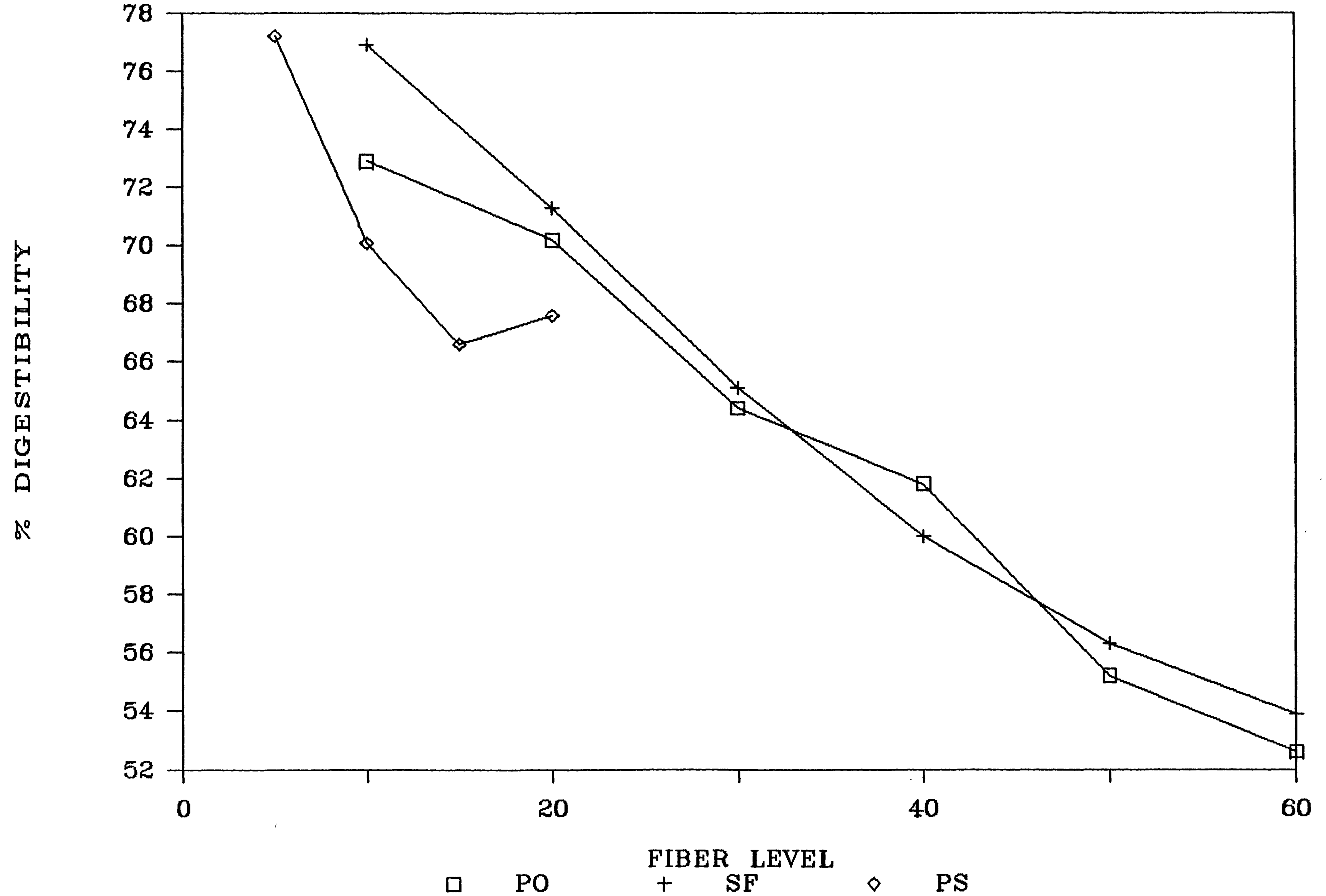
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CHAPTER IV

THE EFFECTS OF SEMI-PURIFIED DIETARY FIBER COMPONENTS ON DIGESTIBILITY IN SWINE

W.N. CANNON, C.V. MAXWELL, D.S. BUCHANAN

AND C.G. BEAMES

Oklahoma State University, Stillwater 74078

Summary

Ten 70 kg Yorkshire barrows fitted with T-cannulas in the distal ileum were used in a digestion trial to determine the effects of semi-purified dietary fiber components on the site of digestion and overall digestibility. Treatments consisted of a basal corn-soybean meal diet with 10 percent of either cornstarch, psyllium seed, guar gum, Solka floc or lignin added by weight to the basal diet. Pre-cecal digestibility of dry matter was reduced ($P<.05$) in pigs fed fiber sources when compared to those fed the control diet. The addition of either guar gum or psyllium seed to the diet shifted 20-25% of the dry matter digestion and crude protein digestion from pre-cecal to post-ileal when compared to pigs fed either the control diet or a diet containing either Solka floc or lignin as the fiber source. Post-ileal digestibility of dry matter and crude protein was increased by the addition of guar gum and psyllium seed. Digestibility of dry matter over the entire tract (fecal digestibility) was decreased ($P<.05$) in pigs fed psyllium seed, Solka floc or lignin, but not guar gum as the fiber source. Apparent overall tract crude protein digestibility was reduced ($P<.05$) by the addition of psyllium seed and lignin. Rate of digesta passage to the ileum was decreased by the addition of guar gum. Plasma lipid levels were not significantly affected by dietary fiber addition. This study suggests that fiber components composed of noncellulosic polysaccharides may decrease pre-cecal digestibility and increase post-ileal digestibility of nonfibrous dietary components whereas fiber components composed of cellulose and lignin have little effect on the site of disappearance of the other dietary nutrients. (Key: Dietary Fiber, Swine, Digestibility, Pre-cecal digestion, Plasma lipids, Digesta passage)

Introduction

Dietary fiber has traditionally been considered to have little effect upon digestion in nonruminants other than as a bulk constituent (Cranwell, 1968) and to provide a nutrient source for microbial digestion in the cecum and large intestines (Friends et al., 1982). Recent studies have indicated that fibrous feed sources may provide an alternative to more traditional corn-soybean meal diets (Pollmann et al., 1980; Robles and Ewan, 1982). However, most workers have observed a negative effect of fiber on digestibility. As the level of fiber in the diet increases there is a decrease in digestibility of dry matter, energy, crude protein, minerals and a reduction in ADG and feed efficiency (Murray, 1976; Kornegay 1978, 1981; Partridge, 1978; Kass et al., 1980; Kidder and Manner, 1980). The depression in growth rate is usually attributed to a dilution of the energy content of the feed (Braid et al., 1970; Powley et al., 1981). Reductions in average daily gain (ADG) may also result from increased digesta transit time (Kass et al., 1981) or the entrapment of dietary components in the fiber matrices (Murray, 1976).

Individual fiber sources vary widely in structure and composition, therefore an understanding of the effects of fiber components on digestion should provide a method to estimate the impact of fiber addition on site and extent of nutrient availibility. While isolation of fiber components may alter the biological activities of those fractions (VanSoest, 1978), an association between the chemical structure and the function of the fiber components should provide a basis to determine the effects of various fiber sources.

This study was undertaken to determine the effects of specific semi-purified dietary fiber components on overall apparent digestibility, site of digestion, digesta flow rate and plasma lipid levels in swine.

Methods and Materials

Ten Yorkshire barrows (70 kg) were fitted with T-cannulas in the distal ileum. The cannula was positioned 10 centimeters anterior to the ileo-cecal junction. Cannulas were make from tygon tubing molding and glued with cyclohexanone. The barrows were randomly allotted to one of five treatments in a replicated 5 x 5 latin square designed experiment. Prior to the initiation of the trial, the pigs were maintained on a corn-soybean meal diet containing 10 percent wheat bran. A corn-soybean meal diet formulated to contain .62 percent lysine and ten percent cornstarch served as the control. One of the four fiber sources was added by weight to the basal diet (table 1) at the expense of cornstarch. The four semi-purified fiber sources selected to represent different fiber components were: (1) psyllium seed (PS) and (2) guar gum (GG), noncellulosic polysaccharides which differ in physical characteristics; (3) Solka floc (SF), a purified form of wood cellulose; (4) indulin (IN), a purified source of lignin. Each pig was maintained in an individual metabolism crate and fed 2 kg per d in two equal feedings at 0800 and 1600 h. One animal developed cannula problems and was removed from the trial. Each period consisted of ten d with d 1 to 5 serving as an adjustment period. Animals were weighed at the beginning and at each subsequent period. Ileal digesta samples were collected into 100 ml plastic bags attached to the cannula starting 4 h after the 0800 feeding on d 6, 7 and 8. A subsample was obtained for ileal pH, dry matter and viscosity determinations. Apparent viscosity was measured using a Brookfield RVF Sychrol-electric Viscometer. Grab fecal samples were collected at 1200 h on d 7, 8 and 9. Samples were frozen and stored at -20o C until analyzed. Blood plasma samples were obtained by anterior vena cava puncture on d 9 at 1200 h. On d 10, one percent ferric oxide was added to the 0800 h feeding and ileal contents were collected continually in half-hour collection periods, for 12 h to determine rate of digesta passage. Lypohilized ileal and fecal samples from each individual pig for each period were composited based on an equal dry matter weight per d and ground before analyses. Samples were analyzed for kjeldahl nitrogen (AOAC, 1975), neutral detergent fiber (NDF) (Robertson and Van Soest, 1977), acid detergent fiber (ADF) (Goering and Van Soest, 1970) and chromic oxide (Hill and Anderson, 1958). Due to the nature of psyllium seed the NDF analysis could not be determined on all samples. Post-ileal digestibility was determined by the difference between digestibility determined at the end of the small intestine and digestibility over the entire tract. The data were analyzed with least square analysis of variance. The model included diet, period, square and pig within squares. If the treatment effect was significant a Duncan's Multiple Range was performed.

Results and Discussion

Animals gained an average of 51$\pm$1 kg during the 50 day trial. There were no significant differences in weight gains among treatments.

Fiber sources altered the physical characteristic of the ileal chyme. The ileal chyme of pigs fed GG was foamy with numerous gas bubbles similar to the results observed by Hansen (1983) when oat bran was evaluated as a fiber source. The ileal chyme of pigs fed PS appeared thick and viscous with little foaming. Ileal chyme of the remaining treatments (control, SF, IN) appeared normal with more free liquid present.

Fiber sources varied in their effect on the percent dry matter of ileal chyme (table 2). Dry matter of ileal chyme ranged from a high of 13.2 percent in pigs fed IN to 8.6 percent in pigs fed PS. Pigs fed PS had reduced ($P<.10$) ileal dry matter percentage when compared to those fed SF and IN. A similar trend was observed in pigs fed GG but the differences were not significant. Viscosity of chyme (table 2) was generally increased with the addition of dietary fiber, although viscosity was increased (P<.05) only in pigs fed GG. This is consistent with the findings of Blackburn and Johnson (1981) and Rainbird and Zebrowska (1982) who observed that guar gum increased digesta viscosity. Pigs fed SF tended to increase viscosity compared to those fed control or IN. The failure of IN to increase viscosity may be due to the fine particle size of this lignin source. It was expected that an increase in viscosity might effect pH, however the pH of the chyme was similar across all dietary treatments.

The effect of dietary fiber on digestibility is presented in table 3. The addition of all fiber sources reduced (P<.05) pre-cecal apparent dry matter digestibility when compared to pigs fed the control diet. Apparent digestibility of the control diet was similar to ileal digestibility reported by other workers (Sauer et al., 1977, 1982; [illegible]ksely et al., 1981). Pre-cecal digestibility was reduced from 79 [illegible] in pigs fed the control diet to 55 percent and 50 percent, in [illegible]iets containing the two noncellulosic polysaccharides, GG and [illegible]pectively. Pigs fed SF and IN diets had reduced pre-cecal dry [illegible]er digestibility of 65 percent and 67 percent compared to pigs fed [illegible]he control diet.

Digestibility was also calculated on a gram basis by using grams of intake times the percent digestibility (table 4). The addition of 10% fiber increased dry matter intake by 173g/d. Pigs fed the control diet digested 1367 g/d of dry matter pre-cecally, while pigs fed GG and PS digested 957 g/d and 865 g/d respectively. The reduction in dry matter digested in pigs fed GG and PS was 414 and 501 g/d, respectively, an amount approximately 2.5 times greater than the amount of fiber added and demonstrates that these fiber sources reduced pre-cecal apparent digestibility of nonfibrous dietary components. The reduction in apparent pre-cecal dry matter digestibility in pigs fed SF and IN were intermediate with digestibility reduced 243 g/d and 208 g/d, respectively. The reduction in dry matter digestibility with SF and IN was 1.4 and 1.2 times the amount of dry matter contributed by the fiber sources and is less than that of the two noncellulosic fiber sources. This demonstrates that while all the fiber sources reduce digestibility, the addition of noncellulosic fiber also reduces pre-cecal dry matter digestibility of other dietary components.

Apparent pre-cecal crude protein digestibility in pigs fed the control diet was similar to values reported in previous studies (Sauer et al., 1982; Jorgensen et al., 1984) and was reduced ($P<.05$) from 76 percent in pigs fed control diets to 48 percent in pigs fed GG and PS diets. Pigs fed SF and IN had apparent pre-cecal crude protein digestibility of 72 and 71 percent respectively, and were similar to pigs fed the control diet. This followed a pattern similar to that of dry matter digestibility. These results are consistent with those of Murray et al. (1977) who observed that gel forming polysaccharides decreased apparent N digestibility at the terminal ileum while cellulose had little effect.

Pre-cecal apparent digestibility of the NDF fraction for pigs fed the control diet was 45% while pigs fed GG and IN had digestibility values of 54% and 56% respectively and those fed SF had a pre-cecal digestibility of 36%. Due to analytical problems digestibility of the NDF fraction of pigs fed PS could not be determined. Pre-cecal apparent digestibility of the NDF fraction was quite variable between pigs and no significant differences between treatments were observed. These results are consistent with those of King and Taverner (1975) who reported a large variability in NDF digestibility among individual pigs and found that high levels of NDF significantly decreased the digestibility of both dry matter and NDF. Taverner and Farrell (1981) reported a high inverse correlation between ileal protein digestion and NDF levels which is consistent with the reduced pre-cecal crude protein digestibility in pigs fed noncellulosic polysaccharides in this study. Daily intake of NDF was increased with fiber addition. Pigs fed the control diet consumed 226 g of NDF daily compared to those fed GG (381 g/d), SF (452 g/d) or IN (195 g/d). An increase in total grams of NDF digested occurred with fiber addition. Pigs fed the control diet digested 102 g of NDF per-cecal compared to those fed GG (206 g), SF (163 g) or IN (225 g). This demonstrates the pigs capacity to digest NDF pre-cecally.

Total daily intake (g) of acid detergent fiber (ADF) (table 4) was similar in pigs fed GG (81 g) or PS (84 g) compared to pigs fed the control diet (76 g), but increased to 256 g in the pigs fed the SF diet and 195 g in those fed the IN diet. Pigs fed the GG and PS diets had a decrease in pre-cecal ADF digestibility which is consistent with the decrease in dry matter digestibility observed. The grams of ADF in the SF treatment consist of ADF from the basal components and cellulose from Solka floc which will be discussed below. The ADF fraction in the IN diet consisted of ADF from the basal diet and ADF from Indulin, a semi-purified lignin component, which as expected, was not digested.

Substantial pre-cecal cellulose digestion occurred in pigs fed the control diet (42%). This is in agreement with the observations of Hansen et al. (1983) who indicated pre-cecal cellulose digestion in the range of 37-52%. Pre-cecal cellulose digestibility was reduced in pigs fed GG (16%), PS (18%), SF (12%) and IN (9%) compared to those fed the control diet (42%). Cellulose intake for pigs fed the GG and PS diets was from corn and soybean meal and pre-cecal apparent cellulose digestibility followed a pattern similar to dry matter digestibility and was reduced compared to pigs fed the control diet. The SF diet contained cellulose from the basal components and cellulose from Solka floc. So while there was a significantly lower percent digestibility (12%) (table 3), total grams of cellulose digested (31 g) (table 4) were similar to pigs fed the control diet (30 g) and reflect digestibility of the cellulose components in the basal fraction.

Post-ileal apparent dry matter digestibility increased ($P<.05$) in pigs fed GG (30%) and PS (28%) diets when compared to those fed the non-fiber control diet (8%) or SF (13%) and IN (9%). This suggests that GG and PS shifted digestion of the nonfibrous dietary components from pre-cecal to post-ileal. Pigs fed GG and PS had an increased digesta viscosity which may have reduced digestibility in the small intestines. In the cecum and large intestines microbial digestion of the noncellulosic polysaccharides may have released entrapped dietary components which had escaped pre-cecal digestion and were then digested post-ileal. Post-ileal apparent dry matter digestibility was not significantly different between pigs fed the control diet and those fed SF or IN. These fiber sources did not decrease pre-cecal digestion of other dietary components and had little effect on post-ileal dry matter digestibility.

Apparent post-ileal crude protein digestibility was 5% in pigs fed the control diet. Post-ileal apparent crude protein digestibility, similar to dry matter digestibility, increased ($P<.05$) in pigs fed the GG (30%) and PS (22%) diets. Digestibility was similar in pigs fed the SF (7%) diet when compared to pigs fed the control diet. Post-ileal apparent crude protein digestibility (1%) tended to decrease in pigs fed the IN diet.

Apparent post-ileal NDF digestibility was similar among treatments. This is surprising in light of the difference in dry matter and crude protein digestibility. However, this is consistent with the findings of Keys et al. (1970), Ehle et al. (1982) and Kuan et al.(1983) who found no significant effect on the digestibility of these components with increasing levels of cell wall components.

Apparent post-ileal ADF digestibility for pigs fed the control diet was 18% compared to pigs fed GG (51%), PS (33%), SF (28%) or IN (5%) diets. Post-ileal ADF digestibility was not statistical different among treatments due in part to the large individual variability; however, the differences between means provide an indication of possible effects. In the control diet 18% ADF and 23% cellulose were digested post-ileal. The increased post-ileal digestibility of the ADF and cellulose fraction in pigs fed GG and PS diets over those fed the control diet probably reflects a shift in digestibility of the basal components from pre-cecal to post-ileal. The 28% post-ileal ADF digestibility of the SF diet represented 72 g of ADF digested compared to the 18% post-ileal digestibility of the ADF in the control diet which represented 14 g. This demonstrated that significantly quantities of SF were digested post-ileal. The ADF fraction of the IN diet consisted of basal components and lignin and only 10 g were digested similar to the 14 g of ADF digested in pigs fed control diets. This indicated that little if and lignin was digested post-ileal.

Apparent post-ileal digestibility of cellulose for pigs fed the control diets was 23% compared to those fed GG (52%), PS (33%), SF (32%) and IN (44%) diets. These results were similar to those for ADF with the exception of IN. The increase in cellulose digestion with pigs fed the IN diet compared to the control diet is probably a refection of an analytical problem which has been reported with this lignin source (Ehle, 1984) and should not be taken to indicate extensive pre-cecal digestibility of lignin.

Apparent overall dry matter digestibility was 87% in pigs fed the control diet compared to GG (85%), PS (78%), SF (77%) and IN (76%). Overall dry matter digestibility was reduced (P<.05) in pigs fed PS, SF or IN diets but not the GG diet when compared to pigs fed the nonfibrous control diet. This demonstrated that GG is digested by the pig while PS, SF or IN are poorly digested or reduced digestibility of other dietary components.

Overall apparent crude protein digestibility in pigs fed the control diet was 81% compared to pigs fed GG (78%), PS (71%), SF (79%) and IN (72%). Overall apparent crude protein digestibility was reduced

(P<.05) in pigs fed the PS and IN diets, but not pigs fed the GG and SF diets when compared to pigs fed the control diet. Various worker have noted that N digestibility was decreased with the addition of fiber (Keys et al., 1970 ; Burrows et al., 1982; Shah et al., 1982). In this study the reduction in apparent overall crude protein digestibility of pigs fed the PS diet may be due to digesta entrapment by gel formation or to increased fecal microbial nitrogen (Misir and Sauer, 1982). The reduced overall crude protein digestion of the IN diet is in agreement with the results observed in chicks (Ricke et al., 1982) and could be due to the anti-microbial effects of the phenolic compounds of lignin decreasing microbial digestion (Jung and Fahey, 1983).

Overall apparent NDF digestibility was 65% in pigs fed the control diet compared to pigs fed GG (79%), SF (54%) and IN (68%) diets,while overall grams of NDF digested for pigs fed the control diet were 147 g compared to GG (301 g), SF (244 g) and IN (273 g). The overall percent NDF digestibility was similar across all treatments however due to differences in actual grams of intake of NDF more grams of NDF were digested with the addition of fiber.

Overall ADF digestibility for pigs fed the control diet was 51% compared to pigs fed GG (60%), PS (42%), SF (36%) and IN (22%). Overall ADF digestibility was reduced (P<.05) in pigs fed IN compared to those fed the control diet. When adjusted to a gram bases pigs fed control digested 39 g of ADF overall compared to GG (49 g), PS (35 g), SF (92 g) and IN (43 g). This indicates that the reduction in percent digestibility with IN compared to control reflects the increased ADF intake and the limited digestibility of this lignin source and not a reduction in the ADF digestibility of the basal components. The 92 g of ADF digested by pigs fed SF compared to the 46 g for those fed the control diet indicates digestibility of the SF fraction.

Overall cellulose digestibility for pigs fed the control diet was 65% compared to those fed GG (68%), PS (50%), SF (40%) and IN (54%). Overall cellulose digestibility, when converted to a gram bases, indicates that pigs fed the control diet digested 46 g, compared to those fed GG (48 g), PS (38 g), SF (102 g) and IN (58 g). The 102 g of cellulose digested by pigs fed the SF diet indicated cellulose digestion of the added SF and exceeds the reported maximum cellulose digestibility of 35/g/d by 40 kg pigs reported by Gargallo and Zimmerman (1980).

These results indicate that the site and extent of diet digestibility is effected by the source of dietary fiber. Noncellulosic fiber sources, may shift the site of digestion from pre-cecal to post-ileal.

The effects of fiber source on dry matter recovery at the terminal ileum are presented in figures 1 and 2. Grams of dry matter collected each hour for 12 h after the 0800 feeding are shown in figure 1. The total dry matter collected for pigs fed the control diet was 134 g compared to those fed GG (124 g), PS (172 g), SF (141 g) or IN (157 g) diets. The graph for grams of dry matter collected is similar for pigs fed either the control or IN diet. Grams collected for pigs fed control and IN diets produced a distinctive peak at 5 h post feeding with a sharp decline thereafter. The graph for pigs fed SF and PS diets tended to peak earlier at 4 h post feeding with a more uniform flow and a gradual decline until 7 h post feeding. Pigs fed the GG diet did not have a distinctive peak but the graph demonstrates a continuous flow of dry matter to the ileam.

Percent recovery after correcting for percent digestibility is shown in figure 2. Based on the percent digestibility, the percent dry matter recovery of digesta at the ileam within 12 h after feeding for pigs fed control was 74%, GG (32%), PS (40%), SF (46%), and IN (55%). By 5 h after feeding 48.7% of the undigested control diet and 48% of the undigested SF diet had reached the terminal ileum. A significantly larger percent of the IN 57.9% had reached the ileum (probably a reflection of the smaller particle size of this lignin source). The PS tended to have a slower rate of passage at 5 h (43.6 %) through the different was not significant. The accumlated percent recovery of GG at 5 hr (34.2) was significantly less than the other treatments.

Rate of passage of the digesta has been reported to increase with increasing fiber level in the diet (Kass et al.,1980; derHartog et al., 1984). Kornegay (1981) suggest that the increasing rate of passage could be responsible for less opportunity of dry matter and N digestion and account for the decrease in digestibility with increasing dietary fiber. Others have reported that guar gum slows gastric emptying and increased the time digesta remained in the small intestines (Poksay and Schmeman, 1983). This data demonstrated that fiber sources not only influenced first appearance but effect the flow of digesta overtime.

The effects of dietary fiber components on plasma lipid levels are presented in table 5. The addition of dietary fiber to the basal diet had no effect ($P<.05$) on plasma lipid levels although the total cholesterol levels when the SF diet was fed was reduced by 18 percent when compared to values obtained when the control diet was fed. Guar gum and psyllium seed have been shown to lower plasma cholesterol levels in man and other species (Jenkins, et al.,1975, 1979; Forsythe, 1978; Turswell and Key, 1975; Aspet et al., 1981). Judd et al., 1976 reported lignin to have a lowering effect on plasma cholesterol in rats. Cellulose has usually had little effect on plasma cholesterol levels in man and other animal species studied (Anderson and Chen, 1979; Story, 1980). Gargallo and Zimmerman (1981) reported that the addition of Solka floc reduced plasma cholesterol in swine and our data tends in that direction. In this trial treatment period consisted of 10 d and may have been too short a time for adaptation of blood plasma lipids. Most studies have taken blood samples after a 12 h fast. In this trial blood samples were not taken at the end of a 12 h fast but 4 h after feeding so that collections coincided with time of maximum absorption. This may have resulted in a failure to detect a lower plasma level; however, levels were similar to those obtained from sows fasted for 20 hr. (Cannon et al., 1983).

These data demonstrated that substantial amounts of fiber can be digested in the pig. The results suggest that fiber sources high in noncellulosic polysaccharide may move the site of digestion from pre-cecal to post-ileal due to increased viscosity of digesta. Fiber addition tends to spread out the flow of digesta thru the small intestines and the type of fiber fraction significantly effected rate of digesta passage to the ileam.

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TABLE 1. COMPOSITION OF EXPERIMENTAL DIETS

Ingredient	%
Corn, ground (IFN 4-02-931)	71.50
Soybean meal (IFN 5-04604)	15.30
Cornstarch[a] (IFN 4-02-889)	10.00
Dicalcium phosphate (IFN 6-01-080)	1.60
Calcium carbonate (IFN 6-01-069)	.75
Salt	.35
Vitamin trace mineral premix[b]	.25
Chromic oxide	.25
Total	100.00
Calculated analysis	
ME, kcal/kg	3392
Crude protein	13.02
Calcium	.71
Phosphate	.60
Lysine	.62

[a] The following fiber sources were added at the expense of cornstarch: psyllium seed (Mucilose Flakes, Winthrop Lab, New York, N. Y.), guar gum (Colony Import Export Corp., New York, N. Y.), lignin (Indulin, Westvasco, Charlestron, S. C.), cellulose (Solka floc, James Rivers Co., Berlin, N.H.)

[b] Vitamin-trace mineral premix supplied 880,000 IU vitamin A, 66,000 IU D_3, 2,200 IU vitamin E, 880 mg riboflavin, 4.4 g d-pantothenic acid, 6.6 g niacin, 176 g choline choride, 3.3 mg vitamin B_{12}, 440 mg menadione sodium bisulfite, 4.4 g Mn, 19.8 g Zn, 44 mg I, 19.8 g Fe and 2.2 g Cu /Kg of premix.

TABLE 2. DIETARY EFFECT OF FIBER COMPONENTS ON ILEAL CONTENTS

	Diet				
ITEM	Control	Guar gum	Psyllium seed	Solka floc	Lignin
Dry Matter	10.25[ab]	11.8[ab]	8.6[b]	12.4[a]	13.2[a]
pH	6.5	6.2	6.0	6.7	6.4
			Viscosity[c]		
RPM[d]					
10.0	900	12800*	5600	1600	880
5.0	1400	23700*	7600	3000	1500
2.5	2160	40400*	9600	8800	2880

ab means in the same rows with different superscripts differ (P<.05)

c centiposie; measurements of viscosity based on Brookfield RVF Viscometer

d RPM of # 4 spindle

* P<.05

TABLE 3. APPARENT DIGESTIBILITY OF DIETS CONTAINING 10% SEMI-PURIFIED FIBER IN SWINE

	Diets				
	Control	Guar gum	Psyllium seed	Solka floc	Lignin
Daily intake, g					
Dry matter	1730	1730	1730	1730	1730
Crude protein	260	265	260	260	268
NDF	226	381		452	402
ADF	76	81	84	256	195
Cellulose	71	70	75	256	108
Pre-cecal digestibility,%					
Dry matter	79[a]	55[cd]	50[d]	65[bc]	67[b]
Crude protein	76[a]	48[b]	48[b]	72[a]	71[a]
NDF	45	54		36	56
ADF	34[a]	10[b]	9[b]	9[b]	17[b]
Cellulose	42[a]	16[b]	18[b]	12[b]	9[b]
Post-ileal digestibility,%					
Dry matter	8[b]	30[a]	28[a]	13[b]	9[b]
Crude protein	5[b]	30[a]	22[a]	7[b]	1[b]
NDF	20	27		19	11
ADF	18	51	33	28	5
Cellulose	23	52	33	32	44
Overall digestibility,%					
Dry matter	87[a]	85[a]	78[b]	77[b]	76[b]
Crude protein	81[a]	78[a]	71[b]	79[a]	72[b]
NDF	65	79		54	68
ADF	51[ab]	60[a]	42[ab]	36[bc]	22[c]
Cellulose	65	68	50	40	54

[abcd] Means with different superscripts in the same row are significantly different (P<.05)

TABLE 4. APPARENT DIGESTIBILITY OF DIETS CONTAINING 10% SEMI-PURIFIED FIBER

	Diets				
	Control	Guar gum	Psyllium seed	Solka Floc	Lignin
Daily intake, g					
Dry matter	1730	1730	1730	1730	1730
Crude protein	260	265	260	260	268
NDF	226	381		452	402
ADF	76	81	84	256	195
Cellulose	71	70	75	256	108
Pre-cecal digestibility, g					
Dry matter	1367	952	865	1124	1159
Crude protein	198	127	125	187	190
NDF	102	206	0	163	225
ADF	26	8	8	23	33
Cellulose	30	11	14	31	10
Post-ileal digestibility, g					
Dry matter	138	519	484	225	156
Crude protein	13	80	57	18	3
NDF	45	103	0	86	44
ADF	14	41	28	72	10
Cellulose	16	36	25	82	48
Overall digestibility, g					
Dry matter	1505	1470	1349	1332	1315
Crude protein	211	207	185	205	193
NDF	147	301	0	244	273
ADF	39	49	35	92	43
Cellulose	46	48	38	102	58

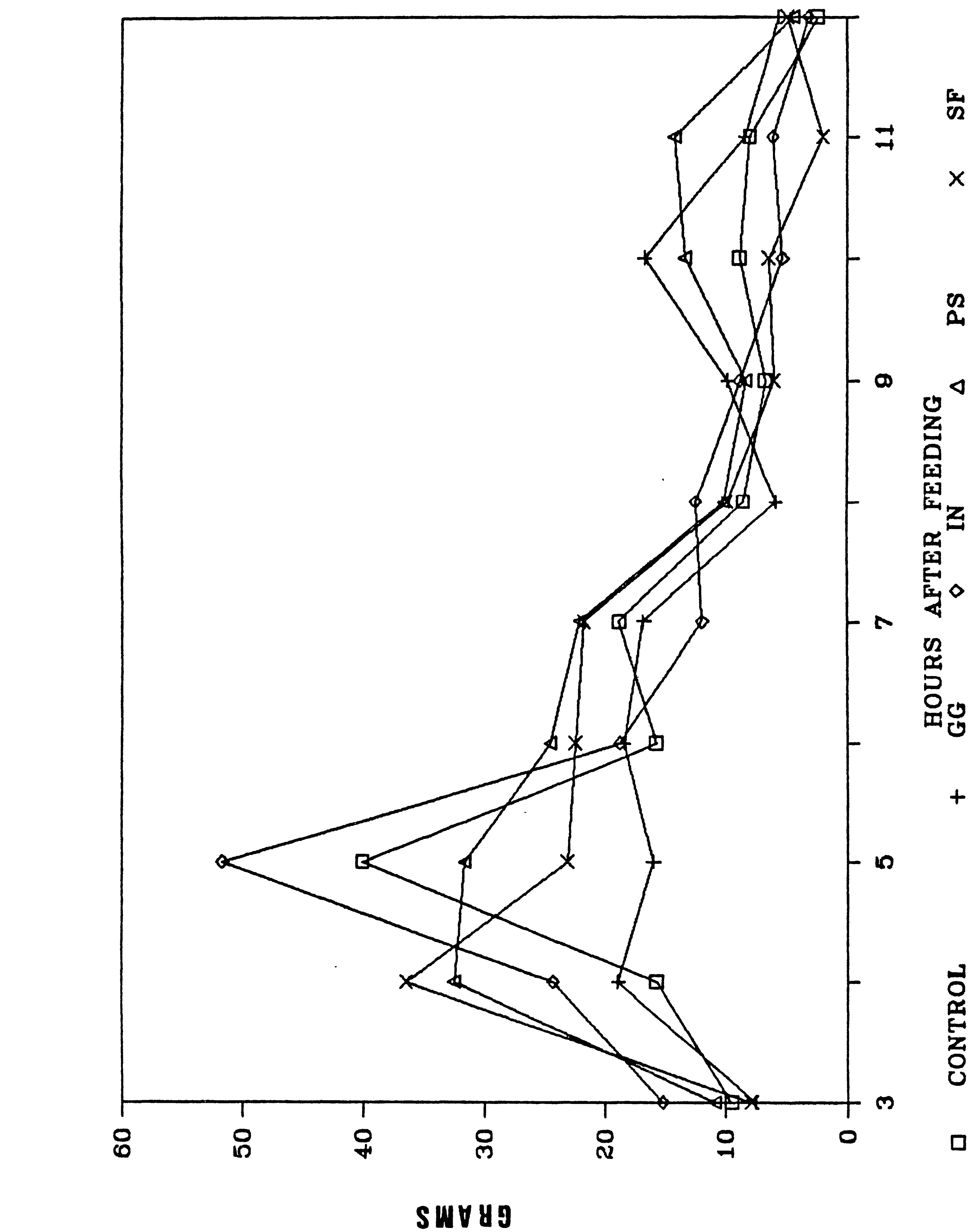
TABLE 5. EFFECT OF DIETARY FIBER COMPONENTS ON PLASMA LIPIDS

Plasma lipid levels	Diets: Control	Guar gum	Psyllium seed	Solka floc	Lignin	SE
	Mg/dl					
Total cholesterol	110	119	115	90	106	7
HDL-cholesterol	30	33	31	24	29	3
Triglyceride	49	60	62	43	59	7

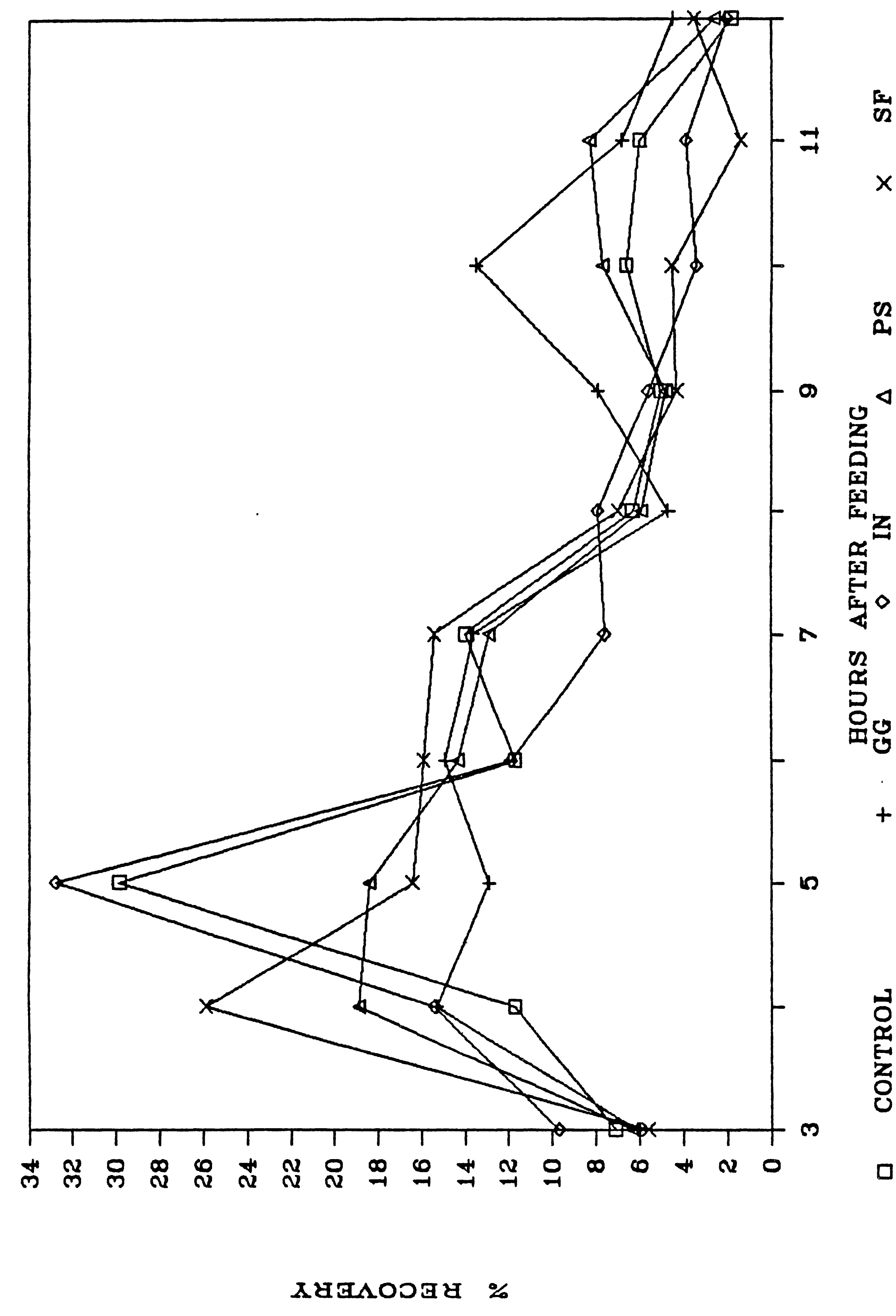
Legend for Figures

Figure 1. The influence of 10 percent dietary guar gum (GG), lignin (IN), psyllium seed (PS) and Solka floc (SF) on grams of dry matter recovered at the ileum in pigs.

Figure 2. The percent recovery of dry matter over time at the ileum in pigs fed diets containing 10 percent added guar gum (GG), lignin (IN), psyllium seed (PS) or Solka floc (SF).



GRAMS
60
50
40
30
20
10
0
3
5
7
9
11
HOURS AFTER FEEDING
CONTROL
GG
IN
PS
SF



% RECOVERY
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
3
5
7
9
11
HOURS AFTER FEEDING
□ CONTROL
+ GG
◇ IN
Δ PS
× SF

CHAPTER V

INFLUENCE OF BEET PULP AND WHEAT BRAN ON DIGESTIBILITY, CECAL PARAMETERS AND PLASMA LIPIDS IN SWINE

W.N. CANNON, C.V. MAXWELL, C.G. BEAMS, JR.
AND T.E. STALEY
OKLAHOMA STATE UNIVERSITY,
STILLWATER, OKLA.

Summary

Two trials were conducted to determine the effect of two fiber sources on site and extent of nutrient availability, lower tract adaptation and plasma lipids levels in swine. In the first trial 60 sows were fed either a corn-soybean meal basal diet, basal + 25% beet pulp diet or the basal + 25% wheat bran diet for 26 weeks. Cecal volume and weight were increased ($P<.05$) in sows fed the beet pulp, but not those fed the wheat bran when compared to sows fed the control diet. Plasma triglyceride levels were elevated 16% ($P<.05$) in sows fed beet pulp, while total cholesterol levels were elevated 16% ($P<.05$) in sows fed wheat bran compared to those fed the control diet. Plasma HLD-cholesterol levels did not differ ($P>.05$) between sows fed the control or those receiving beet pulp and wheat bran diets. A digestion trial was conducted using six 120 kg barrows fitted with simple T-cannulas in the distal ileum to determine the affects of beet pulp and wheat bran on site and extent of digestibility. Pre-cecal dry matter and crude protein digestion were reduced (P<.05) in pigs fed the beet pulp diet. Overall dry matter digestibility was reduced in pigs fed beet pulp and wheat bran diets compared to those fed the control diet. Overall apparent crude protein digestibility was reduced (P<.05) in pigs fed the beet pulp diet, but not those fed the wheat bran diet. This study suggest that dietary fiber addition does not decrease plasma cholesterol levels in swine and that the affects of dietary fiber on cecal size as well as site and extent of digestion are dependent on fiber type.

(Key Words: Dietary Fiber, Plasma Lipids, Cecum, Swine, Digestibility.)

Introduction

Danielson (1970, 1974) and Poe (1975) reported that high fiber forages may form an economical diet for gestating sows. Recent work has indicated that the addition of dietary fiber to the diets of gestating and lactating sows may improve performance (Pollmann et al.,1980; Zoiopolus et al., 1982). Pollmann et al. (1980) reported pig survival rates were 8 percent higher for pigs on sow fed 50% alfalfa during gestation. Fiber addition to the diet of lactating sows has been shown to increase milk fat, VFA production and plasma glucose levels (Zoiopolus et al., 1982; Bryan et al., 1984). Dietary fiber may increase milk fat levels in sows by increasing acetate formation in the lower gut (Zoiopoulis et al., 1982) and therefore provide for improved pig survival rate.

Concurrent with our interest in the effects of dietary fiber on swine production was the usefulness of swine as models for human nutrition studies. Dietary fiber has been proposed as an aid in preventing or delaying the development of arteriosclerosis in humans (Trowell and Burkitt, 1977). The proposed mechanism involves an increased fecal excretion of dietary cholesterol and bile acids due to reduced absorption, caused by gel formation entraping dietary components or to binding by the fiber (Anderson and Chen, 1979). The addition of dietary fiber to diets of man and experimental animals has produced varying effects on blood plasma lipids levels (Kays, 1982). Wheat bran and cellulose have been shown to have little or no effect on plasma lipid levels (Heaton et al., 1976; Kay and Truswell, 1977; Forsythe et al., 1978). The effect of beet pulp on plasma lipids has not been determined, but other gel-forming fiber sources such as guar gum and pectin have a hypocholesterolemic effect (Jenkins, et al., 1975; Jenkins et al., 1979). Additional research is needed to more clearly determine the effects of dietary fiber on plasma lipids. Swine appear to be a suitable animal models due to similar gastrointestinal tracts and cardiovascular systems (Pond and Houpt, 1978).

The objective of this experiment was to compare the effects of two fiber sources on digestibility, cecal adaptation and blood plasma levels in swine.

Materials and Methods

Exp 1

Sixty crossbred sows, approximately 14 months of age, were allotted at random to 12 pens (5 sows/pen) and subsequently to one of three dietary treatments (table 1). The three treatments consisted of a corn-soybean meal control diet, the control diet with 25% beet pulp (BP) added by weight to the control diet, and control diet with 25% wheat bran (WB) added by weight to the control diet. Beet pulp and wheat bran were chosen since both are commonly used in livestock feeding but differ in their fiber composition (NRC, 1982). The diets were balanced on an equivalent lysine/energy ratio and daily feed intake was adjusted to maintain a constant digestible energy and lysine intake across treatments. Tallow was included to increase the level of dietary fat.

Sows were housed in an enviromentally controlled building on slatted floors. Animals were fed once daily and water was available at all times.

Sows were weighed and blood samples were obtained via anterior vena cava puncture at 0, 2, 4, 6, 8, 10, 20 and 26 weeks, following a 20 h fast, into 50 ml centrifuge tubes containing a final concentration of .01% EDTA. Plasma was recovered by low speed centrifugation and stored at 4 C. Samples were analyzed for total cholesterol, HDL-cholesterol (phosphotungstate magnesium method) and triglycerides by enzymatic techniques (Allain, et al.,1974; Fletcher, 1968). At the end of weeks 10, 20 and 26 one third of the sows were slaughtered.

Ceca were excised 5-10 mm above the ileo-cecal junction. Following removal of the contents, the cecum was stripped of mesentery and mesenteric fat and trimmed just distal to the ileo-cecal junction. Volume of the cecum was estimated by quantitating the amount of water required to fill the supported ceca to a constant level. The ceca were then weighed and the length measured from the tip of the cecum to the ileo-cecal junction. Tissue samples were taken from the mid-section, fixed with formalin and slide sections were prepared for subsequent measurements of the muscularis externa.

Exp 2

Six, 120 kg, barrows fitted with simple T-cannulas in the distal ileum were utilized in a digestion trial to determine the effect of beet pulp and wheat bran on site and extent of digestion. The barrows were randomly assigned to treatments in two replicate of a 3 X 3 latin square arrangement of treatments. Treatments consisted of the three diets used in trial one (table 1) with chromic oxide added (.25%) as an indigestible marker. Pigs were maintained individually in metabolism crates and fed 1.0 kg at 0800 and a second 1.0 kg at 1800 h. Each trial period consisted of ten days with d 1-6 serving as an adjustment period. Beginning at 1200 h on d 7,8 and 9 ileal digesta samples were collected by attaching a 100 ml plastic bag to the cannula. Collection was continued until either 200 ml of digesta were collected or for 2 h. Grab fecal samples were collected on d 8,9 and 10 at 1100 h. Ileal and fecal samples were frozen and stored at -20 c until lyophilized. The samples for each pig during each period were composited based on an equal dry matter weight per day. Composited samples were analyzed for nitrogen (AOAC, 1975), neutral detergent fiber (NDF) (Robertson and Van Soest, 1977), acid detergent fiber (ADF) (Goering and Van Soest, 1970) and chromic oxide (Hill and Anderson, 1958).

The data for both experiments were analyzed using least squares analyzes of variance. Body weight was used as a covarient for cecum size and for plasma lipid levels since it has been shown that plasma levels in sows are corrolated with body size (Rothschild and Chapman, 1976). In experiment 1 the model included diet, pen within diet, sow (diet x pen) and time. Pen within diet was used as the error term to test significant effects. In experiment 2 the model included diet, period, latin square and pig within squares.

Results

There were no significant treatment differences in weight gain over the period of the trial. Sows on the control diet gained an average of 33 kg and sows fed either BP or WB gained an average of 30 kg.

The effects of dietary fiber on cecal parameters are presented in table 2. Cecal weights of the sow fed 25% beet pulp were heavier ($P<.05$) than the cecal weights of sows fed either the control diet or the diet containing 25% wheat bran. Although not significant there was a trend for increased cecal volume and length in the sows fed 25% beet pulp compared to sows fed either control diet or WB. Thickness of the cecal circular muscle layer and the longitudinal muscle layer were not different ($P>.05$) between treatments but tended to increase in sows fed WB. Tissue triglyceride and cholesterol levels did not differ ($P>.05$) between the treatments.

The effects of dietary fiber on plasma lipid levels are presented in figures 1-3. When viewed over time, total plasma cholesterol levels (figure 1) were elevated during the first few weeks of treatment. The addition of dietary fiber resulted in a greater increase in plasma cholesterol level compared to sows fed the control diet; however, only the WB caused an increase ($P<.05$). As the trial continued plasma cholesterol levels declined in sows on all treatments. A linear ($P<.01$)

decrease in plasma HDL-cholesterol levels occurred during the trial (figure 2). Plasma triglyceride levels (figure 3) were significantly elevated during the first 10 weeks in sows fed BP.

The effects of dietary fiber on apparent digestibility are presented in tables 3 and 4. Apparent pre-cecal dry matter digestibility was similar in pigs fed the control diet (81.3%) or the WB diet (80.3%) but was reduced ($P<.05$) to 65.9% for pigs receiving the BP diet. Apparent pre-cecal crude protein digestibility was depressed in pigs fed BP ($P<.05$) compared to values obtained for those fed the control or WB diets.

Althrough daily intake of dry matter and crude protein were similar across treatments, the addition of the two fiber sources increased daily intake of NDF and ADF compared to the control diet. Individual pig apparent pre-cecal digestibility of the NDF and ADF fraction was quite variable and no differences between treatments were observed.

Post-ileal digestibility was determined as the difference between pre-cecal digestibility and overall digestibility. Digestibility of dry matter and crude protein in the cecum and large intestines was not different between treatments. Post-ileal apparent NDF digestibility was reduced ($P<.05$) in pigs fed WB (12.5%) compared to values obtained when pigs were fed control (32.0%) or BP (34.6%) diets. However, apparent grams of NDF digested (table 5) did not differ ($P>.05$) between pigs fed the control diet (50 g) and those fed WB (49 g). Percent post-ileal apparent ADF digestibility was reduced ($P<.05$) in pigs fed WB (7.7%) compared to those fed control (30%) while digestibility was intermediate for those fed BP (18%).

Dietary fiber decreased (P<.05) apparent overall dry matter digestibility from 90.3% in pigs fed control to 86.1% and 86.9% in pigs fed BP and WB respectively. Apparent overall crude protein digestibility was reduced with BP (75.5%) but not WB (86.2%) compared to pigs fed the control diet (85.4%). Apparent overall NDF digestibility did not differ (P>.05) between treatments. Apparent overall ADF digestibility was reduced (P<.05) in pigs fed WP (53.5%) but not in pigs fed BP (75.8%) when compared to pigs fed the control diet (74.9%).

Discussion

The increase in cecal size due to the addition of 25% beet pulp is consistent with the work of Farrell and Johnson (1972) who found an increase in cecal size of pigs fed 26% cellulose compared to 8% cellulose. Readily fermentable diets containing alfalfa (Bohman et al., 1963; Kass et al., 1980; Kuan et al., 1983; Pekas et al., 1983) or lactose (Shearer and Dunkin, 1968) have been shown to increase intestinal tract size. The failure of wheat bran to increase cecal size may be due to differences in the amount of digesta bulk or the degree of fermentation between the fiber sources. Calculation of gram amounts from the digestion trial (table 4), indicate that higher (P<.05) levels of dry matter reached the cecum of pigs fed BP (587 g) compared to those fed WB (405 g) or the control (346 g) diets. Pigs fed BP digested 268 g dry matter post-ileal compared to pigs fed WB (166 g) or control (176 g) diets. VFA production in the cecum and colon was reduced in pigs fed diets to which 37.5% wheat bran was added with a substantial reduction in microbial activity in the colon (Dawson et al., 1984). If fermentation is responsible for the increase in cecum size there may have been insufficient fermentation occurring in sows fed WB to provide for cecal growth; however, the increase in cecal size demonstrated by Farrel and Johnson (1972) was accomplished with a minimum of fermentation (less than 3% of the apparent digestible energy intake).

Thicknesses of the circular muscle and the longitudinal muscle layers did not differ. Oku et al. (1982) found that dietary fiber caused both hyperplasia and hypertropitic changes in the cells of the gastrointestinal tract. They reported that the increase in tract weight was due to an increase in number of cells rather than an increase in cell size.

The addition of 25% beet pulp or wheat bran to a corn soybean meal diet failed to lower blood plasma lipids in swine. Collings et al. (1978) found that the addition of wheat middings up to 30% of the diet had no effect on serum cholesterol levels in pigs. Wheat bran has not been shown to have a lowering effect in other species (Jenkins et al., 1975; Heaton et al., 1976); therefore, the failure of wheat bran to lower blood lipid levels was not unexpected. The increase in total plasma cholesterol level of sows fed the wheat bran diet is consistent with similar observations in rats (Forsythe et al., 1978; Asp et al., 1981). It was expected that sows fed the beet pulp diet might have a lower plasma cholesterol level since beet pulp has been reported to lower the cholesterol level in rats (Forsythe et al., 1978). However, no reduction in plasma cholesterol level due to the addition of beet pulp to the diet was observed in this trial.

Figures 1,2 and 3 provide a picture of the affect of dietary beet pulp and wheat bran on blood plasma lipids over time. The initial increase in plasma cholesterol levels on all treatments is probably due to the addition of tallow. These effects of tallow and fiber on swine plasma cholesterol levels are consistent with earlier finding in swine (Fausch and Anderson, 1965). The decline in plasma cholesterol levels after the initial increase may reflect adaption to increases in dietary lipid levels.

The reduction in pre-cecal dry matter and crude protein digestitibility with BP but not WB, is similar to results obtain with pigs on semi-purified diets containing noncellulosic polysaccharides (Cannon, 1985). Pectin in BP may have formed a gel and entraped feed particles and thereby reduced pre-cecal digestibility. Individual pig apparent digestibility of the NDF fraction was quite variable and no significant differences in pre-cecal digestibility of the NDF fraction between treatments were observed. These results were in agreement with King and Taverner (1975) who reported a large variability in NDF digestibility among individual pigs and found that high levels of NDF significantly decreased the digestibility of both dry matter and NDF.

The percent of dietary dry matter reaching the cecum of pigs fed the control diet (20%) and digested post-ileal (10%) were similar to results obtained by other workers (Tanskley et al., 1981). Post-ileal digestibility of dry matter tended to increase in pigs fed BP which corresponds to the increased flow of dry matter to the cecum and large intestines.

The lack of an increase in post-ileal crude protein digestion of pigs fed BP to correspond with the increased dry matter digestion could reflect an increase in microbial protein due to an increase in fermentation.

Post-ileal digestibilities of NDF and ADF were reduced ($P<.05$) in pigs fed the WB diet. While the aleurone layer and cell contents of wheat bran is well digested by microbial activity (Saunders et al., 1974), other portions are poorly digested (Harbers et al., 1980), and may account for the poor digestibility of the NDF and ADF fractions.

Total apparent overall dry matter digestilitity was reduced with the additon of fiber. The decrease in apparent crude protein digestibility in pigs fed PB may be the results of an increase in microbial protein due in part to an increase in the grams of dry matter fermentation post-ileal. The overall decrease in ADF digestion in pigs fed WB reflect reducted post-ileal digestibility.

In conclusion, this study demonstrates that cecal adaptation to dietary fiber is dependent on the fiber source. The addition of 25% dietary fiber to the diet of sows did not decrease plasma cholesterol levels. The addition of 25% dietary BP reduced pre-cecal dry matter and crude protein digestibility in swine.

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TABLE 1. COMPOSITION OF EXPERIMENTAL DIETS

INGREDIENT, %	IFN	Control	Beet pulp	Wheat bran
Corn, ground	(4-02-931)	75.70	55.70	55.80
Soybean meal	(5-04-604)	12.80	8.00	8.20
Tallow		8.00	8.00	8.00
Beet pulp	(4-00-669)		25.00	
Wheat bran	(4-05-190)			25.00
Dicalcium phosphate	(6-01-080)	1.70	2.00	1.80
Calcium carbonate	(6-01-069)	1.20	.70	.60
Salt	(6-04-151)	.35	.35	.35
Vitamin trace mineral premix[a]		.25	.25	.25
Calculated analysis				
Lysine, %		.56	.52	.52
ME, Kg		3544	3317	3320
Intake, Kg / day		1.83	1.95	1.95

[a]Vitamin-trace mineral premix supplied 880,000 IU vitamin A, 66,000 IU D_3, 2,200 IU vitamin E, 880 mg riboflavin, 4.4 g d-pantothenic acid, 6.6 g niacin, 176 g choline choride, 3.3 mg vitamin B_{12}, 440 mg menadione sodium bisulfite, 4.4 g Mn, 19.8 g Zn, 44 mg I, 19.8 g Fe and 2.2 g Cu /Kg of premix.

TABLE 2. THE EFFECT OF 25% DIETARY BEET PULP AND WHEAT BRAN ON CECAL PARAMETERS IN SOWS.

Item	Treatments			SE
	Control	Beet pulp	Wheat bran	
Cecal wt (g)	213^{a}	265^{b}	225^{a}	
Cecal vol (ml)	1535	1964	1482	171
Cecal length (cm)	27.8	29.5	27.6	.8
Circular muscle thickness (cm)	.073	.072	.081	.017
Longitudial muscle thickness (cm)	.106	.097	.113	.022
Tissue Triglyceride (mg/dl)	1.130	1.269	1.338	.164
Tissue Cholesterol (mg/dl)	.255	.212	.241	.044

^{abc} Means in the same row with different superscripts differ (P<.05)

TABLE 3. PERCENT DIGESTIBILITY OF BEET PULP AND WHEAT BRAN IN SWINE

Item	Treatments			SE
	Control	Beet pulp	Wheat bran	
Intake, g				
Dry matter	1832	1959	1955	
Crude protein	225	204	250	
NDF	201	415	390	
ADF	74	160	102	
Pre-cecal digestibility, %				
Dry matter	81.3^{a}	65.9^{b}	80.3^{a}	1.8
Crude protein	81.8^{a}	62.0^{b}	81.6^{a}	2.5
NDF	45.8	37.3	56.4	5.5
ADF	46.0	55.6	46.5	5.5
Post-ileal digestibility, %				
Dry matter	9.6	13.7	8.5	1.4
Crude protein	11.2	5.6	8.3	2.3
NDF	32.0^{a}	34.6^{a}	12.5^{b}	7.9
ADF	30.0^{a}	18.1^{ab}	7.7^{b}	8.6
Overall tract digestibility, %				
Dry matter	90.3^{a}	86.1^{b}	86.9^{b}	
Crude protein	88.4^{a}	75.5^{b}	86.2^{a}	1.5
NDF	77.7	67.8	71.0	2.5
ADF	74.9^{a}	75.8^{a}	53.5^{b}	1.7

[abc] Means in the same row with different superscripts differ ($P<.05$)

TABLE 4. DIGESTIBILITY OF BEET PULP AND WHEAT BRAN IN SWINE

Item	Treatments			
	Control	Beet pulp	Wheat bran	
Intake, g				
Dry matter	1832	1959	1955	
Crude protein	225	204	250	
NDF	201	415	390	
ADF	74	160	102	
Pre-cecal digestibility, g				
Dry matter	1486[a]	1372[b]	1550[c]	14.4
Crude protein	183[a]	129[b]	203[a]	5.9
NDF	80[a]	88[a]	220[b]	13.6
ADF	30[a]	81[b]	48[c]	4.7
Post-ileal digestibility, g				
Dry matter	179	269	164	24
Crude protein	25	19	11	4.7
NDF	50	74	49	9.4
ADF	23	38	6	5.8
Overall tract digestibility, g				
Dry matter	1655	1685	1700	17
Crude protein	199[a]	154[b]	216[b]	2.9
NDF	156[a]	145[b]	279[c]	3.1
ADF	55[a]	121[b]	54[a]	2.1

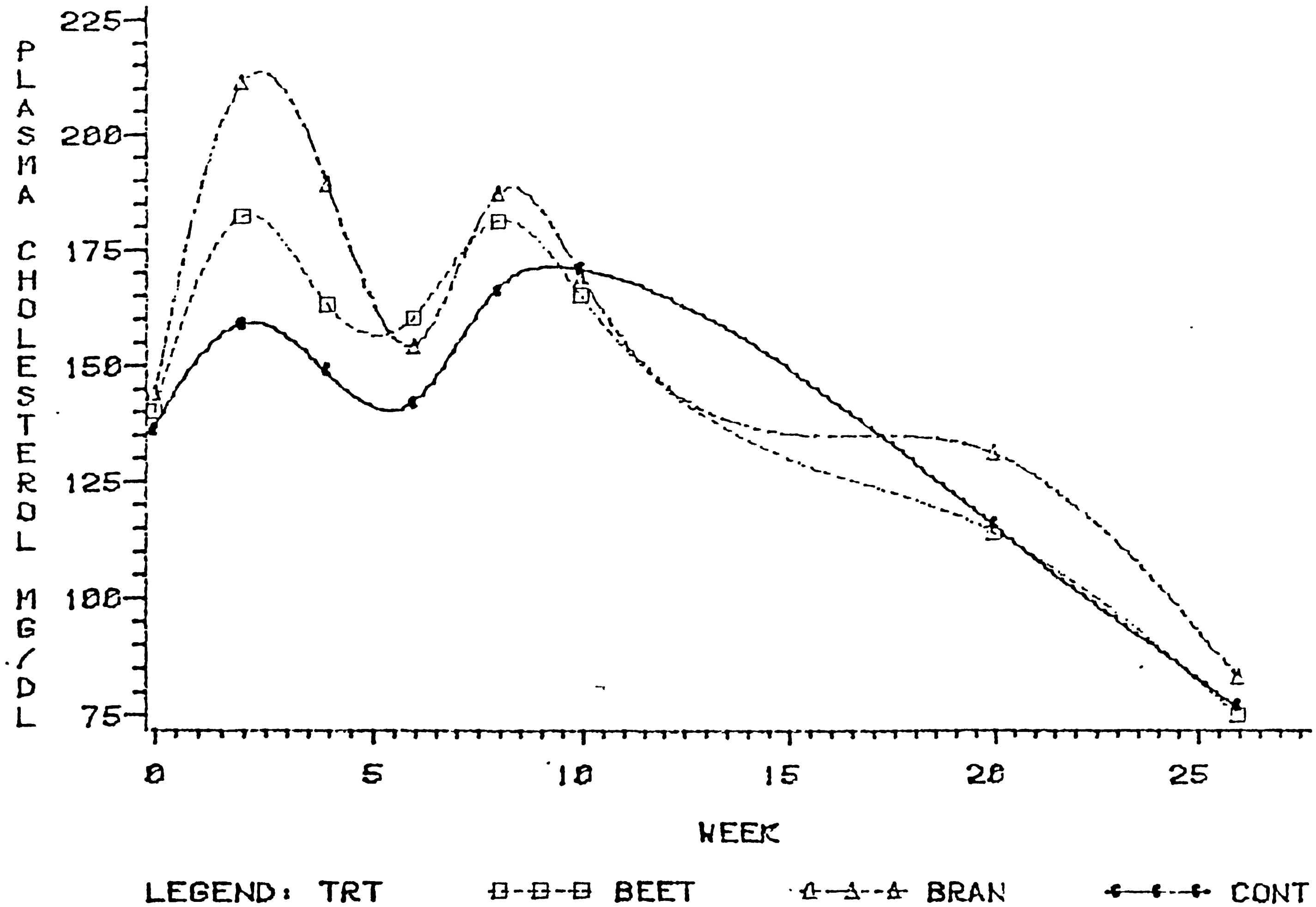
[abc] Means in the same row with different superscripts differ ($P<.05$)

Legend for Figures

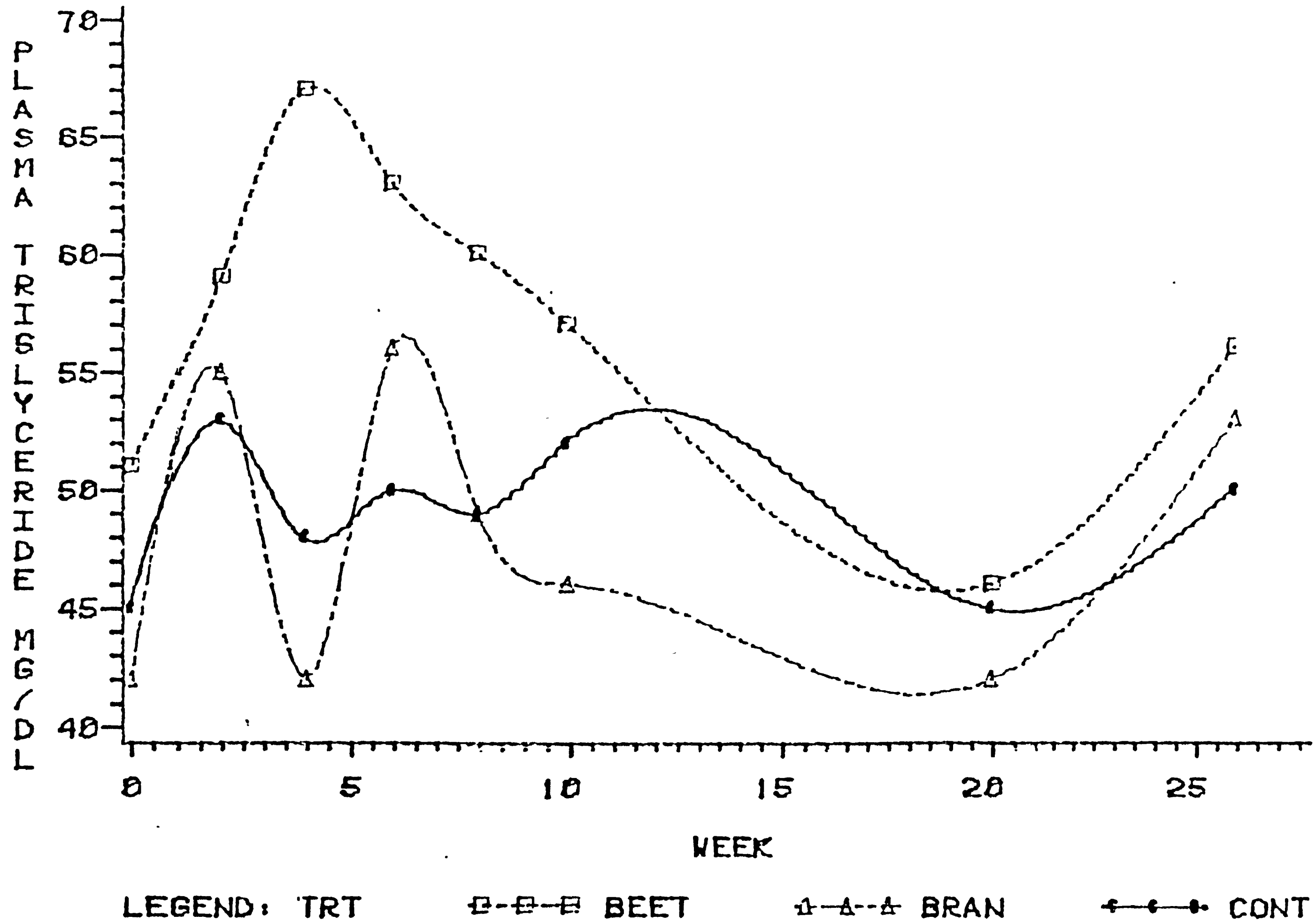
Figure 1. Effect of dietary fiber on plasma cholesterol level in swine.

Figure 2. Effect of dietary fiber on plasma triglyceride level in swine.

Figure 3. Effect of dietary fiber on plasma HDL level in swine.



VALUES REPRESENT THE AVERAGE OF 20 SOWS/TREATMENT



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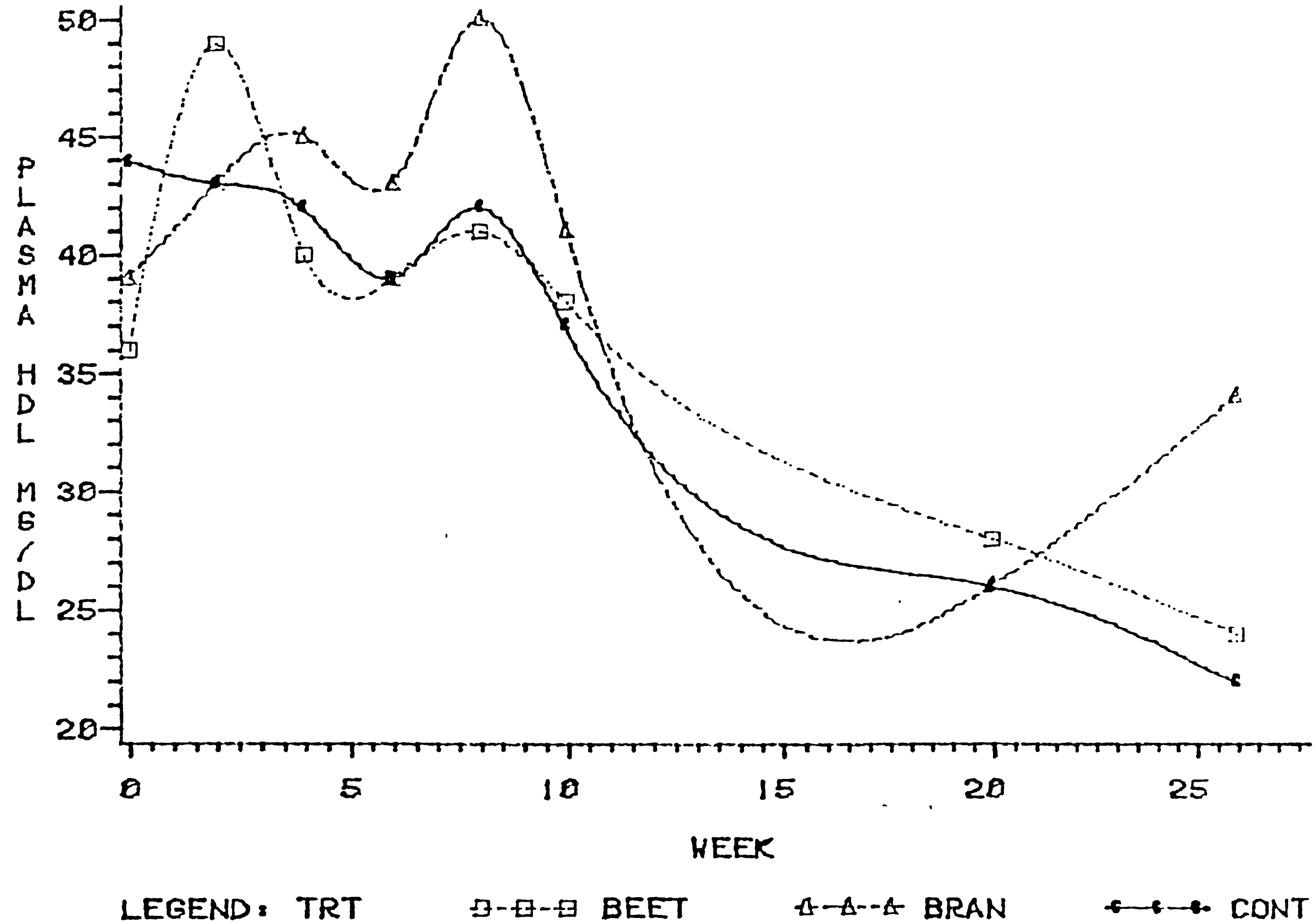

VALUES REPRESENT THE AVERAGE OF 20 SOWS/TREATMENT

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VITA 2

William Nesmith Cannon

Candidate for the Degree of

Doctor of Philosophy

Thesis: EFFECTS OF DIETARY FIBER ON DIGESTION, BLOOD PLASMA LIPIDS AND GASTROINTESTINAL TRACT PARAMETERS IN NONRUMINANTS

Major Field: Animal Nutrition

Biographical:

Personal Data: Born in Meridian, Mississippi, August 19, 1948, the son of William and Nelwyn Cannon.

Education: Received Bachelor of Science Degree in Animal Science from Middle Tennessee State University in May, 1970; received Master of Science in Animal Science from The University of Kentucky in December of 1973; completed requirements for the Doctor of Philosophy degree in Animal Nutrition at Oklahoma State University in December, 1985.

Professional Experience: Research assistant in the Department of Animal Science, The University of Kentucky, 1970-1972; owner of a commercial farm in Hartsville, Tennessee, 1973-1980; Graduate assistant in the Animal Science Department, Oklahoma State University, 1980-1984; Director of Technical Services, Micro-lite, Inc., 1984 to present.