EFFECTS OF HEMICELL® ADDITION TO CORN-SOYBEAN MEAL DIETS ON GROWTH PERFORMANCE, CARCASS COMPOSITION, AND NUTRIENT DIGESTIBILITY IN GROWING AND FINISHING PIGS

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CHAPTER I

Literature Review

Introduction

The addition of enzymes to swine diets to improve the utilization of a specific feed ingredient has long been recognized as potentially favorable for increasing growth, production, and/or nutrient digestibility. Recently, the discovery of an enzyme to counter the negative components of soybean meal has sparked interest in the possibility of improving the growth performance of pigs fed simple corn-soybean meal-based diets commonly used in commercial operations. The enzyme (Hemicell®; beta-mannanase; ChemGen Corp., Gaithersburg, MD) is an isolated product of the *bacillus lentus* bacteria, and has the ability to degrade the mannan chain of the non-starch polysaccharide, galactomannan. This enzyme is not endogenous to the pig, but must be added to the diet in either a solid or liquid form.

The potentially positive implications of Hemicell® addition to swine diets are multifaceted and thus are easily subdivided into specific areas. These include improving the utilization of the carbohydrate portion of a diet, thereby affecting the energy concentration available to the pig. Evidence may also support the possibility of Hemicell® improving the absorption and utilization of other nutrients as well. Also, degradation of beta-mannans may remove the inhibition of regulatory peptides found in the gastrointestinal tract. The following review of literature will focus on the major concepts of energy utilization in the growing pig, formation and abundance of galactomannans in feed ingredients, effects of galactomannans on nutrient utilization in monogastric animals, and the effects of Hemicell® addition to swine and poultry diets containing galactomannans.

Energy Concepts in Swine Nutrition

The ability of all living organisms to work, grow and reproduce requires energy. On a large scale, the primary energy source on earth is the sun. Plants are capable of capturing the sun's energy and using it to synthesize their own nutrients to sustain life. For animals, energy must be obtained from consuming diets with ingredients of plant origin or from animals that have consumed plants. This cycle of energy consumption and usage in animals is a primary factor in determining requirements for all other nutrients.

The metabolism and utilization of energy by swine is outlined in Figure 1. The process begins with the gross energy (GE) content of any feed ingredient, which is determined by the amount of heat that is produced upon combustion. This value is the maximum amount of energy that can be used by the animal. Proteins, carbohydrates, and fats all contribute towards the gross energy concentration of a feed ingredient. During digestion and metabolism energy can be lost in the excretion of feces and urine, termed fecal energy (FE) and urinary energy (UE). Gross energy minus fecal energy loss equals the digestible energy (DE) from the diet, while DE minus UE will tell us the amount of metabolizable energy (ME) in the feed ingredients. Energy can also be lost as gas from the gastrointestinal tract, but is minimal (<1%) and often overlooked. Beyond ME, metabolizable energy is divided into the heat lost from the processes of digestion and metabolism, termed heat increment (HI) and net energy. The net energy portion of the diet must first be used by the animal for maintenance. The energy for maintenance and HI combined is termed heat production (HP). Once maintenance requirements have been met, if any energy remains, production of tissues, milk, etc. can occur.

The measurement of these components of energy utilization in the pig is not necessarily an easy task. To quantify DE and ME concentrations of a diet, the FE and UE must be determined, which requires a metabolism study with the total collection of feces and urine. To evaluate NE used for production, a comparative slaughter technique can be used. This type of experiment involves comparing the energy content of pigs slaughtered at the beginning of the experiment to pigs slaughtered following an adequate feeding period. Direct or indirect calorimetry can also be used to determine HP. The net energy used for maintenance is generally assumed to be related to the metabolic body weight of the pig by the equation: 106 x $BW^{.75}$ (NRC, 1998).

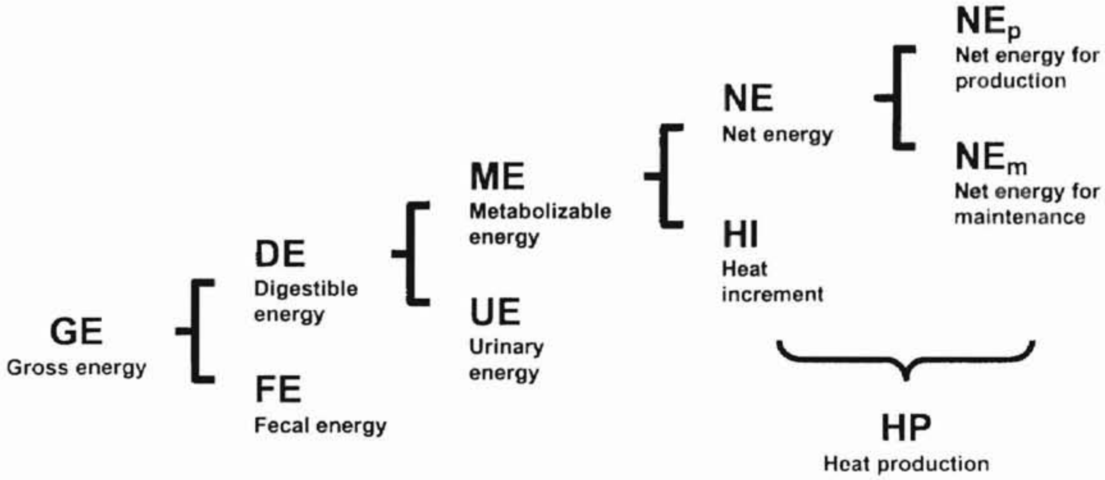

Figure 1. Components of energy utilization in pigs.

Energy can be provided to an animal in a variety of forms. Carbohydrates, proteins, and fats are primary sources of energy from the diet. Generally, carbohydrate provides 3.7 – 4.2 kcal/g, protein provides 5.6 kcal/g, and fat provides 9.4 kcal/g to the gross energy of a feedstuff. Among the three sources of energy, fats and proteins are stored in the body of the pig. The energy cost of depositing fat or protein is estimated to be 12.8 kcal/g and 10.5 kcal/g, respectively (NRC, 1998). The efficiency of protein tissue deposition is less than fat tissue accretion. One gram of protein deposited as tissue also has approximately 4 grams of water, thus requires 1.12 kcal. A gram of fat tissue has .2 grams of water associated with it, and thus requires 7.83 kcal. The efficiency of energy usage by growing pigs depends on the proportion of fat and protein being deposited (Ewan, 1991).

In pigs, the energy required to metabolize starch is higher compared with energy for fat metabolism. In a study conducted to measure the effects of environmental temperature on growth performance of growing pig, diets containing added fat increased feed intake and subsequent growth in a warm environment (Stahly and Cromwell, 1979). This is presumably due to a decrease in heat produced by the pig in the metabolism of the diet. Heat production associated with activity is increased in pigs fed diets with higher amounts of starch as opposed to fiber (Schrama et al., 1996).

The addition of fat to swine diets was reviewed by Pettigrew and Moser (1991). In diets for weanling pigs, fat addition tends to have little effect on ADG, but appears to improve feed efficiency. When the protein-to-energy ratio is held constant, the responses are more favorable for improving rate and efficiency of gain. Fat inclusion in diets for growing-finishing pigs has been shown to be effective in improving efficiency of gain. Dietary fat supplementation also tends to increase ADG and backfat depth.

Biochemistry of seed galactomannans

The structural determination of seed polysaccharides has uncovered several different types of carbohydrates that serve as storage molecules in plant cell walls. These include the mannans, the xyloglucans, and numerous other groups characterized by the presence of distinct molecules such as arabinose or galactose. Within the 'mannan' group is three types that differ in their structure: the pure mannans, the glucomannans, and the galactomannans. The three types are somewhat similar in that they are based on a repeating chain of mannopyranose residues connected by beta-1-4 linkages, and they are typically found in the seed endosperm rather than cotyledons or axes. Pure mannans yield over 90% mannose upon hydrolysis and can carry a small proportion of alpha-D-galactose units connected to mannose by an alpha-1-6 linkage. Glucomannans differ in that glucopyranosyl residues also appear in the mannan chain connected by beta-1-4 linkages. Galactomannans, like mannans, are based on a repeating chain of mannopyranose molecules, but they also can have a high percentage (20-100%) of galactose molecules appearing as sidechains attached in alpha-1-6 linkages to the mannose molecules (Aspinall, 1982; Figure 2).

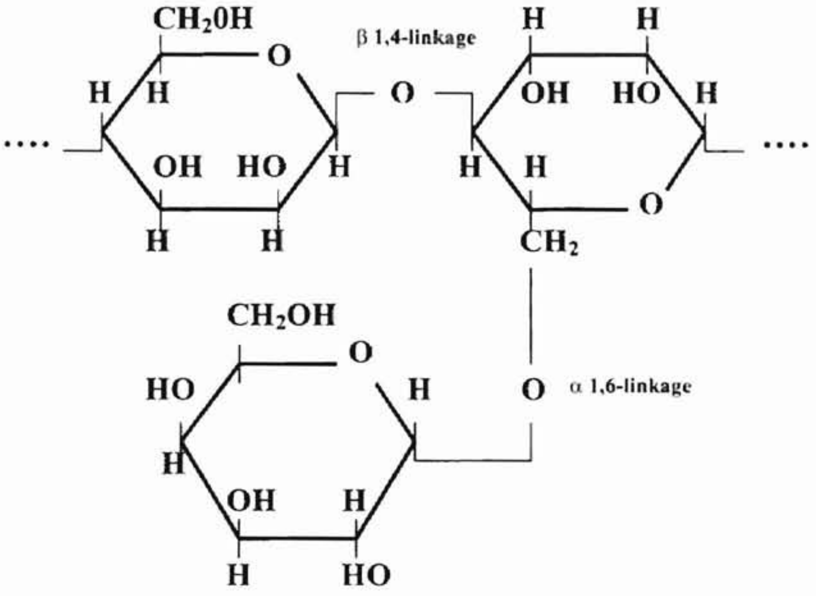

Figure 2. Chemical structure of a repeating galactomannan unit of the guar seed (adapted from Whistler and Smart, 1953)

Due to the nature of galactomannans in leguminous seeds, their role in industry and animal feeds is very important. Therefore, they shall be discussed more thoroughly as opposed to the other mannan-based polysaccharides.

Of the mannan group, perhaps galactomannans have been investigated more extensively due to their widespread occurrence in nature. Only one species of endospermic leguminous seed has been found to not contain galactomannans. Galactomannans from the endosperm are readily soluble in hot water and are similar in structure, regardless of their source. Galactomannans have been found in immature seeds of palm species where mannans are found at maturity, indicating a possible relationship between the two polysaccharide types (Reid, 1985).

Early work in the late 1800's illuminated the presence and development of galactomannans in leguminous seeds. Although the chemical structure was not yet known, many researchers first described galactomannans as storage 'mucilages' for the developing seed. In more recent investigations, the processes that occur in the formation, activity and breakdown of galactomannans have been discovered. Fenugreek (*Trigonella foenumgraecum*) and carob (*Ceratonia siliqua*) seeds have been the most thoroughly investigated. Interestingly, these two seed types represent two opposing galactomannan structures, with the carob having little substitution of galactose on the mannan chain and fenugreek having a comparatively high concentration of galactose.

Reid and Meier (1972) have described the formation of galactomannan in the fenugreek seed. Following anthesis in the seed, cells walls begin to thicken as increasing amounts of galactomannan are laid down along the cell wall. Initially, galactomannan formation begins in cells nearest to the embryo, then moves towards the outer portion of the endosperm. Galactomannan formation continues until the endosperm cells are completely filled with the storage polysaccharide. The contents of the cell (i.e. cytoplasm, vacuole) are diminished and replaced by galactomannan. The cell is then essentially considered 'non-living'. In the seed endosperm, a single-cell-thick aleurone layer surrounds the storage cells and remains unchanged by the galactomannan formation.

Within a 16-hr period following germination of the fenugreek seed, the galactomannan-filled cells begin to provide the energy reserves stored during the dormant phase (Reid, 1971). Mannose, galactose, and manno-oligosaccharides are released, but quickly converted to starch in the seed endosperm (Reid, 1971). The hydrolysis of the galactomannan requires three enzymes; alpha-D-galactosidase to remove the galactose sidechains, beta-D-mannanase to cleave the beta-1-4 linkages of the mannan backbone into oligosaccharides, and beta-D-mannosidase to further cleave the oligosaccharides into mannose molecules (Reid and Meier, 1973). Alpha-D-galactosidases and beta-D-mannanases are believed to be synthesized de novo (Reid et al., 1977); however, further work with guar (*Cyamopsis tetragonolobus*) seeds has shown that beta-D-mannosidases may be present in the resting cells with the galactomannan (McCleary, 1983).

Although extensive research characterized the previously described mechanisms of galactomannan formation and mobilization in various legume seeds, little is known of the specific activities of galactomannan in soybeans (*Glycine max*). The site of galactomannan storage in the soybean seed differs from most legumes. Instead of forming in the cells of the endosperm, galactomannans in the soybean concentrate in the hull portion of the seed (Dea and Morrison, 1975). Investigations into the specific structure of soybean galactomannan have found that they are similar to guar seeds, having a mannose to galactose ratio of approximately 1.5-2.4 (Dea and Morrison, 1975). Lab analysis of soybean meal by ChemGen indicates a dry matter content of 1.3-1.7 % beta-mannan (unpublished data). Similar lab research determined the hull portion of the soybean contains 10-15 % beta-mannan on a dry matter basis.

Guar seeds (*Cyamopsis tetragonolobus*) are among the legumes with the highest galactomannan content. The estimated endospermic portion of the guar seed is 50 % (Whistler and Smart, 1953), which would indicate a high amount of galactomannan if the endosperm were filled with the non-starch polysaccharide. Guar gum is an insoluble fiber originating from the endosperm portion of the guar seed, and impurities notwithstanding, is entirely composed of galactomannan. Guar gums extracted with varying methods and from different sources tend to differ in molecular weight, which can affect sensory qualities, but has no affect on their metabolism in animals (Ellis et al., 1991). The many possible uses for extracted guar gum are related to its physical properties. Galactomannans from guar or locust bean form very viscous solutions when mixed with water. These solutions appear to be unaffected by pH. Galactomannans from both sources have been exploited in the textile, milling, paper, and pharmaceutical industries.

Effects of guar gum in diets for humans, pigs and poultry

The unique properties of galactomannans have led to numerous studies on their effects in the diets of monogastric mammals, including humans. Early studies determined the potential for guar gum inclusion in diets to improve glucose tolerance for persons afflicted with diabetes (Jenkins, 1979) and to reduce blood cholesterol levels (Jenkins et al., 1979). Later work in human subjects has supported this notion as healthy volunteers consuming meals with guar gum had reduced fasting blood glucose levels and lower serum low-density-lipoprotein (LDL) cholesterol (Khalsa and Sharma, 1980; Khan et al., 1981; Landin et al., 1992). Patients afflicted with insulin-dependent diabetes have also shown decreases in fasting blood glucose and LDL cholesterol (Vuorinen-Markkola et al., 1992).

The potential of guar gum to affect serum lipid metabolism was further studied in animal models. Fasting total plasma cholesterol is reduced while high-density lipoprotein (HDL) cholesterol increases in rats fed diets containing guar gum (Chen and Anderson, 1979; Imaizumi et al., 1982). Furthermore, differences in serum lipoprotein content appear to be due to a reduction in lymphatic release of chylomicrons caused by altered fat absorption in the proximal small intestine combined with increased accumulation of triglycerides in villi of the distal small intestine (Imaizumi et al., 1982).

Along with lowering serum lipoprotein levels, guar gum addition has been widely noted for reducing post-prandial plasma glucose concentrations (Blackburn et al., 1984a; Sambrook and Rainbird, 1985; Edwards et al., 1987; Vachon et al., 1988; Malmlof et al., 1989; Cameron-Smith et al., 1994). This response, however, was not observed in humans fed guar-containing wheat bread (Ellis et al., 1991). An associated reduction in post-prandial insulin levels also has been observed (Sambrook and Rainbird, 1985; Edwards et al., 1987; Vachon et al., 1988; Malmlof et al., 1989; Morgan et al., 1990; Ellis et al., 1991).

Inhibited glucose absorption due to the presence of guar gum in the diet may explain reduced plasma glucose and insulin levels. Guar gum significantly reduced the net absorption of glucose from a solution perfused into the small intestine of cannulated pigs (Rainbird et al., 1984) and humans (Blackburn et al., 1984a,b). This same technique was employed in an earlier study with rats, where the absorption of glucose in a section of small intestine was also reduced by the addition of guar gum to the diet (Blackburn and Johnson, 1981). Similar results have been observed with diets fed to humans (Higman and Read, 1992) and pigs (Nunes and Malmlof, 1992). Guar gum also appears to reduce water absorption in pigs (Rainbird et al., 1984) but may increase nitrogen secretion into the small intestine (Low and Rainbird, 1984).

The possibility that guar gums reduce gastric emptying has been suggested as an explanation for decreased nutrient absorption in the small intestine (Holt et al., 1979). The hypothesis that guar gums alter viscosity of digesta was tested in male Wistar rats by

Blackburn and Johnson (1981). Contents of the stomach, small intestine, and large intestine were collected from rats that had been fed diets with 0, 3, 10, or 20 g of dry guar gum for ten days. Adding 10 or 20 g of guar gum to the diet increased the apparent viscosity of stomach and small intestine digesta. In other work, slower passage rates of radiolabelled-meal diets containing guar gum have been observed through the stomach and small intestine of rats (Brown et al. 1988) and humans (Blackburn et al., 1984a) which were attributed to increased viscosity of the digesta.

In two investigations by Rainbird and Low (1986a; 1986b), gastric emptying was measured in cannulated pigs fed diets with various fiber sources. The addition of granulated guar gum to semi-purified diets increased viscosity of stomach digesta in both experiments. However, guar gum had only minimal effects on gastric emptying when fed at high levels. The measurement of dry matter, total nitrogen, and glucose passage into the small intestine revealed no differences in diets with guar gum compared with the control. In human subjects, diets containing guar gum did not affect gastric emptying (Morgan et al., 1985) and, in fact, viscosity of ileostomy effluent was reduced with guar gum addition (Higham and Read, 1992).

An attempt to answer the question of how guar gums inhibit nutrient absorption has been made by several researchers. In humans, guar meal has no effect on the distribution of radiolabelled glucose (Blackburn et al., 1984a) indicating nutrient diffusion across the unstirred layer in the lumen to the epithelium was not disrupted. Due to a lack of evidence showing a direct inhibition of nutrient transport mechanisms by non-starch polysaccharides, viscous contents in the intestinal lumen could potentially inhibit nutrient absorption by preventing natural convective currents created by smooth muscle contractions from properly mixing intestinal contents. Studies conducted *in vitro* revealed that simulated muscle contractions failed to allow maximum glucose movement through dialysis tubing when guar gum was present in the test solution (Blackburn et al., 1984b; Edwards et al., 1988). Clearly, the presence of highly viscous substances, such as guar gums, can affect not only the metabolic capabilities, but also the physiological capacity of the animal itself.

Guar gum addition to the diet appears to have a negative effect on nutrient digestibility in rats. By adding guar gum, digestibility of dry matter and protein were reduced (Harmuth-Hoene and Schwerdtfeger, 1979) and fat accretion was diminished compared with a standard control diet (Davies et al., 1991). The presence of the viscous polysaccharide was also shown to slow the absorption of starch in the small intestine of the rat (Tinker and Schneeman, 1989). However, mineral absorption (Ca, P, Mg, Cu, Fe, Mn, and Zn) was increased with increasing addition of guar gum, leading to increased serum levels of the same minerals (Wood and Stoll, 1991). In the growing pig, apparent digestibility of dry matter, ether extract, or gross energy were unaffected by guar gum addition to the diet up to 50 g/kg (Potkins et al., 1992).

Further investigations into the physiological effects of guar gums have shown elevated secretion of pancreatic bile and an increase in total mass of digestive organs (Ikegami et al., 1990). Growing rats fed a diet with guar gum have longer small intestines and larger cecums compared with rats fed a diet with cellulose (Johnson and Gee, 1986), and have increased crypt cell proliferation rates (Pell et al., 1992). Additionally, guar gum reduces production of insulin-like growth factor-1 (IGF-1) in pigs (Nunes and Malmlof, 1992), gastric inhibitory polypeptide (GIP) in humans and pigs fed diets without fat (Morgan et al., 1985; Morgan et al., 1990; Nunes and Malmlof, 1992), and enteroglucagon (EG) in rats (Pell et al., 1992). Guar gum had no effect on GIP levels in humans fed a diet containing fat (Morgan et al., 1985). Protein-stimulated gastrin release is enhanced when guar gum is added to diets for humans (Morgan et al., 1985) and rats (Pell et al., 1992).

Following the extraction of the gums from guar seeds, the remaining portion of the seed can be processed into a meal for use in animal feeds. Early growth performance assays with growing chicks have determined the detrimental effects of guar meal on growth. The addition of as little as 2 % guar meal to the diets for chicks has caused depressed growth performance (Borcher and Ackerson, 1950; Vohra and Kratzer, 1964; Bakshi et al., 1964). The application of heat to raw guar meal improved the utilization of guar meal diets by chicks (Couch et al., 1967). In contrast, some researchers have found that autoclaving or toasting guar meal or steam pelleting the diets did not improve growth performance in young chicks (Borcher and Ackerson, 1950; Verma and McNab, 1982).

Guar meal has been evaluated by its chemical and physical properties as a potential feed ingredient in diets for young chicks (Nagpal et al., 1971). Guar meal was determined in these studies to have approximately 39% crude protein, comparable to that of fish meal. Lysine and histidine content was high compared with relatively low levels of methionine. Diets were fed to young cockerels to determine gross protein value (GPV) for guar meal and fish meal. The GPV values for guar meal diets, autoclaved guar meal diets, and autoclaved guar meal diets supplemented with lysine and methionine were lower than fish meal diets. The metabolizable energy value of guar meal was determined to be 2,069 kcal/kg. When diets were fed with guar meal as the sole protein source, mortality sharply increased, while growth was markedly reduced. During the feeding period, deceased birds were noted by the authors as having "gizzards full of guar meal particles and intestines with mucilagenous material". Nitrogen retention was also reduced as increasing amounts of guar meal was fed. Random birds were sacrificed following the feeding period and organ collection determined that there was an enlargement of the pancreas, liver, and gall bladder in birds fed diets with high levels of guar meal.

Use of hemicellulases to improve poultry and swine diet utilization

The use of enzymes to improve the utilization of diets containing feedstuffs with high hemicellulose content was first studied using the growing chick as a model. Knowing the poor growth performance observed in chicks fed diets containing guar meal, Anderson and Warnick (1964) tested a variety of enzyme regimes added to diets containing guar meal, guar gum, or locust bean gum. In their first experiment, chicks fed diets containing guar meal showed a marked decrease in ADG and a reduction in G:F compared with chicks fed diets without guar meal. Three enzymes added separately to the diets with guar meal (Cellulase 36, Rhozyme CL, Lipase B) increased ADG and G:F in chicks, matching the performance of chicks fed the control diet. In their second experiment, an enzyme mix (Cellulase 36 and Rhozyme CL) was added to a semi-purified glucose monohydrate/cottonseed meal/fish meal-based diet with and without guar meal. Also used in this study was a diet containing guar meal, but with a heated enzyme mix. The enzyme mix improved ADG and G:F compared with the control. However, chicks fed the diet with the heated enzyme mix performed similar to chicks fed the guar meal diet without enzyme, showing that deactivation of the enzymes by heat occurred. A third experiment found that the utilization of diets containing locust bean gum was improved with the addition of the same enzyme mix used in their second experiment. Finally, a fourth trial showed an improvement in rate of gain by adding the enzyme mix to semi-purified diets containing soybean meal (50% protein). Efficiency of gain was improved the most compared to the control when the enzyme mix was added to a semi-purified diet containing soybean meal (47% protein) and soybean hulls. Along with the growth performance differences observed in these experiments, the authors also noted a subjectively judged decrease in the stickiness of the fecal droppings of chicks fed diets containing guar meal or locust bean meal with the added enzyme mix.

The use of enzymes to improve poultry diets containing guar meal was further tested by Vohra and Kratzer (1965). In their studies, toasted guar meal was mixed with various enzymes in an attempt to improve growth in young chicks. By adding enzymes (Cellulase-36, Rhozyme-CL, and crude Keratinase) to the guar meal in a liquid solution and then drying the meal prior to mixing with the other ingredients, growth of young chicks was improved as compared with chicks fed diets containing untreated guar meal. A further improvement in growth was observed when four grams of dry enzyme (Cellulase-36 or Cellulase CE-100) were added to the guar meal diets. The authors noted that the growth of the chicks fed diets with any of the enzyme regimes never equaled the level of growth for the chicks fed the soybean meal based control. Differences in fiber content and crude protein concentration of the diets could account for this fact. Nevertheless, the recognition that enzymes were effective in removing the growth inhibitory factors found in guar meal was extremely important.

In a later group of studies, Verma and McNab (1982) supported the need for adding enzymes to broiler diets containing 5 to 15 % guar meal. Broilers fed corn-wheat-soybean meal-based diets with 100 or 150 grams of added guar meal consumed significantly less feed and exhibited depressed growth when compared with birds fed the control diet. The addition of a hemicellulase or betaganase to the diets containing guar meal improved growth and efficiency of gain, with the hemicellulase being slightly more effective at alleviating growth depression in birds fed diets with a high galactomannan content. The authors also subjectively determined that enzyme addition tended to improve the 'stickiness' of the fecal droppings noted in numerous trials with guar meal as a dietary component.

Further studies with hemicellulase supplementation to diets containing up to 15% guar meal have indicated that growth performance of broilers and the egg production of laying hens can be improved (Patel and McGinnis, 1985). A purified hemicellulase preparation was also effective at improving the utilization of diets containing 2% guar gum, as observed by increased growth in chicks (Ray et al., 1981).

Addition of Hemicell® to swine diets

Recently, a commercially available, patented feed enzyme has been developed and marketed by the ChemGen Corp., Gaithersburg, MD. This enzyme is a beta-mannanase that has been isolated from the *bacillus lentus* bacteria. By breaking the beta-1-4 linkages in the mannan chain of the galactomannan structure, the negative effects of these non-starch polysaccharides can possibly be alleviated. This feed additive is added to swine or poultry diets as a dry product when fed in meal form diets, or can be applied post-pelletting in a liquid form.

The effects of Hemicell® addition to swine diets on growth performance and carcass traits of finishing pigs was tested by Hahn et al. (1995). Two studies were conducted using crossbred barrows and gilts in the late finishing phase. In the first study, pigs were randomly assigned to six dietary treatments. Diets were: 1) a corn-SBM (44% CP) based diet fed in a meal form; 2) a pellcted corn-SBM diet; 3) a corn-SBM-wheat midd-based diet fed in pellet form; 4) Diet 1 with Hemicell® (.05%); 5) Diet 2 with Hemicell® (.05%); and 6) Diet 3 with Hemicell® (.05%). A dry Hemicell® product was used in Exp. 1. Pigs were fed from 70 to 110 kg, commercially slaughtered and carcass measurements were collected. Neither ADG or ADFI were affected by adding Hemicell®; however, G:F was improved in pigs fed diets with the added enzyme. A trend for increasing LMA was observed in pigs fed diets with Hemicell®, and differences in lean gain and percentage carcass muscle favored Hemicell®. A second experiment was designed to study the effects of adding liquid Hemicell® to corn-SBM (44% CP) diets (.75% Lys). The trial included two dietary treatments: a corn-SBM control, and the control diet with liquid Hemicell® (.14%). Again, pigs were fed from 70 to 110 kg and carcass measurements were collected. There were no differences in any growth or carcass parameters tested; however, trends towards increased ADG, improved G:F, and greater lean gain were observed in pigs fed diets with Hemicell® compared with pigs fed the control diet.

From these two studies, a reliable inclination towards improved feed efficiency and possible improvement in lean gain was discovered for finishing pigs fed corn-SBM diets with Hemicell®. It is also important to note that in Hahn's first study, the dry Hemicell® product appears to have withstood the pelleting process, as shown by the improvement in growth performance with Hemicell® addition. This phenomenon should be viewed with caution, as extreme pelleting temperatures can negatively affect enzyme activity (Anderson and Warnick, 1964).

An unpublished feeding trial and balance test was conducted by the Animal Research Institute of the Taiwan Sugar Corporation. In the feeding trial, sixteen barrows and sixteen gilts (initial wt = 47.5 kg) were fed one of four diet types. A 3% crude fiber diet containing primarily corn, soybean meal (44% CP), and barley hulls served as the control. Diets 2, 3, and 4 four were of the same composition but with 3, 4, and 5% crude fiber, respectively, and with added Hemicell® (.05%). Pigs were fed with two pigs per pen until they reached 100 kg, then backfat was estimated using ultrasound. Pigs fed 3% crude fiber diets with added Hemicell® consumed less feed and were more efficient than pigs fed diets with 5% crude fiber and Hemicell®. Also, pigs fed diets with either 3 or 4% crude fiber and Hemicell® showed numeric trends towards a reduction in F:G compared with the pigs fed the control diet. No differences were found among the three Hemicell® treatments in backfat thickness when compared with the control. In the balance test, eight pigs were assigned to the four dietary treatments as in the feeding trial. There were no differences detected in nitrogen retention as a percentage of intake between the four treatments. Dry matter excretion was reduced and acid detergent fiber digestibility was improved in pigs fed a diet with 3% fiber with Hemicell® compared with pigs fed the control diet. Also, gross energy and calcium digestibility were increased in pigs fed these same diets. This effect was not seen in pigs fed diets with 4 or 5% crude fiber content and Hemicell®.

The effect of Hemicell® addition to swine diets on nutrient digestibility was further investigated by Radcliffe et al. (1999). Twelve crossbred barrows were fitted with steered ileo-cecal cannulas and used to determine the effect of Hemicell® on apparent total tract digestibilities (ATTD) of energy, Ca, P, and the apparent ileal digestibilities (AID) of Ca, P, DM and amino acids. Four dietary treatments were tested in a 4 x 4 Latin square design. All diets were primarily composed of corn and hulled soybean meal (44%). Two different crude protein levels (12 and 16%) and two levels of Hemicell® addition (0 and .5%) comprised the four dietary treatment groups. Pigs were housed in metabolic crates (1.2 m x 1.2 m) and feed was provided at 9 % of each pigs metabolic body weight. Pigs fed either low or high crude protein diets with Hemicell® showed improved ATTD of energy and also a trend towards increased nitrogen digestion. When digestibilities were measured from ileo-cecal samples, an improvement in DM digestibility was observed. All ATTD and AID digestibilities measured showed a numeric improvement in favor of diets with Hemicell®, regardless of crude protein level. Differences in growth performance were not seen in pigs fed diets with added Hemicell®; however, each pig was only fed a diet with Hemicell® for 14 days.

CHAPTER II

Experiments 1 and 2

Effects of Hemicell® addition to nursery diets on the growth performance of weanling pigs.

Abstract - Two experiments were conducted to determine the effects of beta-mannanase (Hemicell®; ChemGen Corp., Gaithersburg, MD) addition to nursery diets on the growth performance of weanling pigs. In Exp. 1, 156 weanling pigs (20-d, 6.27 kg BW) were allotted randomly by weight, sex, and litter to four dietary treatments in a randomized complete block design. Treatments were a factorial arrangement of diet complexity (complex vs simple) and Hemicell® addition (0 vs .05%). Pigs were fed in three dietary phases (Phase 1, d 0-14; Phase 2, d 14-28; and Phase 3, d 28-42). Complex diets contained spray-dried blood meal, spray-dried animal plasma, dried whey, lactose, and fish meal in Phase 1, while simple diets contained only fish meal and lactose. Complex protein sources were reduced in Phase 2 diets, and in Phase 3 all diets were simple corn-SBM-based. Pigs fed complex diets gained faster and were more efficient ($P< .05$) during Phase 1 compared with pigs fed simple diets. For Phases 2 and 3 combined, pigs fed diets with Hemicell® had greater ($P< .01$) G:F. Overall, G:F was improved ($P<.10$) for pigs fed complex diets and for those fed diets with Hemicell®. In Exp. 2, 117 weanling pigs (44-d, 13.62 kg BW) were allotted randomly by weight, sex and litter to three dietary treatments in a randomized complete block design. Diets were a simple corn-soybean meal-based control, the control diet with soybean oil (SBO) added to

increase metabolizable energy by 100 kcal/kg, and the control diet with Hemicell® (.05%). Pigs were fed in Phase 3 of the nursery period (21 d). Pigs fed the diet with soybean oil were similar in rate and efficiency of gain compared with pigs fed the diet with Hemicell®, and both had greater ($P< .01$) G:F compared with the control. Based on these two experiments, the addition of Hemicell® to nursery diets appears to improve ADG and G:F in weanling pigs.

Introduction

Hemicelluloses, non-starch polysaccharides, are known to be present in the cell wall structure of many seeds. A specific hemicellulose, galactomannan, is prevalent in the ungerminated seeds of many legumes. Many of these seeds, including soybeans, are used in swine diets, and can contain up to 22.7 % non-starch polysaccharide content on a dry matter basis (Chesson, 1987). Galactomannans are chemically composed of d-mannose units attached in a chain by beta-1-4 linkages, with d-galactose units attached as sidechains by alpha 1-6 linkages.

Guar meal, being high in galactomannan content, has been used to evaluate the effects of these hemicelluloses when added to poultry or swine diets. These non-starch polysaccharides have been shown to diminish growth performance and inhibit nutrient absorption (Vorha and Kratzer, 1964; Blackburn and Johnson, 1981; Verma and McNab, 1982; Rainbird et al., 1984; Edwards et al., 1988). The addition of enzymes to diets containing guar meal appears to alleviate the inhibitory properties and improve growth performance (Anderson and Warnick, 1964; Vorha and Kratzer, 1965; Patel and McGinnis, 1983).

A commercially available enzyme (beta-mannanase) has been recently marketed under the trade name Hemicell®. Addition of this enzyme to diets containing soybean meal for broilers, turkeys, and laying hens has increased gain and improved feed efficiency (McNaughton et al., 1998; James et al., 1998). Unpublished research conducted by the Taiwan Sugar Corporation found that the addition of Hemicell® to swine diets containing 3% crude fiber improved ADG and G:F during the finishing phase. Also, pigs fed a diet with less digestible energy (≈100 kcal/kg; 4% crude fiber) and Hemicell® had similar ADG and G:F compared with a higher energy diet (3% crude fiber) with no added enzyme. These results suggest that Hemicell® may provide the equivalent of 100 kcal/kg of DE to a typical swine diet.

Complex diets are commonly fed to young pigs to improve post-weaning growth performance. The addition of spray-dried plasma (Sohn et al., 1991; Coffey and Cromwell, 1995), blood meal (Wahlstrom and Libal, 1977; Parsons et al., 1985), and dried-whey (Miller et al., 1971; Cera and Mahan, 1985; Lepine et al., 1991; Mahan et al., 1992) to nursery diets have been shown to increase growth performance of pigs in the early nursery phases.

The objectives of these experiments were to study the effects of adding Hemicell® to complex and simple diets on growth performance of weanling pigs, and also to evaluate any possible energy advantages of adding Hemicell® to corn-soybean meal diets for weanling pigs.

Materials and Methods

Experiment 1. One hundred fifty-six pigs were weaned at 17 to 23 days of age and allotted randomly by weight, sex, and litter to four dietary treatments in a randomized complete block design. Dietary treatments were a factorial arrangement of diet complexity (complex vs simple) and two levels of Hemicell® addition (0 vs .05%). All diets were corn-SBM-based and are shown in Table 2.1. Pigs were fed in three dietary

Table 2.1. Composition of diets in Experiment 1 (as-fed basis).

	Phase 1		Phase 2		Phase 3
Ingredient, % Diet[a]:	C	S	C	S	S
Corn	40.95	30.58	49.32	49.05	64.60
Soybean meal, 48%	15.65	31.42	24.99	34.67	29.87
Whey	20.00	20.00	10.00	10.00	
Plasma, spray-dried	5.00				
Blood meal, spray-dried	1.50		2.00		
Fish meal	5.00	5.00	2.50		
Lactose	5.00	5.00	5.00		
Dicalcium phosphate	1.19	1.26	1.71	1.80	1.86
Limestone	.33	.24	.42	.67	.76
Salt	.20	.20	.20	.20	.30
Soybean Oil	3.25	4.40	3.15	2.95	2.00
L-Lysine-HCl		.02			
DL-Methionine	.15	.10	.10	.05	
Trace Min/Vit premix	.30	.30	.30	.30	.30
Antibiotic	1.00	1.00	.13	.13	.13
Zinc oxide	.30	.30			
Copper Sulfate			.10	.10	.10
Flavor	.10	.10			
Corn starch/Hemicell®[c]	.05	.05	.05	.05	.05
Ethoxyquin	.03	.03	.03	.03	.03
Calculated Analysis					
ME, kcal/kg	3310	3310	3310	3310	3310
Lysine, %	1.50	1.50	1.30	1.30	1.10
Ca, %	.90	.90	.85	.85	.80
P, %	.80	.80	.75	.75	.70

[a] C =complex diet, S =simple diet.

[b] Antibiotic provided 55 mg/kg oxytetracycline and 154 mg/kg neomycin in Phase 1; 110 mg/kg tylosin/sulfamethazine in Phases 2 and 3.

[c] Hemicell® provided 93.1 mm IU/ton and was added at the expense of corn starch.

phases. In Phase 1 (d 0-14; 1.50% Lys), complex diets contained spray-dried blood meal, spray-dried animal plasma, dried whey, lactose, and fish meal, while simple diets only contained fish meal, lactose, and dried whey as alternative protein sources. In Phase 2 (d 14-28; 1.30% Lys), the simple diets only contained dried whey, while complex diets contained dried whey and small amounts of blood meal, fish meal, and lactose. In Phase 3 (d 28-42; 1.10% Lys), all diets were simple in nature. All diets were fed in meal form. Pigs were housed in a temperature-controlled room with 6-7 pigs per pen and allowed *ad libitum* access to feed and water throughout the experiment. Pigs and feeders were weighed weekly to determine ADG, ADFI, and G:F.

Experiment 2. Following a 3-wk adjustment period post-weaning (Phases 1 and 2), 117 pigs were allotted randomly by weight, sex, and litter in a randomized complete block design to three dietary treatments. A fortified corn-SBM-dried whey diet was fed to all pigs during the adjustment period. In the 21-d experimental period, diets (Table 2.2) included a fortified corn-SBM diet as the control, the control diet with 2% soybean oil added to increase ME by approximately 100 kcal/kg, and the control diet with addition of Hemicell® (.05%). Pigs were housed as in Experiment 1 with 3 to 4 pigs/pen. Diets were analyzed for gross energy (GE) concentration by bomb calorimetry and for crude protein by Kjeldahl methodology.

Statistical Analysis - Data were analyzed as a randomized complete block design using analysis of variance procedures as described by Steel and Torrie (1997). Data in Experiment 1 were analyzed as a 2 x 2 factorial with orthogonal contrasts used to compare treatment means. The main effects of diet complexity and Hemicell® addition, and their interaction were tested. In Experiment 2, pre-planned non-orthogonal contrasts were used to compare treatment means. In both studies, pen served as the experimental unit.

Table 2.2. Composition of diets in Experiment 2 (as-fed basis).

	Treatment		
Ingredient, %	Control	Soybean Oil	Hemicell®
Corn, dent grain	62.38	60.18	62.38
Soybean meal, dehulled	34.36	34.55	34.36
Corn starch	.05	.05	
Dicalcium phosphate	1.94	1.97	1.94
Limestone	.39	.37	.39
Salt	.50	.50	.50
Soybean oil		2.00	
Trace Vit/Min premix	.25	.25	.25
Antibiotic[a]	.13	.13	.13
Hemicell®[b]			.05
Calculated Analysis			
ME, kcal/kg	3297	3396	3295
Lysine, %	1.20	1.20	1.20
Ca, %	.75	.75	.75
P, %	.65	.65	.65

[a] Antibiotic provided 110 mg/kg tylosin/sulfamethazine.

[b] Hemicell® provided 136 mm IU/ton and was added at the expense of corn starch.

Results

Experiment 1. Pigs fed complex diets gained faster ($P<.02$) and were more efficient ($P<.03$) as compared with pigs fed simple diets in Phase 1 (Table 2.3). The addition of Hemicell® to Phase 1 diets had no effect on growth regardless of diet complexity. Pigs fed simple diets with Hemicell® gained numerically slower (202.3 vs 224.9 g/d) than pigs fed simple diets without Hemicell®, differing from the trend seen in pigs fed complex diets (diet x Hemicell®, $P<.03$).

In Phase 2, pigs fed complex diets consumed less ($P<.08$) feed than pigs fed simple diets. This decrease in intake led to a trend ($P<.15$) in improved G:F. Pigs fed diets with Hemicell® also showed a trend (P<.17) towards improved efficiency of gain. During Phase 3, the addition of Hemicell® increased (P<.01) G:F in pigs fed simple diets. With all pigs being fed simple diets, no effect on growth performance was seen in pigs that had previously been fed complex diets. When combining the growth performance in Phases 2 and 3, pigs fed diets with Hemicell® were more (P<.01) efficient than pigs fed diets with no added enzyme. Overall, the pigs fed complex diets in Phases 1 and 2 were more efficient through the 42-d experiment than pigs fed simple diets. Also, pigs fed diets with Hemicell® had higher G:F compared with pigs fed diets with no added enzyme.

Table 2.3. Effects of diet complexity and Hemicell® on growth performance of weanling pigs (Exp. 1)[a].

Diet:	Complex		Simple		
Hemicell:	0	.05%	0	.05%	SE
Number of pigs	39	39	39	39	
Initial weight, kg	6.25	6.28	6.23	6.24	
Final weight, kg	21.96	21.27	21.00	21.76	
Phase 1					
ADG kg[b]	.233	.240	.225	.202	.01
ADF, kg	.302	.300	.288	.283	.01
G:F[b,d]	.772	.798	.781	.716	.01
Phase 2					
ADG, kg	.435	.425	.421	.449	.01
ADF, kg[b]	.635	.601	.644	.650	.02
G:F	.686	.708	.654	.691	.01
Phase 3					
ADG, kg	.488	.497	.487	.516	.02
ADF, kg	.952	.924	.961	.945	.02
G:F[c]	.513	.538	.507	.546	.01
Overall					
ADG, kg	.383	.387	.377	.391	.01
ADF, kg	.620	.602	.621	.622	.01
G:F[c]	.618	.646	.607	.628	.01

[a] Least squares means for 6 pens/trt of 6-7 pigs/pen.
[b] Main effect of diet type (P<.10).
[c] Main effect of Hemicell® (P<.10).
[d] Diet complexity x Hemicell® interaction (P<.03).

Experiment 2. Gross energy values for Diets 1, 2, and 3 were: 3,835, 3,941, and 3,859 kcal/kg, respectively. As expected, the addition of 2% soybean oil to Diet 2 increased the gross energy concentration by approximately 100 kcal/kg. For the three diets, the percentage crude protein was 20.5, 22.7, and 20.5 %, respectively.

During the 21-d feeding period, pigs fed diets with an increased energy concentration by adding 2% soybean oil were more (P<.02) efficient than pigs fed the control diet (Table 2.4). Also, pigs fed diets with Hemicell® had higher (P<.01) G:F

Table 2.4. Effects of Hemicell® and soybean oil on growth performance of weanling pigs[a] (Exp. 2).

	Treatment			
Item	Control	Soybean Oil	Hemicell®	SE
Number of pigs	39	39	39	
Initial weight, kg	13.63	13.66	13.54	.07
Final weight, kg	24.77	24.99	25.00	.22
Week 1				
ADG, kg	.410[b]	.406[b]	.427[b]	.02
ADF, kg	.752[b]	.751[b]	.747[b]	.02
G:F	.545[b]	.541[b]	.572[b]	.01
Week 2				
ADG, kg	.614[b]	.650[b]	.611[b]	.02
ADF, kg	.972[b]	.961[b]	.937[b]	.02
G:F	.632[b]	.677[c]	.653[bc]	.01
Week 3				
ADG, kg	.606[b]	.605[b]	.640[b]	.02
ADF, kg	1.154[b]	1.123[b]	1.144[b]	.02
G:F	.526[b]	.538[b]	.559[b]	.02
Overall				
ADG, kg	.543[b]	.553[b]	.558[b]	.01
ADF, kg	.955[b]	.941[b]	.938[b]	.01
G:F	.568[b]	.588[c]	.595[c]	.01

[a] Least squares means of 10 pens/treatment with 3-4 pigs/pen.

[b,c] Means within a row with different superscripts differ (P<.10).

compared with pigs fed the control diet. Average daily gain, ADFI, and G:F were similar (P>.10) for pigs fed diets with soybean oil or Hemicell®.

Discussion

The addition of complex protein sources to diets for weanling pigs is known to increase growth performance compared with simple diets containing soybean meal as the protein source (Himmelberg, 1985). The improved growth performance observed in Experiment 1, when complex protein sources were added to the diet, tends to agree with prior studies. This response was greater in Phase 1, when the diets contained more alternative protein sources. As shown in Table 1, complex diets in Phase 2 contained less whey and fish meal, and had no blood plasma as compared with complex diets in Phase 1. This decrease in alternative protein sources subsequently increased the level of soybean meal in the diet to meet the lysine requirement. With more beta-mannans in the diet from soybean meal, we might expect to see an increased response with the addition of a beta-mannanase.

The addition of Hemicell® to complex and simple diets tended to improve G:F in every phase except Phase 1. Pigs fed simple diets with Hemicell® gained less weight and thus had lower G:F than pigs fed the simple diet with no added enzyme. This response led to an interaction (P<.03) in Phase 1. Yet, pigs fed in this same treatment group gained numerically faster and were more efficient than pigs fed simple diets without Hemicell® in Phases 2 and 3, leading us to believe that a post-weaning lag could account for the interaction rather than a true response from the added enzyme.

Although the beta-mannan content of dehulled soybean meal is relatively low, the addition of Hemicell® to the diet appears to improve growth performance of weanling pigs in the late nursery phases. The increased efficiency observed could potentially indicate an energy advantage by adding the enzyme to a corn-SBM diet.

From the results in the first experiment, the second experiment was designed to compare the growth performance of pigs fed diets with an added fat source, to the performance of pigs fed diets with Hemicell® in the final nursery phase. As might be expected, the increase in metabolizable energy concentration by adding soybean oil slightly decreased feed consumption, while maintaining growth. Comparatively, a decrease in feed intake was also seen in pigs fed diets with Hemicell® compared with the pigs fed the control diet. Yet, they maintained the highest ADG (558.4 g/d) of all treatment groups. Although the mechanisms directing this response were not determined, it does appear that Hemicell® addition to diets containing soybean meal (or possibly any feedstuff with a similar beta-mannan content) can increase the metabolizable energy concentration of those diets. This assertion is only based on the comparative growth response that was observed in this experiment. Certainly the addition of Hemicell® to a diet containing beta-mannans could elicit a growth response, similar to adding fat to the diet, by some other mechanism.

Implications

The addition of Hemicell® to complex or simple diets appears to improve feed efficiency in weanling pigs. The addition of Hemicell® to corn-soybean meal based diets in the late nursery phase can improve growth and efficiency of gain similar to the addition of added fat. The mode of action of increased feed efficiency by adding a beta-mannanase to swine diets is not yet known.

CHAPTER III

Experiments 3 and 4

Effects of Hemicell® addition to corn-soybean meal diets on growth performance, carcass traits, and apparent nutrient digestibility in growing-finishing pigs.

Abstract - Two experiments were conducted to evaluate the effects of Hemicell® addition to corn-SBM diets on growth performance, carcass traits, and apparent nutrient digestibility of growing-finishing pigs. In Exp. 3, 60 pigs (22.5 kg) were allotted randomly by weight, sex, and litter to three dietary treatments in a randomized complete block design. Dietary treatments were: 1) a typical corn-SBM-based diet as the control; 2) the control diet with soybean oil (SBO) added (2%) to increase the metabolizable energy (ME) of the diet by approximately 100 kcal/kg; and 3) the control diet with added Hemicell® (.05%). Dietary treatments were fed in three phases (Phase 1, 23-53 kg; Phase 2, 53-82 kg; Phase 3, 82-109 kg with .95, .80, and .65% lysine, respectively). All diets were fed in meal form. The addition of SBO improved G:F (P<.06) compared with pigs fed the control diet or the diet with Hemicell®. Also, addition of Hemicell® increased ADG compared with pigs fed the control or SBO diets. The G:F of pigs fed the diet with Hemicell® were similar (P>.54) to pigs fed the diet with soybean oil. At 110 kg, pigs were slaughtered and carcass measurements were collected. There were no differences in LMA; however, pigs fed diets with SBO or Hemicell® tended to have less 10th rib fat than pigs fed the control diet. On a fat-free basis, pigs fed a diet with Hemicell® had a higher (P<.03) lean gain and more (P<.03) carcass lean tissue than pigs fed the control or SBO

diet. In Exp. 4, 12 barrows were allotted randomly to one of the three dietary treatments used in Exp. 3. Pigs were penned individually and allowed *ad libitum* access to feed and water for a 14-d period. From d 10 to d 14, chromic oxide was used as a marker to determine apparent total tract digestibility. Addition of Hemicell® had no effect (P>.10) on energy, nitrogen, phosphorus, or dry matter digestibility. These results suggest that Hemicell® may improve growth performance and lean gain in finishing pigs, but has minimal effects on nutrient digestibility.

Introduction

Results observed in Experiment 2 showed an improvement in ADG and G:F in weanling pigs fed corn-SBM diets with either soybean oil (2%) or Hemicell® (.05%). Addition of Hemicell® to a corn-SBM diet may provide the equivalent of 100 kcal/kg of metabolizable energy. Recognizing that fat addition to diets for growing-finishing pigs tends to decrease feed intake and improve G:F (Pettigrew and Moser, 1991), a trial similar to Experiment 2 was designed to further compare the effects of Hemicell® addition with the growth responses seen by adding 2% soybean oil.

Research with finishing pigs has found that Hemicell® addition to diets containing soybean meal improves G:F and may increase lean gain (Hahn et al., 1995). Additional field research in commercial settings (unpublished) has also shown that finishing pigs fed diets with Hemicell® have improved feed efficiency. In poultry, Hemicell® addition increases G:F along with improving energy digestibility when broilers or turkeys are fed corn-SBM based diets. (McNaughton et al., 1998; James et al., 1998). Improvements in the apparent ileal digestibility of energy with Hemicell® addition also have been observed in swine (Radcliffe et al., 1999).

The objectives of these studies were: 1) to determine the effects of adding Hemicell® to corn-SBM diets for growing-finishing pigs compared with pigs fed diets with an added fat source, and 2) to determine the effects of Hemicell® on apparent nutrient digestibility in finishing pigs.

Materials and Methods

Experiment 3 – Sixty growing pigs (22.5 kg BW) were allotted randomly by weight, sex, and litter to three dietary treatments. Diets were: 1) a typical fortified corn-SBM diet to serve as the control, 2) as the control diet with 2% soybean oil (SBO) added to increase the metabolizable energy (ME) concentration by approximately 100 kcal/kg, and 3) as the control diet with added Hemicell® (.05%). All diets contained dehulled soybean meal (48% CP) and were balanced on a total lysine basis (Table 3.1). Dietary treatments were fed in three dietary phases (Phase 1, 23-52 kg; Phase 2, 53-80 kg, Phase 3, 80-109 kg BW) and contained .95, .80, and .65% Lys, respectively. All diets were fed in meal form and were offered on an *ad libitum* basis. Pigs and feeders were weighed every two weeks to determine rate and efficiency of gain.

At an average block weight of 109 kg, all pigs in that block were commercially slaughtered by conventional methods. Carcasses were split along the dorsal midline, weighed and placed in a cooler overnight. The following day, LMA was determined and backfat was measured at four points – first rib, last rib, last lumbar vertebrae, and 7 cm

Table 3.1. Composition of diets in Exp. 3 and Exp. 4[a].

	Treatment		
Ingredient, %	Control	Soybean Oil	Hemicell®
Corn, dent grain	71.68	69.48	71.68
Soybean meal, dehulled	25.28	25.47	25.28
Cornstarch	.05	.05	
Dicalcium phosphate	1.49	1.51	1.49
Limestone	.75	.74	.75
Salt	.25	.25	.25
Soybean oil		2.00	
Trace Min/Vit premix	.25	.25	.25
Antibiotic[b]	.25	.25	.25
Hemicell®[c]			.05
Calculated Analysis			
ME, kcal/kg	3,308	3,407	3,306
Lysine, %	.95	.95	.95
Ca, %	.75	.75	.75
P, %	.65	.65	.65

[a] Dietary treatments were fed in three phases (Phase 1 diets shown).

[b] Antibiotic provided 110 mg/kg chlortetracycline.

[c] Hemicell® provided 109 million IU/ton and was added at the expense of cornstarch.

from the dorsal midline of the tenth rib. All carcass measurements were taken from the left side. Total carcass lean, percentage lean, and lean gain were calculated according to NPPC (1991).

Experiment 4 – Twelve barrows were allotted randomly by weight and litter to the dietary treatments used in Experiment 3. Pigs were penned individually in a randomized complete block design with four pen replicates and were fed their respective diets for 14 days. All diets were fed in meal form and pigs were given *ad libitum* access to feed and water. On d 10, chromic oxide (Cr_2O_3) was added to the diets to serve as an indigestible marker. Fresh fecal samples were taken from each pig on d 13 and d 14 and frozen for later analyses. Feed and freeze-dried feces were analyzed for gross energy by bomb calorimetry (Parr 1261 Isoperibol Calorimeter, Moline, IL). Nitrogen content was determined using Kjeldahl methodology. Phosphorus and chromium concentrations were measured by inductively coupled plasma spectrometry.

Using chromium and nutrient concentrations determined by lab analyses, digestibilities were calculated by the following equation:

$$D = 100 - 100\ (\%\text{ feed Cr} / \%\text{ fecal Cr}) \times (\%\text{ fecal nutrient} / \%\text{ feed nutrient})$$

Diet Analysis – All diets were sampled following mixing, and ground in a Wiley mill equipped with a 1 mm screen. Gross energy concentrations were determined by bomb calorimetry (Parr 1261 Isoperibol Calorimeter, Moline, IL). Nitrogen content was determined using Kjeldahl methodology.

Statistical Analysis – Data in Experiments 3 and 4 were analyzed as a randomized complete block design using analysis of variance procedures as described by Steel and Torrie (1997). In both experiments, pen served as the experimental unit. Pre-planned non-orthogonal contrasts were used to compare treatment means.

Results

Experiment 3 – Gross energy concentrations for the three diets in Phases 1, 2, and 3 were: 3,798, 3,914, 3,815 kcal/kg, 3,845, 3,934, 3,836 kcal/kg, and 3,828, 3,939, 3,874, respectively. Throughout the experiment, pigs fed the diet with a high-energy source (i.e., soybean oil) performed as expected compared with pigs fed the control diet (Table 3.2). Pigs fed the diet with added soybean oil consumed less ($P<.02$) feed and were more

($P<.06$) efficient than pigs fed the control diet. Addition of Hemicell® to the diet increased ($P<.03$) ADG compared with the control diet and the diet with added soybean oil. Pigs fed the diets with soybean oil or Hemicell® were similar ($P>.53$) in G:F.

Table 3.2. Effects of soybean oil and Hemicell® addition to corn-SBM diets on growth performance of growing-finishing pigs[a] (Exp. 3).

	Treatment			
Item	Control	Soybean Oil	Hemicell®	SE
Number of pigs	20	20	20	
Initial weight, kg	22.7^{b}	22.1^{b}	22.6^{b}	
Final weight, kg	108.8^{b}	106.2^{c}	111.9^{d}	.97
Phase 1				
ADG, kg	$.860^{bc}$	$.833^{b}$	$.867^{c}$	.01
ADF, kg	1.89^{b}	1.75^{c}	1.95^{b}	.04
G:F	$.455^{bc}$	$.476^{b}$	$.445^{c}$	.01
Phase 2				
ADG, kg	$.864^{b}$	$.896^{bc}$	$.922^{c}$	.02
ADF, kg	2.55^{b}	2.41^{c}	2.67^{d}	.02
G:F	$.339^{b}$	$.372^{c}$	$.345^{b}$	.01
Phase 3				
ADG, kg	$.801^{b}$	$.761^{c}$	$.835^{d}$	.01
ADF, kg	3.13^{b}	2.91^{c}	2.91^{c}	.08
G:F	$.256^{b}$	$.262^{b}$	$.287^{c}$	.01
Overall				
ADG, kg	$.842^{b}$	$.829^{b}$	$.872^{c}$	.01
ADF, kg	2.50^{b}	2.32^{c}	2.48^{b}	.04
G:F	$.337^{b}$	$.358^{c}$	$.351^{bc}$	.01

[a] Least squares means for 5 pens/treatment with 4 pigs/pen.

[b,c] Means within a row with different superscripts differ ($P<.10$).

There were no differences among the three treatment groups in LMA. But, the addition of soybean oil decreased 10th rib fat compared with the control diet. Pigs fed the diet with Hemicell® had heavier ($P<.04$) carcasses, and were numerically leaner and greater in LMA compared with the pigs fed the control diet. Using NPPC equations, total lean gain, carcass lean tissue, and percentage lean were calculated. All results are expressed on a fat-free basis (Table 3.3). The addition of Hemicell® increased ($P<.03$) lean gain and carcass lean tissue compared with pigs fed the control or soybean oil diets.

Table 3.3. Carcass characteristics of pigs fed diets with soybean oil or Hemicell®[a].

Item	Treatment			SE
	Control	Soybean Oil	Hemicell®	
Number of pigs	20	19	20	
Hot carcass wt, kg	82.9^{b}	81.4^{b}	85.5^{c}	1.70
10th rib fat, cm.	2.24^{b}	2.06^{c}	2.13^{bc}	.05
LMA, in^{2}.	40.8^{b}	40.6^{b}	43.2^{b}	1.21
Fat-free lean				
Carcass lean, kg	41.01^{b}	40.98^{b}	43.02^{c}	.54
Lean, %	49.46^{b}	50.36^{b}	50.40^{b}	.43
Lean gain, kg/d	$.322^{b}$	$.327^{b}$	$.340^{c}$	.01

[a] Least squares means for 5 pens/treatment with 4 pigs/pen.

[b,c] Means within a row with different superscripts differ ($P<.10$).

Experiment 4 – In the 14-d feeding period, barrows fed the diet with soybean oil consumed less ($P<.09$) feed compared with pigs fed the diet with Hemicell®. There were no differences in the apparent digestibility of energy, nitrogen, phosphorus, or dry matter (Table 3.4). However, pigs fed the diet with added Hemicell® tended to have small numeric improvements in digestibility of each nutrient tested compared to pigs fed the control diet.

Table 3.4. Daily intakes and apparent digestibility coefficients of finishing pigs fed corn-SBM diets with soybean oil or Hemicell®[a].

Item	Treatment			SE
	Control	Soybean Oil	Hemicell®	
ADFI, kg	3.04^{bc}	2.84^{b}	3.33^{c}	.38
Energy, %	85.9^{b}	86.9^{b}	86.5^{b}	.42
Nitrogen, %	80.8^{b}	81.9^{b}	80.7^{b}	.88
Phosphorus, %	45.7^{b}	48.5^{b}	50.4^{b}	3.5
Dry Matter, %	91.7^{b}	92.3^{b}	92.1^{b}	.34

[a] Least squares means for 4 pens/treatment with 1 pig/pen.

[b,c] Means within a row with different superscripts differ ($P<.10$).

Discussion

Experiment 3 – Pettigrew and Moser (1991) have reviewed the effects on growth performance associated with adding a high-energy fat source to swine diets. Our results regarding the comparison of the diet containing soybean oil with the control diet seem to comply with those seen previously. Average daily gain was not affected by the addition of soybean oil, but feed consumption was reduced, leading to an improvement in efficiency. Differences in carcass composition, however, did not agree with the majority of studies reviewed. Pigs in this experiment had less backfat when fed a diet containing soybean oil compared with pigs fed the lower-energy control. Typically, the consumption of diets with included fat tends to increase backfat thickness. In Experiment 3, intake of metabolizable energy for the three diets in Phases 1, 2, and 3 were: 6,262, 5,962, 6,437 kcal/d; 8,473, 8,230, 8,866 kcal/d; and 10,424, 9,963, 9,669 kcal/d, respectively. Although ME concentration was increased by adding 2% soybean oil in the second diet, decreased feed consumption reduced ME intake compared with the control diet in each phase. Therefore, less energy was available to the pig for fat accretion. It is possible that the addition of only 2% soybean oil is enough to improve efficiency, but not enough to affect carcass composition.

An improvement in growth performance of growing-finishing pigs fed diets with added Hemicell® has been observed in numerous larger-scaled field studies. Hahn et al. (1995) showed that Hemicell® addition to pelleted or meal diets improved G:F and pigs fed these diets had a trend for an improvement in lean gain. Other unpublished research in commercial swine operations tends to support the improvement in feed efficiency seen with this study (unpublished).

The results observed in Experiment 3 seem to concur with results shown previously in Experiment 2. Although the addition of soybean meal did not significantly increase ADG as with the weanling pigs in Experiment 2, the addition of Hemicell® improved overall feed efficiency in the growing-finishing phases. Pigs fed diets with Hemicell® in the late nursery phase also showed this same improvement in efficiency. Also, in both studies the improvement in G:F was similar to the increase seen by adding 2% soybean oil. It appears that Hemicell® addition to a corn-SBM diet consistently improves growth performance beyond the late nursery period (≈15-kg BW). This improvement also appears to be equivalent to the addition of 100 kcal/kg ME from soybean oil.

Experiment 4 – Radcliffe et al. (1999) showed that Hemicell® addition increased apparent ileal digestibility of dry matter and the apparent total tract digestibility of energy when included in a corn-SBM (44% CP) diet at .5%. Pigs used in the study were cannulated with steered ileo-cecal cannulas. Our observations in Experiment 4 followed the trends seen previously; however, significant differences were not detectable. The methods of measuring digestibility (chromium marker vs total collection) could contribute to the differences in results of the two experiments. Yet realistically, the small content of beta-mannan in dehulled soybean meal is more likely to be the cause of discrepancy. Further research using a total collection of feces and urine with pigs fed diets with dehulled soybean meal may prove useful in determining any improvements in digestibility by adding Hemicell® to the diet.

Implications

The addition of Hemicell® to corn-SBM diets appears to improve ADG and G:F in pigs fed through the growing-finishing period. Also, pigs consuming a diet with Hemicell® have greater lean gain and more carcass lean tissue. In a practical, commercial setting, time on feed can be reduced and carcass quality may be improved. Apparent digestibilities of energy, nitrogen, or dry matter are not affected by Hemicell® addition, therefore further investigation into the mode of action of Hemicell® may be warranted.

CHAPTER IV

Experiment 5

Effects of Hemicell® addition to corn-soybean meal diets on energy utilization and nitrogen balance of growing pigs.

Abstract – A 22-d experiment was designed to evaluate the effects of Hemicell® addition to a corn-SBM diet on the energy and nitrogen balance of growing pigs, and to potentially quantify the metabolizable energy (ME) Hemicell® adds to the diet. Five groups of four littermate barrows (31.3 kg BW) were allotted randomly by weight to four dietary treatments in a randomized complete block design. One barrow from each of the five litter groups was slaughtered at the initiation of the experiment to estimate initial body composition. Dietary treatments were: 1) a fortified corn-SBM diet to serve as the control (1.10% Lys), 2) the control diet with cornstarch added to the daily ration to increase ME by 100 kcal/kg, 3) the control diet with cornstarch added to increase ME by 200 kcal/kg, and 4) the control diet with Hemicell® (.05%). Pigs were housed individually in metabolic chambers and equally fed within litter group. Water was offered on an *ad libitum* basis. The collection of feces and urine was conducted in two 5-d periods (Period 1, d 4-8; Period 2, d 18-22). There were no period x treatment interactions; therefore, the data were pooled across periods. Also, blood samples were taken on d 0 and d 22. The empty carcasses were ground for determination of energy, protein, fat, and water. Average daily feed intake and gross energy intake increased linearly (P<.01) with increasing addition of cornstarch, but there were no differences between pigs fed the control diet and the diet with Hemicell®. Total dry matter fecal excretion, fecal energy losses, total urine excretion, and urinary energy losses were similar for pigs fed the four diets; therefore, DE concentrations increased linearly (P<.01) with increasing addition of cornstarch. Addition of cornstarch linearly increased (P<.01) ME concentration, but the addition of Hemicell® had no effect. Increasing cornstarch addition or adding Hemicell® had no effect on energy retained in the carcass or viscera compared with the control. Accretion rates of energy, protein, and fat were similar (P>.25) for pigs fed the diet with Hemicell® compared with the control, therefore the net energy (NE) of a corn-SBM diet was unaffected by Hemicell® addition. Plasma glucose tended to decrease (P<.19) and plasma insulin increased (P<.01) in pigs fed the diet with Hemicell® compared with pigs fed the control diet. Based on these results, Hemicell® addition appears to have no effect on the ME concentration of a corn-SBM diet fed to growing pigs; however, elevated insulin release with Hemicell® addition warrants further investigation into a possible mode of action of the enzyme on enhancing growth performance.

Introduction

The addition of Hemicell® to typical swine diets containing corn and dehulled soybean meal (48% CP) appears to improve ADG and G:F in weanling pigs and can increase G:F and lean gain in growing finishing pigs as supported by the growth performance assays in Experiments 1, 2, and 3. Additionally, improvements in feed efficiency and lean gain have been observed in finishing barrows and gilts fed diets containing corn and soybean meal (44% CP) with added Hemicell® (Hahn et al., 1995).

These responses observed in swine seem to be consistent with those noted in broilers (McNaughton et al., 1998; Ward and Fodge, 1996) and turkeys (James et al., 1998).

Studies investigating the reason(s) for the improvements in growth performance described above have first looked towards possible improvements in digestibility of nutrients with Hemicell® addition to the diet. Research conducted by Radcliffe et al. (1999) suggests increased total tract digestibility of energy, and increased ileo-cecal digestibility of dry matter in pigs fed corn-SBM (44% CP) diets containing Hemicell®. In Experiment 4, using the chromium marker method, we found no differences in energy digestibility when Hemicell® was added to a corn-SBM (48% CP) diet.

In an unpublished study conducted by the Taiwan Sugar Company, growing-finishing pigs were fed corn-SBM (44% CP) diets containing varied levels of fiber and added Hemicell®. When Hemicell® was added, pigs fed a diet with a reduced DE concentration of approximately 100 kcal/kg, by adding 4% crude fiber, had similar ADG and G:F as pigs fed a diet with only 3% crude fiber. This observation suggests that Hemicell® addition may provide the equivalent of approximately 100 kcal/kg of DE to a corn-SBM-based diet. Improvements in energy, calcium, and dry matter digestibility also were noted feeding the same diets.

Another potential explanation for the improvements in growth performance and carcass traits by adding Hemicell® may be the improved function of gastrointestinal peptides. The addition of high-galactomannan-containing guar gum appears to reduce the production of gastric inhibitory polypeptide (GIP) in humans and pigs (Morgan et al., 1985; Morgan et al., 1990; Nunes and Malmlof, 1992) and inhibits enteroglucagon secretion in rats (Pell et al., 1992). The primary biological activity of these relatively unknown peptides appears to be related to the regulation of insulin release (Brown, 1993).

Our primary objectives for this study were to measure the energy and nitrogen balance of growing pigs fed a typical corn-SBM (48% CP) diet with Hemicell® using a total collection method, and to potentially quantify the metabolizable energy Hemicell® adds to the diet. Furthermore, we looked to determine the composition of growth and to establish any differences in plasma glucose or insulin levels in pigs fed corn-SBM diets with added Hemicell®.

Materials and Methods

Diets, Housing, Management – Five sets of four littermate barrows were blocked by weight and allotted randomly to four dietary treatments. All pigs were housed individually in metabolic chambers (.75 m x 1.0 m) with galvanized mesh floors and had *ad libitum* access to water. Diets were: 1) a fortified corn-SBM diet to serve as the control, 2) the control diet with cornstarch added to the daily ration of each pig to increase ME by 100 kcal/kg, 3) the control diet with cornstarch added to increase ME by 200 kcal/kg, and 4) the control diet with Hemicell® (.05%). The basal diet (control) was balanced on a total lysine basis at 115% of the NRC (1998) requirements for amino acids, calcium and phosphorus (Table 4.1). Pigs were equally fed within litter group to ensure equal consumption of the basal diet and to maintain differences in energy intake. Daily rations of the basal diet were weighed and cornstarch was added and mixed according to

Table 4.1. Composition of basal diet[a].

Ingredient, %	
Ground corn	66.65
Soybean meal, dehulled	30.68
Dicalcium Phosphate	1.09
Limestone	.83
Salt	.25
Trace Vit/Min premix	.25
Antibiotic[b]	.20
Cornstarch/Hemicell®[c]	.05
Calculated analysis	
ME, kcal/kg	3,319
Lysine, %	1.10
Ca, %	.70
P, %	.60

[a] Cornstarch was added to the daily rations to provide 100 or 200 kcal/kg ME in Diets 2 and 3.

[b] Antibiotic provided 110 mg/kg chlortetracycline.

[c] Hemicell® provided 89 million IU/ton and replaced cornstarch in Diet 4.

the respective treatments. The proper amount of cornstarch required to increase ME by 100 or 200 kcal/kg was determined by the following equation:

Amount = (desired increase in ME / ME of cornstarch) x daily ration

An increase of 100 and 200 kcal/kg ME requires the addition of 2.5 and 5% cornstarch to the daily ration, respectively, assuming the ME concentration of cornstarch is 3,985 kcal/kg (NRC, 1998).

Sampling Procedures – The total but separate collection of feces and urine was conducted in two 5-d periods (Period 1, d 4-8; Period 2, d 18-22). Chromic oxide (.25%) was added to the feed to mark the beginning and end of each collection period. Approximately 10 ml HCl was added to the urine collection pans to prevent ammonia loss. Urine and feces were collected daily. Approximately 80 ml of the daily urine volume was kept and stored, along with all feces, in deep-freeze (-20°C) until further analyses. Feces were oven-dried (60°C), ground in a Wiley Mill equipped with a 1 mm screen, and subsampled. All daily urine samples were combined to a 100-ml composite based on the daily percentage of the total 5-d urine volume.

Blood samples were taken from each pig on Day 0 and 22 following a four-hour withdrawal from feed. Blood was drawn by jugular venipuncture into a vacuum tube with heparin, chilled, and plasma was separated by centrifuge at 4°C for 20 minutes (Beckman, Model J-6B, Fullerton, CA).

Following the final collection period, all pigs were humanely slaughtered to determine carcass composition. Pigs were stunned, exsanguinated, and dehaired by standard procedures. The heads were removed and pigs were eviscerated. The viscera was stored in deep-freeze (-20°C) for later analyses. Empty carcasses were split along the dorsal midline, weighed, quartered, and boxed individually for deep-freeze storage.

All carcasses were ground for composition analyses. Frozen carcasses were cut into smaller portions with a band saw and ground three times in a commercial meat grinder (Autio Grinder, Model 801GHP; Astoria, OR) equipped with a .64 cm screen. Dry ice was added each time to prevent moisture loss. Viscera samples were processed in the same manner. Following grinding, approximately 400 g of sample was taken from each carcass and viscera. Samples were freeze-dried and further ground in a Wiley Mill equipped with a 2-mm screen.

Five barrows (31.3 kg BW) from the five litter groups used in the balance study were slaughtered at the initiation of the experiment as described above. Live body weights were regressed against carcass composition to formulate regression equations for total carcass energy (R^2=.98), total carcass protein (R^2=.92), total carcass fat (R^2=.93), and total viscera energy (R^2=.88) for the estimation of the initial composition of the pigs used in the study. Energy, protein, and fat gain were calculated by subtracting final composition from the estimated initial composition for each pig.

Laboratory Analyses – All gross energy determinations were made by bomb calorimetry (Parr 1261 Isoperibol Calorimeter, Moline, IL), and nitrogen determinations were performed by Kjeldahl methodology. Fat content of empty carcasses was determined by standard ether extract procedures. Diets were analyzed for energy concentration and nitrogen content. For Diets 2 and 3, energy and nitrogen values were corrected for cornstarch addition by multiplying by 102.5 and 105 %, respectively. For urinary energy analysis, two milliliters of composite urine was added to one-half gram of cellulose (Solka-Floc) and dried for 24 hr at 100°C. After bomb analysis, the gross energy of the urine was calculated based on the total energy of combustion, energy of combustion of a previously bombed pure cellulose pellet, and the percentages of dry urine and dry cellulose in the combusted pellet.

Blood plasma was allowed to thaw and then analyzed for glucose, plasma urea nitrogen, creatinine, triglycerides, and protein (Roche Diagnostic Systems, Cobas Fara II; Somerville, NJ). Insulin levels were determined using Coat-A-Count Insulin Kit (Diagnostic Products Corporation, Kit no. TKIN2; Los Angeles, CA).

Statistical Analyses – Data were analyzed as a randomized complete block design using analysis of variance procedures as described by Steel and Torrie (1997). Pig served as the experimental unit. The interaction of period x treatment was tested for the balance study. The effects of ME concentration by increasing cornstarch addition were partitioned into linear and quadratic components using orthogonal polynomial contrasts. A pre-planned non-orthogonal contrast was used to compare the effects of adding Hemicell® with the control diet. Hot carcass weight was used as a covariant in the analysis of body composition and viscera data. Blood plasma data were analyzed using Day 0 concentrations as a covariant.

Results

Energy Balance – Gross energy concentrations of the four diets were: 4,455, 4,547, 4,651, and 4,443 kcal/kg, respectively. The addition of increasing levels of cornstarch to the daily rations linearly increased ($P<.01$) gross energy (GE) intake (Table 4.2). Pigs fed the diet with Hemicell® were similar in GE intake to pigs fed the control diet. There were no differences among the four dietary treatments in energy lost as fecal energy (FE) or urinary energy (UE). Thus, using the relationship: $ME = GE - FE - UE$, metabolizable energy (ME) was found to increase linearly ($P<.01$) with increasing levels of cornstarch addition to the pigs' daily ration. Diets containing Hemicell® had similar ($P>.89$) ME values compared with the control diet when expressed on a concentration basis (kcal/kg).

There were no differences among the four dietary treatments in ADG. Dressing percentage was similar for pigs fed the diets with increasing levels of cornstarch, but was slightly ($P<.18$) lower for pigs fed the diet with Hemicell® compared with pigs fed the control diet. Total viscera weight and visceral percentage of the final body weight were reduced in pigs fed diets with cornstarch added to increase ME by 100 kcal/kg causing a quadratic ($P<.05$) effect of cornstarch addition. The total carcass energy content and energy gain in the empty body over the experimental period were unaffected by cornstarch or Hemicell® addition. Cornstarch addition had a quadratic effect ($P<.04$) on the energy content of viscera and the rate of viscera energy gain. Also, pigs fed the diet

Table 4.2. Energy balance of pigs fed corn-SBM diets with increasing levels of cornstarch or Hemicell®^{ab}.

	Treatment^{c}				
Item	Control	+100	+200	Hemicell®	SE
GE, kcal/kg	4,455	4,547	4,651	4,443	
ADFI, g/d^{d}	1,397	1,482	1,510	1,417	16.3
GE intake, kcal/d^{d}	6,222	6,735	7,025	6,297	73.5
FE, kcal/d	740.9	730.8	763.8	738.3	32.3
UE, kcal/d	114.7	108.4	110.6	111.5	3.3
DE, kcal/d^{d}	5,481	6,004	6,261	5,559	73.5
DE, kcal/kg^{d}	3,921	4,053	4,144	3,914	21.1
ME, kcal/d^{d}	5,366	5,896	6,151	5,448	72.8
ME, kcal/kg^{d}	3,840	3,980	4,071	3,836	20.6
ME:DE, %^{d}	97.9	98.2	98.2	98.0	.06
ME:GE, %^{e}	86.2	87.5	87.5	86.3	.46
Energy gain, kcal/d	1,834.8	1,689.7	1,836.9	1,772.3	78.56
Carcass, kcal/d	1,675.7	1,555.2	1,661.8	1,602.6	73.36
Viscera, kcal/d^{f}	159.2	134.5	175.1	169.7	11.02

[a] Least squares means for 5 pigs/treatment; pooled data from two 5-d periods.

[b] All values are expressed on a dry matter basis.

[c] Control = fortified corn-SBM diet; +100 = control + 100 kcal/kg ME from cornstarch; +200 = control + 200 kcal/kg ME from cornstarch; Hemicell® = control + Hemicell® (.05%).

[d] Linear ($P<.01$) for control, +100, and +200.

[e] Linear ($P<.07$) for control, +100, and +200.

[f] Quadratic ($P<.05$) for control, +100, and +200.

with Hemicell® had similar energy retention in both carcass and viscera as pigs fed the control diet.

By increasing the amount of cornstarch added to the daily ration, total body protein decreased linearly ($P<.06$) along with a linear decrease ($P<.01$) in the rate of protein accretion (Table 4.3). Although pigs fed the control diet tended to have a greater ($P<.13$) accretion rate of protein compared with pigs fed the diet with Hemicell®, there was no difference in total body protein or percentage protein of the carcass. There were also no differences in fat accretion due to Hemicell® addition compared with the control.

Table 4.3. Empty body composition of pigs fed diets with increasing levels of cornstarch or Hemicell®[a,b].

	Treatment[c]				
Item	Control	+100	+200	Hemicell®	SE
Carcass, % of BW[d,e]	67.9	68.3	66.8	67.2	.34
Viscera, % of BW[f]	15.0	14.3	15.3	15.5	.29
Total body protein, kg[d]	6.10	6.04	5.93	6.06	.058
Protein, %	17.5	17.4	17.1	17.5	.167
Protein gain, g/d[g]	118.4	111.6	105.6	111.0	3.10
Total body fat, kg	4.26	4.09	4.47	4.27	.175
Fat, %	12.3	11.7	13.0	12.2	.511
Fat gain, g/d	102.6	91.6	107.6	98.0	8.10
Moisture, %	66.4	67.0	66.1	66.5	.454

[a] Least squares means for 5 pigs/treatment.

[b] All values are expressed on a dry matter basis.

[c] Control = fortified corn-SBM diet; +100 = control + 100 kcal/kg ME from cornstarch; +200 = control + 200 kcal/kg ME from cornstarch; Hemicell® = control + Hemicell® (.05%).

[d] Linear ($P<.06$) for control, +100, and +200.

[e] Linear ($P<.07$) for control, +100, and +200.

[f] Quadratic ($P<.05$) for control, +100, and +200.

[g] Linear ($P<.01$) for control, +100, and +200.

Nitrogen Balance – Increasing the level of cornstarch added to the daily rations had no effect on nitrogen balance (Table 4.4). However, nitrogen intake (g/d) was greater ($P<.04$) for pigs fed the control diet compared with pigs fed the diet with added Hemicell®. This increased intake of nitrogen led to a trend towards greater ($P<.10$) absorption of nitrogen on a grams/d basis. Yet, when comparing nitrogen absorption and retention as a percentage of intake, no differences were observed between the two treatments.

Table 4.4. Nitrogen balance of pigs fed corn-SBM diets with increasing levels of cornstarch or Hemicell®[a][b].

	Treatment[c]				
Item	Control	+ 100	+ 200	Hemicell®	SE
N intake, g/d[d]	47.5	47.1	48.1	45.8	.53
Fecal N, g/d	7.2	7.4	7.6	7.2	.46
Urinary N, g/d	14.9	13.7	13.9	14.4	.66
N absorption, g/d	40.3	39.7	40.6	38.5	.69
N retention, g/d	25.3	26.0	26.7	24.2	.80
N absorption, % intake	84.7	84.2	84.2	84.0	.99
N retention, % intake	53.4	55.1	55.4	52.8	1.4

[a] Least squares means for 5 pigs/treatment.

[b] All values are expressed on a dry matter basis.

[c] Control = fortified corn-SBM diet; +100 = control + 100 kcal/kg ME from cornstarch; +200 = control + 200 kcal/kg ME from cornstarch; Hemicell® = control + Hemicell® (.05%).

[d] Hemicell® vs control ($P<.05$).

Plasma Components – The addition of increasing levels of cornstarch to the diet tended to linearly decrease ($P<.19$) plasma glucose levels; however, insulin was linearly increased ($P<.03$) with increasing cornstarch addition (Table 4.5). Hemicell® addition also tended to decrease ($P<.18$) plasma glucose compared with the control, which correlated with an over two-fold increase ($P<.01$) in insulin levels. Plasma urea nitrogen quadratically decreased ($P<.07$) as increasing levels of cornstarch were added to the diets, and it was lower ($P<.06$) in pigs fed a diet with Hemicell® as compared with pigs fed the control diet.

Table 4.5. Plasma concentrations of glucose, triglycerides, PUN, protein, creatinine, and insulin in pigs fed diets with increasing levels of cornstarch or Hemicell®[a].

	Treatment[b]				
Item	Control	+100	+200	Hemicell®	SE
Glucose, mg/dl	111.02	114.61	103.28	103.49	3.67
Triglycerides, mg/dl	44.10	32.46	36.20	34.33	6.31
Plasma urea N, mg/dl[c,d]	20.31	16.69	18.70	17.36	.988
Protein, g/dl	6.46	6.99	6.88	6.12	.344
Creatinine, mg/dl	1.48	1.49	1.53	1.51	.110
Insulin, μIU/ml[e,f]	7.42	9.70	12.32	15.38	1.12

[a] Least squares means for 5 pigs/trt.

[b] Control = fortified corn-SBM diet; +100 = control + 100 kcal/kg ME from cornstarch; +200 = control + 200 kcal/kg ME from cornstarch; Hemicell® = control + Hemicell® (.05%).

[c] Quadratic ($P<.07$) for control, +100, and +200.

[d] Hemicell vs control ($P<.06$).

[e] Linear ($P<.03$) for control, +100, and +200.

[f] Hemicell vs control ($P<.01$).

Discussion

An increase in the metabolizable energy concentration of a diet with increased addition of a high-energy ingredient, such as cornstarch, was observed as expected. Cornstarch was chosen as the means of increasing ME due to its high digestibility and it being a carbohydrate. It has been well documented that fat sources can improve the ME concentration of a corn-SBM diet in pigs, however there may also be differences in digestibility between energy sources from carbohydrates and fats (Phillips and Ewan, 1977; Ewan, 1991). If Hemicell® was increasing the ME concentration of a corn-SBM diet, carbohydrate digestibility would most likely be affected; therefore, to properly compare Hemicell®'s affect on ME, starch was added to the reference diets. Also, we decided to add cornstarch to the daily ration of each pig, as opposed to being formulated as part of the diet, to reduce the total amount that would have to be consumed by the pig. By adding the respective amounts daily, pigs could consume an adequate amount of the fortified basal diet and palatability would not be affected by a 'starchy' diet. Another important consideration was the essentiality of maintaining energy intake differences given that high-energy diets tend to decrease voluntary feed intake (Cole et al., 1968). By feeding equal rations daily to each pig in a litter group, energy intake could be differentiated by cornstarch addition rather than by voluntary eating patterns. The increased gross energy intake we observed in pigs consuming diets with increasing levels of cornstarch addition is shown in Figure 1.

The comparison of ME concentrations of the four diets is shown in Figure 2. By adding increasing levels of cornstarch and feeding the same amount of basal diet to each pig in the litter group, as planned, we observed a linear increase in the ME concentration of the three dietary treatments. This line, only when linear, can be used as a reference to quantify the ME content of the diet with Hemicell®. As seen in Figure 2, Hemicell® added no ME to a corn-SBM diet, thus no increase could be quantified.

Our failure to observe improvements in nutrient digestibility of a corn-SBM diet with added Hemicell® appears to conflict with data reported by Radcliffe et al. (1999). Although the authors observed increases in total tract energy digestibility and ileo-cecal digestibility of dry matter in cannulated pigs fed corn-SBM (44%) diets, we found no differences in the apparent digestibility of energy or nitrogen. The differences in the types of soybean meal used in the two studies could account for this discrepancy. Soybeans differ from most legumes in that the galactomannans are primarily associated with the hull portion of the seed (Dea and Morrison, 1975). By adding dehulled soybean meal, we theoretically reduced the galactomannan content of the diet and therefore may be less likely to see an effect by degrading the beta-mannan backbone. Our observations in this study tend to support those seen in Experiment 3 when a chromium marker method was used to test the apparent digestibility of finishing pigs fed a corn-SBM containing dehulled soybean meal.

Increasing the ME intake of young pigs has been shown to linearly increase the energy retained by the pig (DeGoey and Ewan, 1975). Although this was our intention for this study, we failed to observe an increase in energy retention by adding increasing amounts of cornstarch to the daily rations. Metabolizable energy intake was linearly increased and energy retention remained unaffected; therefore heat production must have been heightened as more starch was added to the diets. Heat increment is known to be higher for carbohydrates as opposed to fats (Cromwell and Stahly, 1979). By adding increasing amounts of a high-energy carbohydrate we possibly increased the energy required to digest and metabolize the diet, thereby reducing the energy available for fat accretion.

Fat accretion was not affected by cornstarch addition, and protein deposition decreased linearly with increasing levels of cornstarch addition. In studies reviewed by Pettigrew and Moser (1991), a constant protein to energy ratio in diets for growing pigs had little effect on ADG, but improved efficiency of gain. The calculated protein:energy ratios for the four dietary treatments in this study were 66.8, 68.8, 70.8, and 66.8 grams of protein/Mcal of ME, respectively.

Pigs fed the diet with Hemicell® were similar in growth performance and body composition to pigs fed the control diet. Hemicell® addition to diets for growing-finishing pigs has been reported in commercial settings to exhibit a trend toward increasing lean gain (Hahn et al., 1995). This response was supported by our results in Experiment 3, where lean gain and total carcass lean tissue were increased in pigs fed a diet with added Hemicell®. Certainly the short period of feeding a diet with the added enzyme in the present experiment could reduce the likelihood of observing any differences in body composition.

Even though differences in carcass traits were undetectable, the numeric decrease in plasma glucose and correlated increase in plasma insulin levels in pigs fed the diet with Hemicell® proved to be enlightening. Diets containing high levels of galactomannan from guar gums have been shown to reduce post-prandial insulin production when fed to pigs (Sambrook and Rainbird, 1985; Malmlof et al., 1989). If galactomannans can somehow reduce the secretion of insulin, then degrading them by adding an enzyme to the diet would expectedly increase the release of insulin into the bloodstream. The most probable site of action of inhibiting the release of insulin by galactomannans appears to be the inhibition of the regulatory peptides, enteroglucagon and gastric inhibitory polypeptide (GIP) in the gastrointestinal tract (Morgan et al., 1985; Nunes and Malmlof, 1992). Glucagon-like peptide 1 (GLP-1) and GIP possibly act synergistically to stimulate the secretion of insulin (Brown, 1993). Results of the current study indicate that even when pigs are fed a corn-SBM diet with a relatively low galactomannan content, insulin release may be inhibited. Furthermore, Hemicell® addition to a diet containing dehulled soybean meal may alleviate the inhibition caused by the presence of galactomannans.

Implications

Although it has been shown in previous experiments to improve rate and efficiency of gain, and increase lean gain in growing-finishing pigs, Hemicell® addition to corn-SBM (48%) diets appears to have no effect on the apparent digestibility of nitrogen or energy. Also, the metabolizable energy concentration of the diet is unaffected by the presence of Hemicell® in the diet. However, the indication that Hemicell® addition to a diet may increase the production of insulin could explain differences in growth performance and body composition previously observed. More extensive research into the serum insulin levels of pigs fed diets containing galactomannans with added Hemicell® is needed to support this theory.

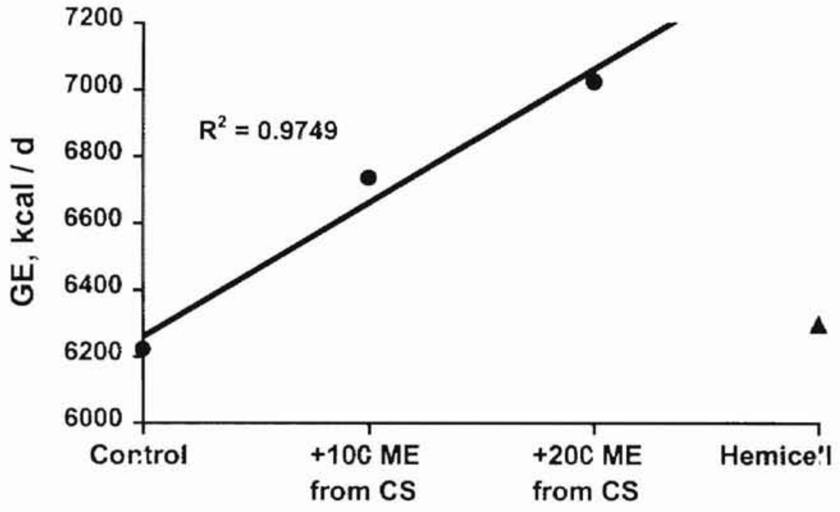

Figure 1. The gross energy (GE) intakes for pigs fed three diets with increasing levels of cornstarch (CS) addition compared with the GE intake for pigs fed a diet with Hemicell®.

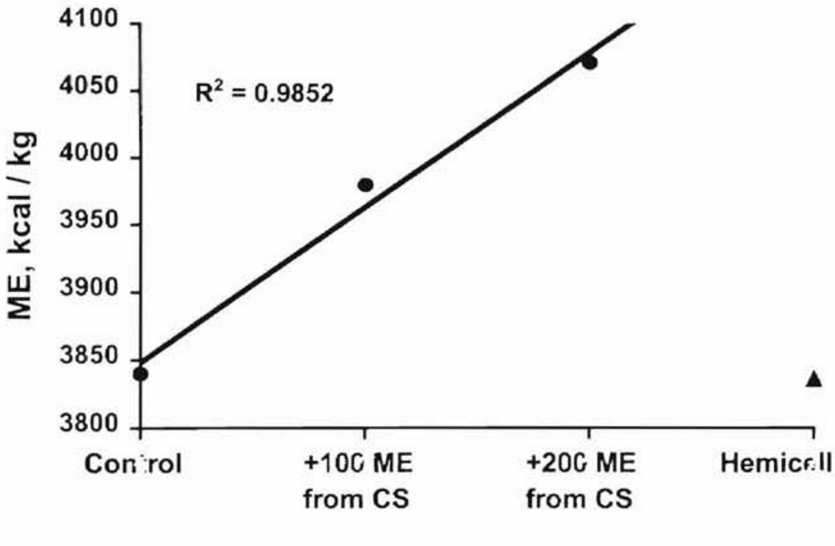

Figure 2. The metabolizable energy (ME) concentrations of three diets with increasing levels of cornstarch (CS) addition compared with the ME concentration of a diet with Hemicell®.

CHAPTER V

Summary and Discussion

The concept of formulating a diet with an enzyme to act on a component of soybean meal is a relatively new idea and can present many challenges. Generally speaking, the initial work presented in this thesis was the first to look at Hemicell® addition to swine diets. During the on-going process of investigating the effects of the enzyme in diets, many new responses were discovered as more data were collected. Likewise, the factors involved in causing the responses observed came to light and new methods of measuring Hemicell®'s effects were utilized. Therefore, it is helpful to summarize the knowledge gained from these studies in a stepwise manner, starting with the basic understanding of galactomannans in feed ingredients, to better comprehend the rationale behind the trials conducted and results obtained.

The presence of non-starch polysaccharides in the ungerminated seeds of most legumes appears to play a vital role in the storage of nutrients to provide for the seed upon the initiation of germination. The primary storage polysaccharides present in legumes are galactomannans. A specific enzyme endogenous to the seed can degrade these molecules to release the stored energy for the seed. This enzyme, beta-D-mannanase, works with other related enzymes to complete the degradation.

These polysaccharides are distinct in their chemical composition, which is primarily galactose and mannose, but the specific structure of the galactomannan is perhaps the most important to its utilization by a monogastric animal. The mannan backbone of the molecule consists of repeating mannan units connected by beta-1-4-linkages, which cannot be cleaved by enzymes present in the gastrointestinal tract of swine, poultry, or humans. A variety of bacterial species have been found to produce beta-D-mannanase capable of degrading the mannan chain of the galactomannan structure. The addition of an external enzyme source to break the mannan chain gives the animal the ability to better utilize feed ingredients containing the galactomannan structure.

Although soybean meal is commonly used as the primary amino acid source for pigs in practically all commercial swine settings, the utilization of this ingredient by pigs may be affected by the presence of galactomannans. Galactomannan content of soybeans appears to be concentrated primarily in the hull portion of the seed, unlike most legumes. Dehulled soybean meal still may contain 1.3-1.7 % beta-mannan content on a dry matter basis. The addition of a beta-mannanase, in the form of Hemicell®, to break the critical beta-1-4 linkage of the galactomannan structure theoretically could improve the utilization of corn-SBM-based diets by pigs.

Our first experiment, conducted to study the effects of Hemicell® addition to corn-SBM based diets for weanling pigs, was designed to measure the advantages in growth performance by adding the enzyme to simple diets and diets with complex protein sources. The addition of Hemicell® to the complex and simple diets increased the efficiency of feed utilization in weanling pigs during the late nursery phase. This improvement in efficiency corresponded to an increase in the presence of soybean meal in the two diets. From this early experiment, it appeared that the small amount of galactomannan in dehulled soybean meal, may in fact be suppressing growth performance, and therefore Hemicell® addition could be removing this inhibition.

An unpublished study conducted by the Taiwan Sugar Corporation was the first to show the potential energy advantages of adding Hemicell® to swine diets. By adding a crude fiber source (barley hulls) at varied levels, the digestible energy concentration of the diets was altered by approximately 100 kcal/kg. Hemicell® addition to a lower energy diet improved ADG and G:F, which equaled the growth performance of pigs fed a higher energy diet containing less crude fiber.

Based on the potential increase of approximately 100 kcal/kg digestible energy by adding Hemicell® to a swine diet, a second experiment with weanling pigs was conducted. Simple corn-SBM-based diets were fed in the final three weeks of the nursery period. A diet containing Hemicell® was compared to a diet with soybean oil (2%) added to increase the metabolizable energy concentration of the diet by approximately 100 kcal/kg. As shown previously in Experiment 1, Hemicell® addition to the diet increased efficiency of feed utilization in weanling pigs compared to the control diet. Also, pigs fed the diet with Hemicell® had similar ADG and G:F as the pigs fed the diet with the increased energy concentration. Based on growth performance, results indicated that Hemicell® may provide approximately 100 kcal/kg ME to a corn-SBM diet, which was supported by the results of the experiments conducted by the Taiwan Sugar Corporation.

In addition to measuring growth performance in Experiment 2, a cost analysis of the three diets was conducted. The results of this comparison are shown in Table 5-1. All ingredient prices used were current market price at the time the experiment was conducted. The cost of the Hemicell® product used was $2/ton of feed, an average price at the time the experiment was conducted. The addition of soybean oil as a high-energy source increased the cost of the second diet compared with the control diet and the diet containing Hemicell®. The addition of Hemicell® did not affect the cost of the diet compared with the control. Therefore, based on the growth performance improvements observed by adding Hemicell® to a corn-SBM diet, the cost per kilogram of gain was decreased when Hemicell® was added to the diet at .05%. Also, the cost per kilogram of gain was lower for the diet with added Hemicell® when compared to the diet containing soybean oil.

Table 5.1. Effects of Hemicell® and soybean oil addition on total cost of corn-SBM-based diets and cost per kg of gain in weanling pigs[a] (Exp. 2).

	Treatment			
Item	Control	Soybean Oil	Hemicell®	SE
Number of pigs	39	39	39	
Initial weight, kg	13.6	13.7	13.5	.07
Final weight, kg	24.8	25.0	25.0	.22
Total gain, kg/pen	44.39^b	45.37^b	45.79^b	.78
Total feed, kg/pen	78.32^b	77.33^b	77.06^b	1.00
Total cost, $/pen	11.14^b	12.18^c	10.95^b	.16
Cost/kg gain	$.250^b$	$.268^c$	$.239^d$	.01

[a] Means of 10 pens/treatment with 3-4 pigs/pen.

[b,c,d] Means within a row with different superscripts differ ($P<.10$).

From the results of Experiment 2, a possible increase in ME concentration of a corn-SBM diet with Hemicell® seemed likely. This benefit of adding an enzyme to the diet would be most advantageous in diets fed to growing and finishing pigs to reduce time on feed and improve feed efficiency. Thus, Experiment 3 was designed to further test the possibility of increasing ME by adding Hemicell® compared with a diet containing soybean oil as an increased energy source.

In this study (Experiment 3), Hemicell® addition increased ADG compared with pigs fed the control diet and pigs fed the diet with soybean oil. The addition of Hemicell® numerically increased G:F compared with the control, which was similar to the addition of soybean oil. Although the strength of the response by adding Hemicell® was not consistent throughout the experiment, there is no doubt that the enzyme showed a similar energy advantage as seen in Experiment 2.

The collection of carcass data following the growth assay allowed us to further ascertain the potential effects of Hemicell® addition. Carcasses of pigs fed the diet with Hemicell® were heavier and showed trends toward an increase in loin muscle area and a decrease in backfat depth. The combination of increased ADG and a trend in leaner carcasses contributed to an increase in lean gain and total carcass lean tissue in pigs fed the diet with Hemicell®. Our observations concur with results found in numerous field trials where pigs were fed similar diets in commercial settings. Hahn et al. (1995) reported trends in increased feed efficiency and lean gain in barrows and gilts fed corn-SBM (44%) diets with added Hemicell®.

The possible reasons for the increased ADG and improved feed efficiency seen in pigs fed diets with added Hemicell® was investigated by Radcliffe et al. (1999). In cannulated pigs, total tract energy digestibility and apparent ileo-cecal digestibility of dry matter were increased with Hemicell® addition to a diet containing soybean meal (44%) with the hull portion added back. Trends were also seen for the improvement of nitrogen digestibility with Hemicell® addition. According to these observations, Hemicell® added to the diet degrades the beta-mannan present in soybeans, thus removing the inhibition of normal nutrient digestion in the small intestine. This perception concurs with growth performance data which suggests that digestibility could be increased leading to improved rate and efficiency of gain in pigs fed corn-SBM diets. Improved digestibility could also support the idea of an increase in energy concentration by adding Hemicell® to the diet observed in early pig studies.

In Experiment 4, the apparent digestibilities of energy, nitrogen, dry matter, and phosphorus were determined in finishing pigs fed diets containing dehulled soybean meal and Hemicell®. Using a chromium marker method to estimate apparent digestibility, no differences were found for any nutrient tested when Hemicell® was added to the diet compared with the control. A slight numeric trend towards increased energy digestibility by adding Hemicell® to the diet indicates that the added enzyme might be improving digestibility, yet a small content of beta-mannan in dehulled soybean meal and few repetitions involved in the experiment could have prevented adequate detection of the differences.

To possibly improve the detection of digestibility improvements when adding Hemicell® to a diet with dehulled soybean meal, Experiment 3 was conducted using a total collection of feces and urine to measure energy and nitrogen balance in growing pigs. Also, it was hoped to potentially quantify the metabolizable energy added to a corn-SBM diet by including Hemicell® in the diet, if, in fact, digestibility was improved. By increasing the metabolizable energy of two diets by 100 and 200 kcal/kg over the control, a reference line showing a linear increase in ME concentration was used to compare with the ME concentration of the diet containing Hemicell®. Hemicell®

addition had no effect on fecal or urinary energy losses; therefore, DE and ME concentrations were also unaffected by the presence of the enzyme in the diet.

The failure to discover any differences in energy or nitrogen digestibility by adding Hemicell® to a corn-SBM diet appears to contradict many of the early studies comparing diets with varied energy concentrations. Although pigs fed diets with Hemicell® exhibit growth performance similar to pigs fed a diet with an increased ME content, improved digestibility may not be the cause. However, caution must be exerted in such an assertion, as only dehulled soybean meal was used in these studies, and soybean meal with a higher beta-mannan content (or any ingredient containing high levels of beta-mannan) may indeed curb digestibility of nutrients in pigs.

In Experiment 5, blood samples were taken from each pig at the initiation and conclusion of the study. Interestingly, plasma glucose levels were reduced by more than 7% in pigs fed the diet with added Hemicell®. Also, Hemicell® addition increased insulin concentrations by over 107%. These numbers must be considered only preliminary indications of Hemicell®'s effect due to the short feeding period of the enzyme in Experiment 5, but they still may provide a direct explanation of the responses seen when Hemicell® is added to diets for swine.

It is reasonable to believe that if the presence of beta-mannans inhibit the release of glucagon-like peptide (GLP-1) and gastric inhibitory polypeptide (GIP), then the secretion of insulin would also be inhibited. It is generally accepted that insulin promotes protein tissue synthesis by stimulating glucose uptake by muscle cells and inhibiting protein catabolism. Therefore, as insulin levels return to levels dictated by genetics rather than by dietary inhibition, lean tissue deposition will also optimize. This new hypothesis could account for the nearly 6 % increases in lean tissue gain and loin muscle area found in Experiment 3. Additionally, the 4.5 % and 4.1 % improvements in efficiency seen in Experiments 2 and 3, respectively, would be expected as protein tissue deposition is increased.

Even as the knowledge base of Hemicell®'s effects on the utilization of diets containing dehulled soybean meal has increased, there is still much to learn. There appears to be a great potential to improve growth performance in pigs fed diets with a high-galactomannan content, which is common in other countries where palm kernel meal and guar meal are cheaper and more plentiful than feed ingredients used in the United States. Hemicell® may have a more profound effect in U.S commercial swine operations when added to diets formulated with soybean hulls. Their higher galactomannan content makes them an ideal feed ingredient to accompany Hemicell® in future research trials.

Literature Cited

Anderson, L. O., and R. E. Warnick. 1964. Value of enzyme supplements in rations containing certain legume seed meals or gums. Poultry Sci. 43:1091-1097.

Aspinall, G. O. 1982. Analysis of Polysaccharides. In: Food Carbohydrates. D. R. Lineback and G. E. Inglett (eds.). AVI Publishing Co., Westport, CT.

Bakshi, Y., C. R. Creger and J. R. Couch. 1964. Studies on guar meal. Poultry Sci. 43:1303.

Blackburn, N. A. and I. T. Johnson. 1981. The effect of guar gum on the viscosity of the gastrointestinal contents and on glucose uptake from the perfused jejunum in the rat. Br. J. Nutr. 46:239-246.

Blackburn, N. A., J. S. Redfern, H. Jarjis, A. M. Holgate, I. Hanning, J. H. B. Scarpello, I. T. Johnson, and N. W. Read. 1984a. The mechanism of action of guar gum in improving glucose tolerance in man. Clin. Sci. 66:329-336.

Blackburn, N. A., A. M. Holgate, and N. W. Read. 1984b. Does guar gum improve post-prandial hyperglyceamia in humans by reducing small intestinal contact area? Br. J. Nutr. 52:197-204.

Borcher, R., and C. W. Ackerson. 1950. The nutritive value of legume seeds. X. Effect of autoclaving and trypsin inhibitor test for 17 species. J. Nutr. 41:339-345.

Brown, J. C. 1993. An overview of gastrointestinal endocrine physiology. Gastrointestinal Hormones in Medicine. 22:719-729.

Brown, N. J., J. Worlding, R. D. E. Rumsey, and N. W. Read. 1988. The effect of guar gum on the distribution of a radiolabelled meal in the gastrointestinal tract of the rat. Br. J. Nutr. 59:223-231.

Cameron-Smith, D., G. R. Collier, and K. O'Dea. 1994. Effect of soluble dietary fibre on the viscosity of gastrointestinal contents and the acute glycaemic response in the rat. Br. J. Nutr. 71:563-571.

Cera, K. R. and D. C. Mahan. 1985. The effect of dried whey and corn oil addition to weanling pig diets on performance and apparent fat digestibility. J. Anim. Sci. 61 (Suppl. 1):299 (Abstr.).

Chen, W-J. L. and J. W. Anderson. 1979. Effects of guar gum and wheat bran on lipid metabolism of rats. J. Nutr. 109:1028-1034.

Chesson, A. 1987. Supplementary enzymes to improve the utilization of pig and poultry diets. In: Recent Advances in Animal Nutrition. pp 71-89. Butterworths, Boston.

Coffey, R. D. and G. L. Cromwell. 1995. The impact of environmental and antimicrobial agents on the growth response of early-weaned pigs to spray-dried porcine plasma. J. Anim. Sci. 73:2532-2539.

Cole, D. J. A., E. Duckworth, W. Holmes, and A. Cuthbertson. 1968. Factors affecting voluntary feed intake in pigs. 3. The effect of a period of feed restriction, nutrient density of the diet and sex on intake, performance and carcass characteristics. Anim. Prod. 10:345-357.

Couch, J. R., Y. K. Bakshi, T. M. Ferguson, E. B. Smith, and C. R. Creger. 1967. The effect of processing on the nutritional value of guar meal for broiler chicks. Br. Poultry Sci. 8: 243-250.

Davies, I. R., J. C. Brown, and G. Livesey. 1991. Energy values and energy balance in rats fed on supplements of guar gum or cellulose. Br. J. Nutr. 65:415-433.

Dea, I. C. M. and A. Morrison. 1975. Chemistry and interactions of seed galactomannans. Adv. Carbohydr. Chem. Biochem. 31:241-312.

DeGoey, L. W. and R. C. Ewan. 1975. Effect of level of intake and diet dilution on energy metabolism in the young pig. J. Anim. Sci. 40:1045-1051.

Edwards, C. A., N. A. Blackburn, L. Craigen, P. Davison, J. Tomlin, K. Sugden, I. T. Johnson, and N. W. Read. 1987. Viscosity of food gums determined in vitro related to their hypoglycemic actions. Am. J. Clin. Nutr. 46:72-77.

Edwards, C. A., I. T. Johnson, and N. W. Read. 1988. Do viscous polysaccharides slow absorption by inhibiting diffusion or convection? Eur. J. Clin. Nutr. 42:307-312.

Ellis, P. R., F. M. Dawoud, and E. R. Morris. 1991. Blood glucose, plasma insulin and sensory responses to guar-containing wheat breads; effects of molecular weight and particle size of guar gum. Br. J. Nutr. 66:363-379.

Ewan, R. C. 1991. Energy utilization in swine nutrition. Pp. 121-132 in Swine Nutrition, E. R. Miller, D. W. Ullrey, and A. J. Lewis, eds. Stoneham, U. K. Butterworth-Heinemann.

Hahn, J. D., M. J. Gahl, M. A. Giesemann, D. P. Holzgraefe, and D. W. Fodge. 1995. Diet type and feed form effects on the performance of finishing swine fed the beta-mannanase enzyme product Hemicell. J. Anim. Sci. 73(Suppl. 1):153 (Abstr.).

Harmuth-Hoene, A-E and E. Schwerdtfeger. 1979. Effect of indigestible polysaccharides on protein digestibility and nitrogen retention in growing rats. Nutrition and Metabolism. 23:399-406.

Higham, S. E. and N. W. Read. 1992. The effect of ingestion of guar gum on ileostomy effluent. Br. J. Nutr. 67:115-122.

Himmelberg, L. V., E. R. Peo, Jr., A. J. Lewis, and J. D. Crenshaw. 1985. Weaning weight response of pigs to simple and complex diets. J. Anim. Sci. 61:18-26.

Holt, S., R. C. Heading, D. C. Carter, L. F. Prescott, and P. Tothill. 1979. Effect of gel fibre on gastric emptying and absorption of glucose and paracetamol. Lancet. 1:636-639.

Ikegami, S., F. Tsuchihashi, H. Harada, N. Tsuchihashi, E. Nishide, and S. Innami. 1990. Effect of viscous indigestible polysaccharides on pancreatic-biliary secretion and digestive organs in rats. J. Nutr. 120:353-360.

Imaizumi, K., A. Tominaga, K. Mawatari, and M. Sugano. 1982. Effects of cellulose and guar gum on the secretion of mesenteric lymph chylomicrons in meal-fed rats. Nutrition Reports International. 26:263-269.

James, R., J. McNaughton, and D. Fodge. 1998. Improved use by turkeys of corn-soy diets with beta-mannanase. Poultry Sci. 77(Suppl. 1):153. (Abstr.).

Jenkins, D. J. A. 1979. Dietary fibre, diabetes, and hyperlipidaemia. Lancet. 2:1287-1290.

Jenkins, D. J. A., A. R. Leeds, B. Slavin, J. Mann, and E. M. Jepson. 1979. Dietary fiber and blood lipids: reduction of serum cholesterol in type II hyperlipidemia by guar gum. Am. J. Clin. Nutr. 32:16-18.

Johnson, I. T. and J. M. Gee. 1986. Gastrointestinal adaptation in response to soluble non-available polysaccharides in the rat. Br. J. Nutr. 55:497-505.

Khalsa, N. and P. K. Sharma. 1980. Effects of guar (Cyamopsis tetragonoloba) on serum lipids, uric acid and proteins. Ind. J. Nutr. 17:297-301.

Khan, A. R., G. Y. Khan, A. Mitchel, and M. A. Qadeer. 1981. Effect of guar gum on blood lipids. Am. J. Clin. Nutr. 34:2446-2449.

Landin, K., G. Holm, L. Tengborn, and U. Smith. 1992. Guar gum improves insulin sensitivity, blood lipids, blood pressure, and fibrinolysis in healthy men. Am. J. Clin. Nutr. 56:1061-1065.

Lepine, A. J., D. C. Mahan, and Y. K. Chung. 1991. Growth performance of weanling pigs fed corn-soybean meal diets with or without dried whey at various L-lysine-HCl levels. J. Anim. Sci. 69:2026-2032.

Low, A. G. and A. L. Rainbird. 1984. Effect of guar gum on nitrogen secretion into isolated loops of jejunum in conscious growing pigs. Br. J. Nutr. 52:499-505.

Mahan, D. C. 1992. Efficacy of dried whey and its lactalbumin and lactose components at two dietary lysine levels on postweaning pig performance and nitrogen balance. J. Anim. Sci. 70:2182-2187.

Malmlof, K., C. S. Nunes, and S. Askbrant. 1989. Effects of guar gum on plasma urea, insulin and glucose in the growing pig. Br. J. Nutr. 61:67-73.

McCleary, B. V. 1983. Enzymic interactions in the hydrolysis of galactomannan in germinating guar: the role of exo-beta-mannanase Cyamopsis tetragonolobus. Phytochemistry. 22:649-658.

McNaughton, J., H. Hsiao, D. Anderson and D. Fodge. 1998. Corn/soy/fat diets for broilers, beta-mannanase, and improved feed conversion. Poultry Sci. 77(Suppl. 1):153. (Abstr.).

Miller, E. R., D. E. Orr, J. P. Hitchock, D. E Ullrey and E. C. Miller. 1971. Rations for pigs weaned at 3 or 4 weeks of age. J. Anim. Sci. 33(Suppl. 1):236 (Abstr.).

Morgan, L. M., J. A. Tredger, A. Madden, P. Kwasowski, and V. Marks. 1985. The effect of guar gum on carbohydrate-, fat-, and protein-stimulated gut hormone secretion: modification of postprandial gastric inhibitory polypeptide and gastrin responses. Br. J. Nutr. 53:467-475.

Morgan, L. M., J. A. Tredger, J. Wright, and V. Marks. 1990. The effect of soluble and insoluble fibre supplementation on post-prandial glucose tolerance, insulin and gastric inhibitory polypeptide secretion in healthy subjects. Br. J. Nutr. 64:103-110.

Nagpal, M. L., O. P. Agrawal, and I. S. Bhatia. 1971. Chemical and biological examination of guar-meal (Cyamopsis tetragonoloba L.). Ind. J. Anim. Sci. 41:283-293.

NPPC. 1991. Procedures to evaluate market hogs. National Pork Producers Council, Des Moines, IA.

NRC. 1998. Nutrient Requirements of Swine (10th Ed.). National Academy Press, Washington, D.C.

Nunes, C. S. and K. Malmlof. 1992. Effects of guar gum and cellulose on glucose absorption, hormonal release and hepatic metabolism in the pig. Br. J. Nutr. 68:693-700.

Parsons, M. J., P. K. Ku, and E. R. Miller. 1985. Lysine availability in flash-dried blood meals for swine. J. Anim. Sci. 60:1447-1453.

Patel, M. B. and J. McGinnis. 1985. The effect of autoclaving and enzyme supplementation of guar meal on the performance of chicks and laying hens. Poultry Sci. 64:1148-1156.

Pell, J. D., J. M. Gee, G. M. Wortley, and I. T. Johnson. 1992. Dietary corn oil and guar gum stimulate intestinal crypt cell proliferation in rats by independent but potentially synergistic mechanisms. J. Nutr. 122:2447-2456.

Pettigrew, J. E., Jr., and R. L. Moser. 1991. Fat in swine nutrition. Pp. 133-146 in Swine Nutrition, E. R. Miller, D. E. Ullrey, and A. J. Lewis, eds. Stoneham, U. K. Butterworths-Heinemann.

Phillips, B. C. and R. C. Ewan. 1977. Utilization of energy of milo and soybean oil by young swine. J. Anim. Sci. 44:990-997.

Potkins, Z. V., T. L. J. Lawrence, and J. R. Thomlinson. 1992. Dietary fibre in the diet of the growing pig: effects on apparent digestibility and resultant implications for its use in reducing the incidence of oesophagogastric parakeratosis. Res. In Vet. Sci. 52:15-21.

Radcliffe, J. S., B. C. Robbins, J. P. Rice, R. S. Pleasant, and E. T. Kornegay. 1999. The effects of Hemicell® on digestbilities of minerals, energy, and amino acids in pigs fitted with steered ileo-cecal cannulas and fed a low and high protein corn-soybean meal diet. J. Anim. Sci. 77(Suppl. 1):197. (Abstr.).

Rainbird, A. L., A. G. Low, and T. Zebrowska. 1984. Effect of guar gum on glucose and water absorption from isolated loops of jejunum in conscious growing pigs. Br. J. Nutr. 52:489-498.

Rainbird, A. L. and A. G. Low. 1986a. Effect of guar gum on gastric emptying in growing pigs. Br. J. Nutr. 55:87-98.

Rainbird, A. L. and A. G. Low. 1986b. Effect of various types of dietary fibre on gastric emptying in growing pigs. Br. J. Nutr. 55:111-121.

Ray, S., M. H. Pubols, and J. McGinnis. 1981. The effect of a purified guar degrading enzyme on chick growth. Poultry Sci. 61:488-494.

Reid, J. S. G. 1971. Reserve carbohydrate metabolism in germinating seeds of trigonella foenum-graecum L. (leguminosae). Planta. 100:131-142.

Reid, J. S. G. and H. Meier. 1972. The function of the aleurone layer during galactomannan mobilization in germinating seeds of fenugreek (trigonella foenum-graecum), crimson clover (trifolium incarnatum L.) and lucerne (medicago sativa L.): A correlative biochemical and ultrastructural study. Planta. 106:44-60.

Reid, J. S. G. and H. Meier. 1973. Enzymic activities and galactomannan mobilization in germinating seeds of fenugreek (trigonella foenum-graecum L. leguminosae): secretion of alpha-galactosidase and beta-mannosidase by the aleurone layer. Planta. 112:310-308.

Reid, J. S. G., C. Davies, and H. Meier. 1977. Endo-beta-mannanase, the leguminous aleurone layer and the storage galactomannan in germinating seeds of trigonella foenum-graecum L. Planta. 133:219-222.

Reid, J. S. G. 1985. Cell wall storage carbohydrates in seeds-Biochemistry of the seed 'gums' and 'hemicelluloses'. Advances in Botanical Research, Vol 2. Academic Press. London.

Sambrook, I. E. and A. L. Rainbird. 1985. The effect of guar gum and level and source of dietary fat on glucose tolerance in growing pigs. Brit. J. Nutr. 54:27-35.

Schrama, J. W., M. W. A. Verstegen, P. H. J. Verboeket, J. B. Schutte, and J. Haaksma. 1996. Energy metabolism in relation to physical activity in growing pigs as affected by type of dietary carbohydrate. J. Anim. Sci. 74:2220-2225.

Sohn, K. S., C. V. Maxwell, and D. S. Buchanan. 1991. Plasma protein as an alternative protein source for early-weaned pigs. J. Anim. Sci. 69(Suppl. 1):362. (Abstr.).

Stahly, T. S. and G. L. Cromwell. 1979. Effect of environmental temperature and dietary fat supplementation on the performance and carcass characteristics of growing and finishing swine. J. Anim. Sci. 49:1478-1488.

Tinker, L. F. and B. O. Schneeman. 1989. The effects of guar gum or wheat bran on the disappearance of 14C-labeled starch from the rat gastrointestinal tract. J. Nutr. 119:403-408.

Vachon, C., J. D. Jones, A. Nadeau, and L. Savoie. 1988. A rat model to study postprandial glucose and insulin in responses to dietary fibers. Nutrition Reports International. 37:1339-1348.

Verma, S. V. S. and J. M. McNab. 1982. Guar meal in diets for broiler chickens. Br. Poultry Sci. 23:95-105.

Vorha, P., and F. H. Kratzer. 1964. Growth inhibitory effect of certain polysaccharides for chickens. Poultry Sci. 43:1164-1170.

Vorha. P., and F. H. Kratzer. 1965. Improvement of guar meal by enzymes. Poultry Sci. 44:1201-1205.

Vuorinen-Markkola, H., M. Sinisalo, and V. A. Koivisto. 1992. Guar gum in insulin-dependent diabetes: effects on glycemic control and serum lipoproteins. Am. J. Clin. Nutr. 56:1056-1060.

Wahlstrom, R. C. and G. W. Libal. 1977. Dried blood meal as a protein source in diets for growing-finishing swine. J. Anim. Sci. 44:778.

Ward, N. E. and D. W. Fodge. 1996. Ingredients to counter antinutritional factors: soybean-based feeds need enzymes too. Feed Manage. 47(10):13-18.

Whistler, R. L. and C. L. Smart. 1953. Polysaccharide Chemistry. Academic Press. New York.

Wood, F. E. and S. J. Stoll. 1991. The effect of dietary guar gum and cellulose on mineral excretion and status in young male Fischer 344 rats. Nutr. Res. 6:621-632.

CHAPTER VII

APPENDIX TABLES

Appendix Table 1

Pen means for average daily gain, average daily feed intake, and gain:feed for Phases 1 and 2 – Experiment 1.

			Phase 1			Phase 2		
Pen	Trt	Rep	ADG (kg)	ADFI (kg)	G:F	ADG (kg)	ADFI (kg)	G:F
2	4	1	.178	.259	.687	.467	.646	.723
3	3	1	.242	.314	.771	.469	.591	.794
4	1	2	.239	.312	.766	.381	.571	.667
5	2	2	.235	.306	.768	.357	.584	.611
6	1	3	.234	.292	.801	.378	.537	.704
7	4	3	.209	.280	.746	.313	.528	.593
9	1	1	.250	.331	.755	.428	.556	.770
10	2	1	.289	.357	.810	.472	.561	.841
11	4	2	.227	.304	.747	.417	.545	.765
12	3	2	.227	.322	.705	.343	.556	.617
13	2	3	.227	.302	.752	.399	.544	.734
14	3	3	.182	.241	.755	.312	.505	.618
22	4	4	.199	.306	.650	.567	.799	.710
23	3	4	.261	.312	.837	.532	.822	.647
24	2	5	.251	.284	.884	.394	.566	.696
25	1	5	.251	.329	.763	.476	.703	.677
26	1	6	.189	.227	.833	.426	.641	.665
27	4	6	.198	.274	.723	.473	.678	.698
29	1	4	.237	.323	.734	.521	.800	.651
30	2	4	.242	.318	.761	.498	.733	.679
31	4	5	.202	.273	.740	.461	.706	.653
32	3	5	.237	.302	.785	.444	.732	.607
33	2	6	.194	.235	.826	.432	.618	.699
34	3	6	.201	.238	.845	.428	.662	.647

Trt 1: Complex diet.
Trt 2: Complex diet + Hemicell® (.05%).
Trt 3: Simple diet.
Trt 4: Simple diet + Hemicell® (.05%).

Appendix Table 2

Analysis of variance for average daily gain, average daily feed intake, and gain:feed for Phases 1 and 2 – Experiment 1.

		Mean Squares					
		Phase 1			Phase 2		
Source	d.f.	ADG	ADFI	G:F	ADG	ADFI	G:F
Total	23						
Error	15	.00225	.00294	.00519	.00496	.00693	.01107
Repetition	5	.00576	.01537	.00611	.07950	.17133	.03465
Treatment	3	.00780	.00258	.02435	.00465	.01434	.01727
Complexity	1	.01540	.00725	.03300	.00079	.02581	.02600
Hemicell	1	.00191	.00041	.00749	.00256	.00574	.02394
Interaction	1	.00608	.00008	.03256	.01058	.01148	.00187
Coefficient of Variation, %		9.57	8.39	5.50	7.38	5.97	7.17

Appendix Table 3

Pen means for average daily gain, average daily feed intake, and gain:feed for Phase 3 and the entire 6-wk period – Experiment 1

			Phase 3			Overall		
Pen	Trt	Rep	ADG (kg)	ADFI (kg)	G:F	ADG (kg)	ADFI (kg)	G:F
2	4	1	.501	.890	.563	.384	.589	.652
3	3	1	.465	.924	.503	.391	.611	.640
4	1	2	.406	.847	.479	.342	.576	.594
5	2	2	.477	.825	.578	.348	.556	.626
6	1	3	.463	.825	.561	.358	.552	.649
7	4	3	.447	.825	.542	.317	.530	.598
9	1	1	.467	.913	.512	.382	.600	.637
10	2	1	.489	.944	.518	.417	.620	.673
11	4	2	.495	.869	.570	.380	.573	.663
12	3	2	.527	.949	.555	.358	.593	.604
13	2	3	.460	.833	.552	.362	.560	.646
14	3	3	.396	.775	.511	.296	.507	.584
22	4	4	.590	1.070	.551	.458	.729	.628
23	3	4	.604	1.132	.534	.469	.758	.619
24	2	5	.452	.803	.563	.367	.551	.666
25	1	5	.515	.967	.533	.417	.669	.623
26	1	6	.554	1.156	.479	.368	.615	.598
27	4	6	.542	1.017	.533	.405	.649	.624
29	1	4	.525	1.000	.525	.433	.712	.608
30	2	4	.599	1.086	.552	.449	.713	.630
31	4	5	.522	.996	.524	.399	.661	.604
32	3	5	.436	.893	.488	.371	.630	.589
33	2	6	.504	1.055	.478	.388	.610	.636
34	3	6	.495	1.091	.454	.376	.630	.597

Trt 1: Complex diet.
Trt 2: Complex diet + Hemicell® (.05%).
Trt 3: Simple diet .
Trt 4: Simple diet + Hemicell® (.05%).

Appendix Table 4

Analysis of variance for average daily gain, average daily feed intake, and gain:feed for Phase 3 and the entire 6-wk period – Experiment 1.

		Mean Squares					
		Phase 3			Overall		
Source	d.f.	ADG	ADFI	G:F	ADG	ADFI	G:F
Total	23						
Error	15	.00670	.01624	.00738	.00234	.00394	.00284
Repetition	5	.04500	.22665	.01014	.03129	.08133	.00424
Treatment	3	.00527	.00686	.02909	.00106	.00282	.01181
Complexity	1	.00238	.00634	.00001	.00016	.00329	.01005
Hemicell	1	.01038	.01335	.08724	.00252	.00246	.02516
Interaction	1	.00306	.00089	.00001	.00050	.00271	.00022
Coefficient of Variation, %		7.47	6.12	4.55	5.70	4.62	3.32

Appendix Table 5

Pen means for average daily gain, average daily feed intake, and gain:feed for the combined Phases 2 and 3 – Experiment 1.

			Phases 2 & 3		
Pen	Trt	Rep	ADG (kg)	ADFI (kg)	G:F
2	4	1	.532	.768	.693
3	3	1	.467	.757	.617
4	1	2	.394	.709	.556
5	2	2	.414	.698	.593
6	1	3	.420	.681	.617
7	4	3	.377	.670	.563
9	1	1	.448	.735	.610
10	2	1	.480	.752	.638
11	4	2	.456	.708	.644
12	3	2	.431	.745	.579
13	2	3	.430	.688	.625
14	3	3	.353	.640	.654
22	4	4	.578	.924	.626
23	3	4	.565	.965	.586
24	2	5	.421	.675	.624
25	1	5	.494	.825	.599
26	1	6	.478	.851	.562
27	4	6	.503	.829	.607
29	1	4	.523	.892	.586
30	2	4	.545	.896	.608
31	4	5	.489	.840	.582
32	3	5	.441	.802	.550
33	2	6	.477	.802	.595
34	3	6	.471	.841	.560

Trt 1: Complex diet.

Trt 2: Complex diet + Hemicell® (.05%).

Trt 3: Simple diet.

Trt 4: Simple diet + Hemicell® (.05%).

Appendix Table 6

Analysis of variance for average daily gain, average daily feed intake, and gain:feed for the combined Phases 2 and 3 – Experiment 1.

		Mean Squares		
Source	d.f.	ADG	ADFI	G:F
Total	23			
Error	15	.00380	.00613	.00454
Repetition	5	.05774	.15197	.00655
Treatment	3	.00719	.00992	.01707
Complexity	1	.00406	.01638	.00534
Hemicell	1	.00960	.00753	.04524
Interaction	1	.00792	.00586	.00064
Coefficient of Variation, %		6.00	4.56	4.01

Appendix Table 7

Pen means for initial weight, average daily gain, average daily feed intake, and gain:feed for Week 1 and 2 – Experiment 2.

				Week 1			Week 2		
Pen	Trt	Rep	Initial Wt.	ADG (kg)	ADFI (kg)	G:F	ADG (kg)	ADFI (kg)	G:F
2	3	1	16.5	.444	.862	.510	.727	1.147	.634
3	2	1	16.2	.459	.881	.521	.632	1.097	.576
4	1	1	16.6	.410	.792	.518	.705	1.148	.614
5	1	2	14.3	.444	.743	.598	.619	1.040	.595
6	3	2	14.4	.301	.677	.445	.658	1.009	.652
7	2	2	14.9	.471	.820	.574	.703	1.092	.644
9	3	3	12.4	.457	.718	.637	.586	.951	.616
10	1	3	12.2	.368	.658	.559	.641	.993	.646
11	2	3	12.7	.433	.748	.579	.609	.975	.625
12	3	4	11.9	.371	.635	.584	.669	.954	.701
13	2	4	11.9	.376	.684	.550	.658	1.007	.653
14	1	4	12.0	.329	.680	.484	.599	.944	.635
15	1	5	10.7	.381	.666	.572	.603	.881	.685
16	3	5	10.8	.340	.630	.840	.596	.898	.664
17	2	5	10.2	.334	.627	.533	.622	.870	.715
18	3	6	12.0	.416	.760	.547	.653	.939	.695
19	1	6	16.9	.488	.849	.575	.624	1.051	.594
20	2	6	17.0	.384	.769	.499	.737	1.071	.688
21	3	7	17.0	.596	1.007	.592	.562	.969	.580
22	2	7	16.9	.476	.938	.508	.886	1.113	.796
23	1	7	17.0	.473	.896	.528	.718	1.160	.619
24	1	8	13.3	.431	.768	.561	.530	.837	.633
25	3	8	13.2	.440	.727	.605	.591	.873	.677
26	2	8	13.2	.387	.684	.566	.619	.813	.761
27	3	9	11.9	.479	.729	.657	.562	.879	.639
28	2	9	12.2	.357	.680	.525	.557	.830	.671
29	1	9	12.4	.377	.724	.521	.523	.797	.656
30	1	10	10.9	.397	.739	.537	.581	.866	.671
31	3	10	10.8	.428	.721	.594	.508	.752	.676
32	2	10	11.3	.386	.674	.573	.479	.745	.643

Trt 1: Simple fortified corn-SBM diet (control).
Trt 2: Control + soybean oil (2%).
Trt 3: Control + Hemicell® (.05%).

Appendix Table 8

Analysis of variance for initial weight, average daily gain, average daily feed intake, and gain:feed for Week 1 & 2 – Experiment 2.

		Mean Squares						
		Initial	Week 1			Week 2		
Source	d.f.	Wt.	ADG	ADFI	G:F	ADG	ADFI	G:F
Total	29							
Error	18	.25848	.01319	.01066	.02599	.01996	.01267	.01143
Repetition	9	85.528	.02965	.11979	.01636	.05829	.19498	.01086
Treatment	2	.17009	.00618	.00032	.01875	.02291	.01542	.02066
Con vs SBO	1	.01458	.00030	.00002	.00025	.03152	.00272	.04131
Con vs HC	1	.18818	.00749	.00056	.02534	.00022	.02934	.00990
SBO vs HC	1	.30752	.01077	.00036	.03066	.03698	.01421	.01077
Coefficient of Variation, %		1.69	12.57	6.25	8.86	10.25	5.33	6.97

Appendix Table 9

Pen means for final weight, average daily gain, average daily feed intake, and gain:feed for Week 3 and the entire 3-wk period – Experiment 2.

				Week 3			Overall		
Pen	Trt	Rep	Final Wt.	ADG (kg)	ADFI (kg)	G:F	ADG (kg)	ADFI (kg)	G:F
2	3	1	29.0	.716	1.342	.534	.625	1.106	.565
3	2	1	28.0	.705	1.251	.564	.593	1.068	.555
4	1	1	28.1	.618	1.202	.514	.576	1.040	.554
5	1	2	24.2	.421	1.098	.383	.498	.954	.522
6	3	2	24.3	.525	1.113	.472	.493	.924	.534
7	2	2	26.8	.620	1.177	.527	.597	1.022	.584
9	3	3	23.1	.562	1.058	.531	.533	.902	.591
10	1	3	22.5	.541	1.041	.520	.515	.890	.579
11	2	3	23.1	.512	.988	.518	.518	.900	.576
12	3	4	21.5	.393	.973	.404	.482	.848	.568
13	2	4	21.8	.450	1.034	.435	.497	.902	.551
14	1	4	21.8	.548	1.047	.523	.489	.883	.554
15	1	5	21.1	.582	1.041	.559	.519	.854	.608
16	3	5	21.4	.675	1.108	.609	.530	.867	.611
17	2	5	20.4	.588	1.030	.571	.511	.833	.614
18	3	6	29.0	.718	1.242	.578	.596	.981	.608
19	1	6	29.6	.708	1.412	.501	.606	1.104	.549
20	2	6	29.4	.649	1.163	.558	.590	1.001	.589
21	3	7	30.2	.724	1.241	.583	.627	1.072	.585
22	2	7	30.9	.627	1.333	.470	.663	1.128	.588
23	1	7	29.4	.585	1.249	.468	.592	1.102	.537
24	1	8	24.5	.630	1.173	.537	.530	.926	.572
25	3	8	25.6	.735	1.170	.628	.589	.923	.638
26	2	8	24.6	.617	1.143	.540	.541	.880	.615
27	3	9	24.1	.692	1.162	.596	.578	.923	.626
28	2	9	22.9	.617	1.053	.586	.510	.854	.597
29	1	9	23.4	.677	1.124	.602	.526	.882	.596
30	1	10	23.1	.756	1.151	.657	.578	.918	.630
31	3	10	21.9	.654	1.035	.632	.530	.836	.634
32	2	10	21.9	.659	1.056	.624	.508	.825	.616

Trt 1: Simple fortified corn-SBM diet (control).
Trt 2: Control + soybean oil (2%).
Trt 3: Control + Hemicell® (.05%).

Appendix Table 10

Analysis of variance for final weight, average daily gain, average daily feed intake, and gain:feed for Week 3 and the entire 3-wk period – Experiment 2.

		Mean Squares						
		Final	Week 3			Overall		
Source	d.f.	Wt.	ADG	ADFI	G:F	ADG	ADFI	G:F
Total	29							
Error	18	2.4055	.01829	.01885	.03367	.00460	.00732	.00273
Repetition	9	158.70	.09441	.14528	.13870	.02682	.12179	.01901
Treatment	2	.81724	.01866	.01229	.02839	.00293	.00405	.01592
Con vs SBO	1	1.1907	.00011	.02346	.01904	.00236	.00481	.01665
Con vs HC	1	1.2600	.02614	.00227	.05629	.00571	.00711	.02934
SBO vs HC	1	.00098	.02972	.01114	.00986	.00073	.00025	.00179
Coefficient of Variation, %		2.82	9.95	5.46	9.76	5.58	4.11	3.05

Appendix Table 11

Pen means for average daily gain, average daily feed intake, and gain:feed for the combined Weeks 1 and 2, and Weeks 2 and 3 – Experiment 2.

			Week 1 & 2			Week 2 & 3		
Pen	Trt	Rep	ADG (kg)	ADFI (kg)	G:F	ADG (kg)	ADFI (kg)	G:F
2	3	1	.586	1.004	.584	.722	1.237	.584
3	2	1	.545	.989	.551	.665	1.168	.569
4	1	1	.557	.970	.574	.664	1.173	.566
5	1	2	.531	.892	.595	.527	1.067	.494
6	3	2	.479	.843	.568	.596	1.057	.564
7	2	2	.587	.956	.614	.664	1.131	.587
9	3	3	.522	.834	.626	.575	1.001	.574
10	1	3	.505	.825	.612	.595	1.015	.586
11	2	3	.521	.862	.604	.564	.981	.575
12	3	4	.520	.795	.654	.542	.963	.563
13	2	4	.517	.845	.612	.562	1.020	.551
14	1	4	.464	.812	.571	.576	.992	.581
15	1	5	.492	.773	.637	.593	.955	.621
16	3	5	.468	.764	.613	.632	.994	.636
17	2	5	.478	.748	.639	.606	.944	.642
18	3	6	.535	.849	.630	.628	1.091	.576
19	1	6	.556	.950	.585	.666	1.232	.541
20	2	6	.561	.920	.610	.693	1.117	.620
21	3	7	.579	.988	.586	.643	1.105	.582
22	2	7	.681	1.025	.664	.757	1.223	.619
23	1	7	.596	1.028	.580	.651	1.204	.541
24	1	8	.480	.803	.598	.580	1.005	.577
25	3	8	.516	.800	.645	.664	1.021	.650
26	2	8	.503	.748	.673	.618	.978	.632
27	3	9	.521	.804	.648	.627	1.020	.615
28	2	9	.457	.755	.605	.587	.941	.624
29	1	9	.450	.761	.591	.600	.961	.624
30	1	10	.489	.802	.610	.669	1.009	.663
31	3	10	.468	.737	.635	.581	.893	.651
32	2	10	.433	.709	.611	.569	.901	.632

Trt 1: Simple fortified corn-SBM diet (control).

Trt 2: Control + soybean oil (2%).

Trt 3: Control + Hemicell® (.05%).

Appendix Table 12

Analysis of variance for average daily gain, average daily feed intake, and gain:feed for the combined Weeks 1 and 2, and Weeks 2 and 3 – Experiment 2.

		Mean Squares					
		Week 1 & 2			Week 2 & 3		
Source	d.f.	ADG	ADFI	G:F	ADG	ADFI	G:F
Total	29						
Error	18	.00526	.00580	.00483	.00821	.01041	.00639
Repetition	9	.03283	.13036	.00804	.02977	.13270	.02586
Treatment	2	.00322	.00504	.01222	.00395	.00788	.02087
Con vs SBO	1	.00641	.00083	.01746	.00663	.01063	.03232
Con vs HC	1	.00128	.00955	.01916	.00512	.01290	.03026
SBO vs HC	1	.00196	.00474	.00004	.00010	.00011	.00003
Coefficient of Variation, %		6.33	4.05	4.24	6.60	4.42	4.75

Appendix Table 13

Pen means for average daily gain, average daily feed intake, and gain:feed for Phases 1 and 2 – Experiment 3.

			Phase 1			Phase 2		
Pen	Trt	Rep	ADG (kg)	ADFI (kg)	G:F	ADG (kg)	ADFI (kg)	G:F
12	3	1	.984	2.160	.456	.980	2.849	.344
23	1	1	.933	2.107	.443	.932	2.806	.332
24	2	1	.921	1.973	.467	.972	2.606	.373
11	2	2	.782	1.634	.479	.981	2.470	.397
22	3	2	.832	2.113	.394	.892	2.833	.315
10	1	2	.840	1.944	.432	.892	2.607	.342
21	1	3	.830	1.805	.460	.887	2.496	.355
20	2	3	.804	1.713	.469	.818	2.321	.352
9	3	3	.859	1.923	.447	.907	2.658	.341
7	1	4	.885	1.902	.465	.821	2.404	.342
19	3	4	.846	1.795	.471	.924	2.527	.366
8	2	4	.821	1.721	.477	.828	2.301	.360
18	2	5	.838	1.711	.490	.881	2.337	.377
17	1	5	.815	1.708	.477	.791	2.446	.323
6	3	5	.814	1.744	.467	.904	2.493	.363

Trt 1: Simple fortified corn-SBM diet (control).

Trt 2: Control + soybean oil (2%).

Trt 3: Control + Hemicell® (.05%).

Appendix Table 14

Analysis of variance for average daily gain, average daily feed intake, and gain:feed for Phases 1 and 2 – Experiment 3.

		Mean Squares					
		Phase 1			Phase 2		
Source	d.f.	ADG	ADFI	G:F	ADG	ADFI	G:F
Total	14						
Error	8	.00300	.04443	.00807	.01019	.01218	.02794
Repetition	4	.16472	.27016	.02199	.03058	.31787	.00189
Treatment	2	.00782	.25095	.02833	.01987	.42699	.09543
Con vs SBO	1	.00912	.24743	.02440	.01225	.25472	.17109
Con vs HC	1	.00049	.03540	.00600	.03956	.17477	.00724
SBO vs HC	1	.01384	.47002	.05461	.00778	.85147	.10795
Coefficient of Variation, %		2.91	5.13	4.12	5.12	1.97	5.87

Appendix Table 15

Pen means for final weight, average daily gain, average daily feed intake, and gain:feed for Phase 3 and for the entire 115-d period – Experiment 3.

				Phase 3			Overall		
Pen	Trt	Rep	Final Wt.	ADG (kg)	ADFI (kg)	G:F	ADG (kg)	ADFI (kg)	G:F
12	3	1	114.6	.942	3.154	.299	.967	2.732	.354
23	1	1	111.7	.935	3.284	.285	.933	2.749	.339
24	2	1	109.1	.835	3.044	.274	.905	2.556	.354
11	2	2	105.0	.805	2.708	.297	.848	2.221	.382
22	3	2	107.8	.859	2.934	.293	.858	2.586	.332
10	1	2	107.9	.874	2.985	.293	.866	2.470	.351
21	1	3	108.8	.652	2.955	.221	.788	2.394	.329
20	2	3	102.6	.651	2.547	.256	.767	2.139	.359
9	3	3	114.4	.740	2.726	.272	.834	2.411	.346
7	1	4	107.7	.818	2.756	.297	.845	2.303	.367
19	3	4	109.7	.895	2.688	.333	.885	2.282	.388
8	2	4	104.1	.826	2.986	.277	.825	2.261	.365
18	2	5	110.2	.686	3.254	.211	.801	2.411	.332
17	1	5	107.9	.728	3.685	.198	.779	2.586	.301
6	3	5	112.9	.740	3.035	.244	.817	2.399	.341

Trt 1: Simple fortified corn-SBM diet (control)

Trt 2: Control + soybean oil (2%)

Trt 3: Control + Hemicell (.05%)

Appendix Table 16

Analysis of variance for final weight, average daily gain, average daily feed intake, and gain:feed for Phase 3 and for the 115-d period – Experiment 3.

		Mean Squares						
		Final	Phase 3			Overall		
Source	d.f.	Wt.	ADG	ADFI	G:F	ADG	ADFI	G:F
Total	14							
Error	8	22.998	.00377	.15471	.06380	.00133	.03672	.01672
Repetition	4	63.897	.13080	.90274	.92030	.04661	.35925	.06503
Treatment	2	197.59	.03405	.41201	.29454	.01192	.24535	.04278
Con vs SBO	1	83.810	.02034	.61703	.03745	.00207	.40441	.08082
Con vs HC	1	114.58	.01391	.61901	.54756	.01102	.00404	.04070
SBO vs HC	1	394.38	.06790	.00000	.29860	.02266	.32761	.00681
Coefficient of Variation, %		2.00	3.48	5.98	6.68	1.95	3.57	4.50

Appendix Table 17

Pen means for hot carcass weight, carcass composition, and calculated lean gain, total carcass lean, and percentage lean (fat-free basis) – Experiment 3.

				Composition		Fat-free lean		
Pen	Trt	Rep	HCW (kg)	LMA (cm^2)	BF (cm)	Lean Gain (kg/d)	Lean (kg)	Lean (%)
12	3	1	87.6	43.9	2.29	.372	43.6	49.7
23	1	1	86.9	41.3	2.39	.357	42.3	48.6
24	2	1	84.4	46.5	2.03	.373	43.7	51.8
11	2	2	81.6	41.3	2.26	.334	40.5	49.8
22	3	2	83.6	42.6	2.26	.338	41.6	49.9
10	1	2	82.2	41.9	2.57	.324	40.0	48.5
21	1	3	83.6	38.1	2.26	.296	40.5	48.4
20	2	3	79.4	37.4	2.36	.283	38.8	48.3
9	3	3	88.1	43.9	2.26	.325	43.9	50.0
7	1	4	80.7	43.2	2.01	.331	41.4	51.3
19	3	4	82.4	40.0	1.98	.340	41.5	50.3
8	2	4	77.8	37.4	1.78	.318	39.4	50.9
18	2	5	83.6	40.3	1.80	.314	42.5	51.0
17	1	5	81.1	39.6	1.91	.300	40.9	50.5
6	3	5	85.7	45.8	1.91	.328	44.5	52.1

Trt 1: Simple fortified corn-SBM diet (control).
Trt 2: Control + soybean oil (2%).
Trt 3: Control + Hemicell® (.05%).

Appendix Table 18

Analysis of variance for hot carcass weight, 10th rib fat, loin muscle area, lean gain, total carcass lean, and percentage carcass lean – Experiment 3.

		Mean Squares					
			Composition		Fat-free lean		
Source	d.f.	HCW	Backfat	LMA	Lean Gain	Lean, kg	Lean, %
Total	14						
Error	8	14.506	.00184	.17464	4.82e-04	7.10891	.9185
Repetition	4	68.069	.02349	.19009	9.07e-03	19.5469	2.759
Treatment	2	106.95	.00613	.25773	2.56e-03	33.2292	1.4127
Con vs SBO	1	28.9	.01225	.00324	8.41e-05	.00441	2.025
Con vs HC	1	82.656	.00289	.34969	4.37e-03	49.3728	2.209
SBO vs HC	1	209.31	.00324	.42025	3.24e-03	50.3105	.004
Coefficient of Variation, %		2.08	5.10	6.49	3.03	2.90	1.91

Appendix Table 19

Pen means for initial and final weight, average daily gain, average daily feed intake, and gain:feed for the 14-d feeding period – Experiment 4.

Pen	Trt	Rep	Initial (kg)	Final (kg)	ADG (kg)	ADFI (kg)	G:F
1	3	1	95.2	104.3	.698	3.14	.222
2	2	1	90.3	90.3	0	1.89	0
3	1	1	93.4	103.0	.732	2.70	.271
4	2	2	85.3	100.2	1.151	3.00	.384
5	3	2	83.0	92.5	.732	2.78	.263
6	1	2	85.3	90.7	.419	2.43	.172
7	3	3	102.0	115.7	.972	3.60	.270
8	2	3	96.2	112.9	1.199	3.29	.365
9	1	3	103.0	115.2	.875	3.48	.251
10	1	4	93.9	103.4	.680	3.52	.193
11	3	4	95.7	109.8	1.004	3.80	.365
12	2	4	93.0	104.3	.810	3.18	.255

Trt 1: Corn-SBM diet (control).

Trt 2: Control + soybean oil (2%).

Trt 3: Control + Hemicell® (.05%).

Appendix Table 20

Analysis of variance for initial weight, final weight, average daily gain, average daily feed intake, and gain:feed – Experiment 4.

		Mean Squares				
Source	d.f.	Initial Wt.	Final Wt.	ADG	ADFI	G:F
Total	11					
Error	6	21.6389	139.111	.532226	.583799	.012033
Repetition	3	622.306	1110.528	.728792	3.32317	.009855
Treatment	2	50.0833	67.0	.153154	1.19792	.001312
Con vs SBO	1	72.0	12.5	.125000	.378015	.001711
Con vs HC	1	0.125	60.5	.297606	.851513	.002211
SBO vs HC	1	78.125	128.0	.036856	2.36423	.000032
Coefficient of Variation, %		2.27	5.17	42.82	11.30	45.22

Appendix Table 21

Pen means for apparent digestibilities of energy, nitrogen, phosphorus, and dry matter – Experiment 4.

			Apparent Digestibility			
Pen	Trt	Rep	Energy	Nitrogen	Phosphorus	Dry Matter
1	3	1	87.0	81.3	57.0	92.6
2	2	1	86.6	83.4	44.2	91.5
3	1	1	86.2	82.1	41.2	92.0
4	2	2	87.6	83.6	59.2	92.8
5	3	2	87.2	82.1	47.4	92.0
6	1	2	88.3	85.8	54.2	92.0
7	3	3	85.9	79.0	50.4	91.0
8	2	3	86.5	77.4	51.2	92.7
9	1	3	84.7	76.7	39.3	92.1
10	1	4	84.2	78.7	48.1	90.8
11	3	4	86.1	80.6	46.8	92.7
12	2	4	86.9	83.1	39.3	92.1

Trt 1: Corn-SBM diet (control).

Trt 2: Control + soybean oil (2%).

Trt 3: Control + Hemicell® (.05%).

Appendix Table 22

Analysis of variance for apparent digestibilities of energy, nitrogen, phosphorus, and dry matter – Experiment 4.

		Mean Squares			
Source	d.f.	Energy	Nitrogen	Phosphorus	Dry matter
Total	11				
Error	6	.69788	3.07123	49.8121	.631111
Repetition	3	2.68797	20.40219	43.3851	.091944
Treatment	2	1.09248	1.564355	22.3029	.310000
Con vs SBO	1	2.12176	2.13799	15.2128	.605000
Con vs HC	1	.894970	.017136	44.1608	.245000
SBO vs HC	1	.260708	2.53794	7.53504	.080000
Coefficient of Variation, %		.97	2.16	14.65	.863

Appendix Table 23

Pen means for gross energy intake, average daily feed intake, fecal energy excretion, and digestible energy (kcal/d, kcal/kg) – Experiment 5 (Period 1).

			Energy Balance				
Pen	Trt	Rep	GE (kcal/d)	ADFI (g)	FE (kcal/d)	DE (kcal/d)	DE (kcal/kg)
1	1	1	6234.0	1400.8	678.5	5561.5	3970.1
2	3	1	6944.1	1493.0	762.8	6181.4	4140.2
3	4	1	6090.5	1370.7	629.0	5461.6	3984.6
4	2	1	6568.2	1445.0	708.2	5860.0	4055.5
5	4	2	5482.1	1233.8	599.5	4882.6	3957.6
6	3	2	6294.5	1353.3	693.5	5601.0	4138.7
7	1	2	5649.9	1268.4	668.8	4981.1	3927.2
8	2	2	5997.6	1319.4	611.4	5386.2	4082.2
13	2	3	5506.6	1211.4	530.9	4975.7	4107.3
14	1	3	5405.0	1213.4	614.2	4790.8	3948.3
15	3	3	5926.7	1274.3	671.4	5255.3	4124.2
16	4	3	5357.6	1205.7	650.4	4707.3	3904.0
17	4	4	5070.0	1141.0	818.3	4251.7	3726.3
18	1	4	5060.5	1136.0	714.5	4346.0	3825.5
19	3	4	5523.2	1187.5	628.5	4894.7	4121.8
20	2	4	5500.9	1210.2	676.7	4824.2	3986.4
21	1	5	5560.9	1248.4	645.1	4915.8	3937.7
22	4	5	5643.8	1270.2	723.9	4919.9	3873.9
23	3	5	6458.0	1388.5	681.4	5776.6	4160.4
24	2	5	6132.7	1349.2	696.9	5435.8	4029.0

Trt 1: Corn-SBM diet (control).
Trt 2: Control + 100 kcal/kg ME from cornstarch.
Trt 3: Control + 200 kcal/kg ME from cornstarch.
Trt 4: Control + Hemicell® (.05%).

Appendix Table 24

Analysis of variance for gross energy intake, average daily feed intake, fecal energy excretion, and digestible energy (kcal/d, kcal/kg) – Experiment 5 (Period 1).

		Mean Squares				
Source	d.f.	GE	ADFI	FE	DE (kcal/d)	DE (kcal/kg)
Total	19					
Error	12	12388.14	547.76	3655.47	6805.48	2003.56
Repetition	4	7.84e05	38171.6	5999.11	7.69e05	9771.77
Treatment	3	5.38e05	10149.4	1959.30	5.36e05	6.65e04
Linear	1	1.04e07	18456.5	1355.13	9.7e05	1.16e05
Quad	1	4064.22	379.425	3214.71	14507.68	1713.07
Control vs HC	1	7404.93	208.392	996.603	13835.42	2654.83
Coefficient of Variation, %		1.91	1.82	9.02	1.60	1.12

Appendix Table 25

Pen means for gross energy intake, average daily feed intake, fecal energy excretion, and digestible energy (kcal/d, kcal/kg) – Experiment 5 (Period 2).

			Energy Balance				
Pen	Trt	Rep	GE (kcal/d)	ADFI (g)	FE (kcal/d)	DE (kcal/d)	DE (kcal/kg)
1	1	1	6860.1	1540.0	757.9	6102.2	3962.4
2	3	1	8395.9	1805.1	904.8	7491.1	4149.9
3	4	1	7421.5	1670.2	568.2	6853.2	4103.2
4	2	1	7530.3	1656.6	807.4	6722.9	4058.2
5	4	2	7262.6	1634.5	889.6	6372.9	3899.1
6	3	2	7587.6	1631.3	740.8	6846.8	4197.0
7	1	2	6679.5	1499.5	784.4	5895.2	3931.4
8	2	2	7409.9	1630.1	547.9	6862.0	4209.5
13	2	3	7988.1	1757.3	941.3	7046.8	4010.0
14	1	3	7672.8	1722.5	782.4	6890.4	4000.3
15	3	3	8184.1	1759.6	759.5	7424.7	4219.5
16	4	3	8014.2	1803.6	813.7	7200.5	3992.3
17	4	4	6567.2	1478.0	862.1	5705.2	3860.2
18	1	4	6650.7	1493.0	931.2	5719.5	3830.8
19	3	4	7814.3	1680.1	950.7	6863.6	4085.3
20	2	4	7318.0	1609.9	753.0	6564.9	4077.8
21	1	5	6436.9	1445.0	832.4	5604.5	3878.5
22	4	5	6063.3	1364.6	828.8	5234.5	3836.1
23	3	5	7121.2	1531.1	844.4	6276.7	4099.6
24	2	5	7398.3	1627.6	1034.2	6364.1	3910.1

Trt 1: Corn-SBM diet (control).

Trt 2: Control + 100 kcal/kg ME from cornstarch.

Trt 3: Control + 200 kcal/kg ME from cornstarch.

Trt 4: Control + Hemicell® (.05%).

Appendix Table 26

Analysis of variance for gross energy intake, average daily feed intake, fecal energy excretion, and digestible energy (kcal/d, kcal/kg) – Experiment 5 (Period 2).

		Mean Squares				
Source	d.f.	GE	ADFI	FE	DE (kcal/d)	DE (kcal/kg)
Total	19					
Error	12	93901.5	4703.63	15759.9	84198.6	5235.53
Repetition	4	8.50e05	41885.1	17069.5	9.75e05	16147.0
Treatment	3	9.51e05	20576.1	1886.51	8.95e05	57577.0
Linear	1	2.31e06	50004.7	1251.49	2.20e06	131781.3
Quad	1	1.19e05	6925.12	485.697	1.34e05	1040.517
Control vs HC	1	1.06e05	6284.05	1584.83	1.33e05	767.732
Coefficient of Variation, %		4.19	4.24	15.37	4.46	1.80

Appendix Table 27

Analysis of variance for gross energy intake, average daily feed intake, fecal energy excretion, and digestible energy (kcal/d, kcal/kg) – Experiment 5 (Pooled).

		Mean Squares				
Source	d.f.	GE	ADFI	FE	DE (kcal/d)	DE (kcal/kg)
Total	39					
Error	16	2.38e05	11686.5	8731.8	2.13e05	3244.63
Repetition	4	8.39e05	41068.5	15182.7	1.01e06	21348.9
Treatment	3	1.43e06	28517.8	2018.48	1.37e06	1.23e05
Linear	1	3.23e06	64610.0	2605.59	3.05e06	2.47e05
Quad	1	8.33e04	5273.25	3099.75	1.19e05	2711.88
Control vs HC	1	2.86e04	2101.87	33.9562	3.06e04	283.626
Rep x Trt	12	5.40e04	2665.48	10401.7	5.40e04	4436.23
Period	1	2.25e07	1.10e06	2.15e05	1.83e07	2410.84
Trt x Period	3	5.60e04	2207.72	1827.33	5.81e04	1343.79
Coefficient of Variation, %		7.43	7.45	12.57	7.91	1.42

Appendix Table 28

Pen means for feces excretion, urine excretion, urinary energy, and metabolizable energy (kcal/d, kcal/kg) – Experiment 5 (Period 1).

			Energy Balance				
Pen	Trt	Rep	Feces (g)	Urine (g)	UE (kcal/d)	ME (kcal/d)	ME (kcal/kg)
1	1	1	148.9	48.8	125.5	5436.0	3880.6
2	3	1	162.5	41.9	110.9	6070.5	4066.0
3	4	1	137.6	42.8	111.1	5350.5	3903.5
4	2	1	153.8	37.4	97.1	5762.9	3988.3
5	4	2	129.2	40.1	102.8	4779.9	3874.3
6	3	2	149.3	42.6	106.1	5494.9	4060.3
7	1	2	141.9	32.9	82.5	4898.5	3862.1
8	2	2	132.4	36.8	92.7	5293.5	4011.9
13	2	3	116.7	39.1	98.6	4877.1	4026.0
14	1	3	130.7	39.0	111.6	4679.2	3856.3
15	3	3	146.1	40.6	104.8	5150.5	4041.9
16	4	3	143.3	36.2	90.8	4616.4	3828.7
17	4	4	173.3	32.1	78.7	4173.0	3657.3
18	1	4	153.6	28.4	68.8	4277.2	3765.0
19	3	4	136.2	35.5	91.4	4803.3	4044.9
20	2	4	144.2	35.3	95.5	4728.8	3907.6
21	1	5	139.5	34.3	91.4	4824.4	3864.5
22	4	5	154.6	34.5	91.0	4828.9	3801.9
23	3	5	146.3	20.6	57.7	5719.0	4118.8
24	2	5	150.9	22.1	60.2	5375.6	3984.4

Trt 1: Corn-SBM diet (control).
Trt 2: Control + 100 kcal/kg ME from cornstarch.
Trt 3: Control + 200 kcal/kg ME from cornstarch.
Trt 4: Control + Hemicell® (.05%).

Appendix Table 29

Analysis of variance for feces and urine excretion, urinary energy, and metabolizable energy (kcal/d, kcal/kg) – Experiment 5 (Period 1).

		Mean Squares				
Source	d.f.	Feces	Urine	UE (kcal/d)	ME (kcal/d)	ME (kcal/kg)
Total	19					
Error	12	147.240	25.7088	192.627	7557.46	1773.64
Repetition	4	249.223	132.703	819.375	7.44e05	9001.21
Treatment	3	82.2536	8.71512	50.5286	5.41e05	70344.8
Linear	1	66.719	.468538	7.921	9.75e05	1.22e05
Quad	1	116.861	18.0383	130.042	1.74e04	2534.60
Control vs HC	1	55.5545	.47380	2.8409	1.34e04	2653.64
Coefficient of Variation, %		8.40	14.07	14.85	1.72	1.07

Appendix Table 30

Pen means for fecal excretion and urine excretion, urinary energy, and metabolizable energy (kcal/d, kcal/kg) – Experiment 5 (Period 2).

			Feces	Urine	Energy Balance		
Pen	Trt	Rep	(g)	(g)	UE (kcal/d)	ME (kcal/d)	ME (kcal/kg)
1	1	1	165.4	68.3	134.8	5967.4	3874.9
2	3	1	197.8	64.0	135.0	7356.1	4075.1
3	4	1	125.0	68.3	144.9	6708.3	4016.5
4	2	1	173.0	57.8	141.4	6581.5	3972.9
5	4	2	189.9	62.3	160.1	6212.8	3801.2
6	3	2	158.4	67.4	135.0	6711.8	4114.3
7	1	2	168.8	73.1	148.8	5746.4	3832.2
8	2	2	118.7	60.4	122.4	6739.6	4134.4
13	2	3	204.9	72.6	148.5	6898.3	3925.4
14	1	3	171.9	72.3	146.0	6744.5	3915.5
15	3	3	167.4	71.3	145.8	7278.9	4136.6
16	4	3	180.5	77.2	151.3	7049.3	3908.4
17	4	4	186.6	48.5	100.9	5604.3	3791.9
18	1	4	200.1	47.6	125.6	5593.9	3746.6
19	3	4	202.1	53.0	114.6	6749.0	4017.1
20	2	4	162.8	52.4	112.9	6452.1	4007.7
21	1	5	180.5	55.7	112.1	5492.4	3800.9
22	4	5	177.3	38.7	83.2	5151.4	3775.1
23	3	5	181.5	50.0	104.9	6171.8	4031.1
24	2	5	222.6	53.0	114.6	6249.5	3839.7

Trt 1: Corn-SBM diet (control).
Trt 2: Control + 100 kcal/kg ME from cornstarch.
Trt 3: Control + 200 kcal/kg ME from cornstarch.
Trt 4: Control + Hemicell® (.05%).

Appendix Table 31

Analysis of variance for total feces and urine excreted, urinary energy excretion, and metabolizable energy (kcal/d, kcal/kg) – Experiment 5 (Period 2).

		Mean Squares				
Source	d.f.	Feces	Urine	UE (kcal/d)	ME (kcal/d)	ME (kcal/kg)
Total	19					
Error	12	699.871	26.6353	141.309	8.15e04	5621.03
Repetition	4	779.824	436.497	1495.35	9.06e05	12396.1
Treatment	3	77.6141	20.7388	42.4152	9.05e05	62102.1
Linear	1	42.3125	12.4610	102.080	2.23e06	1.45e05
Quad	1	29.9400	30.7380	17.618	1.37e05	1556.06
Control vs HC	1	75.2405	47.9712	72.361	1.40e05	1513.39
Coefficient of Variation, %		14.97	8.50	9.21	4.48	1.91

Appendix Table 32

Analysis of variance for feces and urine excreted, urinary energy, and metabolizable energy (kcal/d, kcal/kg) – Experiment 5 (Pooled).

		Mean Squares				
Source	d.f.	Feces	Urine	UE (kcal/d)	ME (kcal/d)	ME (kcal/kg)
Total	39					
Error	16	388.871	43.5995	212.84	2.08e05	3662.53
Repetition	4	637.531	48.0562	2136.04	9.26e05	1.62e04
Treatment	3	83.785	19.364	68.525	1.39e06	1.31e05
Linear	1	107.648	8.8811	83.436	3.08e06	2.66e05
Quad	1	132.551	47.9352	121.695	1.26e05	4031.28
Control vs HC	1	.74498	19.455	51.939	3.32e04	79.5207
Rep x Trt	12	459.122	23.7578	109.71	5.31e04	4251.86
Period	1	10375.2	6077.68	12725.9	1.73e07	752.036
Trt x Period	3	76.0823	10.09	24.418	5.92e04	1695.87
Coefficient of Variation, %		12.27	13.65	13.11	7.98	1.54

Appendix Table 33

Pen means for digestible and metabolizable energy (kcal/kg – as-is), and energy ratios – Experiment 5 (Period 1).

			Energy Balance				
Pen	Trt	Rep	DE (kcal/kg)	ME (kcal/kg)	DE:GE	ME:DE	ME:GE
1	1	1	3505.7	3426.6	.891	.977	.871
2	3	1	3736.2	3669.2	.890	.982	.874
3	4	1	3518.3	3446.7	.897	.980	.879
4	2	1	3671.5	3610.6	.892	.983	.877
5	4	2	3494.4	3420.9	.891	.979	.872
6	3	2	3734.8	3664.0	.890	.981	.873
7	1	2	3467.7	3410.3	.882	.983	.867
8	2	2	3695.6	3632.0	.898	.983	.883
13	2	3	3718.4	3644.8	.904	.980	.886
14	1	3	3486.4	3405.2	.886	.977	.866
15	3	3	3721.7	3647.5	.887	.980	.869
16	4	3	3447.2	3380.7	.879	.981	.862
17	4	4	3290.2	3229.3	.839	.982	.823
18	1	4	3378.0	3324.5	.859	.984	.845
19	3	4	3719.6	3650.1	.886	.981	.870
20	2	4	3609.0	3537.5	.877	.980	.860
21	1	5	3477.0	3412.4	.884	.981	.868
22	4	5	3420.2	3357.0	.872	.982	.856
23	3	5	3754.4	3716.9	.895	.990	.886
24	2	5	3647.5	3607.1	.886	.989	.877

Trt 1: Corn-SBM diet (control).
Trt 2: Control + 100 kcal/kg ME from cornstarch.
Trt 3: Control + 200 kcal/kg ME from cornstarch.
Trt 4: Control + Hemicell® (.05%).

Appendix Table 34

Analysis of variance for digestible and metabolizable energy (kcal/kg – as-is), and energy ratios – Experiment 5 (Period 1).

		Mean Squares				
Source	d.f.	DE (kcal/kg)	ME (kcal/kg)	DE:GE	ME:DE	ME:GE
Total	19					
Error	12	1565.51	1390.42	1.01e-04	7.15e-06	8.92e-05
Repetition	4	7704.66	7112.29	4.89e-04	2.03e-05	4.49e-04
Treatment	3	110340.9	113778.9	2.91e-04	1.01e-05	3.80e-04
Linear	1	182751.2	187354.2	2.05e-04	1.32e-05	3.00e-04
Quad	1	16446.1	18121.0	1.41e-04	5.90e-06	1.90e-04
Control vs HC	1	2087.1	2086.1	6.66e-05	5.0e-08	6.71e-05
Coefficient of Variation, %		1.11	1.06	1.14	.27	1.09

Appendix Table 35

Pen means for digestible and metabolizable energy (kcal/kg – as-is), and energy ratios – Experiment 5 (Period 2).

			Energy Balance				
Pen	Trt	Rep	DE (kcal/kg)	ME (kcal/kg) as-is	DE:GE	ME:DE	ME:GE
1	1	1	3498.8	3421.5	.890	.978	.870
2	3	1	3744.9	3677.4	.892	.982	.876
3	4	1	3623.1	3546.5	.923	.979	.904
4	2	1	3673.9	3596.7	.893	.979	.874
5	4	2	3442.9	3356.3	.876	.975	.856
6	3	2	3787.4	3712.8	.902	.980	.885
7	1	2	3471.5	3383.9	.883	.975	.860
8	2	2	3810.9	3742.9	.926	.982	.910
13	2	3	3630.2	3553.7	.882	.979	.864
14	1	3	3532.3	3457.5	.898	.979	.879
15	3	3	3807.7	3733.0	.907	.980	.889
16	4	3	3525.1	3451.1	.899	.979	.880
17	4	4	3408.4	3348.2	.869	.982	.853
18	1	4	3382.6	3308.3	.860	.978	.841
19	3	4	3686.6	3625.0	.878	.983	.864
20	2	4	3691.7	3628.2	.897	.983	.882
21	1	5	3424.7	3356.2	.871	.980	.853
22	4	5	3387.2	3333.4	.863	.984	.850
23	3	5	3699.5	3637.7	.881	.983	.867
24	2	5	3539.9	3476.1	.860	.982	.845

Trt 1: Corn-SBM diet (control).
Trt 2: Control + 100 kcal/kg ME from cornstarch.
Trt 3: Control + 200 kcal/kg ME from cornstarch.
Trt 4: Control + Hemicell® (.05%).

Appendix Table 36

Analysis of variance for digestible and metabolizable energy (kcal/kg – as-is), and energy ratios – Experiment 5 (Period 2).

		Mean Squares				
Source	d.f.	DE (kcal/kg)	ME (kcal/kg)	DE:GE	ME:DE	ME:GE
Total	19					
Error	12	4189.87	4502.52	2.59e-04	3.12e-06	2.77e-04
Repetition	4	12857.8	9867.97	7.95e-04	1.26e-05	6.10e-04
Treatment	3	99110.9	103079.9	1.60e-04	1.46e-05	2.47e-04
Linear	1	200592.6	212721.1	3.69e-04	3.92e-05	5.93e-04
Quad	1	14396.89	15508.35	9.90e-05	4.03e-06	1.32e-04
Control vs HC	1	589.36	1167.18	9.36e-05	9.41e-06	1.48e-04
Coefficient of Variation, %		1.80	1.91	1.81	.18	1.91

Appendix Table 37

Analysis of variance for digestible and metabolizable energy (kcal/kg – as-is), and energy ratios – Experiment 5 (Pooled).

		Mean Squares				
Source	d.f.	DE (kcal/kg)	ME (kcal/kg)	DE:GE	ME:DE	ME:GE
Total	39					
Error	16	2607.95	2947.17	1.59e-04	6.41e-06	1.79e-04
Repetition	4	16902.5	12790.7	1.06e-03	2.79e-05	8.04e-04
Treatment	3	208405.5	215532.6	3.83e-04	2.25e-05	5.42e-04
Linear	1	383136.0	399672.8	5.62e-04	4.90e-05	8.69e-04
Quad	1	30808.9	33578.6	2.38e-04	9.84e-06	3.18e-04
Control vs HC	1	229.139	66.236	1.15e-06	4.05e-06	7.81e-06
Rep x Trt	12	3498.11	3359.89	2.23e-04	3.42e-06	2.13e-04
Period	1	1898.82	586.26	1.19e-04	2.67e-05	3.78e-05
Trt x Period	3	1046.35	1326.29	6.83e-05	2.28e-06	8.56e-05
Coefficient of Variation, %		1.43	1.55	1.42	.26	1.54

Appendix Table 38

Pen means for initial weight, final weight, average daily gain, hot carcass weight, and pig head weight – Experiment 5.

			Growth Performance				
			Initial Wt.	Final Wt.	ADG	HCW	Head Wt.
Pen	Trt	Rep	(kg)	(kg)	(kg)	(kg)	(kg)
1	1	1	37.64	58.50	.948	39.68	3.69
2	3	1	38.10	58.96	.948	40.59	3.85
3	4	1	38.55	58.96	.928	39.91	3.93
4	2	1	36.73	57.14	.928	39.00	4.03
5	4	2	35.83	54.42	.845	37.41	3.65
6	3	2	32.20	50.79	.845	33.79	3.34
7	1	2	33.56	53.06	.886	36.28	3.71
8	2	2	29.48	49.43	.907	33.33	3.26
13	2	3	33.56	51.70	.825	35.60	3.53
14	1	3	32.65	53.06	.928	36.05	3.29
15	3	3	36.28	57.60	.969	39.23	4.08
16	4	3	31.75	53.97	1.010	36.28	3.69
17	4	4	26.76	46.71	.907	31.52	3.21
18	1	4	28.12	48.53	.928	33.79	3.09
19	3	4	28.57	49.43	.948	32.88	3.38
20	2	4	30.39	48.98	.845	33.11	3.31
21	1	5	23.58	46.26	1.031	31.52	3.10
22	4	5	22.22	39.00	.763	24.26	2.77
23	3	5	24.49	45.35	.948	29.93	3.31
24	2	5	24.94	44.90	.907	30.39	3.29

Trt 1: Corn-SBM diet (control).

Trt 2: Control + 100 kcal/kg ME from cornstarch.

Trt 3: Control + 200 kcal/kg ME from cornstarch.

Trt 4: Control + Hemicell® (.05%).

Appendix Table 39

Analysis of variance for initial weight, final weight, average daily gain, hot carcass weight, and pig head weight – Experiment 5.

		Mean Squares				
Source	d.f.	Initial Weight	Final Weight	ADG	HCW	Head Weight
Total	19					
Error	11	3.550351	4.92932	.00338	3.8728	.02090
Repetition	4	113.127	121.825	.00478	66.297	.01806
Treatment	3	.97095	4.71870	.00143	2.9535	.06052
Linear	1	1.67281	.73984	.00022	.08100	.13577
Quadratic	1	.83000	9.90725	.00399	3.9458	.03337
Con vs HC	1	.01936	4.03225	.00140	6.3044	.11255
HCW	1			.01484		.42641
Coefficient of variation, %		6.03	4.35	6.38	5.67	4.16

Appendix Table 40

Pen means for estimated initial carcass protein, total carcass protein, protein gain, percentage protein, and percentage moisture – Experiment 5.

			Carcass Composition				
Pen	Trt	Rep	Initial Protein (kg)	Protein (kg)	Protein gain (kg/d)	Protein (%)	Moisture (%)
1	1	1	4.34	7.05	.123	17.8	68.5
2	3	1	4.40	6.89	.113	17.0	68.0
3	4	1	4.45	7.05	.118	17.7	67.3
4	2	1	4.23	6.57	.106	16.8	67.7
5	4	2	4.12	6.61	.113	17.7	65.9
6	3	2	3.69	5.80	.096	17.2	63.2
7	1	2	3.85	6.44	.118	17.7	65.0
8	2	2	3.36	5.92	.117	17.8	66.6
13	2	3	3.85	6.09	.102	17.1	64.8
14	1	3	3.74	6.43	.122	17.8	64.6
15	3	3	4.18	6.74	.117	17.2	66.4
16	4	3	3.63	6.23	.118	17.2	64.4
17	4	4	3.03	5.53	.114	17.6	66.5
18	1	4	3.20	5.89	.122	17.4	65.8
19	3	4	3.25	5.68	.110	17.3	66.6
20	2	4	3.47	6.08	.119	18.4	65.4
21	1	5	2.65	5.34	.122	16.9	69.3
22	4	5	2.49	4.13	.075	17.0	66.8
23	3	5	2.76	5.02	.103	16.8	67.0
24	2	5	2.81	5.13	.105	16.9	69.7

Trt 1: Corn-SBM diet (control).
Trt 2: Control + 100 kcal/kg ME from cornstarch.
Trt 3: Control + 200 kcal/kg ME from cornstarch.
Trt 4: Control + Hemicell® (.05%).

Appendix Table 41

Analysis of variance for total carcass protein, initial carcass protein, carcass protein gain, percentage protein, and percentage moisture – Experiment 5.

		Mean Squares				
Source	d.f.	Protein	Initial Protein	Protein gain	Protein %	Moisture
Total	19					
Error	11	.016512	.023962	4.64e-05	.139479	1.03047
Repetition	4	.031175	1.52605	1.94e-04	.321251	9.96479
Treatment	3	.026756	.012405	2.26e-04	.169152	.685374
Linear	1	.074448	.029517	4.12e-04	.437346	.292534
Quadratic	1	.001120	.003591	2.01e-06	.029712	1.720618
Con vs HC	1	.004264	.032858	1.24e-04	.010129	.0051615
HCW	1	1.40374	.312280	8.28e-04	.002729	4.763828
Coefficient of variation, %		2.13	4.47	5.83	2.15	1.53

Appendix Table 42

Pen means for total carcass fat, initial carcass fat, fat gain, and percentage fat – Experiment 5.

			Carcass fat content			
Pen	Trt	Rep	Fat (kg)	Initial fat (kg)	Fat gain (kg/d)	Fat (%)
1	1	1	3.94	2.72	.056	9.9
2	3	1	4.37	2.76	.073	10.8
3	4	1	4.26	2.81	.066	10.7
4	2	1	4.51	2.63	.086	11.6
5	4	2	4.94	2.54	.109	13.2
6	3	2	5.37	2.17	.145	15.9
7	1	2	4.95	2.31	.120	13.6
8	2	2	3.94	1.89	.093	11.8
13	2	3	5.12	2.31	.128	14.4
14	1	3	5.10	2.21	.131	14.1
15	3	3	4.90	2.58	.105	12.5
16	4	3	5.45	2.12	.151	15.0
17	4	4	3.75	1.62	.097	11.9
18	1	4	4.32	1.76	.117	12.8
19	3	4	4.13	1.80	.106	12.6
20	2	4	4.07	1.99	.095	12.3
21	1	5	3.10	1.30	.082	9.8
22	4	5	2.81	1.16	.075	11.6
23	3	5	3.68	1.39	.104	12.3
24	2	5	2.75	1.44	.060	9.0

Trt 1: Corn-SBM diet (control).
Trt 2: Control + 100 kcal/kg ME from cornstarch.
Trt 3: Control + 200 kcal/kg ME from cornstarch.
Trt 4: Control + Hemicell® (.05%).

Appendix Table 43

Analysis of variance for carcass fat, initial carcass fat, fat gain, and percentage carcass fat – Experiment 5.

		Mean Squares			
Source	d.f.	Fat	Initial fat	Fat gain	Fat (%)
Total	19				
Error	11	.152393	.018609	3.28e-04	1.30341
Repetition	4	1.32869	.045650	2.44e-03	10.58021
Treatment	3	.116916	.010298	2.13e-04	1.32131
Linear	1	.113687	.021560	6.40e-05	1.32593
Quadratic	1	.232622	.002812	5.63e-04	2.59416
Con vs HC	1	.000139	.023909	4.61e-05	2.58e-04
HCW	1	.042347	.240413	1.63e-04	3.74548
Coefficient of variation, %		9.14	6.57	18.11	9.29

Appendix Table 44

Pen means for gross energy, total carcass energy, estimated initial carcass energy, carcass energy gain, and energy accretion in carcass and viscera – Experiment 5.

			Energy Retention				
Pen	Trt	Rep	GE (kcal/kg)	Energy (kcal)	Initial energy (kcal)	Energy gain (kcal/d)	Energy accretion (kcal/d)
1	1	1	6241.0	78038.7	50089.8	1270.4	1420.5
2	3	1	6315.7	82123.2	50849.8	1421.5	1584.1
3	4	1	6266.1	81783.8	51609.9	1371.5	1497.5
4	2	1	6443.0	81091.2	48569.7	1478.3	1602.4
5	4	2	6585.8	83927.4	47049.6	1676.3	1841.5
6	3	2	6746.2	83892.1	40969.2	1951.0	2146.6
7	1	2	6491.9	82505.3	43249.4	1784.4	1953.4
8	2	2	6377.2	70893.5	36408.9	1567.5	1724.9
13	2	3	6685.7	83874.8	43249.4	1846.6	1968.6
14	1	3	6606.9	84264.7	41729.3	1938.0	2103.5
15	3	3	6474.8	85350.5	47809.6	1706.4	1860.3
16	4	3	6700.4	86520.9	40209.2	2105.1	2347.7
17	4	4	6410.3	67599.8	31848.7	1625.1	1769.6
18	1	4	6481.7	74861.6	34128.8	1851.5	1996.5
19	3	4	6453.9	70949.8	34888.9	1639.1	1814.0
20	2	4	6449.7	73894.5	37929.0	1634.8	1775.3
21	1	5	6276.5	60671.8	26528.4	1552.0	1702.2
22	4	5	6332.6	50959.5	24248.2	1214.1	1402.7
23	3	5	6407.3	63349.9	28048.4	1604.6	1781.2
24	2	5	6092.3	56049.2	28808.5	1238.2	1376.3

Trt 1: Corn-SBM diet (control).
Trt 2: Control + 100 kcal/kg ME from cornstarch.
Trt 3: Control + 200 kcal/kg ME from cornstarch.
Trt 4: Control + Hemicell® (.05%).

Appendix Table 45

Analysis of variance for gross energy, total carcass energy, estimated initial energy, carcass energy gain, and energy accretion in carcass and viscera – Experiment 5.

		Mean Squares				
Source	d.f.	GE	Energy	Initial energy	Energy gain	Energy accretion
Total	19					
Error	11	14057.6	1.17e07	4.99e06	2.69e04	3.09e04
Repetition	4	85964.9	1.10e08	1.28e07	1.96e05	2.14e05
Treatment	3	6442.96	5.82e06	2.88e06	1.37e04	2.19e04
Linear	1	8032.75	4.10e06	6.24e06	479.53	11.069
Quadratic	1	10925.8	1.29e07	6.18e05	3.96e04	6.57e05
Con vs HC	1	256.747	2.92e04	6.54e06	1.18e04	8617.5
HCW	1	15117.1	7.71e07	6.48e07	1106.52	12.6337
Coefficient of variation, %		1.84	4.56	5.67	10.10	9.85

Appendix Table 46

Pen means for viscera weight, percentage viscera, viscera gross energy, viscera energy, and viscera energy gain – Experiment 5.

			Viscera Composition				
Pen	Trt	Rep	Viscera Wt. (kg)	Viscera (%)	Viscera GE (kcal/kg)	Energy (kcal)	Energy gain (kcal/d)
1	1	1	8.14	13.9	5228.6	9385.1	150.1
2	3	1	8.80	14.9	5374.4	9717.6	162.6
3	4	1	8.57	14.5	5358.5	8971.9	126.0
4	2	1	8.04	14.1	5360.2	8697.4	124.2
5	4	2	8.07	14.8	5437.2	9483.5	165.3
6	3	2	8.05	15.9	5368.3	9681.0	195.6
7	1	2	7.44	14.0	5447.4	9273.4	169.1
8	2	2	7.30	14.8	5518.3	8487.9	157.4
13	2	3	6.88	13.3	5517.2	8237.0	121.9
14	1	3	8.16	15.4	5275.6	9077.4	165.5
15	3	3	7.37	12.8	5443.7	9291.5	153.9
16	4	3	8.11	15.0	5464.7	10657.3	242.6
17	4	4	7.46	16.0	5296.3	7853.5	144.5
18	1	4	7.37	15.2	5190.9	8040.3	145.0
19	3	4	7.57	15.3	5255.5	8754.9	174.8
20	2	4	7.67	15.7	5331.3	8234.2	140.5
21	1	5	6.90	14.9	5307.0	7566.7	150.2
22	4	5	7.56	19.4	5111.0	8235.1	188.6
23	3	5	7.35	16.2	5306.0	8264.8	176.6
24	2	5	6.71	14.9	5363.6	7476.2	138.1

Trt 1: Corn-SBM diet (control).
Trt 2: Control + 100 kcal/kg ME from cornstarch.
Trt 3: Control + 200 kcal/kg ME from cornstarch.
Trt 4: Control + Hemicell® (.05%).

Appendix Table 47

Analysis of variance for viscera weight, percentage viscera, gross energy of viscera, total viscera energy, and visceral energy gain – Experiment 5.

		Mean Squares				
Source	d.f.	Viscera Wt.	Viscera %	Viscera GE	Visceral Energy	Visceral Energy gain
Total	19					
Error	11	.11828	.00416	2787.23	2.59e05	607.048
Repetition	4	.30345	.01129	22463.9	6.10e05	747.729
Treatment	3	.38556	.01301	19832.3	8.61e05	1604.009
Linear	1	.12013	.00160	10362.0	5.57e05	633.908
Quadratic	1	.58114	.02033	49656.3	1.44e06	3275.237
Con vs HC	1	.18996	.00542	16130.4	2.93e05	243.483
HCW	1	.06253	.10758	32447.8	946.33	878.207
Coefficient of variation, %		4.48	4.29	.99	5.80	15.44

Appendix Table 48

Pen means for plasma urea N, protein, and creatinine – Experiment 5.

			PUN		Protein		Creatinine	
Pen	Trt	Rep	Day 0	Day 22	Day 0	Day 22	Day 0	Day 22
1	1	1	13.5	23.3	6.9	7.1	1.38	1.88
2	3	1	12.7	16.3	7.2	6.9	1.34	1.70
3	4	1	10.1	14.6	7.3	7.4	1.58	1.94
4	2	1	11.1	15.2	7.2	6.1	1.27	1.59
5	4	2	16.3	19.5	6.7	6.8	1.12	1.58
6	3	2	14.4	21.4	6.5	6.8	1.18	1.31
7	1	2	15.2	22.3	6.7	6.6	1.24	1.50
8	2	2	12.0	16.1	5.8	6.1	1.09	1.39
13	2	3	13.8	18.8	6.1	6.6	1.04	1.33
14	1	3	15.4	22.4	6.0	6.4	1.11	1.60
15	3	3	12.6	19.6	5.8	5.9	1.24	1.44
16	4	3	15.6	24.1	6.0	5.8	1.17	1.39
17	4	4	14.4	16.1	5.7	5.7	1.13	1.55
18	1	4	10.7	14.9	5.5	6.1	1.06	1.66
19	3	4	11.5	20.0	6.2	8.4	1.20	1.63
20	2	4	9.9	12.8	6.2	8.7	1.18	1.75
21	1	5	8.9	20.6	6.6	5.7	1.51	.66
22	4	5	8.9	15.7	7.9	6.2	1.18	1.06
23	3	5	10.4	16.5	6.0	6.0	1.29	1.52
24	2	5	7.4	15.1	6.2	6.9	1.17	1.55

Trt 1: Corn-SBM diet (control).
Trt 2: Control + 100 kcal/kg ME from cornstarch.
Trt 3: Control + 200 kcal/kg ME from cornstarch.
Trt 4: Control + Hemicell® (.05%).

Appendix Table 49

Analysis of variance for plasma urea N, protein, and creatinine – Experiment 5.

		Mean Squares		
Source	d.f.	PUN	Protein	Creatinine
Total	19			
Error	11	4.882734	.590215	.0609298
Repetition	4	7.215320	1.14899	.2049613
Treatment	3	11.42875	.693224	.0030796
Linear	1	6.390989	.441	.0075396
Quadratic	1	19.05776	.351782	.0011421
Con vs HC	1	21.51950	.246028	.0025207
Initial conc.	1	14.95892	2.063636	.0346415
Coefficient of variation, %		12.10	11.62	16.44

Appendix Table 50

Pen means for plasma glucose, triglycerides, and insulin – Experiment 5.

			Glucose		Triglycerides		Insulin	
			Day 0	Day 22	Day 0	Day 22	Day 0	Day 22
Pen	Trt	Rep						
1	1	1	114	93	44	27	10.14	9.78
2	3	1	118	102	72	25	9.00	15.94
3	4	1	129	106	59	32	8.36	19.39
4	2	1	130	106	63	20	10.35	9.98
5	4	2	120	93	65	30	16.54	11.00
6	3	2	104	90	37	29	9.42	13.86
7	1	2	130	111	56	38	15.22	8.53
8	2	2	107	113	85	24	5.91	12.13
13	2	3	109	112	41	35	8.87	14.34
14	1	3	99	116	32	49	8.87	4.38
15	3	3	104	95	38	19	8.06	13.51
16	4	3	106	102	55	35	16.20	12.95
17	4	4	120	104	47	33	9.08	16.93
18	1	4	109	111	73	39	8.73	8.31
19	3	4	119	114	37	76	3.93	13.71
20	2	4	104	103	43	---	10.43	5.87
21	1	5	179	129	80	67	13.69	---
22	4	5	138	115	62	41	10.49	11.46
23	3	5	123	112	44	34	8.00	9.97
24	2	5	113	135	48	39	11.46	7.46

Trt 1: Corn-SBM diet (control).
Trt 2: Control + 100 kcal/kg ME from cornstarch.
Trt 3: Control + 200 kcal/kg ME from cornstarch.
Trt 4: Control + Hemicell® (.05%).

Appendix Table 51

Analysis of variance for plasma glucose, triglycerides, and insulin – Experiment 5.

Source	d.f.	Mean Squares		
		Glucose	Triglycerides*	Insulin*
Total	19			
Error	11	67.45739	199.27062	6.261764
Repetition	4	190.2889	316.33776	12.81931
Treatment	3	158.648	122.8107	51.08627
Linear	1	130.6884	140.07573	42.476834
Quadratic	1	174.2038	152.70492	.0953849
Con vs HC	1	139.9240	238.72443	130.744704
Initial conc.	1	47.16870	5.527118	21.942572
Coefficient of variation, %		7.60	38.76	21.66

* Contained only 19 observations due to missing values (hemolysis).

Appendix Table 52

Pen means for average feed intake, nitrogen intake, feces excreted, fecal nitrogen, and urine excreted – Experiment 5.

			Nitrogen Balance				
Pen	Trt	Rep	Feed intake (g)	N Intake (g)	Feces (g)	Fecal N (kg)	Urine (g)
1	1	1	1470.4	49.99	166.7	6.769	1139.5
2	3	1	1649.1	52.56	190.2	8.231	838.5
3	4	1	1520.4	49.09	138.2	4.917	1073.5
4	2	1	1550.8	49.27	173.3	7.634	975.0
5	4	2	1434.1	46.31	168.2	7.818	784.5
6	3	2	1492.3	47.56	163.1	7.321	1093.5
7	1	2	1383.9	47.05	164.8	7.013	959.0
8	2	2	1474.8	46.85	132.2	6.075	951.0
13	2	3	1484.4	47.16	168.9	7.139	1233.0
14	1	3	1467.9	49.91	158.8	6.416	1126.5
15	3	3	1516.9	48.35	164.1	6.564	1325.0
16	4	3	1504.7	48.58	169.7	6.191	2395.0
17	4	4	1309.5	42.28	188.2	9.068	625.5
18	1	4	1314.5	44.69	184.9	8.815	1111.5
19	3	4	1433.8	45.70	176.8	8.061	1050.0
20	2	4	1410.0	44.80	160.1	7.084	721.5
21	1	5	1346.7	45.79	167.2	7.074	963.5
22	4	5	1317.4	42.54	173.4	8.098	1918.0
23	3	5	1459.8	46.53	171.1	7.690	1483.0
24	2	5	1488.4	47.29	194.9	9.186	1315.5

Trt 1: Corn-SBM diet (control).
Trt 2: Control + 100 kcal/kg ME from cornstarch.
Trt 3: Control + 200 kcal/kg ME from cornstarch.
Trt 4: Control + Hemicell® (.05%).

Appendix Table 53

Analysis of variance for average feed intake, nitrogen intake, feces excreted, fecal nitrogen, and urine excreted – Experiment 5.

		Mean Squares				
Source	d.f.	Feed intake	N Intake	Feces	Fecal N	Urine
Total	19					
Error	12	1332.73	1.39314	259.8274	1.05572	1.22e05
Repetition	4	20534.1	21.69139	290.0977	2.15602	3.46e05
Treatment	3	14259.2	5.040634	47.3494	.150036	1.07e05
Linear	1	32305.4	1.06476	52.3494	.317297	2.40e04
Quadratic	1	2636.8	1.83139	80.09868	.0026571	1.62e04
Con vs HC	1	1050.9	7.45090	2.23729	3.84e-06	2.24e05
Coefficient of variation, %		2.52	2.51	9.55	13.96	30.25

Appendix Table 54

Pen means for urinary nitrogen, nitrogen absorption and retention (g), and nitrogen absorption and retention as a percentage of intake – Experiment 5.

			Nitrogen Balance				
Pen	Trt	Rep	Urinary N (g)	N Absorption (g)	N Absorption (% intake)	N Retention (g)	N Retention (% intake)
1	1	1	17.848	43.225	.865	25.377	.508
2	3	1	14.699	44.328	.843	29.629	.564
3	4	1	15.682	44.176	.900	28.494	.580
4	2	1	13.579	41.633	.845	28.054	.569
5	4	2	13.798	38.488	.831	24.690	.533
6	3	2	15.903	40.243	.846	24.340	.512
7	1	2	15.129	40.039	.851	24.911	.529
8	2	2	13.775	40.778	.870	27.003	.576
13	2	3	17.234	40.019	.849	22.785	.483
14	1	3	17.394	43.492	.871	26.098	.523
15	3	3	15.896	41.784	.864	25.888	.536
16	4	3	18.704	42.393	.873	23.689	.488
17	4	4	11.188	33.214	.786	22.026	.521
18	1	4	10.545	35.879	.803	25.333	.567
19	3	4	12.897	37.637	.824	24.741	.541
20	2	4	13.292	37.712	.842	24.421	.545
21	1	5	13.742	38.713	.846	24.971	.545
22	4	5	12.377	34.438	.810	22.061	.519
23	3	5	10.165	38.837	.835	28.672	.616
24	2	5	10.573	38.099	.806	27.525	.582

Trt 1: Corn-SBM diet (control).
Trt 2: Control + 100 kcal/kg ME from cornstarch.
Trt 3: Control + 200 kcal/kg ME from cornstarch.
Trt 4: Control + Hemicell® (.05%).

Appendix Table 55

Analysis of variance for urinary nitrogen, nitrogen absorption and retention (g), and nitrogen absorption and retention as a percentage of intake – Experiment 5.

		Mean Squares				
Source	d.f.	Urinary N	N Absorbed	N Absorbed (% intake)	N Retention	N Retention (% intake)
Total	19					
Error	12	2.17672	2.34488	4.99e-04	3.16255	9.66e-04
Repetition	4	22.5270	35.8399	2.14e-03	8.52244	1.96e-03
Treatment	3	1.49713	1.00872	4.64e-05	5.45489	7.86e-04
Linear	1	2.59943	.21957	5.41e-05	4.32997	9.29e-04
Quadratic	1	1.78131	1.97356	1.94e-05	.004925	1.71e-04
Con vs HC	1	.84609	7.4616	1.34e-04	3.28249	9.85e-05
Coefficient of variation, %		10.38	3.85	2.65	6.96	5.74

VITA

Lee Allen Pettey

Candidate for the Degree of

Master of Science

Thesis: EFFECTS OF HEMICELL® ADDITION TO CORN-SOYBEAN MEAL DIETS ON GROWTH PERFORMANCE, CARCASS COMPOSITION, AND NUTRIENT DIGESTIBILITY IN GROWING AND FINISHING PIGS

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