EVALUATION OF PET FOOD BY-PRODUCT AS AN ALTERNATIVE FEEDSTUFF IN NURSERY PIG DIETS

by

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(Under the Direction of Michael J. Azain)

The objective of this work was to demonstrate whether pet food by-product (PFB) can be incorporated into nursery pig diets, as a replacement for more expensive animal-origin protein and energy sources. Two studies on early-weaned pigs were performed to evaluate growth performance as well as digestibility of diets containing various levels of PFB. Results indicate that PFB can serve not only as an effective replacement in nursery diets, but may also confer other long-term benefits.

INDEX WORDS: Nursery pigs, By-product, Growth, Digestibility

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B.S., North Carolina State University, 2000

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

ATHENS, GEORGIA

2002

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ACKNOWLEDGEMENTS

Completing this thesis is another rung on the ladder of life's achievements. However, it would not have been possible without the support of the following individuals. Much gratitude to:

Dr. Azain, for his innovative thoughts and advice, and for serving as my major professor,

Dr. Jones, for his practical knowledge and suggestions, and for serving on my committee,

Dr. Rampacek, for serving on my committee,

Tom, for his expertise and humor,

Sherie, for her assistance in the lab,

Cathy, for her comraderie, knowledge of the swine center, and for being one of Azain's Angels,

Sylvia, for her friendship and optimism,

Suzanne, for being one of Azain's Angels,

My parents, for their constant love and encouragement through it all,

Jeremy, for his patience and assistance.

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CHAPTER 1

INTRODUCTION

Post-weaning lag is of major concern in pork production. To minimize this, much focus has been placed on the importance of high-quality starter diets to stimulate intake and growth. As a result, many expensive specialty ingredients are used, causing nursery diets to bear the highest costs of all diets fed throughout the production cycle. Furthermore, as ingredient competition intensifies, prices will continue to inflate steeply.

Use of alternative feedstuffs may be a practical and feasible way of reducing these high costs. Many by-products are readily available at little or no cost. Industries that produce by-products are more than eager to impart their wastes, thereby minimizing their costs for disposal of the by-product.

There has been concern with by-product use regarding variability of nutrient content, as well as the risk of disease transmission via animal tissue ingestion. With respect to variability, it must be realized that although variability is of concern, many typical ingredients face the same dilemma. It is a matter with which feed manufacturers must cope, depending on genetic and environmental conditions for crops, and various processing and rendering methods to ensure safe products.

Numerous by-products have already been incorporated with success in nursery diets. Potato chip scraps, cheese by-product, and poultry offal meal are a few examples. Yet, there are still numerous valuable feed sources with adequate nutritional value available.

Pet food by-product (PFB) is one such ingredient that may be a cost-effective replacement for the more typical animal protein sources used in nursery diets. It may also serve as an energy source to replace corn. The term by-product is used loosely to describe pet food that has been rejected because it did not meet quality specifications, was damaged during handling or transport, or distributed to a retail outlet and not sold before the expiration date.

Other than cost, PFB also has the advantage of containing previously rendered products. Thus, the risk of disease transmission via animal tissue ingestion is reduced. Pet food manufacturers must adhere to very strict production guidelines. Pet food is also an extruded product, suggesting that it is quite digestible.

CHAPTER 2

LITERATURE REVIEW

Purpose of Starter Diets

As swine operations strive to increase productivity, there has been a trend towards weaning pigs earlier than they are physiologically ready. In a natural setting, pigs would wean themselves between 9 and 16 weeks of age, slowly making the transition from liquid to solid feed (Carroll et al., 1998). In our current industry, it is common to wean pigs as early as 3 weeks of age, allowing for more piglets per sow per year (Turlington et al., 1989). Weaning piglets before they are physiologically ready is the major cause of post-weaning lag. Weaning is probably the most stressful time for a pig. Not only is there the psychological stress of removal from the sow and the environmental stress of being transported to a nursery barn, but there is a great amount of nutritional stress (Funderburke and Seerley, 1990). There is a change in physical diet form, along with a change in energy and protein sources. Pigs accustomed to lactose and casein as the primary sources of energy and protein from sow's milk are not yet fully capable of digesting starch and plant proteins. The necessary digestive enzymes have not yet been established within the gut of an early-weaned pig (Makkink et al., 1994).

The purpose of a starter diet in early-weaned pigs is to minimize post-weaning lag by providing a smooth transition from sow's milk to solid feed. This is typically achieved by a three-phase feeding program that slowly introduces low-cost ingredients, promotes maturation of the gastrointestinal tract, and supplies specialty ingredients to optimize growth performance (Mavromichalis and Baker, 2001). These selected

ingredients should stimulate feed intake and provide highly digestible amino acids in the proper proportions. Increasing the complexity of starter diets by incorporating such ingredients maximizes performance (Tokach et al., 1994). Dritz et al. (1996) fed diets of differing complexities from weaning to approximately 7 weeks of age. Results indicated that as diet complexity increased, ADG was improved from weaning to 1 week post-weaning, but no effect was reported for wks 2 through 7. It was concluded that increasing complexity was most valuable in the early period post-weaning (Dritz et al., 1996).

Additional work focusing on the morphology of the small intestine has demonstrated that weaned pigs have relatively larger small intestine weights per kg empty body weight as compared to pigs of the same age still nursing. This observation may be explained by the fact that a high percentage of nutrients are necessary for tissue development of the small intestine post-weaning (Cera et al., 1988). Thus, the repartitioning of nutrients to visceral development away from lean tissue accretion accentuates the need for optimizing performance immediately post-weaning.

Prevention of post-weaning lag is of critical importance not only from a growth standpoint, but also in terms of health. Feed intake immediately post-weaning is most critical for heat retention, especially in lightweight pigs (Dritz and Tokach, 2000).

There is correlation between nursery phase and subsequent growth performance to market weight. Dritz et al. (1996) concluded that pigs fed a nursery diet of medium complexity (corn, dried whey, soybean meal, blood meal) reached market weight earlier than pigs fed either highly complex (corn, dried whey, soybean meal, plasma protein, fish meal, blood meal) or simple (corn, dried whey, soybean meal) diets (Dritz et al., 1996). Liquid diets have also been shown to promote weanling growth, an advantage that can be maintained through the finisher stage (Kim et al., 2001). Alternatively, reduced growth performance early in life may be exacerbate during subsequent grower-

finisher stages. Mahan et al. (1998) revealed no evidence for compensatory growth of lighter weight pigs upon leaving the nursery during subsequent grower-finisher stages. It appears that feeding a quality, complex starter diet is of utmost importance not only to minimize post-weaning lag, but to accelerate growth through the entire production cycle (Mahan et al., 1998).

The most expensive components of starter diets are typically specialty ingredients such as spray-dried plasma protein, blood meal, and dried whey. As a general premise, animal protein sources are more readily digestible to the young pig whose gastrointestinal system is not fully functional. Wilson and Leibholz (1981) illustrated this by comparing performance of pigs fed milk versus soybean proteins. The substitution of soybean meal for milk protein resulted in an 85% reduction of weight gain and feed efficiency in pigs aged between 7 and 14 d, and a 31% reduction in pigs from 21 to 28 d (Wilson and Leibholz, 1981). A strong inverse relationship exists between blood urea nitrogen (BUN) concentration and lean growth (Puchal, 1962; Coma et al., 1995). Thus, it is not surprising that Wilson and Leibholz (1981) observed plasma urea concentrations to be lowest in pigs fed milk protein.

Very little hydrochloric acid (HCl) is produced by the stomach during the nursing and early post-weaning period. Parietal cells which secrete HCl are not yet functional in the weanling pig. Without HCl to lower pH of the stomach environment and denature dietary proteins, intestinal proteases are less effective at degrading these proteins (Mahan, 1997). However, animal proteins can be digested adequately by weanling pig. This may be due to the high sodium and chloride content in these ingredients, especially chloride (Mahan, 1997). Mahan et al. (1996) evaluated the supplementation of nursery pigs diets with either sodium chloride, sodium phosphate, or HCl. A significant linear effect on performance in the first two weeks post-weaning was evident as dietary chloride level increased. Pigs fed 0.50% versus 0.40% total chloride experienced 23%

and 17% improvements in ADG and ADFI, respectively (Mahan et al., 1996). Increasing dietary chloride also increases nitrogen retention and improves apparent protein digestibility (Mahan, 1997). It is possible that the high chloride content of animal proteins serves as a precursor for the formation of HCl, hence promoting protein digestion in the young pig.

Rationale of Typical Ingredients

Spray-dried plasma protein

Spray-dried plasma protein (SDPP), first introduced in the late eighties, has been referred to as a "revolutionary" ingredient (Mavromichalis and Baker, 2001). Spray-dried plasma protein in early-phase nursery diets significantly improves pig performance compared to dried skim milk, blood meal, and soybean meal (de Rodas et al., 1995). Coffey and Cromwell (1995) demonstrated a 40% growth improvement in piglets fed SDPP in the first and second weeks post-weaning and a 60% increase in consumption of an SDPP diet (Coffey and Cromwell, 1995). The researchers suggested that the advantage is a function of palatability. In a preference trial, Ermer at al. (1994) showed that pigs preferred diets containing SDPP compared to dried skim milk. They also observed that preference grew with time. Sixty percent of feed intake on d 2 was SDPP-containing diets; on d 21, 71% of feed intake was SDPP diets (Ermer et al., 1994). Grinstead et al. (2000) demonstrated that SDPP exhibited increased ADG and ADFI only in the first week post-weaning, thus the duration of response varies (Bergstrom et al., 1997). Proposed modes of action for the superiority of SDPP include palatability, immunoglobulin content (Gatnau et al., 1995; Pierce et al., 1995), and metabolic control via hormones such as insulin-like growth factor-1 (IGF-1), growth hormones, and insulin (de Rodas et al., 1995). Although the mechanism remains unclear, SDPP is widely used to minimize post-weaning lag, particularly during the first week. Bergstrom et al. (1997)

determined that replacement of SBM with either SDPP or fishmeal (FM) improved feed efficiencies regardless of the production system, although there was no effect on ADG and ADFI. They suggest that this was due to lower dietary fiber and increased digestibility of SDPP and FM protein sources relative to SBM (Bergstrom et al., 1997). Burnham et al. (2000) supported this speculation by substituting either SDPP or wheat gluten for dried skim milk. Pigs fed SDPP had greater DM and N digestibility 10 d post-weaning than pigs fed dried skim milk or wheat gluten.

Thomson et al. (1995) explored how SDPP affects energy and nitrogen metabolism using the mouse as a model. Mice consuming an 8.0% SDPP diet had greater nitrogen retention than mice fed dried skim milk. However, energy retention unexpectedly was found to be lower. The authors suggest a higher basal metabolic rate due to greater visceral metabolic activity. This would further explain why increased feed intake is associated with SDPP inclusion; as metabolism increases, energy demand will increase (Thomson et al., 1995).

Evidence of immunoglobulin activity is another means by which SDPP may attest its successfulness in nursery diets. It has been established that pigs weaned before 5 weeks of age exhibit suppressed cell-mediated and antibody-mediated immune responses (Blecha et al., 1983), although it is known that the first 2 days post-weaning are associated with increased cytokine concentrations, namely interleukin-1 (McCracken et al., 1995). Spray-dried plasma protein contains numerous immunoglobulins. Although their biological activity following the spray-drying process has not been confirmed, there is suggestion of such (Jiang et al., 2000b). It has been demonstrated that oral administration of immunoglobulins can provide a passive immunity to piglets (Scoot et al., 1972). Assessment of various fractions of SDPP have shown that the beneficial effects are most associated with the IgG fraction of the serum proteins (Pierce et al., 1995; Gatnau et al., 1995).

Plasma inclusion in diets is also associated with reduced scours of weanling pigs (Coffey and Cromwell, 2001), which undoubtedly reduces the incidence of enteric disease and promotes general health. Scours is often associated with reduced performance resulting in economic loss (Harris et al., 1994). Thus, an ingredient such as SDPP that reduces the incidence of scours contributes to its popularity in starter diets. Overall, evidence for SDPP is such that it has become the standard against which other alternative protein sources are generally compared.

Another study exemplifying the benefits of animal versus plant protein was performed comparing SDPP and extruded soy protein (ESP) (Jiang et al., 2000a). When early-weaned pigs were fed SDPP over ESP, protein intake did not differ, but ADG and gain to protein intake improved 23% and 19%, respectively. Plasma urea levels were 40% lower in SDPP-fed pigs, indicating the efficiency of protein utilization is improved (Jiang et al., 2000a). A strong inverse relationship exists between BUN concentration and lean growth (Puchal, 1962; Coma et al., 1995).

Plasma protein has a high chloride content (1.50%) relative to the .20% requirement of a 5 to 10 kg nursery pig (NRC, 1998). The high chloride content may partly explain the successfulness of plasma protein, in terms of promoting synthesis of HCl and proteolytic activity within the gut. (Mahan et al., 1996).

Fishmeal

Fishmeal (FM) has advantages in nursery diets when compared to SBM. A 4.5% and 9.3% inclusion level of FM increased ADG by 8-12% and ADFI by 16-18% (Stoner et al., 1990). The ADFI increase is thought to be a function of palatability, as pigs tend to prefer FM over SBM. It was hypothesized that ADG improvement associated with FM was due to high selenium (Se) content (Pike, 1979). Another thought is the amino acid profile of FM, which very closely approximates the animal's requirement (Bergstrom et

al., 1997). Bergstrom at al. (1997) found no difference in ADG and ADFI with the inclusion of FM, but reported an increased G:F. The suggested rationale for this improved G:F is the lower dietary fiber and increased digestibility compared to plant protein sources. However, Pike et al. (1984) showed a marked improvement in both ADG and feed efficiency in pigs fed a nutrient-dense FM diet versus a nutrient-dense diet without FM. There were no observed differences in ADFI, thus pigs on FM were able to convert feed to body weight more efficiently. The proposed explanation was enhanced amino acid uptake from the small intestine, resulting in a better balance of amino acids (Pike et al., 1984).

Kim and Easter (2001) further investigated four different FM's in young pig diets. Mackerel or herring-derived FM resulted in the optimal pig performance. A slope-ratio design was used to contrast mackerel FM and SDPP. It was found that SDPP and FM have the same relative bioavailability (RBV) from d 3 to 15 post-weaning, when the diets were balanced for amino acids (Kim and Easter, 2001). An earlier publication reported that mackerel FM has a 115% RBV relative to SDPP (Easter and Kim, 1998).

Jorgensen et al (1984) demonstrated that FM has high bioavailability of amino acids when fed to growing pigs. When compared to sunflower meal and meat and bone meal, FM and SBM had the highest ileal availability of the most limiting amino acid, lysine. Threonine, also often limiting, was found to be highest in FM, followed by SBM (Jorgensen et al., 1984). Green (1989) determined the digestibilities of essential amino acids were greater in both skim milk and FM than in meat meal. A numerical advantage was observed in FM over skim milk with respect to many dispensable and indispensable amino acids (Green, 1989).

Fishmeal is comparable as a partial substitute for SDPP. Veum et al. (1996) replaced SDPP with FM at various levels on a total available lysine basis. Considering a typical phase 1 diet may contain 6% SDPP, they determined that FM could substitute for

up to 4% of the diet without compromising ADG and ADFI (Veum et al., 1996). Fishmeal has a chloride content of 0.55%, exceeding the requirement for a nursery pig (NRC, 1998). The addition of FM in nursery diets at the expense of dried whey decreases fecal moisture, thereby minimizing the incidence of scours in early-weaned pigs (Gore, 1990) and promoting general health.

Spray-dried blood cells and blood meal

Spray-dried blood cells (SDBC), a by-product of plasma production, are often incorporated in nursery diets. In cattle, SDBC is an effective replacement for whey protein in calf milk replacer (Quigley et al., 2000). There are very few refereed publications delving into the use of SDBC in swine. Spray-dried blood cells appear to have the similar nutritional quality as spray-dried blood meal (SDBM), a product that has been more extensively researched (Goodband et al., 1997). Blood meal, although only 20% dry matter by weight, the greatest portion is proteins (90-95% CP) with high biological values. Although a poor isoleucine source, SDBC are rich in lysine and leucine making it a valuable feedstuff (Buraczewski, 1990). Kats et al. (1994) fed increasing levels of SDBM from d 7 through 28 post-weaning yielding improved ADG and G:F ratios. The optimum ADG and G:F was projected at 1.9% inclusion. Spray-dried blood meal did not perform as wellas SDPP, but yielded a growth rate intermediate to FM and SDPP in second-phase diets (Kats et al., 1994). The excessive leucine that is present in SDBM may increased the requirement for isoleucine (Taylor et al., 1977). Edmonds and Baker (1987) illustrated that levels of supplemental leucine up to 4% of the diet were not detrimental. Only at levels of 6% or greater did they observe depressed feed intake resulting in decreased performance (Edmonds and Baker, 1987).

A slope-ratio assay of meat meal, meat and bone meal, and SDBM indicated that lysine bioavailability was greatest in the SDBM, averaging 1.08% for pigs relative to total

lysine content. Meat meal and meat and bone meal averaged 0.71% and 0.70%, respectively (Batterham et al., 1986). Overall, SDBM is considered a high quality protein source for nursery diets as it has good digestibility coefficients, unlike most plant protein sources. Blood cells and blood meal also have sodium and chloride contents that exceed NRC requirement (NRC, 1998).

Corn

The bulk of energy in nursery diets is derived from corn (Mavromichalis and Baker, 2001). This is mainly because corn is the most prevalent grain grown throughout the US. A 2001-2002 estimate of corn production in the US is nearly 9.6 billion bushels, whereas in second place with a mere 0.5 billion bushels is sorghum grain (Muirhead, 2001).

Corn is an excellent energy source. Compared to other grains, feed efficiency of pigs fed corn will be slightly improved, although ADG may be equal. Thus, corn tends to be the most common energy source in swine diets (Goodband et al., 1997). Corn has the lowest neutral detergent fiber content (9.6%) as compared to barley (18.3%), wheat (13.5%), sorghum (18.0%) and oats (27.0%). It has the highest DE and ME values (3525 and 3420 kCal/kg, respectively), and a relatively high fat content (3.9%). Of the most common cereal grains, only oats has a higher CF content (4.7%) than corn (NRC, 1998).

Dried Whey

While consuming sow's milk, piglets receive the greatest amount of energy from lactose that is present in the milk. This corresponds to the high lactase activity in a newborn pig, which generally does not decrease until 4 weeks of age (Ekstrom et al., 1975a). Because dried whey (DW) contains approximately 70% lactose (Ekstrom et al.,

1975b), it is an excellent source of energy for weanling pigs as they make the transition from sow's milk to solid feed.

Whey consists of two main components, lactalbumin and lactose. Mahan (1992) evaluated each of these components and whole DW in a corn-soybean meal diet. It was shown that ADG, ADFI, nitrogen retention and nitrogen digestibility were improved with DW inclusion relative to the basal corn-soybean meal diet. With lactoalbumin only, performance was similar to that of the control. With lactose supplementation only, performance was superior to other diets. The conclusion was that lactose is the component of DW that enhances piglet performance (Mahan, 1992). In a subsequent study, Mahan (1993) again demonstrated that lactose effectively replaces DW, and improves piglet gains throughout a 35-d nursery period (Mahan, 1993). A derivation of DW, whey protein product (WPP), has also been evaluated in starter pig diets. Grinstead et al. (2000) replaced SDPP with WPP at various levels ranging from 25 to 100%. In the first two weeks post-weaning, ADG and ADFI increased with increasing WPP, but returned to average with no effect in the overall nursery period. Although SDPP and WPP result in superior performance, it was suggested that they act via different mechanisms. Whereas, SDPP is thought to be directly related to palatability and increased ADFI, WPP increases ADG as a result of better efficiency of nutrient utilization (Grinstead et al., 2000).

Soybean Meal

Soybean meal (SBM) is the most common plan protein source in any swine diet. This is primarily due to its widespread availability and relatively good amino acid profile. However, SBM is not the best choice for early-weaned piglets. As discussed previously, the substitution of SBM for milk protein resulted in an 85% reduction of weight gain and feed efficiency in pigs aged between 7 and 14 d, and a 31%

reduction in pigs aged 21 to 28 d (Wilson and Leibholz, 1981). Weanling pigs are not yet able to hydrolyze such complex proteins. Dunsford et al. (1989) studied the effects of SBM on small intestine structure. Three post-weaning diets were fed that included casein, SBM, or a corn-SBM blend. Upon slaughter of these pigs at various ages post-weaning, it was observed that pigs fed the SBM had the lowest villus heights, indicative of greatest intestinal damage. Although a corn-SBM based diet showed some improvement in villus height, pigs fed a casein diet were superior, with very little damage evident. Thus, SBM has a detrimental effect on intestinal morphology, contributing to post-weaning lag (Dunsford et al., 1989).

There has also been evidence of a transient hypersensitivity to SBM by nursery pigs. Specific glycoproteins found in soy are considered antigenic in the intestinal lumen, thereby mounting an immune response and contributing to post-weaning lag. As a result, it is generally accepted that the upper limit of SBM inclusion in nursery diets is between the range of 15 and 23%. At these levels, SBM can be fed as part of a high-quality complex diet without compromising overall nursery performance (Friesen et al., 1993). The remainder of protein sources should be animal-derived to enhance performance.

Benefit of By-Products

The greatest benefit of incorporating by-products into any feeding regimen is cost reduction. Feed represents the greatest single expense in swine operations. It has been estimated that the typical starter diet fed from 10 through 25 kg body weight constitutes 50% of total nursery feed cost (Dritz and Tokach, 2000). Prestarter and starter diets account for about 11% of the volume of feed a pig consumes throughout the production cycle, but about 15% of the cost of the total feeding program (Jones, personal communication). Protein in the diet is relatively more costly than energy and

young pigs have higher protein requirements than older pigs. Since use of plant proteins is limited, higher cost animal sources (SDPP, FM, SDBC) are needed to supply nutrients. Many by-products have minimal associated with obtaining them, thus can dramatically reduce feeding costs, while serving as good protein sources.

Another benefit of by-products is the reduction of ingredient competition. Although cereal grain production has increased greatly over time, the demand for direct human use is increasing also (Fahey and Holzgraefe, 1982). Thus, by-products as animal feedstuffs are an effective method of conserving resources and minimizing competition.

A final consideration to integrate by-products is the benefit to the environment. Industries are continuously expanding, thus the production of by-products is expected to increase greatly. Disposal of by-products into landfills is becoming more limited and expensive (Myer, 2001). As agriculture is the predominant contributor to these wastes, it is vital that agriculture begin to formulate new waste-management options (Harpster et al., 1997). One option is using pigs as “opportunity feeders” to recycle these by-product “wastes”. There are federal regulations regarding the feeding of by-products to livestock. In order to prevent disease transmission, it is required for any meat by-product to be boiled for at least 30 min at 100^{o} C as part of the rendering process (Polanski, 1995). An advantage to utilizing pet food by-product is that it has already been subjected to these conditions as part of the manufacturing process.

Criteria and Classification of By-Products

A by-product is any secondary commodity obtained from the processing of a principal commodity that has value as an animal feedstuff. By-products have been used as feed for hundreds of years; only recently have by-products gained increased attention from producers and nutritionists alike (Grasser et al., 1995).

Before a by-product is incorporated into a ration, there are a few considerations that must be acknowledged. As stated in the Pork Industry Handbook, the following questions must be answered: (1) Are there animal and human health hazards associated with the by-products?, (2) Is the nutrient composition suited to swine feeding?, (3) Is the value of the by-product greater than the cost of incorporating the by-product in the diet?, (4) Are there added costs of utilizing the by-product?, (5) Do by-products reduce the cost of production most of the time?, (6) Is by-product availability and quality sufficiently consistent to support longtime use? (Miller, 1994).

By-products have been classified according to their origin. These are based on the primary origin of the by-product, be it animal, grain, sugar/starch, or vegetable (Miller, 1994). This is not an all inclusive classification. Pet food comprises various ingredients, many of which are by-products themselves. Considering the two main categories of pet food ingredients being grain and milling by-products, and animal tissue by-products (Morris and Rogers, 1994), pet food by-product can best be described as falling into two categories.

Variability of By-Products

The most widely recognized disadvantage with by-product utilization is variability in composition. By-products such as bakery waste, although can be of great nutritional value are irregularly available as a consistent product. Other by-products, such as distillers grains, have a more uniform composition (Easter, 1979). Pet food by-product is one that may be quite variable depending on source and type. Different manufacturers will have different formulations, ingredients, and processing techniques. Commercial dog foods vary widely in energy content, from low energy diets diluted with indigestible components to diets formulated for high performance (Morris and Rogers, 1994). There

is diversity between cat food and dog food, as each species has its own set of nutrient requirements.

Although by-products may be variable in composition, it must be realized that many ingredients typically used experience the same dilemma. A study by the North Central Regional Committee on Swine Nutrition to evaluated the nutrient variability of corn and SBM from various locations and in various laboratories throughout the Midwest. Results obtained have been used to update NRC profiles. Corn and SBM have been reported to vary considerably depending on genetics, crop conditions, and processing. Amino acids were the most variable nutrients. It was concluded that although nutrient variability exists, analytical variability is large also. Variability may in fact be greater among labs than among sources of ingredients (Cromwell et al., 1999). Van Barneveld (1999) disagrees, stating that agronomic practices have the greatest influence on nutrient variability, although they did not consider lab to lab variation However, it is evident that amino acid values have the greatest variability, likely a function of methodology of analysis (van Barneveld, 1999).

"For feed manufacturers to produce consistency from inconsistency is no small task" (Duncan, 1988). Variability exists, and it must be managed. By-product variability cannot be overlooked; it is a concern that must be considered. Thus, while variability is of concern with by-products, it is a concern with other ingredients as well. Ideally, diet formulation should be based on actual composition of the available ingredients for the diet.

Successful By-Products

Rahnema and Borton (2000) reported a nursery study indicating substitution of potato chip scraps (PCS) for corn, at levels of 15% and 20%, had no effect on the average daily gain of nursery pigs. Dry matter intake was reduced and overall feed

efficiency improved. The higher lipid content of PCS caused a reduction in intake, yet a finisher phase of the study demonstrated no differences in carcass traits, other than a slight decrease in dressing percentage. It was concluded that potato chip scraps may be utilized as a partial substitute for corn in weanling diets (Rahnema, 2000). Another alternative is potato protein. Often high in glycoalkaloids which can reduce feed intake, there is a low-glycoalkaloid potato protein (LGPP) available. Kerr et al. (1998) demonstrated that up to 8% of LGPP can be included in starter diets as a partial replacement for SDPP without detriment.

Cheese by-product (CB) is another ingredient that has been utilized in starter diets. Sohn and Maxwell (1991) reported that ADG and ADFI did not differ significantly when dried skim milk (DSM) was replaced with CB as the primary protein source in weanling pigs. It was observed that CB-fed pigs had numerically higher ADG (+10%) than pigs fed DSM. A significant improvement in G:F (+19%) was noted in the second week when pigs were fed CB (Sohn and Maxwell, 1991).

Sohn et al. (1993) examined the incorporation of poultry offal meal (POM) in place of FM in early-weaned pig diets. Although it was not recommended to fully replace FM with POM, results showed that POM can effectively replace 50% of FM in complex nursery diets (Sohn et al., 1993).

Spray-dried whole egg is another alternate for SDPP. Pigs fed phase 1 diets containing 3% and 6% whole egg exhibited similar performance from d 0 through 15 to the control SDPP-fed pigs. At the 9% and 12% inclusion levels, there was some depression in ADG. Overall nursery performance did not differ across any of the dietary treatments (Nessmith et al., 1995). It was concluded that whole egg can replace 50% of the SDPP content in a phase 1 nursery diet.

Numerous other by-products and alternative feedstuffs have been examined, especially in finisher diets. Dehydrated restaurant food waste (DFW) has the potential to

be a nutritious feedstuff for pigs (Myer, 1999). The inclusion of DFW at a level of 40% yielded no effect on ADG, but on G:F. Pigs fed DFW averaged 11% less feed per unit of gain (Myer, 1999). Similar results were obtained utilizing recycled cafeteria food waste (Westendorf, 1998).

Another category of by-products are fibrous ingredients, such as grasses, milling or distillery by-products. As omnivores, swine have some ability to ferment fiber in their large intestine. It has been predicted that up to 30% of the energy needs of a growing pig can be met with the use of fibrous ingredients, without any detriment to performance (Varel and Yen, 1997). Yet, such ingredients are probably better suited to older pigs with more developed hindgut fermentation.

Another successful alternative has been blue-green algae (***Spirulina platensis***). It has proven successful in broilers as a replacement for FM (Venkataraman et al., 1994). Sweet potato tuber meal has been substituted up to 40% of the amount of corn with no adverse effects reported (Ravindran and Sivakanesan, 1996). The scope of by-products is vast, encompassing nearly every agricultural industry.

Pet Food By-Product

Pet food by-product is another potential substitute for nursery diets; however, reports of its use are lacking in the literature. A comparison of adult dog and nursery pig nutrient requirements show several similarities (Table 2-1). The term by-product is used loosely to describe pet food that has been rejected because it did not meet quality specifications, was damaged during handling, or distributed to a retail outlet and not sold before the expiration date. The US pet food industry is an 11.8 billion dollar enterprise that continues to expand annually (Corbin, 2001), as the number of pet owners and the popularity of pet superstores increases. Premium specialty pet foods are on the rise, promising better quality ingredients, glossier coats, and healthier joints, to consumers

who are concerned with their pet's wellness (Riaz, 1998). As more pet food is produced each year, more by-product will become available as an alternative feedstuff. The United States is the largest exporter of pet food throughout the world. According to a 1997 statistic, U.S. pet food exports have more than tripled in volume since 1990 (USDA-FAS, 1997). A recent statistic further quantifies an 18.5% increase in export volume from 2000 to 2001, yielding a total export value of nearly 1 billion dollars (USDA-FAS, 2002).

Twenty-five years ago, it was suggested that the pet food industry was more dependent upon cereal and soy products than on other types of ingredients (Rhodes, 1975). Two decades later, the trend has been for the pet food industry to rely heavily on animal protein by-products and cereal grains for energy. It has been estimated that between 25 and 40% of the ingredients found in specialty dog foods are by-products of animal origin (Murray et al., 1997). One of the most extensively used ingredients in cat food is poultry by-product meal, while dog food is primarily meat and bone meal (Morris, 1990).

One reason for the inclusion of animal protein is that using plant sources, namely soybean meal, often results in decreased acceptance by cats and increased flatulence of dogs (Morris, 1990). Dogs and cats are carnivores and have digestive tracts adapted to digest and absorb meat. Animal by-products contain considerable amounts of bone, thus are effective sources of both calcium and phosphorous (Morris, 1990). Animal tissue is necessary in providing a source of both arachidonic acid and taurine for cats, which cannot synthesize on their own (Earle and Smith, 1991) (MacDonald et al., 1984). It is expected that in the future the pet food industry will continue to depend heavily on animal by-products as protein sources (Morris, 1990).

Depending on the quality of the pet food, it may contain mostly animal protein, or a portion of plant protein. Commercial dog foods can range from approximately 20%

animal tissue in dry formulations, to approximately 30% in semi-moist diets, and between 75 to 90% in canned foods (NRC, 1985). Combining multiple protein sources, known as protein complementation, is advantageous to improve protein quality (Gross et al., 2000). Most pet foods contain a blend of various protein sources such that the weaknesses of one source are counterbalanced by the strength of another source. Typical protein sources include egg, soybean meal, meat meal, and meat by-products (Tiekert, 1999).

The most predominant form of energy found in commercial pet foods are cereal grains such as corn, wheat, oats, and barley (NRC, 1985). The starch found in these grains provide highly digestible energy, especially after extrusion processing, as the starch becomes gelatinized (Gross et al., 2000).

Although research to determine nutrient requirements for dogs and cats has not been as extensive as that for pigs, commercial pet foods have been shown to support excellent growth, reproduction, and maintenance in companion animals (Morris and Rogers, 1994). It is not surprising that such a by-product could serve as a suitable ingredient in diets for other species, particularly a species with similar digestive tract physiology.

Summary

Pigs have long carried the notion of being able to eat anything; although perhaps not true, pigs are capable of utilizing a diversity of feedstuffs. By-products may be suitable during seasons of high costs or shortages of more typical ingredients. As the amount of refuse is expected to increase with the evergrowing population, new disposal options will need to be implemented to accommodate the excess. Feeding edible wastes or by-products to swine is a means of recycling some of what would end up in a landfill (Myer, 2001).

Using by-products can account for a 40 to 60% reduction in grain use by swine, without compromising performance. However, it has been recommended not to include more than 20% of any by-product in any complete diet (Pond, 1982). The effective use of any by-product requires an understanding of the nutritional value and any limitations or anti-nutritional factors present. Many by-products have already been used extensively as feeds; their use has allowed for more economical livestock production. Yet, there are still numerous valuable feed sources with substantial nutritional value, available inexpensively and in large quantities (NRC, 1983). "Virtually any by-product containing nutrients is a potential feed for animals" (Schingoethe, 1991). Unlike most by-products, PFB consists of many nutrients, as it is formulated feed in itself.

Admittedly, as the costs of traditional feedstuffs escalate, by-products and alternative sources become more attractive to the swine industry (Rea, 1993). Pet food by-product can potentially be incorporated as a means of maximizing the profit margin in pork production, while minimizing competition and pollution.

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Table 2-1 – Comparison of Adult Dog[a] and Nursery Pig[b] Nutrient Requirements

Nutrient	Adult Maintenance Dog	Nursery Pig (5-10 kg)
Protein, %	18.0	23.7
Amino Acids, %		
Arginine	0.51	0.49
Histidine	0.18	0.38
Isoleucine	0.37	0.65
Leucine	0.59	1.20
Lysine	0.63	1.19
Methionine + Cystine	0.43	0.68
Phenylalanine + Tyrosine	0.73	1.12
Threonine	0.48	0.74
Tryptophan	0.16	0.22
Valine	0.39	0.81
Fat, %	5.0	-
Linoleic Acid, %	1.0	0.10
Minerals, %		
Calcium	0.60	0.80
Phosphorous	0.50	0.65
Potassium	0.60	0.28
Sodium	0.06	0.20
Chloride	0.09	0.20
Magnesium	0.04	0.04
Minerals, mg/kg		
Iron	80	100
Copper	7.3	6.0
Manganese	5.0	4.0
Zinc	120	100
Iodine	1.50	0.14
Selenium	0.11	0.30
Vitamins, IU/kg		
A	5000	2200
D	500	220
E	50	16
Vitamins, mg/kg		
Thiamin	1.0	1.0
Riboflavin	2.2	3.5
Pantothenic Acid	10.0	10.0
Niacin	11.4	20.0
Pyridoxine	1.0	1.5
Folic Acid	0.18	0.30

Table 2-1 – Comparison of Adult Dog[a] and Nursery Pig[b] Nutrient Requirements (cont'd)

Nutrient	Adult Maintenance Dog	Nursery Pig (5-10 kg)
Vitamins, mg/kg		
Vitamin B_{12}	0.022	0.018
Choline	1200	500

[a]AAFCO dog food nutrient profiles. Corbin, J. 2001. Pet foods and feeding. Feedstuffs Ref. Issue 73: 70-75.
[b]NRC. 1998. Nutrient requirements of swine, Natl. Acad. Press, Washington, DC.

CHAPTER 3

EVALUATION OF PET FOOD BY-PRODUCT AS AN ALTERNATIVE FEEDSTUFF IN NURSERY PIG DIETS

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Abstract

A total of 368 weanling pigs were used in two experiments to evaluate pet food by-product (PFB) in nursery starter diets on pig performance. In Exp. 1, 288 early-weaned pigs (5.2 kg at 14 d) were used in 2 replicates to determine the effects of replacing animal-protein and energy sources with PFB at 0%, 10%, 30%, and 50% inclusion levels in phase I (d 0 to 7 post-weaning) and phase II (d 7 to 21 post-weaning) diets. There was no effect of PFB in phase I diets. In phase II, ADG and ADFI was increased with PFB inclusion ($p<0.0001$). There was a trend for improved gain:feed ($p<0.10$) also. Serum urea nitrogen values were not different among diets. Post-nursery follow-up indicated that pigs that were fed PFB during the nursery phase maintained a growth advantage into the finisher phase. At wk 22 ($p<0.05$) and wk 26 ($p<0.01$), pigs that were fed PFB were 8-11% heavier than control pigs. There was no significant effect of PFB inclusion on backfat thickness or loin eye area (***longissimus dorsi***) estimates based on realtime ultrasound at wk 28. In Exp. 2, 80 weaned pigs (6.7 kg at 21 d) were used to further evaluate phase II experimental diets. There were no differences in ADG, ADFI, or gain:feed across treatments. Serum urea nitrogen values were similar across treatments, except the 50% PFB inclusion level which yielded significantly greater values. Sixteen barrows were selected for a digestibility trial (d 6 through 13), using chromic oxide as a marker. Dry matter digestibility, protein digestibility, and digestible

energy showed no statistical differences among diets. Considering the essential amino acids, histidine ($p<0.05$), lysine ($p<0.01$), threonine ($p<0.05$), and valine ($p<0.05$) digestibilities were significantly greater as PFB was increased. There was a trend ($p<0.10$) for improved digestibilities of arginine and methionine as PFB increased. These studies demonstrate that pet food by-product can effectively be used as a partial replacement for animal-protein sources and grain energy sources in the diets of young nursery pigs.

Introduction

The purpose of a starter diet in early-weaned pigs is to minimize post-weaning lag, provide a smooth transition to solid feed, and to do so as quickly and effectively as possible (Mavromichalis and Baker, 2001). As a result, most starter diets are formulated for palatability, utilizing many high quality, albeit expensive, ingredients.

Feed costs are the greatest variable expense in swine production. The typical starter diet fed from 10 through 25 kg constitutes 50% of total nursery feed cost (Dritz and Tokach, 2000). Alternative feedstuffs, such as by-products from various industries, can be a cost-effective option. The variety and quantity of by-products is likely to increase with time, while disposal in landfills will become more limited and costly. Thus, the role of pigs as recyclers may become a more important waste-management option (Myer, 2001).

Pet food by-product (PFB) is one ingredient that may be a cost-effective replacement for the more typical expensive animal-protein sources used in nursery diets, namely spray-dried plasma protein, fish meal, and blood cells. It may also serve as an energy source to replace corn or other ingredients. The term by-product is used loosely to describe pet food that has been rejected because it did not meet quality specifications, was damaged during handling, or distributed to a retail outlet and not sold

before the expiration date. The US pet food industry is a $11.8-billion dollar enterprise that continues to expand annually (Corbin, 2001). As more pet food is produced each year, more by-product will become available as an alternative feedstuff.

Replacement of expensive protein sources with lower-cost alternatives requires the assessment of pig performance. The objective of Exp. 1 was to determine the effect of inclusion of pet food by-products in starter rations on the performance of early-weaned pigs (14 d) and to establish a recommendation on the maximum inclusion rate in nursery diets. As growth trials alone do not provide information regarding nutrient utilization, the objective of Exp. 2 was to determine the nutrient digestibility of PFB diets in nursery pigs (21 d).

Experimental Procedure

General. Experimental protocols were approved by the University of Georgia Institutional Animal Care and Use Committee. Pet food by-product was obtained from one source for both trials (Callaway Farms, Rayle, GA). The product was Nutro Natural Choice Large Breed Senior dog food (Nutro Products, Inc., City of Industry, CA). Proximate analysis (CP, CF, EE, DM, Ca, P) of the PFB was performed. Nitrogen content was determined using a nitrogen analyzer (LECO FP-528, LECO Corp., St. Joseph, MI). Separation and analysis of amino acids was performed on an amino acid analyzer (Beckman 6300, Beckman Coulter, Inc., Palo Alto, CA) following acid hydrolysis (Amos et al., 1976). Norleucine was used as the internal standard. Gross energy determination was performed on a bomb calorimeter (Parr 1261, Parr 1563, Parr Instrument Co., Moline, IL). Digestible and metabolizable energies were calculated (Noblet and Perez, 1993). The experimental diets were variations of standard University of Georgia phase I and phase II nursery diets. The inclusion of pet food by-product increased incrementally (0%, 10%, 30%, and 50% inclusion rates, respectively) at the

expense of plasma protein (in phase I diets), blood cells and soybean meal (in phase II diets), fish meal and corn. Dried whey and soybean meal were maintained at 27.50% and 18.75% respectively in phase I diets. Dried whey was also maintained in phase II diets at 10.00%. Diets were formulated to specific lysine requirements (1.50% and 1.35% for phases I and II, respectively) and to maintain relatively constant lysine to energy ratios. However, crude protein increased with higher inclusion levels due to the nature of the product (Table 3-2). All experimental diets were fed in meal form.

Experiment 1. The study was conducted at the University of Georgia Swine Center in two replicates using pigs from consecutive farrowing groups. Two hundred and eighty-eight terminal crossbred pigs (Hampshire x Landrace x Large White/DRU) were weaned at approximately 14 days of age (average weight 5.2 kg). Pigs were housed in pens with dimensions of 1.22 m x 2.84 m. Temperature was maintained at 27.8 ^{o}C. In replicate 1, pigs were allotted on basis of sex, ancestry, and weaning weight into one of 4 dietary treatments into 16 pens with 8 pigs per pen split-sexed. In replicate 2, pigs were allotted similarly, but with 10 pigs per pen. At weaning, pigs were given 0.5 kg/head and 0.25 kg/head in replicates 1 and 2, respectively, of a commercial creep feed (Akey Pig 3000, Akey, Inc., Lewisburg, OH). This was followed with phase I diets from d 0 through 7. At d 7, pig body weights were measured and feeders emptied to measure feed intake. Phase II diets were fed from d 7 through 21. At d 21, pig body weight and feed intake was measured. Pigs were then placed on a common phase III ration (Table 3-3) until d 31, at which time final nursery body weights and feed consumption were measured.

On d 14, blood samples were drawn from four average weight pigs per pen in replicate 1, and two average weight pigs per pen in replicate 2. Blood was drawn again on d 28 on the same pigs. These dates were selected to assay serum urea nitrogen (SUN) concentration to determine protein status (Coma et al., 1995) after being on the

experimental diets for 2 wks, and after returning to a common diet for 7 d. After centrifugation, blood serum was removed and frozen for later analysis. A commercial kit was utilized to measure endpoint SUN concentration indirectly by coupled enzyme reactions involving urease and glutamate dehydrogenase (Sigma BUN endpoint kit, Sigma Diagnostics, Inc., St. Louis, MO).

From each replicate, 64 pigs (four average weight pigs per pen) were ear tagged for further follow-up after the nursery phase. These pigs were weighed at 12, 17, 22 and 26 weeks of age. Realtime ultrasound was performed at approximately 28 weeks (average weight 95.2 kg) at the 10^{th} rib to measure backfat thickness and loin eye area (***longissimus dorsi***) (Aloka 500, Aloka 633, Aloka Co., Ltd., Wallingford, CT).

Experiment 2. The study was conducted at the University of Georgia Large Animal Research Unit. Eighty crossbred pigs (Hampshire x Landrace x Large White/DRU) were weaned at approximately 21 days of age (average weight 6.7 kg). Pigs were housed in a nursery growth room in pens with dimensions of 0.94 m x 1.83 m. Temperature was maintained at 27.2 ^{o}C. Pigs were allotted on basis of sex, ancestry, and weaning weight into one of 4 dietary treatments into 16 pens with 4 pigs per pen mixed-sex. Four additional pens were allotted with 4 barrows each which were later used in the digestibility trial. At weaning, piglets were placed on a common first-phase ration (Table 3-3) from d 0 through 6. At d 6, pig body weights were measured and feeders emptied to measure feed intake. The same experimental phase II diets fed in Exp. 1 (Table 3-2) were fed from d 6 through 22, with the exception of 0.25% chromic oxide inclusion as an external indicator. At d 13 and d 22, pig body weight and feed intake were measured. Pigs were then placed on a common phase III diet (Table 3-3) for 7 d, when final body weights and feed consumption were measured.

On d 6, the 4 pens of barrows were moved to the metabolism room in the UGA Large Animal Research Unit. Pigs were individually housed in stainless steel

metabolism crates measuring 0.71 m H x 0.59 m W x 0.81 m D. Temperature was maintained at 27.2 ^{o}C. Pigs were fed ad libitum twice daily during the 6-day adjustment period. Water was freely accessible at all times. During the 4-day collection period, feed was offered ad libitum throughout the day. In the evening, pigs were taken off feed, and fecal screens and trays cleaned. This was done to prevent contamination of fecal samples with feed. Every morning feces were collected and frozen. At the end of the collection period, fecal samples were composited for each individual pig across the 4-day collection. Samples were freeze-dried, finely ground, and kept in a dessicator under constant vacuum to prevent any moisture return until analysis.

On d 21, blood samples were drawn from 2 average weight pigs per pen in the growth trial, and all 16 pigs housed in the metabolism crates. After centrifugation, blood serum was removed and frozen for later analysis of SUN (Coma et al., 1995). A commercial kit was utilized to measure endpoint SUN concentration indirectly by coupled enzyme reactions involving urease and nitroprusside (Sigma BUN endpoint kit, Sigma Diagnostics, Inc., St. Louis, MO).

To determine digestibility, fecal and diet samples were digested with a sodium molybdate-perchloric acid mixture until a color change occurred. Chromic oxide content was determined by assessing the sample absorbance on a UV spectrophotometer (UV160U, Shimadzu Corp., Columbia, MD) (Fenton and Fenton, 1979). In addition, energy, protein, and individual amino acid digestibility was determined using procedures mentioned previously on diet and fecal samples.

Statistical Analysis. Data was analyzed using the General Linear Models procedure (PROC GLM) of SAS (SAS Institute, Inc., Cary, NC). Experiment 1 was analyzed as a 4 by 2 factorial with treatment and gender as factors. Experiment 2 was a randomized block design with 4 treatments. The experimental unit in both trials was pen. Least squares means, probabilities of differences, and standard errors of the

means were obtained to evaluate differences among treatment means. Differences were considered significant at $p<0.05$, whereas a trend was suggested at $p<0.10$. For parameters which were deemed significantly different, a linear contrast was used to compare the control diet versus any level of PFB inclusion.

Results

Pet Food By-Product Analysis. Proximate analysis of PFB indicated potential as a high quality feedstuff (Table 3-1). All values have been reported on an as-fed basis. Dry matter content was 92.8%. Nitrogen content was 3.35%, yielding a CP value of 20.94%. Fat content as estimated by ether extract value was 8.29%. Gross energy was used to calculate an ME value of 3980 kCal/kg. Calcium and phosphorous content were 0.82% and 0.84%, respectively. The amino acid profile of PFB complements nursery pig nutrient requirements (Table 3-1).

Experiment 1. From d 0 through 7 post-weaning (phase I), no differences in any parameter of pig performance were observed for pigs fed the experimental diets. From d 7 through 21 (phase II), ADG and ADFI increased with pet food inclusion ($p<0.0001$, Table 3-4). On d 21, pigs fed 10% PFB were 1.0 kg heavier than the control pigs (9.15 vs. 8.16 kg, respectively, $p<0.0001$). There was a trend for improved feed efficiencies ($p<0.10$) with 10% and 30% PFB inclusion. With 50% inclusion PFB, gain:feed did not differ from the control.

When all pigs were fed a common diet (d 21 through 31 after weaning), no differences were observed. Similarly, there were no differences in overall nursery performance from weaning through d 31. There was no effect of sex and no interaction between sex and treatment across any parameter.

Serum urea nitrogen concentrations did not differ across treatments (Table 3-5) after being fed experimental diets for 2 wks (d 14), or upon returning to a common diet

for 1 wk (d 28). There was, however, a numerical decrease in SUN concentration at d 14 with PFB inclusion.

In the post-nursery phase, there were no significant differences observed in wk 6 body weights (Table 3-6). At wk 12, pigs that consumed 10% or 30% PFB during the nursery phase were approximately 7% heavier than control pigs ($p<0.05$). The 50% inclusion level was not statistically different from the control. No differences were reported for wk 17. At wk 22, pigs that were fed PFB averaged 8-11% heavier than control pigs ($p<0.05$), with the 30% inclusion as the heaviest group. This was also apparent in wk 26 ($p<0.01$). There was a trend for a sex effect ($p<0.10$) noted at wks 6, 12, and 17, and a marked sex effect ($p<0.05$) at wks 22 and 26, with barrows being heavier than gilts. Considering ADG from wk 6 through 26, as well as wean through wk 26, pigs that were fed any level of PFB had increased ADG ($p<0.005$). There was also evidence of a 3-way treatment by sex by replicate interaction noted at wks 17 ($p<0.10$) and 22 ($p<0.01$). Barrows in both replicates exhibited a linear response to PFB inclusion, whereas the gilts did not. The cause is unknown. At wk 26, the 3-way interaction was no longer present

Estimates of carcass composition based on ultrasound indicated no significant effect of nursery diet on backfat thickness (Table 3-6). There was a trend, however, for differences in loin eye area between treatments ($p<0.10$). Larger loin eye area were associated with the 10% and 30% inclusion levels. The 50% inclusion level, although numerically greater, was not different from the control. There was a marked sex effect ($p<0.001$) in 10th rib back fat thickness, with barrows averaging nearly 26% thicker than gilts. There were no interactions between treatment and sex. When adjusted to market weight (109 kg) as per Guidelines for Uniform Swine Improvement Federation (NSIF, 2002), there were no treatment effects on backfat, loin eye area, or predicted percent lean tissue. A linear contrast of no PFB versus any level of PFB inclusion showed some

differences in loin area (control = 35.05 vs. PFB = 37.39, $p<0.10$) and predicted lean (control = 47.87 vs. PFB = 49.20, $p<0.10$).

Experiment 2. Given the results of Exp. 1, focus was placed on Phase II diets in Exp. 2. There were no observed statistical differences in any performance parameter across any of the treatments (Table 3-7). During wk 1 (d 6 through 13) of phase II, pigs on PFB had numerically higher ADG values than the control group, whereas in wk 2 (d 13 through 22), their performance was numerically less than that of control piglets. Overall nursery performance also did not differ across treatment groups. There were no effects of sex and no interactions between sex and treatment for any parameter.

Serum urea nitrogen concentrations were affected by treatment ($p=.05$, Table 3-5), with the 50% inclusion being statistically higher than the other treatment means. Although the control, 10% and 30% treatments were not different, the 10% inclusion level was numerically lowest.

All digestibility values are reported on a dry-matter basis. There were no statistical differences among diets for dry matter and protein digestibility (Table 3-8). There was a numerical increase in total dry matter digestibility and protein digestibility, with the peaks at the 10% and 50% inclusion levels, respectively. Considering the essential amino acids, histidine ($p<0.05$), lysine ($p<0.01$), threonine ($p<0.05$), and valine ($p<0.05$) digestibilities were significantly greater as PFB was increased. There was a trend ($p<0.10$) for improved digestibilities of arginine and methionine as PFB was increased also. There were also a number of significant differences for the non-essential amino acids. Tryptophan, although typically a limiting amino acid in swine diets, could not be reported due to the methodology. Acid hydrolysis causes significant losses of tryptophan (Finley, 1985). Tyrosine, although not destroyed, is not reported due to high experimental error. Digestible energy was reported as percent digestibility because the indicator method of digestibility was used. Total fecal collections would be

needed to calculate absolute digestible energy. There were no observed differences in percent digestible energy between diets.

Discussion

Pet food by-product was an effective replacement for more expensive animal protein sources in nursery diets and may result in other long-term benfits, such as less days to market weight. The results of Exp. 1 show a significant improvement in BW, ADG and ADFI in pigs fed PFB during the phase II period. This ADG improvement may be a function of increased palatability and hence. This observation was not duplicated in Exp. 2. Two possible explanations for this lack of replication are smaller sample size (n=288 in Exp. 1, n=80 in Exp. 2) and differences in weaning age. In Exp. 1, pigs were weaned at approximately 2 wks of age, whereas pigs in Exp. 2 were 3 wks at weaning. The longer period of time spent with the sow allows the digestive system more time to develop before consuming non-milk feedstuffs. Earlier research demonstrated that the substitution of soybean meal for milk protein at 75% of dietary protein reduces ADG and feed efficiency by 85% in pigs 7 to 14 d old, but only 31% in pigs 21 to 28 d old (Wilson and Leibholz, 1981).

There was no effect of PFB in phase I diets. It may be necessary to feed phase I diets for a longer period of time to detect performance differences. However, the experimental diets supported piglet performance equally well as the control. Given the reduced diet cost as a function of using a by-product, PFB is still a viable alternative.

Feed efficiency values were not statistically different across treatments in both experiments, with the exception of a trend for improved efficiencies in pigs fed PFB in the phase II period of Exp. 1. It has been suggested that lean gain is well correlated with gain:feed (Whang and Easter, 2000). Hence, the slight improvement in feed efficiencies may be indicative of greater lean tissue accretion in pigs consuming PFB.

Serum urea nitrogen values in Exp. 1 were not different. Puchal et al. (1962) indicated that porcine plasma urea values to be inversely proportional to weight gain and feed efficiency. More recent research further supported a strong inverse relationship between SUN concentration and lean growth (Coma et al., 1995). This suggests that the animal with a lower SUN concentration is in a greater anabolic state, supported by the significantly higher ADG and trend for improved gain to feed exhibited in phase II.

In Exp. 2, pigs fed PFB at the 50% inclusion level had significantly greater SUN concentrations. This is indicative of excess protein consumption. It was expected that a higher SUN level would have been observed in both experiments, due to excess dietary protein in experimental diets. The reason for this inconsistency is unknown. However, the lowest SUN concentration was demonstrated by the 10% PFB inclusion, as in Exp. 1, supporting the idea that pigs fed this level of PFB were in optimal protein status.

Although it was demonstrated that PFB inclusion diets have a valuable effect on nursery performance, it must be recognized that there are other factors to consider. Other research has shown that weaning heavier pigs has a greater effect on post-weaning performance than the feeding of a complex nursery diet (Mahan et al., 1998). The benefit of these trials was that the lightest and heaviest weight pigs were not used, thus variability was minimized, allowing more conclusions to be drawn regarding the experimental diets.

Pigs that are heavier at the end of the nursery period tend to continue this advantage into the grower phase, although not necessarily into the finisher phase (Mahan et al., 1998). This is consistent with Exp. 1, as the heaviest pigs leaving the nursery phase were either fed 10% or 30% levels of PFB (13.96 and 14.13 kg, respectively, compared to the control at 13.41 kg). Six wks later, these groups were still the heaviest (31.29 and 32.54 kg, respectively, compared to the control at 29.70 kg). However, it was observed in this study that pigs maintained this advantage into the

finisher phase with a final net difference of approximately 10 kg between the 10% inclusion and the control. The gender differences in growth and body composition are typical in finisher pigs (Cromwell et al., 1993).

In terms of carcass evaluation, there was a trend for greater loin eye areas in pigs fed PFB, but no effect on back fat at the 10th rib. No effect was observed in data adjusted to equal market weight of 109 kg. This is indicative that the composition of growth was not detrimentally affected by the inclusion of PFB. Other nursery feeding programs, such as those using liquid diets, have been shown to accelerate growth to market weight, with no difference observed in back fat or loin area upon ultrasound (Kim et al., 2001). The suggestion of greater loin area is too preliminary and in need of further verification. Again, the reported sex effect in back fat thickness is typical of finisher pigs (Cromwell et al., 1993).

A numerical improvement in digestibility was observed in diets that contained PFB. This perhaps can be accounted for by the small increase in energy content of the 30% and 50% inclusion diets, associated with higher fat content. Increased fat intake tends to increase digestibility by decreasing passage rate through the digestive tract (Mateos et al., 1982). Another plausible explanation for the increased digestibility is the additional processing that pet food undergoes. Extrusion processing is used in more than 95% of dry-type pet food being processed by extrusion (Corbin, 2001). Extrusion improves animal performance. Extrusion improves energy and nitrogen digestibility in young pigs fed sorghum grain, and increases metabolizable energy of soybeans. (Noland, 1976). Herkelman et al. (1990) showed no change in protein digestibility when young pigs are fed extruded versus non-extruded yellow corn. However, digestible energy and metabolizable energy values were greater in diets containing extruded corn (Herkelman et al., 1990). Although results are variable when considering different ingredients and nutrients, extrusion has benefit on nutrient utilization of animals.

Implications

These studies demonstrate that pet food by-product can be used as a partial replacement for expensive animal-origin protein and energy sources in diets for weanling pigs. The suggested inclusion level currently is no greater than 30% based on maximizing pig performance. The 50% inclusion level, however minimizes cost per unit gain and is still advantageous. As always, conventional feed markets will determine the degree of use. Increases are likely if the market price of PFB remains consistently lower than typical ingredients.

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Table 3-1 – Proximate Analysis of Pet Food By-Product (as-fed basis)

Nutrient	Content
ME, kCal/kg[a]	3980
CP, %	20.94
CF, %	1.7
EE, %	8.29
DM, %	92.8
Ash, %	5.65
Ca, %	0.82
P, Total %	0.84
K, %	0.74
Na, %	0.22
Cl, %	0.32
Mg, %	0.15
Mn, mg/kg	85.8
Fe, mg/kg	151.8
Cu, mg/kg	4.4
Zn, mg/kg	292.6
Amino Acids:	
Essential:	
Arginine, %	1.60
Histidine, %	0.53
Isoleucine, %	0.90
Leucine, %	1.59
Lysine, %	1.25
Methionine, %	0.45
Phenylalanine, %	0.97
Threonine, %	0.82
Valine, %	1.05
Non-Essential:	
Alanine, %	1.28
Aspartate, %	1.89
Cystine, %	0.09
Glutamate, %	3.66
Glycine, %	1.60
Proline, %	1.20
Serine, %	0.89

[a]Calculated value.

Table 3-2 – Composition of Experimental Nursery Diets (as-fed basis)

Treatment	Control	10%	30%	50%
PHASE I, Exp. 1				
Ingredient, %				
Corn	39.29	32.71	17.60	1.16
Whey	27.50	27.50	27.50	27.50
Soybean Meal	18.75	18.75	18.75	18.75
PFB	-	10.00	30.00	50.00
Plasma Protein	5.00	4.00	2.00	-
Fish Meal	3.00	2.40	1.20	-
Fat	2.89	1.31	-	-
Limestone	0.54	0.50	0.34	0.19
Dical Phosphate	1.02	0.85	0.66	0.48
Zinc Oxide	0.38	0.38	0.38	0.38
Vitamin Premix[a]	0.25	0.25	0.25	0.25
TM Premix[b]	0.15	0.15	0.15	0.15
Antibiotic[c]	1.00	1.00	1.00	1.00
L-Lysine HCl	0.14	0.12	0.09	0.07
DL-Methionine	0.10	0.09	0.08	0.07
DL-Tryptophan	-	-	-	0.01
Calculated Composition				
CP, %	21.68	22.06	22.68	23.20
Lysine, %	1.50	1.50	1.50	1.50
Met + Cys, %	0.90	0.90	0.90	0.90
Tryptophan, %	0.26	0.26	0.27	0.26
Threonine, %	0.97	0.97	1.05	1.02
Ca, %	0.90	0.90	0.90	0.90
Avail P, %	0.59	0.59	0.59	0.59
ME, kCal/kg	3300	3300	3383	3525

Table 3-2 – Composition of Experimental Nursery Diets (as-fed basis, cont'd)

Treatment	Control	10%	30%	50%
PHASE II, Exp. 1 and 2				
Ingredient, %				
Corn	52.94	47.13	33.31	18.97
Soybean Meal	25.09	23.76	21.27	18.04
Whey	10.00	10.00	10.00	10.00
PFB	-	10.00	30.00	50.00
Fat	2.83	1.23	-	-
Fish Meal	2.50	2.00	1.00	-
Blood Cells	2.50	2.00	1.00	-
Limestone	0.49	0.51	0.41	0.34
Dical Phosphate	1.92	1.69	1.33	0.97
Zinc Oxide	0.25	0.25	0.25	0.25
Vitamin Premix	0.25	0.25	0.25	0.25
TM Premix	0.15	0.15	0.15	0.15
Antibiotic	1.00	1.00	1.00	1.00
L-Lysine HCl	-	-	-	0.03
DL-Methionine	0.07	0.05	0.02	-
Chromic oxide[d]	***0.05***	***0.05***	***0.05***	***0.05***
Calculated Composition				
CP, %	21.77	22.06	22.22	22.13
Lysine, %	1.35	1.35	1.35	1.35
Met + Cys, %	0.81	0.81	0.81	0.81
Tryptophan, %	0.27	0.26	0.26	0.24
Threonine, %	0.93	0.94	0.94	0.92
Ca, %	0.90	0.90	0.90	0.90
Avail P, %	0.54	0.54	0.54	0.59
ME, kCal/kg	3300	3300	3389	3533

[a]The vitamin premix provided the following per kilogram of complete diet: 11000 IU vitamin A, 1650 IU vitamin D, 44 IU vitamin E, 4.4 mg vitamin K, 9.9 mg riboflavin, 55 mg niacin, 33 mg pantothenic acid, 44 ug vitamin B_{12}.
[b]The trace mineral premix provided the following per kilogram of complete diet: 165 mg iron, 16.5 mg copper, 39.6 mg manganese, 165 mg zinc, 0.3 mg iodine, and 0.3 mg selenium.
[c]Aureomycin 50, Hoffman-La Roche, Nutley, NJ.
[d]Phase II diets for Exp. 2 were identical to those in Exp. 1 with the addition of chromic oxide as an external indicator to determine digestibility.

Table 3-3 – Composition of Common Nursery Diets (as-fed basis)

	PHASE I, Exp. 2	PHASE III, Exp. 1 and 2
Ingredient, %		
Corn	39.25	62.95
Whey	27.5	-
Soybean Meal	18.75	29.5
Plasma Protein	5.0	-
Fish Meal	3.0	-
Fat	2.9	3.0
Limestone	0.5	0.65
Dical Phosphate	1.1	-
Zinc Oxide	0.375	-
Vitamin Premix[a]	0.25	0.25
TM Premix[b]	0.15	0.15
Antibiotic[c]	1.0	1.0
L-Lysine HCl	0.135	0.2
DL-Methionine	0.095	0.045
Calculated Composition		
CP, %	22.07	19.86
Lysine, %	1.50	1.25
Met + Cys, %	0.90	0.75
Tryptophan, %	0.26	0.21
Threonine, %	1.01	0.81
Ca, %	0.90	0.75
Avail P, %	0.59	0.39
ME, kCal/kg	3300	3300

[a]The vitamin premix provided the following per kilogram of complete diet: 11000 IU vitamin A, 1650 IU vitamin D, 44 IU vitamin E, 4.4 mg vitamin K, 9.9 mg riboflavin, 55 mg niacin, 33 mg pantothenic acid, 44 ug vitamin B_{12}.
[b]The trace mineral premix provided the following per kilogram of complete diet: 165 mg iron, 16.5 mg copper, 39.6 mg manganese, 165 mg zinc, 0.3 mg iodine, and 0.3 mg selenium.
[c]Phase I – Apralan 7.5, Elanco Animal Health, Indianapolis, IN.
Phase III - Mecadox 22, Pfizer, Inc., Ann Arbor, MI.

Table 3-4 – Effect of PFB in Phase I and Phase II Diets on Nursery Pig Performance (Exp. 1)

Treatment	Control	10%	30%	50%	SEM	P
Body Weight, kg						
Wean	5.21	5.13	5.14	5.17	0.07	NS
Day 7	5.64	5.62	5.65	5.70	0.06	NS
Day 21	8.16[a]	9.15[b]	9.02[b]	8.83[b]	0.13	0.0001
Day 31	13.23	13.52	13.69	13.46	0.24	NS
Gain, g/d						
Wean – Day 7	68	65	70	77	8.6	NS
Day 7 – Day 21	180[a]	249[b]	240[b]	223[b]	7.5	0.0001
Day 21 – Day 31	494	437	468	463	16.4	NS
Wean – Day 31	261	269	275	267	7.9	NS
Feed Intake, g/d						
Wean – Day 7	178	177	183	203	12.1	NS
Day 7 – Day 21	339[a]	431[b]	409[b]	410[b]	10.5	0.0001
Day 21 – Day 31	754	746	760	737	23.3	NS
Wean – Day 31	435[a]	473[b]	471[b]	465[b]	10.3	0.06
Gain:Feed						
Wean – Day 7	0.373	0.379	0.352	0.393	0.039	NS
Day 7 – Day 21	0.530[a]	0.579[bc]	0.590[c]	0.547[ab]	0.017	0.10
Day 21 – Day 31	0.653	0.585	0.615	0.638	0.024	NS
Wean – Day 31	0.599	0.569	0.585	0.578	0.016	NS

Results represent least squares means for a total of 288 pigs in 32 split-sex pens of 8-10 pigs each.
Means within a row lacking a common superscript letter differ at respective p-level.

Table 3-5 – Effect of PFB Inclusion on Serum Urea Nitrogen Values (Exp. 1 and 2)

Treatment	Control	10%	30%	50%	SEM	P
SUN, mg/dL						
Exp. 1						
Day 14	17.38	16.83	17.27	16.96	0.20	NS
Day 28	17.64	18.13	18.05	17.98	0.18	NS
Exp. 2						
Day 21	17.38[a]	16.85[a]	17.81[a]	20.56[b]	1.05	0.05

Results represent least squares means for a total of 96 pigs in Exp. 1, and 48 pigs in Exp. 2.
Means within a row lacking a common superscript letter differ at respective p-level.

Table 3-6 – Effect of PFB in Nursery Diets on Post-Nursery Pig Performance (Exp. 1)

Treatment	Control	10%	30%	50%	SEM	P Diet	P Gender
Body Weight, kg							
Week 6	13.41	13.96	14.13	13.51	0.33	NS	0.10
Week 12	29.70[a]	31.29[ab]	32.54[b]	29.48[a]	0.87	0.05	0.10
Week 17	50.90	53.66	54.61	52.79	1.61	NS	0.10
Week 22	69.77[a]	76.45[b]	77.52[b]	75.41[b]	2.08	0.05	0.01
Week 26	80.78[a]	89.23[b]	94.00[b]	92.89[b]	3.05	0.01	0.05
Gain, kg/d							
Week 6 – Week 26	0.485[a]	0.537[b]	0.572[b]	0.565[b]	0.05	0.05	0.10
Wean – Week 26	0.415[a]	0.462[b]	0.488[b]	0.482[b]	0.05	0.05	0.05
Carcass							
Backfat, cm	2.08	2.17	2.22	2.06	0.13	NS	0.001
Loin eye area, cm^2	30.61[a]	34.62[b]	34.67[b]	31.62[ab]	1.42	0.10	NS
Adjusted Carcass							
Backfat, cm	2.75	2.67	2.64	2.59	0.15	NS	0.05
Loin eye area, cm^2	35.05	37.87	37.38	36.93	1.15	NS	0.05
Predicted lean, %	47.87	49.25	49.18	49.16	0.65	NS	0.001

Results represent least squares means for a total of 128 pigs, approximately 32 per treatment.
Means within a row lacking a common superscript letter differ at respective p-level for diet.
Gender differences were apparent at respective p-level for gender.
Carcass values adjusted to market weight (109 kg).

Table 3-7 – Effect of PFB in Phase II Diets on Nursery Pig Performance (Exp. 2)

Treatment	Control	10%	30%	50%	SEM	P
Body Weight, kg						
Wean	6.82	6.91	6.90	6.84	0.23	NS
Day 6	7.96	8.06	7.94	8.17	0.26	NS
Day 13	8.90	9.41	8.99	9.19	0.35	NS
Day 22	12.91	12.85	12.77	12.97	0.48	NS
Day 29	17.35	17.46	17.47	17.42	0.63	NS
Gain, g/d						
Wean – Day 6	191	192	173	221	0.020	NS
Day 6 – Day 22	324	315	309	310	0.019	NS
Day 6 – Day 13	***168***	***212***	***185***	***169***	***0.022***	***NS***
Day 13 – Day 22	***445***	***427***	***391***	***419***	***0.031***	***NS***
Day 22 – Day 29	593	612	658	580	0.046	NS
Wean – Day 29	363	364	363	365	0.018	NS
Feed Intake, g/d						
Wean – Day 6	220	218	211	225	0.013	NS
Day 6 – Day 22	490	469	478	431	0.042	NS
Day 6 – Day 13	***295***	***303***	***268***	***281***	***0.026***	***NS***
Day 13 – Day 22	***642***	***600***	***651***	***549***	***0.056***	***NS***
Day 22 – Day 29	968	939	987	996	0.037	NS
Wean – Day 29	540	526	527	520	0.035	NS

Table 3-7 – Effect of PFB in Phase II Diets on Nursery Pig Performance (Exp. 2, cont'd)

Treatment	Control	10%	30%	50%	SEM	P
Gain:Feed						
Wean – Day 6	0.873	0.871	0.835	0.993	0.051	NS
Day 6 – Day 22	0.661	0.668	0.647	0.751	0.061	NS
Day 6 – Day 13	***0.383***	***0.603***	***0.451***	***0.353***	***0.103***	***NS***
Day 13 – Day 22	***0.691***	***0.561***	***0.578***	***0.851***	***0.131***	***NS***
Day 22 – Day 29	0.621	0.676	0.633	0.606	0.040	NS
Wean – Day 29	0.660	0.692	0.647	0.751	0.025	NS

Results represent least squares means for a total of 64-80 pigs in 16-20 pens of 4 pigs each.
Means within a row lacking a common superscript letter differ at respective p-level.

Table 3-8 – Digestibility of Pet Food in Phase II Diets (dry-matter basis, Exp. 2)

Treatment	Control	10%	30%	50%	SEM	P
Dry Matter Digestibility, %	81.92	84.97	82.22	83.70	1.09	NS
Protein Digestibility, %	86.45	86.94	87.13	89.01	0.78	NS
Amino Acid Digestibility, %						
Essential:						
Arginine, %	74.75[a]	79.58[b]	78.22[ab]	81.25[b]	1.51	0.10
Histidine, %	79.94[a]	83.72[ab]	83.11[a]	87.75[b]	1.49	0.05
Isoleucine, %	88.08	88.12	87.64	89.86	0.82	NS
Leucine, %	84.48	86.20	85.62	88.02	1.07	NS
Lysine, %	86.17[a]	87.64[a]	88.43[a]	91.75[b]	0.80	0.01
Methionine, %	85.87[a]	91.56[b]	90.15[b]	91.75[b]	1.52	0.10
Phenylalanine, %	85.45	88.05	87.31	88.91	1.04	NS
Threonine, %	85.12[a]	87.07[a]	86.21[a]	91.33[b]	1.30	0.05
Valine, %	84.53[a]	86.51[a]	85.59[a]	91.75[b]	1.49	0.05
Non-Essential:						
Alanine, %	84.79[a]	86.49[a]	86.56[a]	90.94[b]	1.42	0.05
Aspartate, %	81.23[a]	84.26[a]	84.23[a]	90.70[b]	1.53	0.01
Cystine, %	81.43[a]	85.73[b]	83.44[ab]	92.43[c]	1.32	0.001
Glutamate, %	75.69[a]	78.67[a]	78.03[a]	86.34[b]	2.23	0.05
Glycine, %	83.37[a]	85.46[ab]	82.77[a]	89.27[b]	1.66	0.10
Proline, %	77.93[a]	81.26[ab]	78.09[a]	86.71[b]	2.20	0.05
Serine, %	79.11[a]	82.99[a]	81.79[a]	89.14[b]	1.85	0.05
Digestible Energy, %	84.20	86.67	84.45	84.83	0.94	NS

Results represent least squares means for 16 barrows with 4 per treatment.
Means within a row lacking a common superscript letter differ at respective p-level.

CHAPTER 4

CONCLUSIONS

A series of trials were conducted to evaluate pet food by-product (PFB) as an alternative feedstuff in nursery pig diets. The addition of PFB improved weanling pig performance during phase II at all inclusion levels. Performance was maximized with 10% and 30% inclusion. No significant differences were seen in phase I with PFB inclusion nor in phase III while on a common diet. Yet, PFB supported performance equally well as the control diet. This is very positive considering the cost-effectiveness of PFB. Advantages of PFB in phase II were at least partially maintained in phase III. Serum urea nitrogen concentrations, acknowledged to be inversely correlated to protein status, were not significant. Post-nursery phase follow-up revealed that pigs which performed better during the nursery phase maintained this advantage through the grower and finisher phases. No detrimental effect of previous diet on estimates of carcass composition was observed.

A second performance trial showed no performance advantage as a result of feeding PFB in phase II diets, nor in overall nursery performance on ADG, ADFI, and G:F. Protein digestibility, dry matter digestibility, and digestible energy were not significantly different between diets. There was a significant improvement in digestibility for nearly all amino acids as PFB inclusion increased, with the 50% inclusion yielding the highest values. Serum urea concentrations of pigs fed 50% PFB were greater than the other diets, suggesting that these pigs were in a state of protein excess. The lower

inclusion levels were not different from the control, suggesting optimal protein status despite dietary excess.

These findings suggest that the incorporation of PFB into starter pig diets may provide a pronounced improvement on early-weaned growth rate. There is also evidence of maintaining this advantage through the production cycle. Nonetheless, even when no significant differences were observed, this is good news. PFB has proved to be as effective as other specialty ingredients, but at much lower cost.

As with all by-products, the success of their use imparts the swine industry with alternatives for conventional ingredients. Least-cost alternatives can be an attractive consideration, while curtailing ingredient competition and waste accumulation.

APPENDIX A

TABLES

Table A-1 – Analyzed Composition of Experimental Diets (as-fed basis, Exp. 1)

Treatment	Control	10%	30%	50%
PHASE I				
CP, %	20.7	20.4	20.4	22.5
CF, %	1.50	1.90	-	-
EE, %	4.25	3.51	3.39	4.14
DM, %	88.7	88.8	90.2	90.3
Ca, %	1.00	0.95	1.00	1.20
P, Total %	0.78	0.72	0.75	0.91
Amino Acids, %				
Essential:				
Arginine	1.07	1.24	1.16	0.18
Histidine	0.47	0.53	0.52	0.46
Isoleucine	1.60	1.76	1.74	1.50
Leucine	0.78	0.90	0.92	0.80
Lysine	1.19	1.67	1.28	1.16
Methionine	0.41	0.58	0.29	0.32
Phenylalanine	1.01	1.12	0.87	0.64
Threonine	0.82	0.94	0.91	0.83
Valine	0.88	1.02	1.02	0.90
Non-Essential:				
Alanine	0.95	1.09	1.08	1.02
Aspartate	1.72	1.98	2.12	1.84
Cystine	0.09	0.11	0.10	0.07
Glutamate	4.49	4.87	4.32	3.54
Glycine	0.82	1.00	0.12	1.07
Proline	1.24	1.39	1.18	0.90
Serine	0.98	1.11	1.05	0.90
Tyrosine	0.69	0.77	0.65	0.66
Fatty Acids, mg/g				
C 16:0	5.39	3.76	3.71	5.29
C 16:1	1.28	0.78	0.74	1.23
C 18:0	1.14	0.85	0.89	1.35
C 18:1	8.02	5.60	5.72	8.54
C 18:2	7.76	6.10	6.83	8.11
C 18:3	0.41	0.28	0.31	0.30

Table A-1 – Analyzed Composition of Experimental Diets (as-fed basis, Exp. 1, cont'd)

Treatment	Control	10%	30%	50%
PHASE II				
CP, %	19.0	20.4	22.9	22.2
CF, %	1.60	-	-	-
EE, %	6.01	5.76	4.19	4.81
DM, %	87.9	88.6	89.0	89.4
Ca, %	1.20	0.85	0.92	1.10
P, Total %	0.86	0.59	0.67	0.92
Amino Acids, %				
Essential:				
Arginine	1.16	1.06	0.94	0.97
Histidine	0.56	0.56	0.54	0.49
Isoleucine	0.78	1.25	1.69	1.56
Leucine	1.78	1.28	0.80	0.76
Lysine	1.18	1.15	1.16	1.29
Methionine	0.30	0.32	0.30	0.31
Phenylalanine	0.99	0.89	0.80	0.72
Threonine	0.82	0.80	0.82	0.77
Valine	0.94	0.94	0.94	0.89
Non-Essential:				
Alanine	1.11	1.07	1.09	1.06
Aspartate	1.91	1.85	1.96	1.81
Cystine	0.23	0.23	0.09	0.04
Glutamate	3.65	3.51	3.70	3.50
Glycine	0.88	0.84	1.03	1.09
Proline	1.96	0.92	1.01	0.86
Serine	0.96	0.93	0.98	0.92
Tyrosine	0.57	0.62	0.72	0.70
Fatty Acids, mg/g				
C 16:0	5.65	4.07	5.42	4.43
C 16:1	1.29	0.77	1.11	0.94
C 18:0	1.27	0.94	1.28	1.17
C 18:1	8.59	6.08	8.58	7.26
C 18:2	9.03	8.17	10.70	7.34
C 18:3	0.45	0.40	0.40	0.24

Table A-2 – Analyzed Composition of Experimental Diets (as-fed basis, Exp. 2)

Treatment	Control	10%	30%	50%
PHASE II				
CP, %	22.1	21.5	23.3	22.6
CF, %	1.50	1.70	2.00	1.70
EE, %	4.90	4.40	4.01	4.83
DM, %	88.4	88.6	89.2	89.9
Ca, %	1.00	1.30	1.30	1.40
P, Total %	0.82	0.82	0.88	0.93
Amino Acids, %				
Essential:				
Arginine	1.31	0.94	1.06	1.22
Histidine	0.66	0.58	0.59	0.49
Isoleucine	0.83	0.85	0.92	0.88
Leucine	2.20	2.05	2.20	2.09
Lysine	1.41	1.24	1.26	1.05
Methionine	0.42	0.26	0.30	0.31
Phenylalanine	1.32	1.21	1.27	0.88
Threonine	1.27	1.21	1.27	0.88
Valine	1.46	1.38	1.45	0.99
Non-Essential:				
Alanine	1.73	1.65	1.81	1.28
Aspartate	3.25	2.89	3.06	2.01
Cystine	0.15	0.13	0.15	0.10
Glutamate	5.92	5.61	6.11	4.45
Glycine	1.40	1.37	1.58	1.16
Proline	1.71	1.61	1.80	1.31
Serine	1.65	1.52	1.57	1.06
Tyrosine	0.68	0.11	0.13	0.14
Fatty Acids, mg/g				
C 16:0	4.36	3.80	5.26	4.74
C 16:1	0.82	0.66	1.01	0.95
C 18:0	0.97	0.85	1.16	1.23
C 18:1	6.57	5.73	7.56	7.77
C 18:2	7.80	7.53	10.40	8.58
C 18:3	0.42	0.40	0.34	0.34

APPENDIX B

FIGURES

Figure B-1 – Effect of PFB in Phase II Diets on Nursery Pig Performance (Exp. 1)

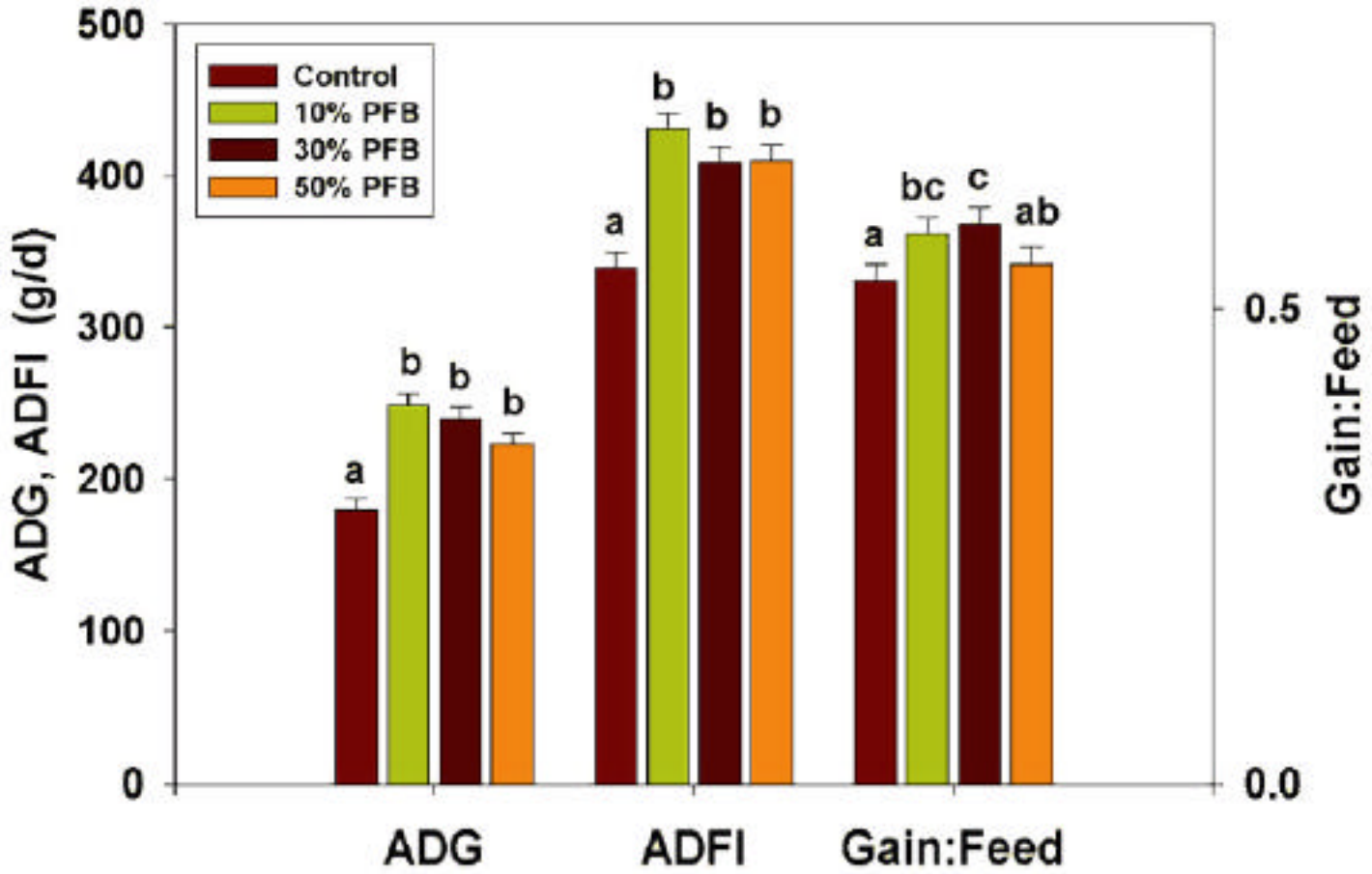

Figure B-2 – Effect of PFB in Nursery Diets on Overall Nursery Pig Performance (Exp. 1)

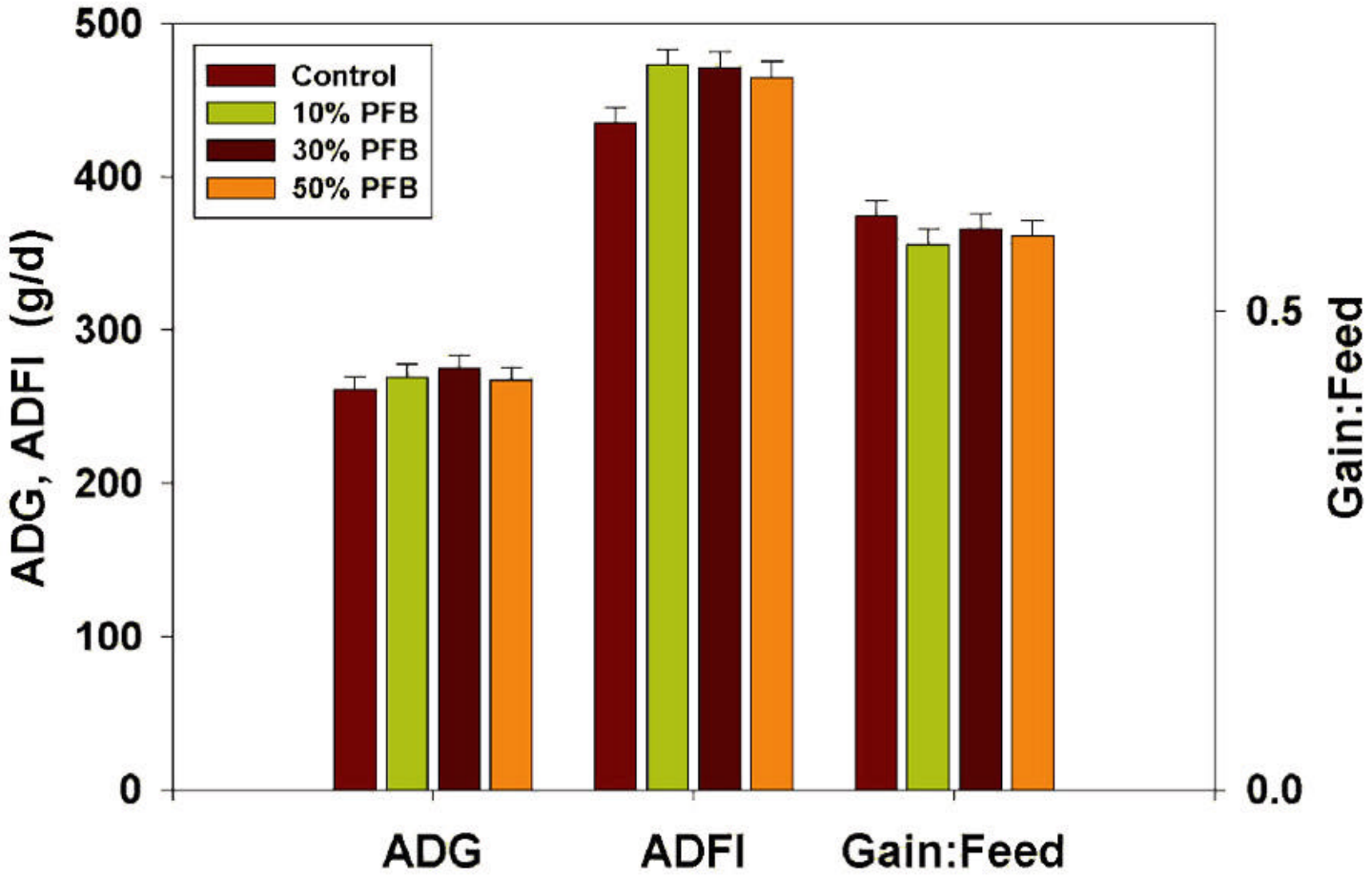

Figure B-3 – Effect of PFB in Nursery Diets on Post-Nursery Pig Performance (Exp. 1)

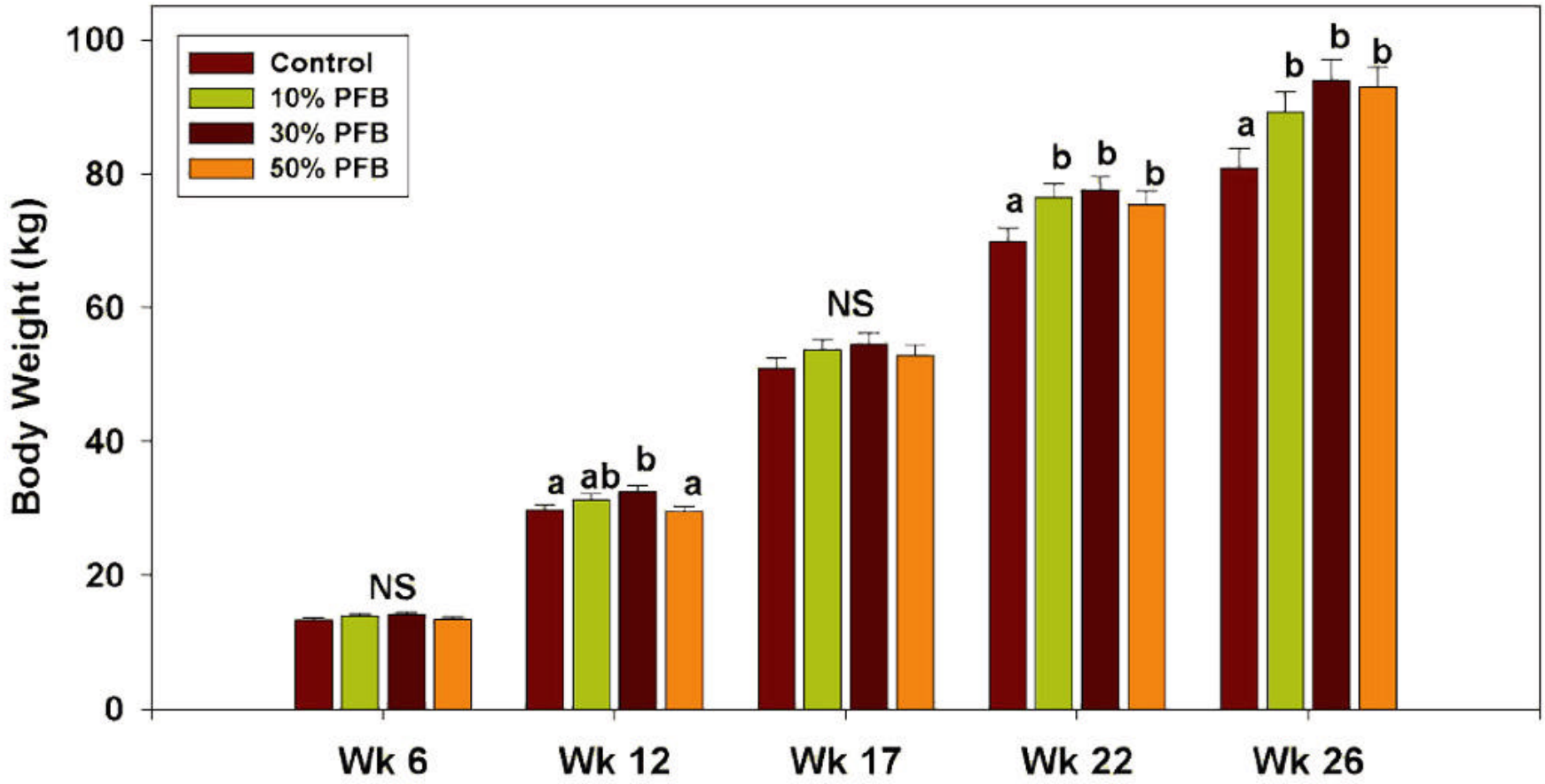

Figure B-4 – Effect of PFB in Nursery Diets on Limiting Amino Acid Digestibilities (dry-matter basis, Exp. 2)