Alternative Management and Feeding Strategies

Joel M. DeRouchey, PhD, and Steve Dritz, DVM PhD
Kansas State University

Nursery pig enteric disease continues to be prevalent in the modern swine industry. Adapting health improvement technologies such as segregated early weaning and all-in/all-out production schemes have not eliminated enteric disease concerns. Clinical disease is the biological sum of a number of production system inputs. These inputs include presence and dose of pathogen, a genetically susceptible population, diet composition, weight and age of weaned pig, environmental management, presence of confounding pathogens, and general farm management practices (Madec and Josse, 1983; Madec et al, 2000; Vannier et al., 1983). Thus, ensuring the health of nursery pigs depends on managing many interrelated challenges.

A large, recently published epidemiological study designed to determine the relative risk of several factors associated with nursery pig enteric disease indicated that feeding management (33.6 odds ratio) in the first week after weaning and hygiene status (7.8 odds ratio) were two of the most important risk factors associated with decreased amounts of enteric disease in the nursery (Madec et al., 1998). In addition, new research indicates that bacterially reduced feed ingredients can improve growth performance in nursery pigs (DeRouchey et al., 2001a,b,c,d and 2002a,b). The specific reason(s) for this increase is not currently known, but it is believed to be associated with a reduction in the bacteria in certain feed ingredients in diets for nursery pigs.

Therefore, this paper will focus on reviewing hygiene procedures and feeding management factors that are associated with decreased amounts of enteric disease and improved growth performance in nursery pigs.

Hygiene Practices

The primary objective of hygiene practices is lowering the dose of infectious pathogens that can be transmitted from the environment. It has been well documented that animal performance is increased in “clean vs dirty” environments and cleanliness is probably responsible for a large percentage of the growth performance benefits from all-in/all-out production (Klassing et al, 1988; Amass et al, 2001). Also, because the young pig is more susceptible to infections from enteric organisms, sanitation is especially critical for nursery facilities. Fortunately, most swine pathogens only survive for a brief amount of time outside the host in the absence of organic materials or moisture. Up to 99% of bacteria can be removed by cleaning alone under experimental conditions. However, the relative importance of the stages of sanitation include: 1) 90% removal by removing all visible organic matter, 2) 6 to 7% killed by disinfectants, and 3) 1 to 2% killed by fumigation (Morgan-Jones, 1987). However, recent reports indicate that environmental contamination is an important contributor of Salmonella infection. From one study in North Carolina, 27% (7/26) of drag samples obtained from a fully slatted finishing floor just prior to placement of pigs were found to be positive for salmonella (Davies et al., 1999).

The basic principles of hygiene practices to decrease transmission from group to group from environmental contamination include: 1) Building materials that are easy to clean. Rough surfaces such as concrete are more difficult to clean than smooth surfaces such as wire. Smooth nonporous surfaces will provide easier removal of fecal matter and faster drying. 2) Thorough cleaning and removal of organic matter such as feces and feed. In general, organisms are protected against agents of disinfection by organic materials such as pus, serum, or feces. 3) Proper use of disinfectants, including dilution to proper dosage and application to the proper coverage area. 4) Proper downtime and drying of rooms. Anecdotal observations from our group indicate that there is a seasonal nature to enteric problems in nurseries during the late winter and early spring period. We have observed that during this time period, due to environmental conditions, nursery spaces take longer time periods to dry and pigs are commonly placed in nurseries with moist surfaces and humid environments.

A survey of nursery hygiene practices on 129 French farms indicated several practices associated with decreased residual contamination (Madec et al., 1999). These practices included damping of the rooms immediately after the removal of the pigs. The researchers hypothesized that damping prevented dying of the fecal matter and increased the ease and thoroughness of cleaning. Use of a detergent also was suggested as associated with decreasing residual contamination. However, in another study evaluating the impact of detergent the researchers were unable to detect any impact and residual contamination after thorough washing (Kihlstrom et al., 2001). This indicates that using a detergent may be useful to improve the ease of cleaning. However, the detergents may not have much impact on the final amount of residual contamination if cleaning procedures are thorough.

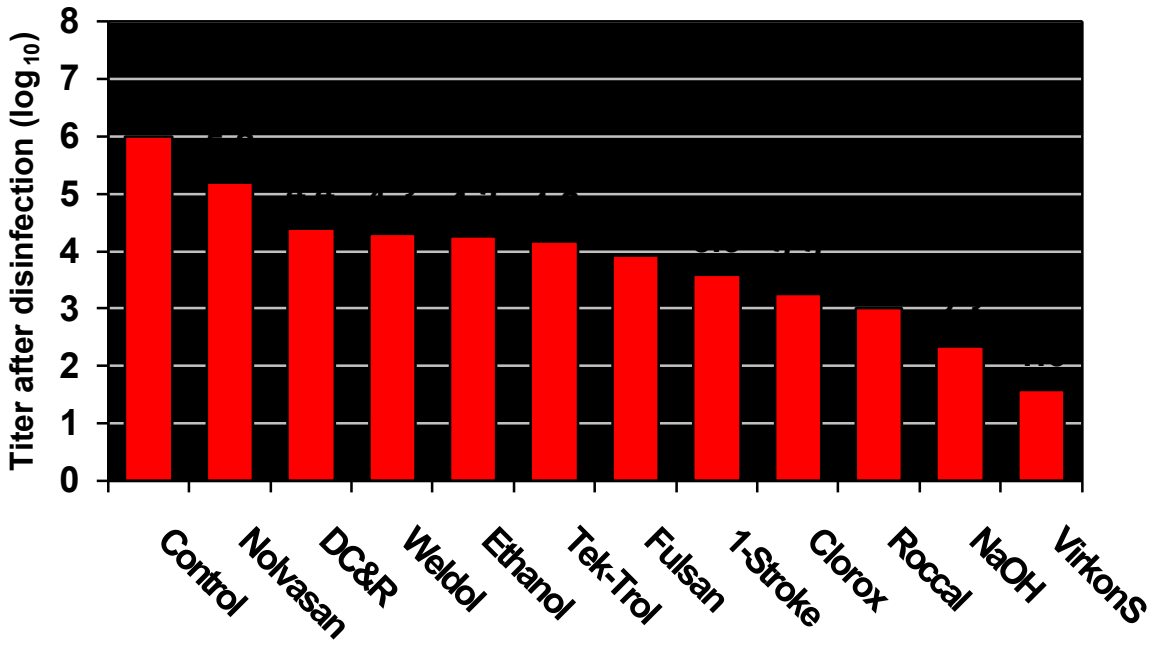
As supported by several other studies, the study by Madec et al. (1999) indicated that thorough cleaning of organic matter resulted in less residual contamination (Amass et al., 2000, 2001; Kihlstrom et al, 2001). Additionally, greater distances between the surface of the slurry and the floor were associated with less residual contamination. The authors attributed this risk factor to splash back and recontamination during the cleaning process. Finally, factors associated with disinfectant usage were important. These included proper dilution and application of disinfectant. An evaluation of disinfectant ability to reduce infectivity of porcine circovirus type 2 (PCV2) indicates that commonly available disinfectants vary widely in their ability to neutralize the virus (Figure 1; Royer et al., 2001). This study evaluated 11 commonly used disinfectants in swine farms and research laboratories that included the following disinfectant classes (products tested): ethanol (alcohol), iodine (Weldol), phenol (1-Stroke, Tek-Trol), quaternary ammonium (Roccal D Plus, Fulsan), oxidizing agent (Clorox, VirkonS), alkali (NaOH), and chlorhexidine (Nolvasan). The mean titer after disinfection ranged from $10^{5.2}$ for the chlorhexidine to $10^{1.6}$ for the oxidizing agent VirkonS. This compares to the control titer without disinfection of 10^6. Thus, a reduction from 10^6 to 10^5 results in a 90% reduction, to 10^4 a 99% reduction, to 10^3 a 99.9% reduction and to 10^2 a 99.99% reduction. There are two important points to remember from this study:

1) PCV2 is a small enveloped virus similar to Parvovirus and, thus, difficult to neutralize with disinfectants.

2) This study was done under controlled laboratory conditions and optimized for maximal disinfectant activity. Disinfectant activity may be even less effective in the field setting.

3) Nonetheless, VirkonS appeared to have the best activity.

Figure 1. Reduction in infectivity of PCV2 after a 10 min exposure to disinfectant. Royer et al., 2001.



Until recently, there has been little objective scientific evidence to evaluate hygiene practices in swine operations. With an increased emphasis on evaluating biosecurity practices there have been several recent studies. In addition to the PCV2 disinfectant evaluation, these include the evaluation of farrowing house cleaning protocols (Kihlstrom et al., 2001), boot bath cleaning procedures and disinfectants (Amass et al, 2000, 2001), and methods of rapid evaluation of surface contamination in swine facilities (Kelly et al., 2001).

Briefly, the evaluation of farrowing house cleaning protocols evaluated the amount of bacterial surface contamination in a sequential manner after low pressure washing of surfaces, high pressure with or without a detergent, and after application of disinfectant. Bacterial counts were generally lowered by two logs (99%) between the low and high pressure washing irrespective if a surfactant was used or not. Counts were generally lowered by another two logs after disinfection. The major conclusion from this study is that sequential washing and disinfection steps result in reductions in bacteria and each step contributes to the decontamination process.

While boot baths are widely implemented on swine farms there appears to be little scientific literature supporting their usage. A recent study by Dr. Amass from Purdue indicates that disinfecting boots was ineffective at reducing bacterial load of boots if the

fecal matter had not been removed before disinfecting (Amass et al., 2000). She indicated that removal of fecal matter alone without disinfecting was responsible for a large proportion of bacterial load on the boots. A follow up study indicated that regardless of weather boots were cleaned with water first and then placed in a VirkonS bath for 30 seconds or cleaned in a VirkonS boot bath both methods resulted in rapid disinfection of boots. As with the previous study cleaning of the boots with scrubbing was an essential step of the process. Just stepping into the boot bath was not effective.

Feeding Management Practices

The basic rules for a successful nutritional program for the nursery pig can be summarized as follows: 1) start with as heavy of pig as possible; 2) feed as simple of diets as possible, and 3) focus on nursery feeding management. We cannot overlook the importance of initial pig weight and age and quality of husbandry and their influence on feeding management practices.

1) Importance of pig weight and age.

The optimal feeding patterns for lactating sows continue to be debated. However, the research results in this area are clear. Restricting feed, protein, or energy intake during any period of lactation will reduce milk production, decrease litter-weaning weight, and impair subsequent reproductive performance (King and Martin, 1989; Koketsu and Dial, 1998; Tokach et al., 1992). With the implementation of early weaning strategies, the importance of litter weaning weight has increased. Pigs weaned at heavier weights and older ages are simply easier to manage in the nursery and have lower risk of developing enteric disease (Cranwell et al., 1995; Madec et al., 1998). Other data indicate that pigs with lighter weight at weaning are at a higher risk of death (Deen et al., 1998). Unfortunately, management-induced energy deficiency during lactation leading to failure to achieve potential weaning weights is a major problem on many commercial swine farms.

In a recent experiment, we characterized the importance of weaning age on growth performance in the first 28 d after weaning. We grouped pigs by age (12 to 15 d, 16 to 18 d, and 19 to 21 d old) and weight (light or heavy) within each age category (Table 1). We found a weaning age by growth performance interaction ($P < .07$). Note that the difference in average weight between the heavy and lightweight categories was approximately 1 kg (Figure 2). Thus, the heavy 12 to 15-d and the light 16 to 18-d old categories averaged similar weights at weaning. The heavy 16 to 18-d and light 19 to 21-d old categories also averaged similar weights at weaning.

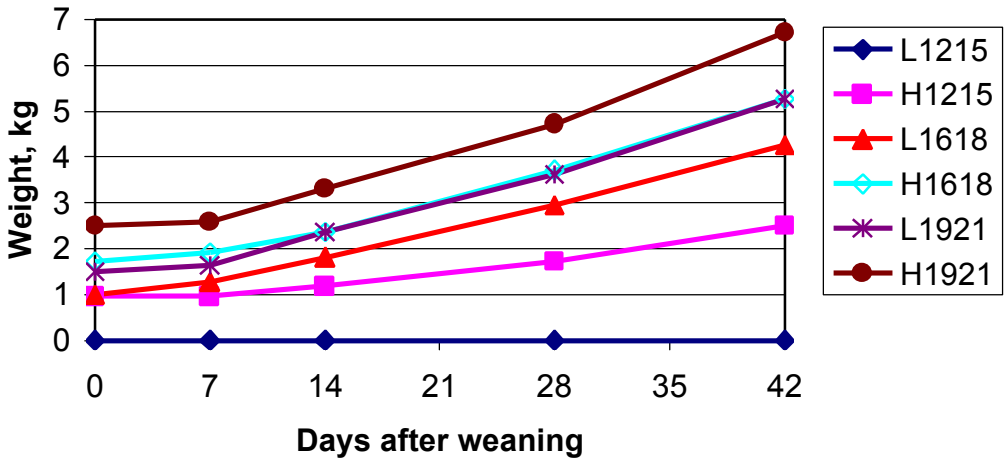
Table 1. Influence of weaning age (d) and weaning weight (lb) on nursery performance.

Age:	12 to 15		16 to 18		19 to 21			P Value		
Item Wt:	Light	Heavy	Light	Heavy	Light	Heavy	SEM	Weight	Age	Wt x Age
d 0 to 28										
ADG, g	213	241	286	286	309	295	5	0.05	0.01	0.07
ADFI, g	309	331	381	395	395	409	9	0.04	0.01	0.79
Feed/gain	1.46	1.38	1.35	1.39	1.37	1.39	0.02	0.83	0.10	0.04

Each number is the mean of 12 pens (21 pigs/pen) and pigs averaged 5.3 kg at weaning.

The youngest pigs at weaning gained the least from day 0 to 42 after weaning. The data clearly show that weaning weight is important with all ages of pigs; however, the impact of weaning weight was not as important as weaning age. When comparing pigs that were 16 days or older at weaning, the weight differences at weaning were only slightly increased by day 42 after weaning. Weaning weight was also important for pigs weaned at less than 16 days; however, age also becomes a critical factor as pigs with heavier weaning weights within the 12 to 15 d old category were not able to compensate for their young age. The heavy 12 to 15 day old pigs had the same weaning weight as the light 16 to 18 day old pigs; however, they were 2 kg lighter at day 42 after weaning. Weaning weight differences also become magnified with young pigs. Note that while the light 12 to 15 d old pigs were 1 kg lighter at weaning than the light 16 to 18 d old pigs the difference had magnified to 4 kg by 42 d after weaning.

Figure 2. Influence of weaning weight and age on weight difference between groups



Average age at weaning or lactation length calculated at weaning is based on the date of the last recorded wean event for the sow in most record keeping systems. In many farms where pigs are weaned multiple times per week, the heaviest pigs in a litter are weaned before the remainder of the litter. Thus, the actual average weaning age of the pigs will be lower than that stated on the summary report. We have observed actual weaning age as much as 1 day younger than that reported from average lactation length calculated from the sow wean event. Another common practice, even on farms that have strict policies about movement of pigs among rooms, is to hold back older lightweight pigs to wean them at an older age. This is another phenomena that will not be highlighted in records because the average age at weaning will be calculated based on the wean event of the sow.

Strict adherence to maximum weaning age has been advocated to minimize transfer of infectious disease. Also, a narrow spread of weaning age has been indicated as desirable for success of isowean programs with a maximum of 20 d of age suggested for the elimination or control of most swine pathogens (Harris, 2000). Our experience indicates that the actual weaning age of groups of pigs is highly variable based on farrowing house management practices. Therefore, even though most nursery pig

nutritional programs are based on pig weight, we believe understanding the mean and variation in age are important for successful feeding management practices.

2) Feed as simple of diets as possible.

We adhere to three key concepts when formulating diets for the nursery pig. First, the economics of today's swine industry dictate that we must adjust pigs to the simplest and relatively lowest cost diets (i.e., grain and soybean meal) as quickly as possible after weaning. Second, we must remember that the newly weaned pig is in an extremely energy dependent stage of growth and that maximizing feed (energy) intake is essential. Third, we must remember the digestive physiology of the nursery pig and formulate the initial diets with highly digestible ingredients that complement the pattern of digestive enzymes secreted at weaning.

Strategies for feeding soybean meal to newly weaned pigs. One example emphasizing all three of these concepts is the practice of using soybean meal in diets fed immediately after weaning. An all milk or soy based diet was evaluated in a study using gnotobiotic pigs weaned at 21 d of age, challenged with an attaching and effacing *E. coli,* and fed the all milk or soy based diet for 14 d (Neff et al., 1994). Pigs fed the all milk diet grew faster than the soy fed pigs and had no evidence of attaching and effacing small intestinal lesions compared to the soy based pigs that did. Another study evaluating edema disease in pigs found an increased clinical expression and more microscopic evidence of disease when feeding diets that contained more crude protein from soybean meal (Bosworth et al., 1996). Therefore, some nutritionists believe that weanling pigs should be fed diets with no or very little soybean meal immediately after weaning and that the level should be steadily increased over time. This slow and very gradual introduction of soybean meal into the pig's diet will minimize the potential for delayed-type hypersensitivity to the soy proteins, conglycinin and beta-conglycinin (Li et al., 1990a,b; 1991a,b) and, thus, generally results in excellent growth performance initially after weaning. However, it also leads to very high nursery feed cost. A second option is to feed a diet with a moderate level (10 to 15% of the diet for pigs weaned between 15 and 21 days of age) of soybean meal as a partial replacement for more expensive specialty protein sources (Friesen et al., 1993a). This approach is a compromise between feeding extremely expensive all milk- and animal specialty protein-based diets and too simple grain-soybean meal-based diets. As a result, the pig's feed intake is stimulated by the lactose and specialty protein sources, which are highly digestible and palatable and, thus, increase energy intake. At the same time, the pig becomes exposed to the moderate amount of soybean meal protein, minimizing the negative effects of a delayed-type hypersensitivity response. As a result the amount of soybean meal in the diet can be quickly increased in a phase feeding program to decrease the need for the more expensive specialty protein sources.

The net result of using soybean meal in this fashion is that we can still provide a highly digestible complex diet that stimulates feed intake immediately after weaning, and then quickly reduce diet complexity by increasing the amount of soybean meal protein (Dritz et al., 1996). This strategy takes advantage of the fact that the impact of diet complexity on feed intake and pig performance decreases rapidly after weaning, especially in high health pigs. Thus, a feeding program can be developed that nutritionally allows for maximum growth performance and yet will be economically competitive.

Ingredient Selection Based on Digestive Capacity. Selection of different types and amounts of other feed ingredients also should be based on the three primary criteria of quickly reducing diet complexity to lower feed cost, maximizing feed (energy) intake, and physiology of the digestive system. Indeed, ingredient selection in addition to cost, should be based on factors including nutrient digestibility, amino acid density, lactose concentration, and stimulatory affects on feed intake and(or) growth. Another consideration is how an ingredient or combination of ingredients will react under various feed processing methods. The use of added fat is an example of this latter consideration. Although added fat is not well utilized by the pig as an energy source immediately after weaning, its inclusion is essential if diets containing high levels of milk and other specialty protein sources are to be pelleted.

The newly weaned pig's digestive system is relatively immature but, at the age of weaning, well adapted to digest the proteins, lactose, and lipids secreted in sow's milk. It has been well established that inclusion of lactose containing ingredients assists in the transition at weaning from sow's milk to a dry diet (Tokach et al., 1989; Mahan, 1992; Nessmith et al., 1997)**.** However, evidence may suggest that despite our best attempts to mimic the nutrient composition of sow's milk in a dry diet, there are dramatic changes that take place in the size, shape, and functioning of the villi in the small intestine (Cera, 1988; Li et al., 1990a, 1991a,b; and Jiang et al., 2000). The anatomical changes in the villi after weaning may be a possible cause for poor utilization of some ingredients. For example, the anatomical changes in the villi may cause the reduction in secretion of fatty acid binding protein, which correlates with poor fat utilization by pig for approximately 10 to 14 days after weaning (Reinhart et al., 1990). Ingredient selection also can change the degree to which these changes in the structure and functioning of the villi take place. An example is the shearing of villi caused by the delayed-type hypersensitivity reaction to excessive soybean meal fed immediately after weaning (Li et al. 1990a,b). Certain ingredients, such as spray-dried animal plasma also may have a positive effect on intestinal development (Jiang et al., 2000). Although our understanding of the influence of ingredient selection on structure and functioning of the villi has improved, the rapid change in function of the villi at weaning still seems to be a primary challenge in weanling pig nutrition. Despite the changes in digestive physiology at the time of weaning, protein source solubility within the intestine appears to be the primary limitation to digestion in the early-weaned pig (Asche et al., 1989a,b).

Post-weaning diarrhea and Zinc Oxide. Post weaning diarrhea associated with hemolytic *Escherichi coli* is a common, and potentially emerging problem in early wean pigs. Supplementing nursery diets with 3000 ppm ZnO post-weaning has also been observed to have beneficial effects in helping control post-weaning *E. coli* associated challenges under field conditions (Holm and Poulsen, 1996, Tokach et al., 2000).

A case study by Tokach et al. (2000), clearly illustrated the clinical and economic impact zinc oxide can have in controlling post-weaning diarrhea. Piglets were being weaned from a 1400-sow unit and sent to three different producers in loads of 600 pigs per week. Production records indicated poorer performance and a greater problem with *E. coli* associated diarrhea in one herd compared to pigs from the other two (394 g vs. 436 g of average daily gain (ADG) and 8.0% vs. 0.96% mortality for the case herd and other two herds, respectively). No environment and management differences on the sow farm of origin were found to explain the performance differences in these three groups of pigs.

When diet formulations were reviewed, it was discovered that the first two diets fed to the weaned pigs in the case herd contained 612 ppm zinc from zinc oxide, instead of the specified 3,000 ppm. Comparable diets for the pigs in the other two locations did contain 3,000 ppm zinc. The diet formulation error was corrected, and performance of the next groups of pigs improved. This case study demonstrated the value of closeout records in determining the economic impact of the diet formulation error, which was calculated to be a loss of $3.13 to 5.88 per weaned pig.

In a challenge study, Jensen-Waern et al. (1998) found that adding 2500 ppm of zinc from zinc oxide to the diet prevented postweaning diarrhea without affecting the numbers of *E. coli* excreted in the feces. In another challenge study (Mores et al., 1998), high concentrations of zinc from any of four zinc oxide sources reduced the occurrence of *E. coli* diarrhea without affecting fecal shedding of the *E. coli*. In these experiments, a high prevalence of diarrhea occurred in pigs that did not receive high concentrations of zinc oxide when challenged.

Another recent study, demonstrated that pigs supplemented with ZnO at 3,000 ppm had a reduced translocation of bacteria to the ileal-mesenteric lymph node (Huang et al., 1999). The potential mechanism for this finding, as well as the other beneficial effects demonstrated above is not clearly understood. Zinc has been demonstrated to have an effect on cells undergoing rapid turnover, as it is needed for DNA and protein synthesis. Zinc also seems to play a role in stabilizing cell membranes and modify membrane functions (Bray and Bettger, 1990) Therefore, zinc's beneficial impact may be in part due to a direct supportive or protective role of intestinal epithelial cells (Huang et al., 1999).

Managing post-weaning *E. coli* challenges is increasingly becoming a more complex. These challenges need an ongoing effort for improved prevention or intervention techniques. Utilizing excess supplemental zinc early in the nursery phase is one option available to help minimize these challenges and promote growth. The environmental concerns associated with feeding zinc are significant. This concern reemphasizes the desire to restrict the 3,000 ppm ZnO inclusion in the first two weeks after weaning when feed intake is the lowest and the benefit the greatest.

3) Focus on nursery feeding management.

Many nutritionists and veterinarians recommend restricting intake by limit feeding or adding fiber in the first diets after weaning to control enteric disease. Restricting nutrient intake by adding fiber and reducing protein and energy levels has been shown to reduce clinical disease (Bertschinger et al., 1978). However, these dietary options tend to substantially increase feed cost and reduce growth potential. Subsequent to this work have been many research trials evaluating highly digestible protein and carbohydrate sources for nursery pigs based on digestive capacity (Tokach et al., 2002). This research demonstrated that decreasing the damage to the small intestine and reducing the load of undigested substrate in the colon consistently results in maximal growth performance. Additionally, work from Australia indicates that pigs fed a highly digestible rice and animal protein based diet had fewer enterotoxigenic *E coli* recovered after challenge than when fed the same diet supplemented with guar gum to provide high levels of non-starch polysaccharides (McDonald et al., 1997). Fiber contains high levels of non-starch polysaccharides. A subsequent follow up study using a commercial wheat-

lupin based diet compared to the rice and animal protein based resulted in significantly more pathogens isolated (Hampson et al., 2001).

Therefore, the scientific evidence appears to clearly indicate that adding fiber or restricting feed intake are not viable options for controlling enteric disease. In fact as mentioned before lower feed intake in the first week after weaning is significantly associated with greater risk of enteric disease (Madec et al, 1998). However, maximizing feed intake does not mean that feeders should be left wide open with excessive amounts of feed in the feed pan.

"If your fingers don't ache from cleaning the feed gates, you are not adjusting them properly."

We have observed decreased growth rate as a result of improper feeder adjustment. In an attempt to stimulate feeding behavior, large amounts of the first diet are placed in the feeding pan. Although intention is correct, the outcome is negative. Energy deficiency can result from pigs "sorting" the diet and a buildup of fines in the feeding pan. These fines then lodge in the feed agitator mechanism, making it difficult for new feed to flow from the feeder. This problem is remedied by management of the amount of feed flow in the pan to stimulate development of feeding behavior. Approximately 25 to 50% of the feeding pan should be visible in the first few days after weaning. As the pigs become more accustomed to the location of the feed and adjust feeding behavior, the amount of the feed in the feeding pan should be decreased rapidly to 25% or less coverage. Also, feed agitators need to be tested frequently to ensure that the buildup of fines does not prevent them from working freely.

The data in Table 2 depict growth performance before and after the institution of an aggressive feeder-management strategy. Contrary to popular belief, reducing the amount of feed present in the pan did not reduce average daily gain. Feed efficiency and daily gain both improved because of decreased wastage and continual access to fresh feed. Our recommendations are to have feed accessible for newly weaned pigs at all times in feeders that are adjusted correctly to teach the proper feeding behavior.

Table 2. Comparison of pig performance before and after institution of an aggressive feeder-management strategy in the first week after weaning.

	Strategy Change	
Item	Before	After
Weaning weight, lb	5.6	5.3
Day 0 to 7 after weaning		
ADG, lb	73	100
F/G	2.15	1.27

A total of 3,360 pigs used in analysis. Each number is the mean of 2 groups (Before) or 3 groups (After). Each group consisted of 32 pens each with 21 pigs.

In conclusion, nursery hygiene practices are focused on controlling the dosage of exposure to infectious pathogens. Feeding management practices are focused on controlling the clinical expression enteric disease. Attention to both practices is important for ensuring healthy nursery pigs.

4) Bacterially Reduced Feed Ingredients.

Animal feed has long been recognized as an introductory source of pathogenic microorganisms for farm livestock (Davies and Hinton, 2000). The first reports of bacteria, such as *Salmonella* were first discovered in feeds in 1948 (Williams, 1981). Introduction of bacteria to animals through ingestion of feed can ultimately lead to proliferation of bacteria in the digestive system, which may pose a threat for carcass contamination if proper sanitation and procedures are not followed at slaughter (Chau et al., 1978). The majority of the research evaluating the presence of bacteria in feed ingredients and complete feeds have involved *Salmonella*, which can survive for months or years in stored animal feed (Allen, 1997; Davies and Wray, 1996). Thermal processing (Israelsen et al., 1997; Jones et al., 1991) and chemical treatment (Hinton and Linton, 1988; Humphrey and Lanning, 1988; Duncan and Adams, 1972), and irradiation (DeRouchey et al., 2001a,b,c,d, and DeRouchey et. al., 2002a,b) have been used as means to reduce bacteria in feed ingredients and the whole diet.

Currently, gamma ray (cobalt-60 source) and electron beam are the two forms of irradiation processing currently available for commercial use. An examination of irradiation on microbiology effects of animal plasma was conducted by gamma rays at doses of 0, 5, 10, 15, and 20 kGy (Brankova and Dimitrova, 1975). A dosage of 15 kGy resulted in marked reductions of bacteria, with a dosage of 20 kGy resulted in sterility of the animal plasma. Irradiation dosages of 5, 10, and 15 kGy from both electron beam or gamma ray sources to freeze-dried porcine plasma resulted in bacterial concentrations less then 10 cfu/g (Hayashi et al., 1991). The initial microbial concentration of the dried plasma was 2.2 ? 10^4 cfu/g. Upon testing of the irradiated samples, they observed no significant changes in the functional properties of protein solubility and emulsifying capacity from both gamma ray and electron beam treated dried plasma. However, solubility slightly declined linearly as the dosage increased for dried plasma treated with both types of irradiation. Also, irradiation (from 0 to 20 kGy) of blood meal did not influence pH or protein solubility (Dimitrova, N., and R. Brankova, 1975). Furthermore, no differences in digestibility or biological value of irradiated (28 kGy) wheat gluten and corn protein has been reported (Metta and Johnson, 1951). In addition, no loss of available lysine in a guinea pig diet made from natural ingredients when irradiated at 25 kGy has been shown (Metta and Johnson, 1951). Research has demonstrated that the total amino acid, true digestibility, biological value and net protein utilization of a complete rat diet when irradiated at 25 and 100 kGy were not significantly affected (Ford, 1976). Also, the solubility, emulsifying capacity, and viscosity of spray-dried blood meal at gamma ray irradiation doses of 0, 1.0, 2.0, 3.0, 4.0, 5.0, 10,0,16.7, 20.0, and 50.0 kGy found all functional properties of blood meal were unaffected by irradiation doses up to 5 kGy (Uchman et al., 1987.).

Irradiated Spray-died Blood Meal. In an experiment evaluating the effects of spray-dried blood meal pH and irradiation of nursery pig performance, it was reported (DeRouchey et al., 2001c) that pigs fed irradiated spray-dried blood meal (5% of the complete diet) had improved ADG, ADFI, and feed efficiency by 24, 15, and 8%, respectively, compared to blood meal that was not irradiated (Table 3). In addition, no differences in pig performance were detected when pigs were fed spray-dried blood meal with varying pH ($P > 0.21$). The pH of spray-dried blood meal decreases with an increase in storage time prior to spray-drying, which is associated with an increase in bacterial concentrations as bacteria use protein as a food source (Mayes, 2000). The concentration of bacteria rose (3.7 ? 10^6, pH 7.6) as storage time increased until d 8 (1.2 ? 10^7, pH of 6.0), and then declined slightly at d 12 of spray drying (6.6 ? 10^6, pH of 5.9). The greatest reduction in blood meal pH was seen when blood was stored for 8 d with minimal changes with further storage. Irradiation of the blood meal with a pH of 5.9 reduced the bacteria concentration from 6.6 ? 10^6 to 9.0 ? 10^1 cfu/g. In a second experiment evaluating the effects of irradiation source, it was reported (DeRouchey et al., 2001b) that there was no differences in growth performance when nursery pigs were fed diets containing blood meal (5% of the complete diet) that had been irradiated with either gamma ray (cobalt-60 source) and electron beam irradiation ($P > 0.26$; Table 4). Also, no differences ($P > 0.11$) were detected in growth performance when pigs were fed blood meal that had been irradiated at increasing dosage levels (2.5, 5.0 10.0, and 20.0 kGy). However, ADG and F/G were increased by approximately 9 and 6%, respectively, for pigs fed irradiated blood meal compared to those fed blood meal that was not irradiated.

Irradiated Spray-dried Animal Plasma. In an experiment that evaluated the effects of irradiated animal plasma from two different commercial ingredient suppliers, it was reported (DeRouchey et al., 2001a) that pigs fed irradiated animal plasma had increased ADG by 18 and 12%, respectively, from source one and source two animal plasma compared to pigs fed the regular nonirradiated plasma during the treatment period (d 0 to 10; Table 5). Also, pigs fed irradiated spray-dried plasma from each source had improved ADFI (11%) compared to pigs fed nonirradiated animal plasma. Furthermore, after a 2 week period where all pigs were fed a common phase II diet, pigs initially fed irradiated spray-dried animal plasma were heavier ($P < .05$) compared to pigs fed the no plasma added control diet, whereas pigs on the treatment diets with regular spray-dried plasma were not. This study also demonstrated that spray drying is not detrimental to protein quality as pigs fed irradiated freeze dried animal plasma (dried at ambient temperature) had similar performance as pigs fed irradiated animal plasma. However, pigs fed plasma source two had improved ADG and ADFI compared to pigs fed plasma source one, irregardless of whether the plasma was irradiated or not. These results are in agreement with previous research that concluded differences in animal plasma quality exist between and even within ingredient suppliers (Steidinger et al., 2000).

Additionally, research reported that pigs fed irradiated feed grade (initially high bacteria), but not food grade (initially low bacteria) animal plasma, had improved growth performance compared to pigs fed their nonirradiated forms (DeRouchey et al., 2002a; Table 6). Pigs fed irradiated feed grade plasma had increased performance compared to pigs fed regular feed grade plasma, whereas pigs fed irradiated food grade plasma did not. In addition, irradiation did no alter the IgG, crude protein, or endotoxin levels when comparing the regular and irradiated forms of each (Table 7). They concluded that the

initial bacteria level, or certain bacteria associated with feed grade animal plasma should be eliminated or reduced to enhance the quality of this ingredient to improve growth performance when included in nursery pig diets.

Irradiated or Formaldehyde Treated Spray-dried Animal Plasma. Termin-8? is a formaldehyde-based antimicrobial feed additive that has been used to reduce the bacteria and help prevent recontamination in complete feeds for poultry (Anderson et al., 2001; Kaiser, 1992), finishing pigs (Anitox, 1996a) and sows (Anitox, 1996b). To help determine if the improved growth found when irradiating plasma is due to the decrease in the bacterial level, a study was conducted to evaluate Termin-8? as a comparative model in two separate experiments (DeRouchey et al., 2001d). In Exp. 1, the inclusion of Termin-8? into animal plasma was less effective in decreasing the total bacterial level of animal plasma compared to irradiation (Table 8). However, regardless of processing technique, pigs had improved ($P < 0.05$) ADG when fed diets with decreased bacteria in the animal plasma portion of the diet compared to the control containing regular animal plasma. However, pigs fed whole diets treated with Termin-8? did not have different growth performance from pigs fed the control, and in fact had numerically suppressed ADFI. However, the reason that the improved performance is lost when the entire diet was treated with Termin8? is unknown.

In Exp. 2 (DeRouchey et al., 2001d), it was reported that pigs had higher ADG and F/G when fed diets containing Termin-8? treated animal plasma or base mix (specialty protein products, milk products, ground oat groats, soy flour, flow agent, vitamins, and minerals) compared to pigs fed the control diet for the first eight days after weaning (Table 9). Although the final pig weight at the end of the nursery phase was not significantly different, pigs that had originally consumed diets with Termin-8? treated animal plasma or base mix maintained the weight advantage that was seen after the first eight days.

Irradiation of Other Feed Ingredients and/or the Complete Diet. Researchers have evaluated the effects of whole diet irradiation and have concluded that irradiation is effective in reducing the bacterial concentration without decreasing the nutritional value of the diet (Borsa, 1989, 1990; Matin, 1985). Since no decreases in nutritional value in those experiments were detected, an experiment evaluating the effects of irradiation of individual ingredients or whole diet for nursery pigs was conducted (DeRouchey et al., 2002b). For this experiment, the authors used a control diet, then diets that included either irradiated corn, soybean meal, whey, animal plasma, fishmeal, soybean oil, all microingredients combined (antibiotic, salt, monocalcium phosphate, limestone, zinc oxide, vitamin and trace mineral premixes, and DL-methionine), a diet with all irradiated ingredients, or the control diet that was subsequently irradiated. Pigs fed diets containing irradiated spray-dried animal plasma or soybean meal had increased ($P < 0.05$) ADG compared to the control diet with no irradiated ingredients and the complete diet that was irradiated (Table 10). Also, ADFI ($P < 0.05$) was higher for pigs consuming the diet with irradiated soybean meal compared to those fed the irradiated whole diet. Finally, pigs fed irradiated spray-dried animal plasma had superior F/G ($P < 0.05$) compared to those fed diets containing irradiated microingredients or if all ingredients had been irradiated before manufacturing. They also reported that the initial bacteria levels in spray-dried animal plasma (4.1×10^5) and corn (1.4×10^5) were the highest, with minimal concentrations detected in spray-dried whey (2.3×10^2) and soybean oil (1.5×10^2; Table

11). In this experiment, there was no benefit with irradiating the whole diet, which is similar to the results seen with Termin8? treatment of the whole diet (DeRouchey et al., 2001d).

Research evaluating the effects of individual ingredient or whole diet irradiation revealed that the issue of bacteria levels in feed ingredients and the effect on animal performance is complex. It is currently unproven why pigs fed only certain ingredients that are irradiated respond with increased growth performance, while others do not. In addition, it is unclear why when the complete diet is irradiated no improvements in growth performance are seen.

Conclusions

In conclusion, nursery hygiene practices are focused on controlling the dosage of exposure to infectious pathogens. Feeding management practices are focused on controlling the clinical expression enteric disease. Attention to both practices is important for ensuring healthy nursery pigs. Furthermore, the use of bacterially reduced dried blood products in diets for nursery pigs can be used practically in commercial production to improve growth performance.

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Table 3. Effects of blood meal pH on growth performance in phase II nursery diets[a,b]

		Blood meal pH						Probability (P<)	
Item	No blood meal	7.6	6.9	6.0	5.9	Irradiated 5.9[c]	SE	No blood meal vs others[d]	pH 5.9 vs pH 5.9 irradiated
d 0 to 7									
ADG, lb	.30	.34	.31	.33	.31	.43	.04	.62	.03
ADFI, lb	.68	.64	.68	.65	.58	.69	.04	.32	.03
G/F	.45	.53	.46	.51	.53	.62	.05	.15	.13
d 7 to 14									
ADG, lb	.63	.74	.71	.74	.69	.82	.05	.13	.09
ADFI, lb	.89	.94	.83	.89	.86	.92	.06	.87	.46
G/F	.71	.79	.86	.83	.80	.89	.04	.02	.09
d 0 to 14									
ADG, lb	.47	.54	.51	.54	.50	.62	.04	.18	.02
ADFI, lb	.78	.79	.76	.77	.72	.80	.04	.56	.13
G/F	.60	.68	.67	.70	.69	.78	.03	.004	.02

[a]A total of 180 pigs (five pigs per pen and six pens per treatment) with an average initial BW of 14.95 lb at the beginning of phase II. All pigs were fed a common phase I diet for the first five days postweaning. Thus, d 0 of the experiment is actually 5 d after weaning.

[b]Growth performance for the first 5 d after weaning were: overall ADG = .24 lb, ADFI = .23 lb, and G/F = 1.04.

[c]Irradiated at an average dose of 9.54 kGy.

[d]No blood meal pH effects for levels of 7.6, 6.9, 6.0 and 5.9 (nonirradiated), P > .15.

Table 4. Effect of source and dosage level of irradiation on growth performance in phase II nursery pigs.[a]

Item	No Blood Meal Control	Blood Meal Nonirradiated	Blood Meal Irradiated Gamma Ray Dosage, kGy				Blood Meal Irradiated Electron Beam Dosage, kGy				SEM[bc]
			2.5	5.0	10.0	20.0	2.5	5.0	10.0	20.0	
Day 0 to 14											
ADG, lb	.70	.70	.75	.75	.76	.77	.75	.76	.75	.75	.038
ADFI, lb	.96	1.01	1.02	1.04	1.02	1.05	1.02	1.04	.97	1.02	.043
F/G[d]	1.37	1.44	1.36	1.39	1.34	1.36	1.36	1.37	1.29	1.36	.052

[a]A total of 300 pigs (five pigs per pen and 6 pens per treatment) with an average initial BW of 23.7 lb at the beginning of phase II. All pigs were fed a common phase I diet for the first four days postweaning. Thus, d 0 of the experiment is actually 4 d after weaning.

[b]No effect of control diet vs added blood meal diets ($P > 0.10$).

[c]No effect of gamma ray verses electron beam irradiation ($P > 0.10$).

[d]Nonirradiated vs irradiated blood meal ($P < 0.10$).

Table 5. Effects of source, processing technique, and irradiation of plasma on weanling pig growth performance and bacteria concentrations[a]

Item	No plasma Control	Plasma source 1			Plasma source 2		SEM
		Spray-dried	Spray-dried and irradiated	Freeze dried and irradiated	Spray-dried	Spray-dried and irradiated	
Initial wt, lb	13.10	13.09	13.07	13.09	13.02	13.10	
d 0 to 10							
ADG, lb[bd]	.53[f]	.56[fg]	.66[hi]	.64[gh]	.65[hi]	.73[i]	.03
ADFI, lb[be]	.62[f]	.65[f]	.72[fg]	.68[f]	.72[fg]	.80[g]	.04
F/G	1.17	1.16	1.09	1.06	1.11	1.10	.03
Pig wt, lb							
d 10[bd]	18.39[f]	18.60[fg]	19.62[hi]	19.45[gh]	19.51[hi]	20.37[hi]	.32
d 10 to 24							
ADG, lb	.88[f]	.88[f]	.89[f]	.76[g]	.79[g]	.82[fg]	.03
ADFI, lb[d]	1.08[fg]	1.00[f]	1.12[g]	.99[f]	.99[f]	1.06[fg]	.03
F/G	1.23[f]	1.14[g]	1.26[f]	1.30[f]	1.25[f]	1.29[f]	.04
Pig wt, lb							
d 24[be]	28.11[f]	29.71[fg]	31.27[g]	29.49[fg]	29.92[fg]	31.31[g]	.77
Animal plasma[j], cfu/g							
Total plate count	N/A	9.0×10^4	4.5×10^1	0	2.6×10^4	3.5×10^2	--
Total coliform count	N/A	0	0	0	0	0	--
Whole diet[k], cfu/g							
Total plate count	3.7×10^4	1.0×10^4	3.1×10^2	6.8×10^3	1.0×10^4	7.6×10^3	--
Total coliform count	2.8×10^4	6.7×10^3	3.0×10^2	2.1×10^2	6.0×10^3	1.0×10^3	--

[a]A total of 180 pigs (five pigs per pen and six pens per treatment) with an average initial BW of 13.1 lb.
[b]Control vs mean of plasma trts ($P < .05$).
[c]Control vs mean of plasma trts ($P < .10$).
[d]Spray-dried plasma vs spray-dried and irradiated plasma ($P < .05$).
[e]Spray-dried plasma vs spray-dried and irradiated plasma ($P < .10$).
[fghi]Means in same row with superscripts differ ($P < .05$).
[j]Samples obtained prior to manufacturing of complete feed.
[k]Samples obtained at initiation of the feeding experiment.

Table 6. Effect of irradiation on various types of spray-dried animal plasma on growth performance of the nursery pigs (Exp.1)[a]

		AP 820		Food grade		
Item	Control	Regular	Irradiated	Regular	Irradiated	SEM
Initial wt, lb	13.43	13.37	13.45	13.46	13.43	.03
d 0 to 14						
ADG, lb[b]	.50	.52	.59[eg]	.57[c]	.59[e]	.03
ADFI, lb	.52	.51	.57[f]	.56	.58[f]	.03
F/G[b]	1.04	.97[c]	.96[e]	.98[c]	.98[e]	.02
d 14 to 24						
ADG, lb	.92	.88	.96	.94	.91	.05
ADFI, lb	1.23	1.08[d]	1.26[g]	1.23	1.18	.07
F/G	1.33	1.23[d]	1.32[h]	1.32	1.30	.04
d 0 to 24						
ADG, lb	.69	.67	.74[fg]	.73	.73	.03
ADFI, lb	.81	.75[d]	.86[g]	.84	.83	.04
F/G	1.19	1.11[c]	1.15	1.16	1.14	.02
Final wt, lb	29.89	29.45	31.32[fg]	30.89	30.99	.80

[a]A total of 175 pigs (five pigs per pen and 7 pens per treatment) with an average initial BW of 13.4 lbs. All pigs were fed experimental diets from d 0 to 14, and then switched to a common phase II diet from d 14 to 24.
[b]Control vs mean of plasma trts ($P < .05$).
[c]Control vs regular, $P < .05$.
[d]Control vs regular, $P < .10$.
[e]Control vs irradiated, $P < .05$.
[f]Control vs irradiated, $P < .10$.
[g]Irradiated vs regular, $P < .05$.
[h]Irradiated vs regular, $P < .10$.

Table 7. Chemical analyses of spray-dried animal plasma (Exp. 1)

	AP 820		Food grade	
Item	Regular	Irradiated[a]	Regular	Irradiated[a]
CP, %	69.28	69.16	71.15	71.75
IgG, %	17.3	17.6	15.7	15.4
Endotoxin, ng/g	38,708	38,592	56	187
Aerobic plate count, cfu/g	$> 3.0 \times 10^5$	2.0×10^2	5.6×10^3	1.0×10^2
Total coliform count, cfu/g	< 3.0	< 3.0	< 3.0	< 3.0
E. Coli, cfu/g	< 3.0	< 3.0	< 3.0	< 3.0

[a]Irradiated at an average dosage of 8.0 kGy via electron beam.

Table 8. Effects of irradiation or Termin8? of Plasma and/or whole diet on weanling pig growth performance (Exp. 1)[a]

Item	Control	Irradiated plasma	Termin8? plasma[b]	Termin8? whole diet[b]	Termin8? whole diet[b] with irradiated plasma	SEM
d 0 to 14						
ADG, lb	.52[e]	.59[d]	.59[d]	.48[e]	.50[e]	.027
ADFI, lb	.62[de]	.66[cd]	.70[c]	.55[e]	.56[e]	.029
F/G	1.20	1.12	1.20	1.14	1.14	.068
Aerobic Plate Count						
Plasma, cfu/g	1.8×10^5	0	9.1×10^4	1.8×10^5	0	--
Whole diet, cfu/g	4.8×10^4	5.0×10^4	6.3×10^4	6.5×10^3	1.1×10^4	--

[a]A total of 325 pigs (five pigs per pen and thirteen pens per treatment) with an average initial BW of 12.7 lb.
[b]Termin8? inclusion rate of 6 lb/ton of plasma or whole diet.
[cde]Means in same row with superscripts differ ($P < .05$).

Table 9. Effects of Termin8? on growth performance in weanling pigs (Exp. 2)[a,b]

Item	Control	Termin8? Application		SEM[c]
		Plasma	Base mix	
Initial wt[dg]	10.80	11.17	11.13	.13
d 0 to 8				
ADG, lb[fhi]	.38	.49	.45	.01
ADFI, lb	.39	.40	.41	.01
F/G[fhj]	1.05	.84	.92	.03
d 8 wt[fhi]	14.05	15.00	14.66	.08
d 0 to 40				
ADG	.77	.78	.79	.01
ADFI	1.25	1.26	1.27	.02
F/G	1.63	1.61	1.62	.02
d 40 wt, lb	41.56	42.16	42.23	.30

[a]A total of 1698 pigs with 12 to 19 pigs/ pen (uniform within block) and 36 pens/trt with an average initial BW of 11.03 lb.

[b]Pigs were budgeted 5 lb of phase I diet, which contained either no Termin8? , only plasma treated with Termin8? , or the entire base mix (specialty protein products, milk products, vitamins, and minerals) treated with Termin8? . Pigs were then fed a common phase II, phase III (d 13 to 28), and phase VI (d 28 to 40) diets for the remainder of the experimental period.

[c]Initial wt used as a covariate for growth performance and ending wt.

[d]Control vs base mix with Termin8? treatment ($P < 0.10$).

[e]Control vs base mix with Termin8? treatment ($P < 0.05$).

[f]Control vs base mix with Termin8? treatment ($P < 0.01$).

[g]Control vs plasma with Termin8? treatment ($P < 0.05$).

[h]Control vs plasma with Termin8? treatment ($P < 0.01$).

[i]Base mix vs plasma Termin8? treatments ($P < 0.01$).

[j]Base mix vs plasma Termin8? treatments ($P < 0.10$).

Table 10. Effects of irradiation of ingredients and whole diet on nursery pig performance[a]

		Portion of diet treated with irradiation prior to manufacturing									
Item	Control	Corn	SB Meal	Whey	Plasma	Fishmeal	SB Oil	Micro's[b]	All	Complete[c]	SEM
Phase I[d]											
ADG, lb	.35^{f}	.40^{fg}	.41^{g}	.38^{fg}	.41^{g}	.39^{fg}	.38^{fg}	.36^{fg}	.40^{fg}	.36^{fg}	.022
ADFI, lb	.40^{fg}	.44^{f}	.44^{f}	.43^{fg}	.44^{f}	.43^{fg}	.42^{fg}	.40^{fg}	.43^{fg}	.38^{g}	.019
F/G	1.17^{f}	1.13^{fg}	1.07^{g}	1.12^{fg}	1.07^{g}	1.09^{fg}	1.10^{fg}	1.12^{fg}	1.09^{dg}	1.07^{g}	.035
Phase II[e]											
ADG, lb	.63	.63	.67	.67	.68	.63	.65	.63	.62	.64	.024
ADFI, lb	.79	.82	.85	.83	.83	.79	.82	.83	.83	.80	.024
F/G	1.30^{fg}	1.33^{gf}	1.28^{fg}	1.28^{fg}	1.25^{f}	1.27^{fg}	1.30^{fg}	1.33^{fg}	1.36^{g}	1.30^{fg}	.036
Overall											
ADG, lb	.49^{h}	.52^{fgh}	.54^{fg}	.53^{fgh}	.55^{f}	.51^{fgh}	.51^{fgh}	.50^{gh}	.51^{fgh}	.50^{h}	.017
ADFI, lb	.60^{fg}	.63^{fg}	.64^{f}	.63^{fg}	.64^{fg}	.61^{fg}	.62^{fg}	.62^{fg}	.63^{fg}	.59^{g}	.018
F/G	1.24^{fg}	1.22^{fg}	1.19^{fg}	1.21^{fg}	1.17^{f}	1.20^{fg}	1.22^{fg}	1.25^{g}	1.25^{g}	1.20^{fg}	.025

[a]Values are representative of two trials. Trial 1 had a total of 400 pigs (8 pigs per pen and five pens per treatment) with an average initial BW of 10.8 lb. Trial 2 had 480 pigs (8 pigs per pen and six pens per treatment) with an average initial BW of 11.3 lb.
[b]Antibiotic, salt, monocalcium phosphate, limestone, zinc oxide, vitamin and trace mineral premixes, and DL-methionine.
[c]Complete diet manufactured then irradiated.
[d]Phase I is from d 0 to 7 in trial 1 and d 0 to 6 in trial 2.
[e]Phase II is from d 7 to 14 in trial 1 and d 6 to 12 in trial 2.
[f,g,h]Means in same row with superscripts differ ($P < 0.05$).

Table 11. Aerobic Bacteria Concentration of Feed Ingredients[a]

	Total Plate Count, cfu/g		Total Coliform Count, cfu/g	
Ingredient	Regular	Irradiated[a]	Regular	Irradiated[a]
Corn	1.4×10^5	1.3×10^2	6.8×10^4	1.0×10^1
Soybean meal (46.5%)	4.1×10^4	8.5×10^1	5.7×10^2	0
Spray-dried whey	2.3×10^2	9.0×10^1	0	0
Spray-dried animal plasma	4.1×10^5	8.0×10^1	0	0
Select menhaden fish meal	1.5×10^3	4.0×10^2	0	0
Soybean oil	1.5×10^2	1.2×10^1	0	0
Micronutrients[b]	3.2×10^3	1.4×10^2	2.1×10^2	0

[a]Average bacterial concentration from both experiments (Irradiated with gamma ray (Exp 1) and electron beam (Exp 2) at an average dose of 8.5 kGy.

[b]Medication, monocalcium phosphate (21% P), limestone, zinc oxide, vitamin and trace mineral premixes, salt, and DL-Methionine.

Dr. Joel DeRouchey

Dr. DeRouchey is employed with Kansas State University Research and Extension as the Northeast Area Livestock Production and Management Extension Specialist. Joel is originally from south central South Dakota where his family has been involved in the purebred swine, sheep, and cattle livestock operations. DeRouchey graduated from South Dakota State University in 1997 with a B.S. in Animal Science, and then attended Kansas State University where he focused his graduate work on swine nutrition and completed his M.S. in 1999 and Ph.D. in 2001. His research activities have included the areas of ingredient quality, feed processing, feed additives, and livestock waste management. Joel is also involved in numerous 4-H youth livestock activities coordinated by Kansas State University.

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