# Effect of irradiation of individual feed ingredients and the complete diet on nursery pig performance[1]

**J. M. DeRouchey[2], M. D. Tokach, J. L. Nelssen, R. D. Goodband, S. S. Dritz, J. C. Woodworth, B. W. James, and D. E. Real**

Department of Animal Sciences and Industry, Kansas State University, Manhattan, 66506-0201

**ABSTRACT:** A total of 1,210 nursery pigs was used in two experiments to evaluate the effects of irradiation of typical nursery diet ingredients, specialty protein products, and the whole diet on nursery pig performance. In Exp. 1, 880 barrows and gilts (15 ± 2 d of age at weaning) were used in two growth trials (14 d and 12 d for Trials 1 and 2, respectively) to determine the effects of individual ingredient and whole-diet irradiation on nursery pig performance. Overall (d 0 to 14 of Trial 1 and d 0 to 12 of Trial 2), ADG was greater ($P < 0.05$) for pigs fed irradiated animal plasma compared with pigs fed the control, the diet containing irradiated microingredients, and the diet that was manufactured and irradiated. Also, pigs fed irradiated soybean meal had greater ($P < 0.05$) ADFI compared with pigs fed the manufactured diet that was irradiated. Pigs fed the diet containing irradiated animal plasma had improved feed efficiency (G:F; $P < 0.05$) compared with those fed the diet with irradiated microingredients and when all ingredients were irradiated before manufacturing of complete feed. Finally, pigs fed irradiated corn, whey, fishmeal, soybean oil, microingredients, or if all ingredients or the whole diet were irradiated, had similar ADG, ADFI, and G:F ($P > 0.12$) to control pigs. In Exp. 2, 330 nursery pigs (20 ± 2 d of age at weaning) were used to determine the effects of irradiation of commercially available specialty protein products in diets for nursery pigs. Overall, ADG was greater ($P < 0.05$) when pigs were fed diets containing nonirradiated spray-dried animal plasma and egg combination (SDAPE) and dried porcine digest (DPD) compared with pigs fed the control diet containing no specialty protein products. In addition, G:F was improved ($P < 0.05$) when pigs were fed diets containing nonirradiated SDAPE, DPD, spray-dried beef muscle (SDBM), and spray-dried whole egg (SDWE) compared with pigs fed the control diet. Pigs fed irradiated SDAPE and SDBM had greater ($P < 0.05$) ADG than pigs fed the nonirradiated forms. Pigs fed irradiated SDBM had improved ($P < 0.05$) G:F compared with pigs fed the nonirradiated form. In Exp. 1 and 2, an irradiation treatment level of 8.5 kGy was effective in reducing the total bacterial concentration of all ingredients evaluated, as well as the whole diet in Exp.1. Irradiation of certain ingredients, but not the complete diet, increased growth performance of nursery pigs.

Key Words: Bacteria, Growth, Ingredients, Irradiation, Pigs, Protein Sources

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## Introduction

In 1963, the International Atomic Energy Agency made recommendations to use irradiation treatment of animal feeds to reduce their bacterial concentrations, particularly with regard to *Salmonella*. Irradiation was shown to reduce bacterial concentrations in protein meals of animal origin that were fed in commercial diets for livestock (Carpenter, 1963) without damaging protein quality, unlike that caused by heat treatment for sterilization. At that time, many European countries required the resterilization (heat treatment of the meals for at least 45 min at 125°C) of imported meat and bone meal and other protein meals of animal origin (Veterinary Directorate, 1959). Furthermore, a review of the literature by Adamiker (1979) suggested that irradiation could effectively replace heat and chemical sterilization methods as a means to reduce the bacterial and pathogen concentration of diets for germ-free and specific pathogen-free animals. More recently, DeRouchey et al. (2001a,b,c) reported that irradiated spray-dried blood meal or animal plasma in diets for nursery pigs resulted in improved growth performance. Although no definite mode of action for this improvement was given, the authors theorized that this response may be due to a reduction or elimination of specific detrimental bacteria associated with these

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[2] Correspondence—phone: 785-532-2280; fax: 785-532-7059; E-mail: jderouch@ksu.edu.

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**Table 1.** Chemical analyses of specialty protein products (as-fed basis; Exp. 2)

| Item, % | Spray-dried animal plasma | Spray-dried animal plasma and egg combination | Dried porcine digest | Spray-dried beef muscle | Spray-dried whole egg |
|---|---|---|---|---|---|
| CP (N × 6.25) | 80.55 (78.0)[a] | 75.34 (77.0)[b] | 31.29 (30.0)[b] | 68.13 (65.0)[b] | 50.18 (47.0)[b] |
| Amino acid | | | | | |
| Arginine | 4.55 (4..55) | 4.37 (4.64) | 1.58 (1.50) | 3.84 (4.27) | 3.01 (2.93) |
| Histidine | 2.64 (2.55) | 2.41 (2.60) | 0.70 (0.65) | 1.88 (2.69) | 1.12 (1.11) |
| Isoleucine | 2.93 (2.71) | 2.79 (3.08) | 1.12 (1.20) | 2.92 (2.96) | 2.84 (2.87) |
| Leucine | 7.55 (7.61) | 7.30 (7.66) | 2.07 (2.20) | 5.55 (5.73) | 4.37 (4.03) |
| Lysine | 7.38 (6.84) | 6.43 (6.90) | 2.03 (2.05) | 4.97 (5.20) | 3.65 (3.09) |
| Methionine | 0.71 (0.75) | 0.72 (0.71) | 0.52 (0.55) | 1.55 (1.64) | 1.62 (1.48) |
| Cystine | 2.61 (2.63) | 2.42 (2.54) | 0.56 (1.00) | 0.38 (0.20) | 1.23 (1.09) |
| Phenylalanine | 4.46 (4.42) | 4.24 (4.58) | 1.17 (1.20) | 2.82 (3.00) | 2.61 (2.59) |
| Tyrosine | 3.98 (3.53) | 3.89 (4.17) | 1.01 (1.05) | 2.22 (2.66) | 1.99 (1.91) |
| Threonine | 4.19 (4.72) | 4.20 (4.40) | 1.25 (1.25) | 2.35 (2.36) | 2.16 (2.25) |
| Tryptophan | 1.42 (1.36) | 1.55 (1.48) | 0.10 (0.40) | 0.79 (0.71) | 1.08 (0.73) |
| Valine | 5.19 (4.94) | 4.93 (5.38) | 1.47 (1.55) | 3.59 (3.78) | 3.33 (3.30) |

[a] Values in parenthesis were provided by NRC (1998) and used in diet formulation.

[b] Values in parenthesis were provided by ingredient suppliers and used in diet formulation.

products. Furthermore, no research to determine the effects of irradiation of ingredients typically included into nursery pig diets or irradiation of the whole diet itself has been conducted. Therefore, the objective of these experiments was to determine the effects of irradiation of typical nursery pig diet ingredients, specialty protein products, and the whole diet on nursery pig performance.

## Materials and Methods

### *General*

The Kansas State University Institutional Animal Care and Use Committee approved all experimental protocols used in this study.

The nutrient composition of ingredients in the NRC (1998) was used in diet formulation, except for some specialty protein proteins in Exp. 2, in which nutrient profiles provided by ingredient suppliers were used. All diets were formulated to meet or exceed the NRC (1998) nutrient requirements and were fed in pelleted form (Tables 1 and 2). Each pen (Exp. 1, 1.5 $m^2$ and Exp. 2, 1.2 $m^2$) had slatted metal flooring and contained a stainless steel self-feeder and either one (Exp. 2) or two (Exp. 1) nipple water(s) to allow ad libitum consumption of feed and water.

Ingredient samples were collected before diet manufacturing while complete feed samples were collected at the start of each trial for analyses. All ingredients and whole diets in Exp. 1 were analyzed for total bacterial and coliform concentrations (Carter and Cole, 1990). The specialty protein products used in Exp. 2 were analyzed for total bacterial concentrations expressed as cfu/g, CP, and individual AA (AOAC, 1995).

### *Experiment 1*

A total of 880 barrows and gilts (Line 327 sire × C22 dams; PIC, Franklin, KY) were used in two growth assays (14 and 12 d for trial 1 and 2, respectively) with all pigs being 15 ± 2 d of age at weaning. Pigs had an initial BW of 4.90 kg in trial 1 and 5.12 kg in trial 2. All pigs were blocked by weaning weight and randomly allotted to one of 10 experimental treatments. In trial 1, there were five replicate pens per treatment with eight pigs per pen. In trial 2, there were six replicate pens per treatment with eight pigs per pen.

For experimental diets, a control diet was used containing ingredients that were not irradiated. Other treatments included diets that had specific individual ingredients irradiated, which included corn, soybean meal, whey, animal plasma, fishmeal, soybean oil, and all other microingredients combined (medication, salt, monocalcium phosphate, limestone, zinc oxide, vitamin and trace mineral premixes, and DL-methionine). The ninth diet included all ingredients that had been irradiated, and the 10th diet was made from nonirradiated ingredients and subsequently irradiated after feed manufacturing. All irradiated ingredients and complete feed were exposed to gamma-ray irradiation (cobalt-60 source; SteriGenics, Schaumburg, IL) in trial 1, whereas electron beam irradiation (Iowa State University, Ames, IA) was used in trial 2. An average dose of 8.5 kGy was used in both assays. Individual lots of each ingredient were constant across all treatments; therefore, no ingredient quality variation should exist among experimental treatments. For trial 1, ADG, ADFI, and feed efficiency (**G:F**) were determined by weighing pigs and measuring feed disappearance on d 7 and 14, whereas in trial 2, this was done on d 6 and 12. Phase-I data represents means from d 0 to 7 of assay 1 and d 0 to 6 of assay 2, whereas Phase II data represents means from d 7 to 14 for assay 1 and d 6 to 12 for assay 2.

### *Experiment 2*

A total of 330 barrows and gilts (Line 42; PIC, Franklin, KY) were used in a 14-d growth assay, with all pigs

**Table 2.** Composition of experimental diets (as-fed basis; Exp. 1 and 2)

| | | Experiment 2 | | | | | |
|---|---|---|---|---|---|---|---|
| Ingredient, % | Experiment 1[a] | Control | Spray-dried animal plasma | Spray-dried animal plasma and egg combination | Dried porcine digest | Spray-dried beef muscle | Spray-dried whole egg |
| Corn | 38.98 | 34.87 | 42.36 | 42.24 | 33.68 | 39.76 | 35.15 |
| Soybean meal, (46.5% CP) | 15.72 | 32.81 | 20.84 | 20.75 | 29.52 | 23.78 | 27.66 |
| Spray-dried whey | 25.00 | 20.00 | 20.00 | 20.00 | 20.00 | 20.00 | 20.00 |
| AP 920 | 6.00 | — | 5.00 | — | — | — | — |
| ProtiOne | — | — | — | 5.00 | — | — | — |
| DPS 30 | — | — | — | — | 5.00 | — | — |
| Peptide-Plus | — | — | — | — | — | 5.00 | — |
| Spray-dried egg | — | — | — | — | — | — | 5.00 |
| Soybean oil | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 |
| Fishmeal | 6.00 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 | 2.50 |
| Monocalcium P, (21% P) | 0.57 | 1.21 | 1.10 | 1.24 | 1.22 | 0.47 | 1.22 |
| Limestone | 0.60 | 0.75 | 0.89 | 0.77 | 0.62 | 0.86 | 0.77 |
| Antibiotic[b] | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Salt | 0.25 | 0.37 | 0.25 | 0.31 | 0.19 | 0.07 | 0.38 |
| Zinc oxide | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 | 0.39 |
| Vitamin premix[c] | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 | 0.25 |
| Trace mineral premix[d] | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 |
| Sodium bicarbonate | — | 0.38 | — | — | — | — | 0.28 |
| Calcium chloride | — | — | — | 0.08 | 0.18 | 0.38 | — |
| L-Lysine·HCl | — | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 |
| DL-Methionine | 0.09 | 0.13 | 0.10 | 0.15 | 0.10 | 0.14 | 0.07 |
| L-Threonine | — | 0.04 | 0.01 | 0.02 | 0.04 | 0.08 | 0.03 |
| L-Tryptophan | — | — | 0.01 | — | 0.01 | 0.02 | — |
| Calculated analyses | | | | | | | |
| Lysine, % | 1.50 | 1.50 | 1.50 | 1.50 | 1.50 | 1.50 | 1.50 |
| Methionine:lysine ratio, % | 30 | 32 | 28 | 28 | 31 | 35 | 31 |
| Met and Cys:lysine ratio, % | 60 | 57 | 57 | 57 | 57 | 57 | 57 |
| Threonine:lysine ratio, % | 68 | 64 | 64 | 64 | 64 | 64 | 64 |
| Isoleucine:lysine ratio, % | 60 | 66 | 61 | 61 | 65 | 64 | 69 |
| Tryptophan:lysine ratio, % | 19 | 19 | 19 | 19 | 19 | 19 | 19 |
| Ca, % | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 | 0.90 |
| P, % | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 | 0.80 |
| Na, % | 0.48 | 0.46 | 0.46 | 0.46 | 0.46 | 0.46 | 0.46 |
| Cl, % | 0.50 | 0.58 | 0.58 | 0.58 | 0.58 | 0.58 | 0.58 |
| ME, kcal/kg | 3,517 | 3,449 | 3,495 | 3,494 | 3,479 | 3,468 | 3,583 |

[a] Same diet was used with various ingredients irradiated and included into the diet.

[b] Provided 55 mg of carbadox per kg of complete feed.

[c] Provided per kilogram of complete diet: 11,025 IU of vitamin A; 1,654 IU of vitamin D3; 44 IU of vitamin E; 4.4 mg of vitamin K (menadione sodium bisulfite); 55.1 mg of niacin; 33.1 mg of pantothenic acid (as d-calcium pantothenate); 9.9 mg of riboflavin; and 0.044 mg of $B_{12}$.

[d] Provided per kilogram of complete diet: 39.7 mg of Mn (oxide), 165.4 mg of Fe(sulfate), 165 mg Zn (oxide), 16.5 mg of Cu (sulfate), 0.30 mg of I (as Ca iodate), and 0.30 mg of Se (as Na selenite).

being 20 ± 2 d of age at weaning. Pigs had an average initial BW of 6.1 kg. Pigs were blocked by weaning weight and allotted to one of 11 dietary treatments. There were six replicate pens per treatment with five pigs per pen.

Experimental treatments included a control diet or the control diet with 5% of the following specialty protein sources: spray-dried animal plasma (**SDAP**; American Protein Corp., Ames, IA), spray-dried animal plasma and egg combination (**SDAPE**; DuCoa L.P., Highland, IL), dried porcine digest (**DPD**; Nutra-Flo Protein Products, Sioux City, IA), spray-dried beef muscle (**SDBM**; Esteem Products Inc., Irving, TX), or spray-dried whole egg (**SDWE**; California Spray Dry Co., Stockton, CA). All specialty protein products were fed irradiated or as is and originated from the same lot for each source. Irradiated protein sources were processed with gamma-ray irradiation (cobalt-60 source; SteriGenics, Schaumburg, IL) irradiation at an average dose of 8.5 kGy. Because all added specialty protein products were included at 5% of the total diet, soybean meal was allowed to vary depending on the nutrient profile of the specialty protein product. Because all specialty protein products were included in the diet at a fixed amount and not on a nutrient profile basis, a direct comparison between specialty protein products was not made, nor was it an objective of this experiment. In addition, 2.50% fishmeal and 0.15% crystalline lysine was added to all diets with other crystalline AA (methionine, threonine, isoleucine, and tryptophan) included (if necessary) to maintain similar ratios of AA relative to lysine.

**Table 3.** Bacteria concentration of feed ingredients (Exp. 1)[a]

| | Aerobic plate count, cfu/g[b] | | Total coliform count, cfu/g[b] | |
|---|---|---|---|---|
| Ingredient | Regular | Irradiated[c] | Regular | Irradiated[c] |
| Corn | $1.4 \times 10^5$ | $1.3 \times 10^2$ | $6.8 \times 10^4$ | $1.0 \times 10^1$ |
| Soybean meal (46.5% CP) | $4.1 \times 10^4$ | $8.5 \times 10^1$ | $5.7 \times 10^2$ | 0 |
| Spray-dried whey | $2.3 \times 10^2$ | $9.0 \times 10^1$ | 0 | 0 |
| Spray-dried animal plasma | $4.1 \times 10^5$ | $8.0 \times 10^1$ | 0 | 0 |
| Select menhaden fishmeal | $1.5 \times 10^3$ | $4.0 \times 10^2$ | 0 | 0 |
| Soybean oil | $1.5 \times 10^2$ | $1.2 \times 10^1$ | 0 | 0 |
| Microingredients[d] | $3.2 \times 10^3$ | $1.4 \times 10^2$ | $2.1 \times 10^2$ | 0 |

[a] Average bacterial concentration from Trials 1 and 2.

[b] Colony forming units per gram.

[c] Irradiated with either gamma ray (Trial 1) or electron beam (Trial 2) at 8.5 kGy.

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

### *Statistical Analyses*

Data from both experiments were analyzed using the GLM procedure of SAS (SAS Inst. Inc., Cary NC) as randomized complete block designs with pen as the experimental unit. In Exp. 1, no trial × treatment interactions were detected ($P < 0.10$) for the growth response criteria, so data were pooled from the two individual trials. Statistically significant differences will be noted when $P < 0.05$, and statistical tendencies will be reported when $P < 0.10$.

## Results

### *Experiment 1*

Irradiation of individual feed ingredients and complete diet reduced the total aerobic bacteria concentrations (Tables 3 and 4). The initial bacterial concentration varied between ingredients, but was highest for SDAP ($4.1 \times 10^5$ cfu/g) and lowest for soybean oil ($1.5 \times 10^2$ cfu/g).

For Phase I, nursery pigs fed diets containing either irradiated soybean meal or SDAP had greater ($P < 0.05$) ADG, whereas pigs fed irradiated corn tended ($P < 0.07$) to have higher ADG compared with pigs fed the control diet (Table 5). In addition, pigs fed irradiated corn, soybean meal, or SDAP had increased ADFI ($P < 0.05$) compared with pigs fed the diet that was irradiated after manufacturing. Also, pigs fed irradiated soybean meal, SDAP, or the manufactured and irradiated diet had greater G:F ($P < 0.05$) compared with the control diet with no irradiated ingredients. Pigs fed irradiated fishmeal, soybean oil, or the diet with all ingredients irradiated tended ($P < 0.08$) to have improved G:F compared with the control diet.

For Phase II, G:F was improved ($P < 0.05$) and ADG tended to be greater ($P < 0.07$) for pigs consuming diets with irradiated SDAP compared with those fed the diet with all ingredients that were irradiated before diet manufacturing. No difference in ADFI ($P > 0.11$) was detected among treatments.

Overall, ADG was greater ($P < 0.05$) for pigs fed irradiated SDAP compared with those fed the control, the diet containing all irradiated microingredients, or the diet that was manufactured and then irradiated. Also, pigs fed irradiated soybean meal had greater ($P < 0.05$) ADFI compared with the manufactured diet that was irradiated and tended to have improved ADFI ($P < 0.07$) compared with pigs fed the control. Pigs fed the diet containing irradiated animal plasma had improved G:F ($P < 0.05$) compared with those fed the diet containing irradiated microingredients and when all ingredients were irradiated. Also, pigs fed irradiated animal plasma tended ($P < 0.06$) to have improved G:F compared with pigs fed the control diet. Finally, pigs fed irradiated corn, whey, fishmeal, soybean oil, microingredients, or if all ingredients or whole diet was irradiated had ADG, ADFI, and G:F ($P > 0.12$) similar to those of pigs fed the control.

### *Experiment 2*

Chemical analyses of specialty protein products showed similar values to those provided by each supplier (Table 1).

Based on duplicate analyses of samples from a single lot, the respective aerobic bacteria plate count (cfu/g) before and after irradiation, respectively, were 87,000 and 7 for SDAP, 6,900 and 30 for SDAPE, 3,000 and 30 for DPD, 260 and 10 for SDBM, and 4,700 and 10 for SDWE.

For d 0 to 7 (Table 6), pigs fed regular (nonirradiated) SDAP, SDAPE, and DPD had greater ADG ($P < 0.05$), whereas pigs fed regular SDWE tended to have greater ($P < 0.10$) ADG compared with pigs fed the control diet. Also, pigs fed regular SDAPE had greater ADFI ($P < 0.05$), whereas pigs fed regular SDAP and SDBM tended ($P < 0.10$) to have increased ADFI compared with those fed the control diet. Furthermore, G:F was improved ($P < 0.05$) for pigs fed diets containing regular SDAPE, DPD, and SDWE, whereas pigs fed SDAP and SDBM tended to show improved ($P < 0.10$) G:F compared with pigs fed the control diet. Irradiation of SDAP ($P < 0.05$) and SDAPE ($P < 0.10$) resulted in greater ADG vs. pigs fed diets containing their regular form. Irradiation of SDBM tended to improve G:F ($P < 0.10$) over pigs fed regular SDBM.

**Table 4.** Bacteria concentrations of manufactured diets (Exp. 1)[a][b]

| | | Portion of diet treated with irradiation before manufacturing | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Item, cfu/g | Control | Corn | Soybean meal | Spray-dried Whey | Spray-dried animal plasma | Fishmeal | Soybean oil | Microingredients[c] | All | Complete[d] |
| Aerobic plate count | $5.1 \times 10^4$ | $1.4 \times 10^4$ | $1.3 \times 10^4$ | $2.6 \times 10^4$ | $2.2 \times 10^4$ | $9.1 \times 10^4$ | $4.2 \times 10^3$ | $1.2 \times 10^3$ | $8.9 \times 10^2$ | $4.5 \times 10^2$ |
| Total coliform count | $3.0 \times 10^3$ | $8.0 \times 10^2$ | $4.4 \times 10^3$ | $3.0 \times 10^3$ | $1.0 \times 10^2$ | $5.5 \times 10^3$ | $1.7 \times 10^2$ | $2.0 \times 10^1$ | $2.0 \times 10^2$ | $2.0 \times 10^2$ |

[a] Average bacterial concentration from Trials 1 and 2.

[b] Individual ingredients and complete diet irradiated at 8.5 kGy.

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

[d] Irradiated after feed manufacturing.

From d 7 to 14, pigs fed regular SDAPE and DPD had greater ADG and G:F ($P < 0.05$) compared with pigs fed the control diet. Overall, ADG was greater ($P < 0.05$) when pigs were fed diets containing regular SDAPE and DPD and tended ($P < 0.10$) to increase with regular SDAP compared with pigs fed the control diet. In addition, G:F was improved ($P < 0.05$) when pigs were fed diets containing regular SDAPE, DPD, SDBM, and SDWE compared with pigs fed the control diet. Pigs fed irradiated SDAP and SDBM had greater ($P < 0.10$) ADG than pigs fed their respective regular form. Pigs fed irradiated SDBM had improved ($P < 0.05$) G:F compared with those fed the regular form.

## Discussion

Previous research has shown that irradiation reduces bacterial concentrations. However, these same experiments report that irradiation may improve, not change, or decrease the nutritive value of feed ingredients or the complete diet. Metta and Johnson (1951) reported in a rat growth assay that there were no differences in digestibility or biological value of irradiated (28 kGy) wheat gluten and corn protein. In a review detailing the effects of irradiation on fishmeal, Eggum (1979) concluded that irradiation (50 kGy) did not diminish the nutritional value to any significant extent, and should be given preference over heat treatment sterilization, which reduces the nutritional value. Metta and Johnson (1951) reported no loss of available lysine in a guinea pig diet manufactured from natural ingredients when irradiated at 25 kGy. Ford (1976) reported no significant effect on the total AA, true digestibility, biological value, or net protein utilization of a complete rat diet when irradiated at 25 and 100 kGy. However, they observed a slight reduction in lysine availability at both irradiation dosage levels. In contrast, Carpenter (1963) observed no decreased lysine availability for meat and bone meal or for blood meal when irradiated at 50 kGy. Diehl (1995) concluded that no significant changes in AA composition occurred when the irradiation dose was below 50 kGy.

DeRouchey et al. (2001c) reported similar growth performance in pigs fed diets containing irradiated SDBM irradiated at 2.5, 5.0, 10.0, or 20.0 kGy. Also, DeRouchey et al. (2001a,c) reported improved performance of nursery pigs fed diets containing SDAP irradiated at dose of 9.50 to 9.75 kGy.

In Exp. 1, no detrimental effects on growth performance when pigs were fed irradiated soybean oil were seen, but other researchers have demonstrated that the irradiation of fats will have a negative impact on their nutritional quality. Schreiber and Nassett (1959) reported that irradiation of fats containing high levels of polyunsaturated fatty acids increases the onset of oxidative rancidity caused by peroxidation of the unsaturated bond. Ford (1979) reported that the peroxide values increased six to nine times when complete cat diets (4 to 14% total fat content) were irradiated at 25 kGy. Irradiation (50 kGy) of a complete swine diet resulted in vitamin

**Table 5.** Effects of irradiation of ingredients and whole diet on nursery pig performance (Exp. 1)[a]

| | Portion of diet treated with irradiation before manufacturing[b] | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Item | Control | Corn | Soybean meal | Spray-dried whey | Spray-dried animal plasma | Fishmeal | Soybean oil | Microingredients[c] | All | Complete[b] | SEM |
| Phase I[d] | | | | | | | | | | | |
| ADG, g | $157^{f}$ | $183^{fg}$ | $188^{g}$ | $174^{fg}$ | $188^{g}$ | $179^{fg}$ | $177^{fg}$ | $164^{fg}$ | $180^{fg}$ | $163^{fg}$ | 10.3 |
| ADFI, g | $183^{fg}$ | $201^{g}$ | $200^{g}$ | $195^{fg}$ | $198^{g}$ | $195^{fg}$ | $189^{fg}$ | $182^{fg}$ | $194^{fg}$ | $172^{f}$ | 8.7 |
| Gain:feed | $0.83^{f}$ | $0.90^{fg}$ | $0.94^{g}$ | $0.90^{fg}$ | $0.95^{g}$ | $0.93^{fg}$ | $0.94^{fg}$ | $0.91^{fg}$ | $0.94^{g}$ | $0.94^{g}$ | 0.03 |
| Phase II[e] | | | | | | | | | | | |
| ADG, g | 287 | 287 | 306 | 303 | 309 | 287 | 302 | 288 | 281 | 289 | 11.0 |
| ADFI, g | 360 | 374 | 384 | 377 | 378 | 359 | 373 | 377 | 377 | 364 | 10.9 |
| Gain:feed | $0.80^{fg}$ | $0.77^{fg}$ | $0.80^{fg}$ | $0.81^{fg}$ | $0.82^{g}$ | $0.80^{fg}$ | $0.80^{fg}$ | $0.77^{fg}$ | $0.76^{f}$ | $0.80^{fg}$ | 0.02 |
| Overall | | | | | | | | | | | |
| ADG, g | $222^{f}$ | $235^{fgh}$ | $247^{gh}$ | $239^{fgh}$ | $249^{h}$ | $233^{fgh}$ | $240^{fgh}$ | $226^{hf}$ | $230^{fgh}$ | $226^{f}$ | 7.8 |
| ADFI, g | $272^{fg}$ | $287^{fg}$ | $292^{g}$ | $286^{fg}$ | $288^{fg}$ | $277^{fg}$ | $281^{fg}$ | $279^{fg}$ | $285^{fg}$ | $268^{f}$ | 8.1 |
| Gain:feed | $0.82^{fg}$ | $0.83^{fg}$ | $0.85^{fg}$ | $0.84^{fg}$ | $0.87^{g}$ | $0.85^{fg}$ | $0.85^{fg}$ | $0.81^{f}$ | $0.82^{f}$ | $0.85^{fg}$ | 0.02 |

[a] Values are representative of two trials. Trial 1 used 400 pigs (eight pigs per pen and five pens per treatment) with an average initial BW of 4.90 kg. Trial 2 used 480 pigs (eight pigs per pen and six pens per treatment) with an average initial BW of 5.12 kg. ADFI is reported on an as-fed basis.

[b] Irradiated at 8.5 kGy.

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

[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 different superscripts differ ($P < 0.05$).

E losses of approximately 40%, whereas vitamin A, thiamin ($B_1$), pyridoxine ($B_6$), and folic acid each decreased by approximately 20% (Van Kooij, 1979). Furthermore, Ford (1979) reported the vitamin A content was decreased by approximately one to eight times when complete cat diets were irradiated at 25 kGy.

Spray-dried animal plasma had the highest numeric concentration of total bacteria of any ingredient in either experiment. In both experiments, pigs fed irradiated SDAP had increased performance over pigs fed nonirradiated SDAP. This would be consistent with previous research (DeRouchey et al., 2001b). In Exp. 2, pigs fed irradiated soybean meal had increased growth over pigs fed the control diet with regular soybean meal. Soybean meal was another protein source in the diet that had one of the highest bacterial concentrations of all ingredients used. El-Din and Farag (1998) reported that irradiation of full-fat soybeans reduced the trypsin inhibitor activity and lysine availability linearly when dosages of 15 to 60 kGy were applied. However, we used a lower dosage level

**Table 6.** Growth performance of nursery pigs fed specialty protein products (regular or irradiated; Exp. 2)[a]

| | | Spray-dried animal plasma | | Spray-dried animal plasma and egg combination | | Dried porcine digest | | Spray-dried beef muscle | | Spray-dried whole egg | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Item | Control | Regular | Irradiated | Regular | Irradiated | Regular | Irradiated | Regular | Irradiated | Regular | Irregular | SEM |
| Day 0 to 7 | | | | | | | | | | | | |
| ADG, g | 195 | $238^{b}$ | $274^{d}$ | $266^{b}$ | 267 | $240^{b}$ | 234 | 194 | $225^{c}$ | $225^{c}$ | 209 | 12.7 |
| ADFI, g | 195 | $223^{c}$ | 250 | $225^{b}$ | 229 | 194 | 203 | $174^{c}$ | 179 | 192 | 174 | 10.8 |
| Gain:feed | 1.00 | $1.08^{c}$ | 1.10 | $1.20^{b}$ | 1.16 | $1.23^{b}$ | 1.15 | $1.11^{c}$ | $1.24^{e}$ | $1.17^{b}$ | 1.20 | 0.05 |
| Day 7 to 14 | | | | | | | | | | | | |
| ADG, g | 262 | 269 | 283 | $308^{b}$ | 288 | $324^{b}$ | 311 | 269 | 290 | 276 | 279 | 14.6 |
| ADFI, g | 232 | 327 | 244 | 333 | 320 | 342 | 342 | 302 | 304 | 316 | 308 | 15.4 |
| Gain:feed | 0.81 | 0.83 | 0.83 | $0.92^{b}$ | 0.90 | $0.95^{b}$ | 0.92 | 0.89 | 0.97 | 0.86 | 0.91 | 0.04 |
| Day 0 to 14 | | | | | | | | | | | | |
| ADG, g | 229 | $253^{c}$ | $279^{e}$ | $287^{b}$ | 277 | $282^{b}$ | 273 | 231 | $258^{c}$ | 250 | 244 | 10.2 |
| ADFI, g | 259 | 275 | 297 | 279 | 274 | 268 | 273 | 238 | 242 | 254 | 241 | 11.2 |
| Gain:feed | 0.88 | 0.93 | 0.95 | $1.03^{b}$ | 1.01 | $1.05^{b}$ | 1.00 | $0.98^{b}$ | $1.07^{d}$ | $0.98^{b}$ | 1.02 | 0.03 |

[a] Included a total of 330 pigs (five pigs per pen and six pens per treatment) with an initial BW of 6.1 kg. ADFI is reported on an as-fed basis.

[b] Control diet vs. nonirradiated (regular) specialty protein source, $P < 0.05$.

[c] Control diet vs. nonirradiated (regular) specialty protein source, $P < 0.10$.

[d] Irradiated vs. nonirradiated (regular) specialty protein source, $P < 0.05$.

[e] Irradiated vs. nonirradiated (regular) specialty protein source, $P < 0.10$.

in our experiments and the soybean meal was already processed to have lower trypsin inhibitor activity, unlike whole soybeans. However, the benefits from irradiating SDAP and soybean meal were lost when all irradiated ingredients were combined together in a whole diet or when the whole diet with regular ingredients was irradiated compared with when they were fed individually.

The results in previous research in chicks evaluating the effect of irradiated diets has been mixed. Borsa et al. (1989 and 1991) demonstrated that chicks had improved growth performance when fed irradiated diets compared with chicks fed the same diet that was not irradiated. However, Matin et al. (1985) reported no differences in growth performance when chicks were fed an irradiated diet. Furthermore, Hijikuro et al. (1983) reported no differences in performance with irradiated poultry diets (5 or 10 kGy), but after 1 mo of storage at 30°C and 80% relative humidity, chicks fed the control diet had decreased performance, whereas chicks fed the same diet that had previously been irradiated had similar performance compared with a freshly made diet.

In trying to understand the bacterial relationship in feed ingredients, it must first be recognized that bacteria species differ for individual ingredients. The species present would depend on many factors including, but not limited to, previous environmental exposure, type of previous processing and handling, opportunity for recontamination after processing, and the availability and type of energy sources for bacterial survival associated with each ingredient. In addition, certain strains of bacteria might have a negative impact on growth performance of animals, whereas others may not. Irradiation of individual ingredients or whole diet did not negatively impact pig performance compared with nonirradiated diets, and therefore would be considered a safe processing technique for feed ingredients.

## Implications

Irradiation can be used effectively to reduce the bacterial concentrations of ingredients typical of those in nursery diets. The exact mechanism for this increase in nursery pig performance when fed certain irradiated ingredients is not known. Additional research is needed to clarify whether this response is due to a reduction in the bacterial concentration or deactivation of an unknown antinutritional factor associated with those ingredients, or other factors yet to be discovered.

## Literature Cited

Adamiker, D. 1979. Practical experiences with irradiation of laboratory animal feeds. Page 113 in Decontamination of Animal Feeds by Irradiation. International Atomic Energy Agency, Vienna, Austria.

AOAC. 1995. Official Methods of Analysis. 16th ed. Assoc. Offic. Anal. Chem., Arlington, VA.

Borsa, J., M. D. El-Din, and H. Farag. 1989. Radiation pasteurization of poultry feed: Preliminary results of feeding tests. InterAmerican Mtg. Harmonization of Reg. Related to Trade in Irradiated Foods, Orlando, FL.

Borsa, J., H. Farag, and M. D. El-Din. 1991. Radiation pasteurization of animal feed. Proc. 1991 Annu. Mtg. Canadian Nuclear Assoc./Canadian Nuclear Society. Canadian Nuclear Assoc., Ottawa, Canada.

Carpenter, K. J. 1963. Measurement of the nutritive value of protein supplements. Page 104 in Recent Advancements in Food Science. Butterworths, London, England.

Carter, G. R., and J. R. Cole Jr. 1990. Diagnostic Procedures in Veterinary Bacteriology and Mycology. 5th ed. Academic Press, San Diego, CA.

DeRouchey, J. M., J. L. Nelssen, M. D. Tokach, R. D. Goodband, S. S. Dritz, B. J. James, and M. J. Webster. 2001a. Irradiation reduces the bacteria in animal plasma and improves growth performance in nursery pigs. J. Anim. Sci. 79(Suppl. 2):217. (Abstr.)

DeRouchey, J. M., J. L. Nelssen, M. D. Tokach, R. D. Goodband, S. S. Dritz, J. C. Woodworth, M. J. Webster, and B. J. James. 2001b. Effects of gamma ray and electron beam irradiation levels in spray-dried blood meal on nursery pig performance. J. Anim. Sci. 79(Suppl. 2):165. (Abstr.)

DeRouchey, J. M., M. D. Tokach, J. L. Nelssen, R. D. Goodband, S. S. Dritz, J. C. Woodworth, B. J. James, M. J. Webster, and D. E. Real. 2001c. Effects of pH and irradiation of spray-dried blood meal on nursery pig performance. J. Anim. Sci. 79(Suppl. 2):218. (Abstr.)

Diehl, J. E., 1995. Chemical effects of ionizing radiation. Page 71 in The Safety of Irradiated Food. 2nd ed. Marcel Dekker, Inc., New York.

Eggum, B. O. 1979. Effect of radiation treatment on protein quality and vitamin content of animal feeds. Page 55 in Decontamination of Animal Feeds by Irradiation. International Atomic Energy Agency, Vienna, Austria.

El-Din, M. D., and H. Farag. 1998. The nutritive value for chicks of full-fat soybeans irradiated at up to 60 kGy. Anim. Feed Sci. Tech. 73:319–328.

Ford, D. J. 1976. The effect of methods of sterilization on the nutritive value of protein in a commercial rat diet. Br. J. Nutr. 35:267–276.

Ford, D. J. 1979. Observations on the influence of irradiation on fat and vitamin A in dry laboratory cat diets. Page 113 in Decontamination of Animal Feeds by Irradiation. International Atomic Energy Agency, Vienna, Austria.

Hijikuro, S., M. Takemasa, H. Ita, and T. Kume. 1983. Effect of gamma irradiation on disinfection and the nutritive value of diets for chicks. Bull. Nat. Inst. Anim. Ind. 40:57–64.

IAEA. 1963. Pages 148 in Radiation Control of Salmonella in Food and Feed Products. T. R. S. No. 22. International Atomic Energy Agency, Vienna, Austria.

Matin, M. A., M. R. Amin, S. Rahman, B. Rokeya, and M. A. Malek. 1985. Nutritional value of poultry feed decontamination by irradiation. Ind. Vet. J. 62:251–254.

Metta, V. C., and B. C. Johnson. 1951. Biological value of gamma irradiated corn protein and wheat gluten. J. Agric. Food Chem. 7:131–133.

NRC. 1998. Nutrient Requirements of Swine. 10th ed. Natl. Acad. Press, Washington, DC.

Schreiber, M., and E. S. Nasset. 1959. Digestion of irradiated fat in vivo. J. Appl. Physiol. 14:639–642.

The Veterinary Directorate. 1959. Destruction regulations. In Danish Regulations Governing Processing Factories. Dept. of Meat Inspection, Copenhagen, Denmark.

Van Kooij, J. G. 1979. Chemical and biological evaluation of the nutritive value of heat-sterilized and radappertized feed mixtures. Page 113 in Decontamination of Animal Feeds by Irradiation. International Atomic Energy Agency, Vienna, Austria.