BIOAVAILABILITY OF IRON IN SPRAY-DRIED BLOOD CELLS

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Abstract

The objective of this study was to determine the bioavailability, for 5 to 10 kilogram pigs, of iron (Fe) in spray-dried blood cells (SDBC, American Protein Corporation, Ames IA). A slope-ratio design was used involving fifty-six pigs from eleven litters of Line 326 sires x Camborough 22 dams (Pig Improvement Company, Franklin, KY). Pigs were reared to weaning (21 days of age) without supplemental Fe. At weaning they were moved to elevated-deck nursery pens and randomly assigned to treatment from outcome groups formed on the basis of litter and weight. Blood samples were obtained by jugular puncture and hemoglobin (Hb) and hematocrit (Ht) concentrations were measured colorimetrically. Diets were based on dried skim milk and corn with the common basal diet containing 27 milligrams per kilograms total iron. Experimental diets were formulated from aliquots of the basal diet to have incremental additions of 25, 50, and 100 milligrams per kilograms iron via substitution of corn starch with either ferrous sulfate or spray-dried blood cells. Pigs were given ad libitum access to their assigned diet for three weeks with feed disappearance and weight gain recorded for the period. Blood samples were collected at the end of the three-week feeding period and again analyzed for hemoglobin and hematocrit. Final hemoglobin values were plotted and through use of slope ratios the bioavailability of iron in spray-dried blood cells was calculated to be 23.94% that of ferrous sulfate. Statistical analysis showed significant differences among source in regard to final hemoglobin for the highest iron level (3.517 vs 7.436, for diets based on ferrous sulfate and spray-dried blood cells, respectively; $P < .002$). No significant differences were detected between test diets for hematocrit values, however there was a trend toward higher hematocrit values for pigs on ferrous sulfate diets.

Introduction

The use of by-product feed ingredients has been on the increase for the last two decades. Increased use of by-products, especially in nursery pig diets, has been prompted by both the feed industry and producers in an effort to identify those ingredients which contain highly digestible and palatable nutrients which are important for pigs weaned at earlier ages. While a plethora of research has been directed at these ingredients in the past decade, little has been done in the area of iron bioavaibility. Because iron-deficient anemia is more prevalent in humans than livestock, except for the neonatal pig, much of the research in the area of iron bioavailability has centered around foods and sources for human consumption (Morris, 1987). The bioavailability of iron in animal by-products has been estimated to be in the range of 50 to 60% while it is believed that blood products are probably higher (Conrad et al., 1980). However, these are estimates not measured determinations of iron bioavailability. Fritz et al. (1970) reported large variation (8 to 53%) in iron bioavailablity estimates for fish protein concentrates. These variations could be attributed to iron content and processing procedures of the products.

Therefore, this experiment was conducted to determine the iron bioavailability, using a hemoglobin repletion, of a common nursery diet ingredient, spray-dried blood cells, relative to ferrous sulfate.

Materials and Methods

Seventy-two weanling pigs obtained by the mating of PIC Line 326 boars and Camborough 22 dams (Pig Improvement Co., Franklin, KY) with an average body weight of 5.15 ± .89 kilograms were used to determine the bioavailability of iron in spray-dried blood cells (SDBC) in comparison to ferrous sulfate.

Pigs were farrowed and reared in farrowing facilities at the University of Illinois Swine Research Center, Champaign, IL. Upon farrowing, 11 litters were selected for use in this study. Rearing procedures differed from conventional practices in only two aspects: supplemental iron injections were not given at birth and access to creep feed was denied. Pigs were weaned at an average of 21.53 days of age, at which time they were weighed and randomly allotted on the basis of ancestry and weight to a nursery facility for the duration of the study.

Pigs were housed individually in raised deck pens where special attention had been given to the removal of all possible environmental iron sources. Pen dimensions were .61 meters x 1.22 meters giving a space allowance of .74 square meters per pig. Pen work consisted of fiberglass fencing with wooden dividers. The flooring in the pens was plastic-coated wire supported over either plastic or wooden gutters allowing for manure storage and removal. Each pen was equipped with individual one-hole stainless steel feeders and water nipples for ad libitum access to feed and water.

A common basal diet was formulated with 27 milligrams per kilograms iron. Experimental diets were then formulated from aliquots of the basal diet to have incremental levels of additional iron, in either the form of spray-dried- blood cells or ferrous sulfate. The additional 25, 50, and 100 parts per million of iron in the experimental diets were achieved by substitution of corn starch with either product. Composition of basal and experimental diets are given in Table 1.

The first three days of the study were an acclimation period in which pigs were given ad libitum access to the basal diet. Pigs were then given ad libitum access to their respective experimental diets from day 4 to completion of the study on day 24. Feed was weighed into the feeders daily with feeder weights taken on day 4 and day 24 of the study for determination of total feed and iron intake, average daily feed intake and average daily iron intake. Pigs were also weighed on day 4 and day 24 for determination of total gain and average daily gain. Upon completion of the study gain:feed ratios were calculated from the above data.

Blood samples were taken on day 1 and day 24 of the study via jugular puncture. Vacuum tubes containing potassium EDTA were used to store blood until it could be transferred to the Clinical Pathology Laboratory at the University of Illinois for hematological analysis. Samples were analyzed for hemoglobin (Hb) concentration and percent hematocrit (Ht) with a Celldyn (Abbot Labs, Chicago, Il).

Means for average daily gain, total gain, average daily feed intake, total feed intake, initial and final values for hemoglobin and hematocrit, gain:feed efficiency, and iron intake were analyzed for significant differences using PROC GLM procedure of SAS (1990). Hemoglobin concentrations for both test ingredients were analyzed using the linear regression function of SAS (1990) and compared in a slope-ratio equation.

Results

Least square means for average daily gain, average daily feed intake, feed efficiency, average daily iron intake, initial hemoglobin concentration and final hemoglobin concentration are given in Table 2. A graphic illustration of the regression lines used for the determination of bioavailability by slope ratio of iron in spray-dried blood cells is provided in Figure 1.

Average daily gain increased numerically in response to both supplemental iron sources, though diet G was significantly higher than diets A and E (Table 2). Average daily feed intakes were similar across treatments except for that of pigs fed diet G which was significantly higher than diets A, D, and E (Table 2). There was a general trend for increasing gain:feed as iron concentration increased for the ferrous sulfate supplemented diets; however, this was not the case with the spray-dried blood cell diets (Table 2). Average iron intakes were similar between iron sources for treatments, although diet G had significantly higher iron intakes than all other treatments (Table 2). Pigs on diet B had significantly higher initial hemoglobin concentrations than pigs on the other treatments, which were similar in that respect. Final hemoglobin concentrations, for pigs on the ferrous sulfate supplemented diets, demonstrated a general trend for increasing hemoglobin concentration as dietary iron was increased with pigs fed diet G eliciting significantly higher hemoglobin concentrations than all other diets. Iron bioavaiability was determined using PROC ANOVA function of SAS (1990) and the use of regressions. The slope for the control diet and three ferrous sulfate supplemented diets was .080314. The slope for the control and spray-dried blood cell supplemented diets was .019229. The bioavailability was then determined by dividing the slope of the spray-dried blood cell regression by the slope of the ferrous sulfate regression. This gives a iron bioavailability coefficient of spray-dried blood cells of 23.94% relative to ferrous sulfate.

Discussion

Hemoglobin repletion has been identified as a valid method for determining iron bioavailabilities since the 1920's (Mitchell and Schmidt, 1926). It is a valid response parameter in determining iron bioavailability due to the relatively high proportion of body iron (approximately 60-80%) associated with hemoglobin. This makes hemoglobin a sensitive indicator of iron status in the neonatal pig. This study utilized the repletion method outlined by Amine et al. (1972) in which graded levels of both the standard and test ingredient are added to the a common basal diet and slope ratios calculated. The bioavailability derived in this experiment was 23.94% relative to ferrous sulfate. This value is lower than previous estimates by Conrad et al. (1980) who estimated iron in animal by-products at 50 to 60% available with blood meals probably higher in bioavailability. However, the estimates of Conrad et al. (1980) were estimations of bioavailability, not absolutes.

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Table 1. Percentage Composition of Diets[1]

Ingredient	*Diet A 27 ppm*	*Diet B 52 ppm*	*Diet C 77 ppm*	*Diet D 127 ppm*	*Diet E 52 ppm*	*Diet F 77 ppm*	*Diet G 127 ppm*
Corn	52.2422	52.2422	52.2422	52.2422	52.2422	52.2422	52.2422
Skim milk, dried	24.1500	24.1500	24.1500	24.1500	24.1500	24.1500	24.1500
AP 920[2]	6.9000	6.9000	6.9000	6.9000	6.9000	6.9000	6.9000
Soybean oil	3.6800	3.6800	3.6800	3.6800	3.6800	3.6800	3.6800
Soybean meal dehulled	2.6590	2.6590	2.6590	2.6590	2.6590	2.6590	2.6590
Limestone	1.0120	1.0120	1.0120	1.0120	1.0120	1.0120	1.0120
Monosodium phosphate	.9200	.9200	.9200	.9200	.9200	.9200	.9200
Salt	.2300	.2300	.2300	.2300	.2300	.2300	.2300
Vitamin premix[3]	.1840	.1840	.1840	.1840	.1840	.1840	.1840
Mineral premix[4]	.0228	.0228	.0228	.0228	.0228	.0228	.0228
Corn starch	8.0000	7.0740	6.1485	4.2962	7.9875	7.9750	7.9500
AP 301[5]	.0000	.9260	1.8515	3.7038	.0000	.0000	.0000
Ferrous sulfate	.0000	.0000	.0000	.0000	.0125	.0250	.0500
Total:	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000	100.0000

[1] "As-is" basis of calculation

[2] Spray-dried animal plasma (American Protein Corporation, Ames, IA)

[3] Provided per kg of diet: 13200 IU vitamin A, 1320 IU vitamin D_3, 58 IU vitamin E, 6.60 mg vitamin K, 81.30 mcg vitamin B_{12}, 19.625 mg riboflavin, 58.181 mg d-pantothenic acid, 87.115 mg niacin, and 1217.795 mg choline.

[4] Provided per kg of diet: 10 mg copper (as copper sulfate), .20 mg iodine (as calcium iodide), 20 mg manganese (as manganese oxide), .30 mg selenium (as sodium selenate), and 100 mg zinc (as zinc oxide).

[5] Spray-dried animal blood cells (American Protein Corporation, Ames, IA)

Table 2. Least square means for response parameters of bioavailability study.

Diet *Iron concentration (ppm)*	*A* *27*	*B* *52*	*C* *77*	*D* *127*	*E* *52*	*F* *77*	*G* *127*	*SEM*
Ave. daily gain, kg	$-.001^{a}$	$.099^{a,b}$	$.106^{a,b}$	$.115^{c,d}$	$.072^{a,b}$	$.114^{b,d}$	$.234^{c,d}$	.042
Ave. daily feed intake, kg	$.314^{a}$	$.383^{a,b}$	$.411^{a,b}$	$.335^{a}$	$.352^{a}$	$.395^{a,b}$	$.515^{b}$	.052
Gain:feed	$.016^{a}$	$.242^{a,b}$	$.224^{a,b}$	$.351^{b}$	$.180^{a,c}$	$.202^{a,b}$	$.470^{b}$	.095
Ave. daily iron intake, mg	8.08^{a}	$19.07^{a,b}$	$30.78^{b,c}$	$42.03^{c,d}$	$17.68^{a,b}$	$29.61^{b,d}$	64.41^{e}	6.27
Initial hemoglobin, g/dL	3.978^{a}	4.585^{b}	$3.938^{a,b}$	3.549^{a}	$3.905^{a,b}$	$3.921^{a,b}$	$3.964^{a,b}$	.370
Final hemoglobin, g/dL	2.993^{a}	3.789^{a}	3.116^{a}	3.460^{a}	3.974^{a}	4.818^{a}	7.357^{b}	.695

$^{a-e}$Means in the same row with unlike superscripts differ ($P<.05$).