THE EFFECTS OF NUTRIENT UNIFORMITY AND MODIFIED FEED PROCESSING ON ANIMAL PERFORMANCE

by

PATRICK MICHAEL CLARK

B.S., KANSAS STATE UNIVERSITY, 2000
M.S., KANSAS STATE UNIVERSITY, 2004

AN ABSTRACT OF A DISSERTATION

Submitted in partial fulfillment of the

requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Grain Science and Industry
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2006

Abstract

A series of experiments were conducted evaluating the effects of marker selection and mix time on feed uniformity, feed uniformity on animal performance, and the addition of cracked corn to a concentrate pellet on broiler performance. Utilizing a common corn-soybean meal based poultry diet, as mix time increased, there was an overall decrease in % Coefficient of Variation (CV) observed, which was independent of which marker was used. Crude protein should be considered to be an inferior marker as several ingredients in the batch contribute some level of protein and overall decreased numerically less than 1% CV. Synthetic amino acids (methionine and lysine) prevailed as the most consistent markers reducing in magnitude by 60.32% and 55.97% (methionine and lysine, respectively).

To evaluate the effects of feed uniformity on broiler performance, as determined by CV, methionine was added to a basal diet and mixed for 10, 20, 30, 40, or 120-s, with methionine being the only ingredient varying. During the starter period (d 0 to 16) ADG increased significantly (quadratic $P<0.001$) as well as F:G (quadratic $P<0.001$). However, in overall (d 0 to 41) growth performance only ADG improved (quadratic $P<.001$). Average daily feed intake appeared to be a contributing factor in growth performance for all stages of growth.

Cracked corn was added to a concentrated pellet to evaluate growth performance on broilers and potential cost reductions at the feed manufacturing facility. A linear decrease was observed overall (0 to 41 d) for ADG, ADFI, and F:G ($P<0.003$, respectively). Gizzard weight and gizzard yield were significantly increased ($P<0.043$ and $P<0.008$, respectively) as cracked corn level increased.

THE EFFECTS OF NUTRIENT UNIFORMITY AND MODIFIED FEED PROCESSING ON ANIMAL PERFORMANCE

by

PATRICK MICHAEL CLARK

B.S., KANSAS STATE UNIVERSITY, 2000
M.S., KANSAS STATE UNIVERSITY, 2004

A DISSERTATION

Submitted in partial fulfillment of the

requirements for the degree

DOCTOR OF PHILOSOPHY

Department of Grain Science and Industry
College of Agriculture

KANSAS STATE UNIVERSITY
Manhattan, Kansas

2006

Approved by:

Major Professor
Dr. Keith C. Behnke

THE EFFECTS OF NUTRIENT UNIFORMITY AND MODIFIED FEED PROCESSING ON ANIMAL PERFORMANCE

PATRICK MICHAEL CLARK

2006

Abstract

A series of experiments were conducted evaluating the effects of marker selection and mix time on mix uniformity, mix uniformity on animal performance, and the addition of cracked corn to a concentrate pellet on broiler performance. Utilizing a common corn-soybean meal based poultry diet, as mix time increased, there was an overall decrease in % Coefficient of Variation (CV) observed, which was independent of which marker was selected. Crude protein should be considered to be an inferior marker as several ingredients in the batch contribute some level of protein and overall decreased numerically less than 1% CV. Synthetic amino acids (methionine and lysine) prevailed as the most consistent markers reducing in magnitude by 60.32% and 55.97% (methionine and lysine, respectively).

To evaluate the effects of mix uniformity on broiler performance, as determined by CV, methionine was added to a basal diet and mixed for 10, 20, 30, 40, or 120-s, with methionine being the only ingredient varying. During the starter period (d 0 to 16) ADG increased significantly (linear $P<.001$ and quadratic $P<.001$) as well as F:G (linear $P<.001$ and quadratic $P<.001$). However, in overall (d 0 to 41) growth performance only ADG showed a response (quadratic $P<.001$). Average daily feed intake appeared to be a contributing factor in growth performance for all stages of growth.

Cracked corn was added to a concentrated pellet to evaluate growth performance on broilers and potential cost reductions at the feed manufacturing facility. A linear decrease was observed overall (0 to 41 d) for ADG, ADFI, and F:G ($P<.001$, $P<.001$, and $P<.003$, respectively). Gizzard weight and gizzard yield was significantly increased ($P<0.043$ and $P<0.008$, respectively) as cracked corn level increased.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER I

CHAPTER II

CHAPTER III

CHAPTER IV

CHAPTER I
Effects of Mix Time and Marker Selection on Diet Uniformity

Abstract

An experiment was conducted evaluating markers to determine diet uniformity. Treatment diets were formulated similar to a broiler chick starter fed from 0 to 17 d post hatch. Dietary nutrients or tracers evaluated included: 1) crude protein; 2) HCl-Lysine; 3) DL-Methionine; 4) manganese; 5) phosphorus; 6) salt (chloride ion); 7) iron particles (Micro Tracer™ Red #40 by absorbance); 8) iron particles (Micro Tracer™ Red #40 by count); 9) iron particles (Micro Tracer™ RF Blue Lake); 10) roxarsone; and 11) semduramicin. All minor and micro ingredients were individually hand weighed and added to the mixer to insure accuracy and were added at the same location for all treatments. Diets were mixed using a Sprout-Waldron double ribbon mixer at three different mix times (0.5, 2.5, and 5.0 min). Mash was then collected in 22.7 kg aliquots continuously online to prevent mixing in the sack-off bin. With the exception of protein (7.7 to 7.3 % CV) and Micro Tracer™ Red (absorbance) (21.1 to 20.5%), all marker data reported a considerable reduction in Coefficient of Variation (CV) as a percent, ranging from 17.3% (roxarsone) to 52.9% (phosphorus) from 0.5 to 2.5 minute mix time. From 2.5 to 5.0 minutes, salt, roxarsone, and Micro Tracer™ Red (count) CV increased, while all other markers had a continued reduction in CV. Overall, from 0.5 to 5.0 minutes all markers showed a reduction in CV. Protein should not be considered as a marker due to, all major components in the batch of feed contribute some level of protein and results can be confounding. Synthetic amino acids (methionine and lysine) demonstrated to be the most desirable with considerable decreases over time (60.32% and 55.97%, respectively).

Introduction

A principle goal of nutritionists is to provide animals with the optimum balance of dispensable and indispensable nutrients to maximize animal performance. Nutrient levels and ratios are continuously being tailored in expectation of management, environmental, economic, and social challenges. However, many times little or no attention is paid to the manufacturing of the diet. Feed manufacturing, in many integrated companies, is thought of as nothing but a cost center. Nutritionists often assume that the dietary formula precisely calculated by a computer is what is actually presented to the target animal. Nutrient uniformity becomes even more critical for proper nutrition when feed is being consumed by animals with low daily feed intake such as baby chicks and nursery pigs (Ensminger et al., 1990). The concept of nutrient uniformity is both intuitive and fundamental. If for example, a broiler operation has a typical batching system with a 5-ton capacity and a baby chick, on average for the first two weeks of growth, consumes approximately 40 grams/day, a single batch of feed would have the ability to provided 113,500 meals. Beumer (1991) indicated mix uniformity as one of the critical quality control points in feed manufacturing. Uniformity was also mentioned as one of the loss or cost factors which are underestimated in the accurate delivery of approximately 20% of the feed additives (based upon available data). Concerns for creating a uniform mix would include: 1) nutritional over-fortification by the nutritionist (Wicker and Poole, 1991); 2) regulatory aspects (Feed Additive Compendium, 2006); and 3) animal performance (McCoy, 1992).

From a feed manufacturer's perspective, uniformity in mixed feeds is necessary to be in compliance with Food and Drug Administration's (FDA) Good Manufacturing Practices (GMPs) regulations (Title 21 C.F.R. 225.30), which states, "All equipment used in the manufacture of medicated feed shall be suitable for its intended use and shall have the capability to produce a homogeneous medicated feed of the intended potency". In addition to GMPs, the Feed Additive Compendium (2006) has the following CAUTION statement on several feed additives: Must be thoroughly mixed in feeds before use. This statement is not only for the regulatory aspect in showing an FDA official that your mixer is performing adequately, but one must be able to report assay results for feed additives and other nutrients to guarantee concentration levels stated on feed labels. Tolerances are allowed for analytical variation (AV) dealing with nutrients and feed additives for laboratory error. However, these AV's do not allow for careless proportioning, mixing, sampling, or accounting errors (Latimer, 2004).

During the last 50 years, considerable structural change in the United States, which has resulted in an overall consolidation in the animal production industries, has occurred. Animal production has evolved into a highly integrated, volume-based business. This is particularly true for the swine and poultry industries. Consequently, costs associated with, for example, feed manufacturing can be applied over a greater number of animals or units of sellable product, making feed manufacturing more economically feasible. However, along with the growth and consolidation of animal agricultural, there is an extremely competitive business

environment with very narrow profit margins. Accordingly, eliminating waste and utilizing resources as efficiently as possible is the principle goal.

The economic costs associated with nutritional over-fortification are obvious. Formula input costs are dramatically increased to compensate and insure that animals will consume proper nutrients for maximal growth. Not only is there a concern for deficiencies for all nutrients, there are nutrients or feed additives (monensin sodium, selenium, calcium:phosphorus ratio, etc.) which potentially could be toxic if over-fortified and consumed due to an improperly mixed feed. Monetary costs are a result of reduced animal performance.

McCoy (1992) reported an increase in average daily gain (ADG) (23.6 to 30.6g); average daily feed intake (ADFI) (43.1 to 52.7g), and Gain:Feed (0.548 to 0.576) during the growing phase as mixer revolution (mix time) was increased. In addition McCoy (1992) reported a reduction of mortality from 12.0% to 0.0% as mixer revolution increased. In contrast, Holden (1988) stated improper mixing of one batch of feed will seldom cause problems for on-the-farm feed manufacturing.

However, problems exist for feed manufacturers to obtain a uniform mix. In a survey conducted by Wicker and Poole (1991), feed mill mixers were tested for mix uniformity using synthetic amino acids. Over 50% of the mixers tested had a CV of over 10% and over 16% tested had a CV of greater than 20%. Many companies attempt to increase production by either over filling the mixer or reducing mix cycle time. Neglecting the designed capabilities of a mixer can often result in poor results for mix uniformity. Wicker and Poole (1991) reported mixing a six-ton batch of feed in a typical “5-ton”mixer and were unable to reduce the CV

below 29.8 % even as mix time was increased (using synthetic methionine and lysine as markers). Once the batch size was reduced to five tons in the same mixer, mix uniformity (CV) improved dramatically from 34.6% to 2.6% and 12.0% to 4.6% as mix time was increased (synthetic methionine and lysine as markers, respectively).

To evaluate mix uniformity, individual batches are measured by: randomly collecting 10 samples directly from the mixer (or at the mixer gate during discharge, whichever method is accessible and safe for the operator); running laboratory analysis of each individual sample; and calculating the coefficient of variation (CV) of the samples within a single batch of mixed feed. Representative samples must be collected to ascertain an accurate measurement. Microingredients in Feeds (1959) states if a CV of 5% or less is attained, the feed mill is probably doing a good job. The industry standard for CV is <10%. When determining mix uniformity at the mixer in the feed plant, this only takes into account mixer performance and not post-manufacturing variations (Pfost, 1966). Pfost (1976) stated uniformity should be tested at the site of consumption (i.e. at the feeder of the animal at which the feed is consumed) to predict the effect of uniformity on animal performance.

Coefficient of variation is calculated by:

$$\%CV = s/m * 100$$

$$m = (\Sigma X_i)/n$$

$$s^2 = (\Sigma(x_i^2)-nm^2)/n-1$$

Where:

% CV = Percent Coefficient of Variation

s = Standard Deviation

s^2 = Variance

m = Mean

n = number of samples assayed

For assaying a mixer, samples collected will contain a defined "marker". In selecting a marker to test for mix uniformity one should evaluate several characteristics such as: accuracy of the laboratory assay; ease of the assay; assay cost; on-site analysis; common ingredient; single source. Pfost et al. (1966) also stated criteria for marker selection which included: 1) Do not select markers which variation will not affect animal performance (e.g. Vitamin A); 2) Select ingredients with similar physical properties (particle size and density); 3) Do not utilize characteristics in which almost or all ingredients carry (e.g. ash); 4) Analytical assay variability must be less than mixer variability; 5) Feed additives (drugs) can make good tracers because degree of mixing is important from a legal and animal performance standpoint; and 6) Mineral elements can be good tracers because of density and particle size, however high assay costs may be prohibitive.

ASAE (2003) contains standard S303.3, "Test Procedure for Solids-Mixing Equipment for Animal Feeds". This standard states that for testing a batch mixer it should be charged with 98% of volume capacity with ground shelled corn (U.S. Grade #2) and 2% sodium chloride salt. It is also stated, "Other tracers may be used, but the chemical component of the tracer material should not be found in large amounts in other ingredients". There are several markers commonly used today in

the feed industry ranging from dietary nutrients (salt) to feed additives (semduramicin). Markers, in general, are micro-ingredients with inclusion levels typically less than 0.5% in the formula. Markers can provide indications of potential problems occurring in the mixer such as: irregularity of ingredient particle size (McEllhiney and Olentine, 1982); mixer buildup (Wilcox and Unruh, 1986); worn or broken parts (Wilcox and Unruh, 1986); over/under filling (Wilcox and Unruh, 1986; Wicker and Poole, 1991); ingredient sequencing (Stark et al, 1993); improper mixer adjustment (Wilcox and Balding, 1986); or inadequate mix time (Hermann and Behnke, 1994). The objective of this trial was to evaluate the effects of marker selection and mix time on Coefficient of Variation in the mixing process.

Materials and Methods

Experimental Diet and Markers

A corn-soybean meal based diet was formulated for broiler chickens during the starter phase (0-17 d; Table 1) to meet or exceed National Research Council (1984) requirements for all nutrients. The diet was formulated to 22.2 % CP, 0.96% total methionine + cystine, and 1.23% total lysine. For the evaluation of mix uniformity, dietary nutrients or tracers in the feed which were analyzed, included: 1) DL-methionine; 2) HCl-lysine; 3) crude protein; 4) mixing salt (chloride ion); 5) phosphorus; 6) manganese; 7) iron particles (Micro Tracer^{TM} Red #40 by count; MTC); 8) iron particles (Micro Tracer^{TM} Red #40 by absorbance; MTA) 9) iron particles (Micro Tracer^{TM} RF Blue Lake; MTB); 10) roxarsone; and 11) semduramicin.

Feed Manufacturing and Sampling Procedures

Diets were mixed using a Sprout double ribbon mixer with a 454 kg (1000 lb) capacity (single port discharge). The mixer was physically cleaned prior to mixing to reduce confounding effects of mixer build-up on final CV. Diets were batched as to utilize full capacity of the mixer on a weight basis (454 kg/batch). Fat was added to all batches at 1%. Mix times (Table 2) included both a dry mix time and wet mix time. Dry mix time began with all dry ingredients added in an idle mixer and the instant the mixer began to turn. At the completion of the dry mix cycle, the wet mix cycle immediately began and continued while fat was being applied into the mixer. All minor and micro ingredients were individually hand weighed and added to the mixer at the same location to insure accuracy of inclusion rates and consistency.

After the required mix time, the mixer was stopped and the discharge gate was opened. Mixed feed was conveyed by a screw conveyor to a bucket elevator, elevated 21.34 m (70 ft), and discharged through a gravity spout 16.76 m (55 ft), passing through a turn head to a packaging bin where the mash was sacked off "on-line". Mixed feed was sacked-off continuously to reduce potential further mixing in the bin upon discharge. Mash samples (5 kg) were taken from every other baggede sack (n = 10; i.e. 1,3,5, etc.) using a multi-port sample probe (Burrows Equipment Co., Evanston, IL) and then divided, using a sample splitter into appropriate aliquots for laboratory analysis. Within each sample, all markers were analyzed for that batch.

Laboratory Analysis

Laboratory analyses used for marker determination are reported in Table 3.

Results and Discussion

Results for mix uniformity, as determined by CV over time, are reported in Table 4. With the exception of CP and MTA, all marker data resulted in a considerable reduction in CV as a percent, ranging from 17.3% (roxarsone) to 52.9% (phosphorus) reduction from 0.5 to 2.5 minute mix time. From 2.5 to 5.0 minutes, salt, roxarsone, and MTC, CV increased slightly, while all other markers continued to reduce in CV. Overall, from 0.5 to 5.0 minutes all markers showed a reduction in CV. These data would be in agreement with McCoy (1992) who evaluated salt (chloride and sodium), Micro Tracer™ Red (by count), Micro Tracer™ Blue (by count), and chromium and reported a considerable reduction in CV during the first period (~25%) of the mix cycle and then continued to reduce, however at a slower rate. This rapid reduction is also in agreement with Wilcox and Unruh (1986), who tested several models of mixers, evaluating CV. Creger (1957) investigated the dispersion of sodium chloride and nitrophenide simultaneously in a series of experiments with these markers incorporated into: 1) soybean meal; 2) corn ground through a 1/8" screen(1/8" corn); 3) corn ground through a 6/64" screen (6/64" corn); and 4) complete poultry diet. The author reported findings, which suggested reducing particle size of the carrier (SBM, 1/8" corn, 6/64" corn, or complete diet) had a significant impact on mix uniformity. Differences in particle size and density of the marker could also have had an effect on the final distribution of the material. Not only did the physical characteristics of the markers and the

mash result in different responses on mix uniformity, but neither marker followed similar trends for estimating mix uniformity. This would be in agreement with McCoy (1992) who tested four different markers simultaneously at an intermediate mix time and had results which ranged from 12.1% to 23.2%, depending upon which method was chosen for CV determination.

The current experiment was designed for a practical application. It should be stated that all markers which were analyzed, with the exception of the Microtracer™ products, are utilized in a typical broiler diet in the poultry industry. Inclusion levels of the micro ingredients and/or nutrient concentrations are comparable to what is practiced in the industry. With this being said, inclusion levels, on a weight percentage basis are different, and statistical analysis proves to be difficult. For example, if a nutritionist was to compare the effects of three protein sources on animal performance, he/she would formulate the diets as to be iso-caloric and iso-nitrogeonous so as conclusions could be made about the protein source (i.e. digestibility). The same design is not possible with many of the tracers used due to the physical and analytical constraints.

These data indicate crude protein should not be considered for use as a marker due to the fact that all major components contribute some level of protein (in addition to certain minor or micro ingredients) and it can be difficult to determine if the batch has been mixed adequately or not. At the initial mix time, protein had a CV of <10% and the mixer had only operated for 30-s. Once again, in practice, feed manufacturers would never have a mix time of 30-s. An illustration to verify why crude protein is an inferior choice for a marker would be, assume a 2-ton mixer is

filled with 1-ton of SBM (48%CP) and 1-ton of porcine meat meal (50% CP). If the mixer was not turned on but ten samples were taken for mixer analysis (and we assume no sampling error and exact nutrient profiles), 2.15% CV is the highest the coefficient of variation could be.

Phosphorus has a similar response of crude protein in that, it started with a relatively low CV initially (13.72%) and reduced to only 6.46 and 6.27% CV for 2.5 and 5.0 minute mix time, respectively.

Salt (chloride ion) followed similar trends as McCoy (1992) with a decrease from the initial mix time to the intermediate mix time and but then a slight increase from the intermediate to the high mix time. One would assume salt as a single source, however analytical tests were performed searching for the chloride ion and Lysine-HCl does contain a chloride ion and also the potential to distort the results. Choline Chloride was not included into this experimental diet, but it is readily used in the industry and it must be considered if a chloride analysis is used.

Manganese showed a reduction in CV from 0.5 to 2.5 min (36.25 to 20.80%) however, during the last period (2.5 to 5.0 min) Mn showed a slightly (20.80 to 17.59 %, respectively) reduced CV.

All Microtracer^{TM} markers (MTC, MTA, and MTB) resulted in an overall reduction (0.5 to 5.0 min) in CV (21.77 to 15.08%, 21.13 to 16.88%, and 32.49 to 18.64%, respectively). Other opportunities, which would be apparent, would include the use of Microtracer^{TM} products to identify product carryover within the batching system.

Roxarsone had a minimal reduction in CV overall (30.42 to 25.54%), while Semduramicin resulted in a CV reduction of 27.40 to 11.23% from 0.5 to 5.0 minutes, respectively.

Finally, the CV for both DL-methionine and lysine decreased significantly over mix times evaluated (0.5 to 5.0 min) from 23.86% and 19.755 to 9.47% and 8.70%, respectively.

In conclusion, crude protein and phosphorus are not desirable markers as there are many ingredients which are a potential source and could confound the results. Feed additives (drugs) could be used however, the potential analytical costs can be prohibitive, and Analytical Variability (AV) could be unfavorable. Manganese, phosphorus, and salt did show a reduction in CV, however the laboratory analysis for Mg and P is time consuming and costly. DL-methionine and lysine prevailed as the most consistent markers, reducing in magnitude of their CV's by 60.32% and 55.97%, respectively, over the entire mix time. This would agree with Pfost et al (1966) in which synthetic amino acids are single sources in the mixer and are of similar particle size with the mash in which it is incorporated with.

Regardless of marker selected for a mix uniformity analysis, each mixer analysis will be unique due to diet formulation, particle size of the raw ingredients, use and wear on the mixer parts, mixer cleanliness, individual sampling, and mix time.

Literature Cited

American Society of Agricultural Engineers (ASAE). 2003. ASAE S303.3, Test Procedure for Solids-Mixing Equipment for Animal Feeds. Standards 2003. Am. Soc. Agric. Eng., St. Joseph, MI.

Beumer, I. H. 1991. Quality assurance as a tool to reduce losses in animal feed production. Adv. Feed Tech. 6:6-23.

Creger, C. R. 1957. A Study of Distribution of Microingredients in Mixed Feeds. Masters Thesis, Kansas State University.

Ensminger, M. E., J. E. Oldfield, and W. W. Heinemann. 1990. Feeds and Nutrition. 2nd ed. Ensminger Publishing Co., Clovis, CA.

Feed Additive Compendium. 2006. S. Muirhead, ed. Miller Publishing Co. Minnetonka, MN.

Hermann, T. and K. Behnke. 1994. Testing Mixer Performance. MF-1172. KSU Cooperative Extension Service. Manhattan, KS.

Latimer, G. 2004. Analytical variations (AV) based on AAFCO check sample program. Pages 230-233 *in*: Official Publication of the Association of American Feed Control Officials Incorporated.

McCoy, R. A. 1992. Effect of mixing uniformity on broiler chick performance. Masters Thesis, Kansas State University, Manhattan, KS.

McEllhiney, R. R. and C. Olentine. 1982. Problems with mixing. Feed International. 3(5): 34-38.

Pfost, H. B. 1966. Criteria for evaluating feed mixer performance. Feedstuffs 38(43):30-32.

Pfost, H. B., Deyoe, C., Stevens, C., Morgan, E. 1966. Testing feed mixtures, mixers and related equipment. Feedstuffs 38(46):32-46.

Pfost, H. B. 1976. Feed Mixing. Pages 85-103. in: Feed Manufacturing Technology. H.B. Pfost, ed. American Feed Manufacturers Association, Inc. Arlington, VA.

Stark, C., K. C. Behnke, C. H. Fahrenholz. Double Action Rotating Drum Mixer: Drumming up a better mix. Feed Management 44 (9): 37-38.

Wicker, D. L., and D. R. Poole. 1991. How is your mixer performing? Feed Management 42 (9): 40-44.

Wilcox, R. A., and J. L. Balding. 1986. Feed manufacturing problems-incomplete mixing and segregation. C-555 Revised. KSU Cooperative Extension Service. Manhattan, KS.

Wilcox, R. A., and D. L. Unruh. 1986. Feed Mixing Times and Feed Mixers. MF-829. KSU Cooperative Extension Service. Manhattan, KS.

Table 1. Composition of experimental broiler starter diets (0-17 d; as-fed basis)

Item,	
Ingredient, %	
Corn	60.48
Soybean meal (48.5%)	31.55
Meat meal (Porcine 50% CP)	3.50
Soybean Oil	1.35
Calcium Carbonate (38% Ca)	0.95
Monocalcium Phosphate (21.0% P)	1.20
Salt	0.34
Lysine - HCl	0.03
DL-methionine	0.25
Vitamin/mineral premix[a]	0.25
3-Nitro 20[b]	0.05
Aviax 5%[c]	0.05
Marker[d] (mg/kg)	55.00
Marker[e] (mg/kg)	55.00
Calculated Diet Composition	
Metabolizable energy, kcal/kg	3,058
CP, %	22.20
Total lysine, %	1.23
Methionine + cystine, %	0.96
Ca, %	0.95
Total P, %	0.70

[a]Provided (per kg of complete diet): 7717 IU vitamin A; 1653 IU vitamin D; 16 IU vitamin E; 0.83 mg vitamin K; 385 mg biotin; 24 mg of copper; 3.3 mg of iodine; 110 mg of iron; 220 mg of manganese; 27 mg of niacin; 6 mg of pantothenic acid; 6 mg of riboflavin; .3 mg of selenium; 1mg of thiamin.
[b]Provided 50 mg of roxarsone per kilogram of complete diet.
[c]Provided 25 mg of semduramicin per kilogram of complete diet.
[d]Microtracer ™ Red #40 iron marker.
[e]Microtracer ™ RF-Blue Lake iron marker.

Table 2. Experimental mix times for determination of mixer coefficient of variation.

Mix Level	Dry Mix (seconds)	Wet Mix (seconds)	Total Mix Time (minutes)
Low	0	30	0.5
Medium	60	90	2.5
High	120	180	5.0

Table 3. Laboratory analysis utilized for marker detection.

	Method of Analysis
Marker	
DL-Methionine	AOAC 994.12
Lysine-HCl	AOAC 994.12
Crude Protein	AOAC 990.03
Chloride Ion (as sodium chloride)	Appendix A
Phosphorus	Appendix B
Manganese	AOAC 968.08
Microtracer ™ Red #40 (count)	Appendix C
Microtracer ™ Red #40 (absorbance)	Appendix D
Microtracer ™ RF-Blue Lake	Appendix E
Roxarsone (3-Nitro®)	AOAC 971.47
Semduramicin (Aviax®)	Phibro S188.2[a]

[a]Assay and Identity of Semduramicin in Feeds by Normal-Phase Liquid Chromatography with Post-Column Reaction.

Table 4. Effect of marker selection and mix time on Coefficient of Variation in the mixing process

	Mix Time (min)		
Item	0.5	2.5	5.0
Marker, %CV			
DL-Methionine	23.86	14.56	9.47
Lysine-HCl	19.75	16.00	8.70
Crude Protein	7.73	7.29	6.86
Chloride Ion (as sodium chloride)	20.26	12.75	15.08
Phosphorus	13.72	6.46	6.27
Manganese	36.25	20.80	17.59
Microtracer ^{TM} Red #40 (count)	21.77	11.72	15.08
Microtracer ^{TM} Red #40 (absorbance)	21.13	20.52	16.88
Microtracer ^{TM} RF-Blue Lake	32.49	20.09	18.64
Roxarsone (3-Nitro®)	30.42	25.15	25.54
Semduramicin (Aviax®)	27.40	16.11	11.23

APPENDIX A
Quantab® Chloride Titrator Procedure

(Quantab®, Hach Co., Loveland, CO, 80539)

Analysis for chloride ion.

1) Weigh 10 g of sample into a cup.
2) Add 90 mL of boiling distilled water; stir for 30-s; wait 60-s; stir another 30-s.
3) Fold a circle of filter paper in half twice, open the cone-shaped cup and place the filter into the solution. Allow liquid to permeate filter paper.
4) Place the titrator in the solution with the filter cone. DO NOT PUNCTURE A HOLE INTO THE FILTER PAPER. The titrator capillary tube may become plugged with small feed particles.
5) Leave titrator strip in the solution until the yellow indicator strip across the top has turned dark blue.
6) Remove the titrator and record the reading to the nearest one-half division on the numbered scale.
7) Convert the reading to percentage salt using calibration tables provided with the titrators.
8) Multiply percentage of salt from the table by 10 to adjust for the dilution.
9) Calculated CV for each set of samples analyzed.

APPENDIX B

Phosphorus determination in Biological Material

Reagents

MS Solution: Dissolve 5 gm sodium molybdate ($Na_2MoO_4 + 2H_2O$) in 500 ml water. Add 14 ml conc. H_2SO_4 and bring to 1 liter with water.

Elon Solution: Dissolve 1 gm elon (p-methylaminophenol sulfate) in 100 ml 3% sodium bisulfate ($NaHSO_3$). Store under refrigeration.

Standards: From potassium dihydrogen phosphate (KH_2PO_4) prepare standards containing 20, 40, 60, 100, and 200 mcg P/ml.

Sample Preparation

Weigh 2 g into acid- washed crucibles. Ash at 600 C, increasing temperature slowly. Dissolve 5 ml 6N HCl, bring to a boil, and bring to 100 ml. Add 0.3 ml to MS solution and read against standards prepared by diluting 0.3 ml of phosphorus standards containing 50, 100, and 200 mcg P per ml, with MS solution.

Procedure

Dilute a sample volume containing 30 mcg P with 4 ml MS solution. Mix, and add 0.5 ml of Elon solution. Mix again, and let stand 1 hour. Read at 700 on spectrophotometer.

APPENDIX C
Microtracer ™ Rotary Detector Procedure (Red Count)

1) Remove upper hopper.
2) Place a 7 cm circle of #1 Whatman filter paper, with a hole in the center, on the rotary magnet.
3) Replace upper hopper.
4) Turn the rotary detector on.
5) Slowly pour a 25 g sample through the upper hopper. Run the sample through the rotary detector a second time to increase particle recovery. Turn off rotary detector.
6) Remove the upper hopper and carefully remove the filter paper from the rotary magnet.
7) Transfer particles form the filter paper to a brass or aluminum scoop. Brush the filter paper if necessary.
8) Slowly pass a bulk tape demagnetizer under the scoop, gradually moving it downward. This demagnetizes the particles and causes them to appear individually.
9) Transfer the particles form the scoop to a circle of #1 Whatman filter paper (11 cm or larger) spreading them as uniformly as possible.
10) Place the piece of filter paper with evenly distributed particle on a pie pan and thoroughly wet with 70% ethanol.
11) Place the pie pan on a preheated hot plate to dry the filter paper.
12) After the filter paper has dried, brush it clean and count the number of spots of each color.

13) Repeat the process the additional time and determine the particle count for a 100 g sample.

14) Calculate the CV for each set of samples tested.

APPENDIX D

Microtracers™ Red # 40 Absorbance Procedure.

Equipment

1. Spectrophotometer with 1 cm cell.
2. Rotary Detector with Rare Earth Magnet.
3. 50 ml screw-cap culture tubes.
4. 20 ml or 10 ml calibrated pipette.
5. Balance suitable for weighing 100 g with gradient of 0.1 g or better.

Reagents

1. Microtracer RF-Blue Lake.
2. De-ionized water.

Tracer Addition

Microtracer RF-Blue Lake should be added at 50 ppm, i.e. 50 grams of tracer per metric ton of final feed. This tracer should be premixed in 250 grams carrier (i.e. ground corn, salt etc) before adding the tracer to the mix.

Assay

Mix 50 mg RF-Blue#1 lake (Lot# A-5965) with 1000 g mash feed sample in small mixer for 20 minutes.

1) Take a 75g sub sample, and pass the sub sample twice through the Rotary Detector with Rare Earth Magnet to retrieve iron particles. Recovery of the tracer will be 99%+.
2) Transfer all the retrieved iron particles to a 30 ml weigh scoop. Place the scoop on a demagnetizer, sliding it while blowing across it gently to free retained dust as much as reasonably possible.
3) Transfer the retrieved iron to a 50 ml screw-cap culture tube, and add 20.00 ml of de-ionized water by a calibrated pipette. Agitate the tube by shaking vigorously for 20 minutes to release and disperse the dye.
4) If the solution is turbid, filter the solution using slow or medium qualitative filter paper.
5) Read the absorbance at 630 nm after establishing a “blank” on the spectrophotometer with de-ionized water.

APPENDIX E

Microtracers™ RF-Blue#1 Procedure.

Equipment

1. Spectrophotometer with 1 cm cell.
2. Rotary Detector with Rare Earth Magnet.
3. 50 ml screw-cap culture tubes.
4. 20 ml or 10 ml calibrated pipette.
5. Balance suitable for weighing 100 g with gradient of 0.1 g or better.

Reagents

1. Microtracer RF-Blue Lake.
2. 1 % Sodium Carbonate aqueous solution.

Tracer Addition

Microtracer RF-Blue Lake should be added at 50 ppm, i.e. 50 grams of tracer per metric ton of final feed. This tracer should be premixed in 250 grams carrier (i.e. ground corn, salt etc) before adding the tracer to the mix.

Assay

Mix 50 mg RF-Blue#1 lake (Lot# A-5965) with 1000 g mash feed sample in small mixer for 20 minutes.

1) Take a 75g sub sample, and pass the sub sample twice through the Rotary Detector with Rare Earth Magnet to retrieve iron particles. Recovery of the tracer will be 99%+.
2) Transfer all the retrieved iron particles to a 30 ml weigh scoop. Place the scoop on a demagnetizer, sliding it while blowing across it gently to free retained dust as much as reasonably possible.
3) Transfer the retrieved iron to a 50 ml screw-cap culture tube, and add 20.00 ml of 1% sodium carbonate aqueous solution by a calibrated pipette. Agitate the tube by shaking vigorously for 20 minutes to release and disperse the dye.
4) If the solution is turbid, filter the solution using slow or medium qualitative filter paper.
5) Read the absorbance at 630 nm after establishing a “blank” on the spectrophotometer with 1 % sodium carbonate aqueous solution.

CHAPTER II
EFFECTS OF DIET UNIFORMITY ON BROILER PERFORMANCE

Abstract

The effects of mix uniformity on broiler growth performance from d 0 to 41 by varying only synthetic (added) DL-Methionine was evaluated. A common corn-soybean meal based diet was formulated to meet or exceed the NRC requirements for broilers during the starter (d 0 to 16), grower (d 17 to 32), and finisher (d 33 to 41) period. Treatments, as described by mix time, for all three phases of growth remained constant. Treatments were: 1) 10-s; 2) 20-s; 3) 30-s; 4) 40-s; and 5) 120-s mix time. A basal diet consisting of all ingredients, with the exception of DL-Methionine and soybean oil, was mixed and placed into an ingredient bin. The basal mash was weighed as a single ingredient to the appropriate percentage of the diet and the mixer was then charged. DL-Methionine was hand weighed for accuracy and added to the mixer at the same location for all treatments. For all treatments, the exact level required of both the basal diet and DL-Methionine was added to the mixer, the only variable was mix time.

During the starter phase (d 0 to 16), both a linear ($P<0.001$) and quadratic ($P<0.001$) effect was observed for both ADG and F:G. During the grower period, ADFI responded quadratically ($P<0.003$), while no other differences. Overall (d 0 to 41) there was a quadratic response for ADG ($P<0.001$) and ADFI ($P<0.002$) with no statistical differences in F:G. In addition, total BW was different (quadratic, $P<0.01$), varying approximately 110 grams (2,408g vs. 2,519g). Feed intake appeared to be a factor in total BW.

Introduction

As early as 1955, Burns *et al*. stated mix uniformity or "mix time" could have an influence on poultry performance. This information was based upon limited data on amino acid utilization and coccidiostat performance. They also noted that particle size, density, and particle packing had a direct impact on the "degree of dispersion" within the mixer. Mix uniformity becomes even more critical when diets are consumed by animals with low daily feed intake such as baby chicks and nursery pigs (Ensminger *et al*, 1990). If for example, a broiler operation has a batching system with a 4-ton capacity and a baby chick, on average, for the first two weeks of growth consumes approximately 40 grams/day, a single batch of feed would provide 90,800 meals. Thus, if the batch of feed has poor mix uniformity each potential meal consumed by the chick may not have adequate nutrition to support initial growth.

Other statements were made about the necessity of mix uniformity which came as early as 1966 (Pfost et al., 1966), in which researchers made determinations utilizing data from rat studies in which delays of only one hour in supplying lysine reduced or inhibited animal performance. Creger (1957) evaluated the effects of simulated mix uniformity on broiler performance. Vitamin A was intermittently fed each day over the grow-out period. Treatments with intermittent feeding schedules would be fed 2 times the level of vitamin A, so as all chicks received the same total vitamin A over the entire experimental period. Differences were found in feed efficiency comparing feeding continuous vitamin A and intermittent doses of 1 day off/1 day on and 3 days off/ 3 days on. However, questions arose in the ability of the chick to store vitamin A and if differences noted were attributed to actual simulated mix uniformity. Duncan (1973)

studied the effects of nutrient uniformity (or lack of) on broiler performance. The author found that the lack of dietary crude protein uniformity affected broiler chick performance negatively as a function of protein consumption. Intuition suggests similar results on animal performance would be attained with decreasing mix uniformity. In contrast, Holden (1988) stated that, only rarely, would poor mixing of a single batch of feed cause serious problems for on farm manufacturing of swine feed disease and environmental stress factors should be more of a concern.

From a feed manufacturer's perspective, uniformity in mixed feeds is necessary to be in compliance with Food and Drug Administration (FDA) Good Manufacturing Practices (GMPs) regulations (Title 21 C.F.R. 225.30), which states, "All equipment used in the manufacture of medicated feed shall be suitable for its intended use and shall have the capability to produce a homogeneous medicated feed of the intended potency". In a survey conducted by Wicker and Poole (1991), feedmill mixers were tested for mix uniformity. Over 50% had a coefficient of variation (CV) of over 10% and over 16% had a CV of greater than 20%. Stark et al. (1991) reported similar results for on-farm feed mixers.

However, the effect of mix uniformity on animal performance was not studied until McCoy (1992) evaluated mixer revolutions (mix time) on broiler performance. With that study the dispersion of ingredients, or mix uniformity was more fully appreciated. A corn-soybean meal based diet was formulated to 80% of NRC (1984) recommendations for crude protein (CP), lysine, methionine, calcium (Ca), and phosphorus (P) to accentuate differences on broiler performance. Mix times were represented by poor, intermediate, and high uniformity. The author reported an

improvement in ADG (23.6 to 30.6g), ADFI (43.1 to 52.7g), and G:F (0.548 to 0.576) during the growing phase as mixer revolutions (mix time) increased. Maximum growth performance was found at 12 to 23% CV, depending upon method of analysis. In addition, McCoy (1992) reported a reduction of mortality from 12.0% to 0.0% as mixer revolutions increased. Traylor (1997) reported nursery pigs require a CV of less than 12% for maximum growth. Johnston et al. (2000) evaluated simulated mix uniformity of phytase on growth performance on broiler chicks. Findings stated calcium and phosphorus retention and gain were numerically decreased, and phosphorus excretion was numerically increased as phytase CV increased, however, increasing the CV had little effect on growth performance.

To analyze mix uniformity, the feed is evaluated by collecting 10 samples directly from the mixer (or at the mixer gate during discharge), and calculating CV with the use of a "marker" (Hermann *et al,* 1994). A marker is a micro ingredient or nutrient, which is incorporated into a diet at less than 0.5%. Representative random samples must be collected to ascertain an accurate measurement. The industry standard for CV is <10%.

Coefficient of variation is calculated by:

$\%CV = s/m * 100$

$m = (\Sigma X_i)/n$

$s^2 = (\Sigma(x_i^2)-nm^2)/n-1$

Where:

%CV = Percent Coefficient of Variation

s = Standard Deviation

s^2 = Variance

m = Mean

n = number of samples assayed

Even with the data generated by McCoy (1992), Traylor (1997), and Johnston et al. (2000), and the subsequent appreciation for the effects mix uniformity on animal performance, questions still arise on the effects of mix uniformity on animal performance through the entire grow out period (e.g. 0 to 41 d). Previous studies (McCoy (1992), Traylor (1997), and Johnston et al. (2000)) have only evaluated animal performance over a moderately short frame of time (or one stage of growth) during the grow-out period (e.g. 24 d). While these studies set a good foundation for understanding the effects of mix uniformity on animal performance, some confusion does still exist. For these trials, all ingredients are mixed to treatment specific times and fed to animals, however, it proves to be difficult in determining what impacts animal performance negatively (e.g. methionine deficiency, monensin sodium toxicity, or improper calcium:phosphorus ratios). Therefore, the objective of this study is to determine the effects of mix uniformity on broiler performance from d 0 to 41 by varying only synthetic (added) DL-methionine.

Materials and Methods

Experimental Diets

A corn-soybean meal based diet was formulated for broiler chickens during the starter phase (0 to 16 d), grower phase (17 to 31 d), and finisher phase (32 to 41 d)

(Table 1) to meet or exceed National Research Council (1994) requirements for all nutrients.

Feed Manufacturing

Corn was ground using a 30 HP full circle hammermill (Model P-240, Jacobson Machine Works, Minneapolis, MN) equipped with a 3.175 mm screen to achieve a grind of ~600µ geometric mean particle size (d_{gw}). Diets were mixed using a Sprout Waldron double ribbon mixer with a 454 kg (1000 lb) capacity (single port discharge). The mixer was physically cleaned prior to mixing to reduce mixer build-up. Treatments, as described by mix time, for all three phases of growth remained constant. Treatments were: 1) 10-s; 2) 20-s; 3) 30-s; 4) 40-s; and 5) 120-s mix time.

Treatment times were determined based upon preliminary mixing trials using 997 pounds of corn and 3 pounds of salt, mixing for the previously stated treatment times and measuring the uniformity testing for the chloride ion. Initial CV's from salt (chloride) analysis were 58, 45, 32, 20, 13, and 6 % CV for 10, 20, 30, 40, and 120-s mix times, respectively.

A basal diet consisting of all ingredients, with the exception of DL-methionine and soybean oil, was mixed and placed into an ingredient bin. The basal mash was weighed as a single ingredient to the appropriate percentage of the diet and the mixer was then charged. DL-methionine was hand weighed for accuracy and added to the mixer at the same location for all treatments. For all treatments, the exact level required of the basal diet and DL-methionine was added to the mixer, the only variable was mix time. Diets were batched to utilize the full capacity of the mixer on a weight basis (454 kg/batch). After the required mix time, the mixer was stopped to prevent further

mixing, and the discharge gate was opened. Mixed feed was conveyed by a screw conveyor to the boot of a bucket elevator, elevated 21.34 m (70 ft), and conveyed by gravity spout 16.76 m (55 ft) passing through a turn head to a packaging bin where the mash was sacked off on-line. Mixed feed was sacked-off continuously to reduce potential further mixing in the sack-off bin. Residual feed remaining in the mixer was discharge by hand rotating the mixer reel as to minimize further mixing. Mash samples (500 g) were taken from sacks (n=10; i.e. 1,3,5, etc.) using a multi-port sample probe (Burrows Equipment Co., Evanston, IL) for laboratory analysis and DL-Methionine analysis. Sacks (22.7 kg) were labeled in the order they were produced to retain integrity throughout the manufacturing process.

Diets were then pelleted using a CPM pellet mill (Master Model HD, series 1000, Crawford, IN) equipped with a 4 mm x 32 mm (5/32" x 1 1/4") pellet die. Prior to pelleting, diets were conditioned to 82° C in a short-term (12-15 s) conditioner. Diets were pelleted 22.7 kg at a time in the order the mash was sacked-off to prevent further mixing. After cooling, pellets were sacked continuously similar to the procedure for mash collection. Post-pellet fat was then applied to each individual 22.7 kg sack using a small capacity double ribbon mixer.

Animals and Housing

Forty day-old male broiler chicks (Cobb-Vantress) of a slow-feather strain were randomly distributed to each of 60 floor pens (1.47m x 1.93m) in a curtain-sided, positive pressure ventilated house. Twelve pens were assigned to each of the five treatments and location within the house was used as blocking criteria. Each pen contained nipple drinkers and a Choretime® feed pan adapted as a feed hopper. Feed

and water were consumed *ad libitum.* Feeders were checked twice daily to ensure constant flow. Birds were maintained on a lighting schedule as suggested by the bird supplier. Mortalities were collected, weighed, and recorded as they occurred. Growing periods were as follows: starter (0-16 d); grower (17-31 d); and finisher (32-41 d). At the end of each growing period, data was collected which included total pen weight and feed consumption for calculation of feed efficiency.

Statistical Analysis

Experimental design was a randomized complete block. Pen served as the experimental unit for all analyses. Data was analyzed using the *Mixed* procedure of SAS ((Release 8.2 for Windows, SAS Institute, Cary, NC) by orthogonal contrasts evaluating linear and quadratic responses. Level of significance was fixed at $P<0.05$.

Results and Discussion

The effect of CV on broiler growth performance is shown in Table 2. For each growth phase, CV reduced dramatically from 10-s to 20-s mix time and then a gradual reduction over the balance of mix time. For each phase of growth, CV followed similar trends over time. At 120-s mix time, the CV was well below the industry standard of 10% for the starter, grower, and finisher phase (3.38%, 3.45%, and 5.64% respectively).

As anticipated, during the starter phase of growth, for both ADG and Feed:Gain (F:G), a significant linear ($P<0.001$) and significant quadratic ($P<0.001$) negative response to mix time was observed. With a range of only 1.40 g between the averages of all treatments (41.51 g to 42.91 g) in ADFI, the necessity of creating a uniform mix is shown since all required ingredients were placed into the mixer for optimal performance and the only variable was mix time.

During the grower phase there were no statistical differences in ADG and F:G. There was a quadratic response ($P<0.003$) in ADFI with treatments of 20, 30, and 40-s mix time having an increased feed intake over 10-s and 120-s. Finally, during the finisher phase, there were no statistical differences in ADG, ADFI, and F:G (linear ($P>0.15$) and quadratic ($P>0.07$)).

Overall, performance data from 0 to 41 d shows a quadratic ($P<0.001$) response for ADG and a quadratic ($P<0.002$) response for ADFI. Since both ADG and ADFI followed similar trends, F: G reported no significant differences. ADG was lower for the 10-s treatment (56.85 g) than 120-s mix time (57.88 g). A lower ADFI for 10-s mix time versus 120-s mix time (105.79 g and 106.35 g, respectively) was also found. Even with no statistically significant differences in F:G for overall growth performance, many integrated broiler companies find two points of feed conversion (in this study 1.86 vs. 1.84) to be economically significant.

Summary

It was shown that mix uniformity significantly affects the growth of broilers during the starter phase; however, the differences over an entire growth period are more subtle. Feed consumption appears to be the controlling factor for similar growth and feed efficiency in overall performance through the grow out period in which the animal is over consuming to alleviate nutritional deficiencies. Further research needs to investigate mix uniformity in which all ingredients can vary over time. Finally CV should be measured at both the mixer (or discharge chute), and at the individual feeder where the diet is consumed, to confirm that what the animal is fed is what was formulated and how subsequent animal performance is impacted.

Literature Cited

Burns, L. V., R. W. Lewis, and G. D. Miller. 1955. The Influence of Mixing in Poultry Nutrition. Poult. Sci. 34:1185.

Creger, C. R. 1957. A Study of Distribution of Microingredients in Mixed Feeds. Masters Thesis, Kansas State University.

Duncan, M. 1973. Nutrient Variation: Affect on Quality Control and Animal Performance. Doctoral Dissertation, Kansas Stated University.

Ensminger, M. E., J. E. Oldfield, and W. W. Heinemann. 1990. Feeds and Nutrition. 2nd ed. Ensminger Publishing Co., Clovis, CA.

Hermann, T. and K. Behnke. 1994. Testing Mixer Performance. MF-1172. KSU Cooperative Extension Service. Manhattan, KS.

Holden, P. 1988. Diagnosing Feed Mixing Problems in Swine Herds. Agri-Practice 9:3-4.

Johnson, S. L. and L. L. Southern. 2000. The Effect of Varying Mix Uniformity (Simulated) of Phytase on Growth Performance, Mineral Retention, and Bone Mineralization in Chicks. Poult. Sci. 79:1485-1490.

McCoy, R. A. 1992. Effect of mixing uniformity on broiler chick performance. Masters Thesis, Kansas State University, Manhattan, KS.

National Research Council. 1994. Nutrient Requirements of Poultry. 9th ed. National Academy Press, Washington, DC.

Pfost, H. B., Deyoe, C., Stevens, C., Morgan, E. 1966. Testing feed mixtures, mixers and related equipment. Feedstuffs 38(46):32-46.

Stark, C., K. C. Behnke, C. H. Fahrenholz. Double Action Rotating Drum Mixer: Drumming up a better mix. Feed Management 44 (9): 37-38.

Traylor, S. L. 1997. Effects of feed processing on diet characteristics and animal performance. Masters Thesis, Kansas State University, Manhattan, KS.

Wicker, D. L., and D. R. Poole. 1991. How is your mixer performing? Feed Management 42(9): 40-44.

Table 1. Ingredient and calculated nutrient composition of experimental broiler diets.

Item	Starter	Grower	Finisher
Ingredient, %			
Corn	60.54	64.61	68.05
Soybean Meal (48% CP)	31.55	27.85	24.80
Meat Meal (Porcine)	3.50	2.50	---
Soybean Oil	1.35	1.95	3.60
Limestone (38% Ca)	0.95	1.05	1.15
Monocalcium, (21% P)	1.20	1.15	1.55
Salt	0.34	0.35	0.39
L-lysine HCl	0.03	---	---
DL-methionine	0.25	0.19	0.15
Vitamin/mineral premix[a]	0.25	0.25	0.25
Coccisiostat[b]	0.05	0.05	0.05
Calculated Composition, %			
CP	22.20	20.12	17.50
Total methionine	0.60	0.52	0.45
Total methionine+cystine	0.96	0.85	0.76
Total lysine	1.23	1.07	0.92
Calcium	0.95	0.90	0.84
Phosphorus-Total	0.73	0.67	0.65
Phosphorus-Available	0.49	0.44	0.43

[a]Provided (per kg of complete diet): 7717 IU vitamin A; 1653 IU vitamin D; 16 IU vitamin E; .83 mg vitamin K; 385 mg biotin; 24 mg of copper; 3.3 mg of iodine; 110 mg of iron; 220 mg of manganese; 27 mg of niacin; 6 mg of pantothenic acid; 6 mg of riboflavin; .3 mg of selenium; 1mg of thiamin.

[b]Provided 60g/ton of salinomycin.

Table 2. Effect of mix time, with DL-methionine as a single variable, on broiler growth performance and mix uniformity.[a]

	Mix Time (seconds)						Probability	
Item,	10	20	30	40	120	SE	Linear	Quadratic
d 0 to 16								
CV,%[b]	144.61	52.19	24.75	17.13	3.38			
ADG, g	28.60	30.57	31.27	31.52	30.40	.43	0.001	0.001
ADFI, g	41.51	42.11	42.60	42.91	42.27	.56	0.174	0.184
F:G, g:g	1.45	1.38	1.36	1.36	1.39	.01	0.001	0.001
d 17 to 32								
CV,%	129.35	78.13	29.12	35.76	3.45			
ADG, g	77.20	81.57	79.41	81.17	79.51	1.87	0.447	0.215
ADFI, g	130.05	134.60	134.34	134.62	127.75	2.02	0.445	0.003
F:G, g:g	1.69	1.66	1.70	1.67	1.61	.04	0.259	0.413
d 33 to 41								
CV,%	134.83	21.22	23.16	20.57	5.64			
ADG, g	82.04	77.16	81.38	77.73	81.89	2.56	0.973	0.278
ADFI, g	176.42	180.03	181.64	180.43	181.03	2.19	0.159	0.270
F:G, g:g	2.17	2.34	2.26	2.35	2.23	.07	0.535	0.078
d 0 to 41								
ADG, g	56.85	58.99	59.29	59.60	57.88	.63	0.143	0.001
ADFI, g	105.79	108.85	109.40	109.15	106.35	1.06	0.654	0.002
F:G, g:g	1.86	1.85	1.85	1.84	1.84	.02	0.427	0.757
Total BW, g	2,408.3	2,502.4	2,497.7	2,519.8	2,452.5	31.27	0.265	0.010
Mortality, %	7.50	11.46	8.95	7.92	8.54			

[a]Twelve pens per treatment; forty birds per pen.
[b]Mixer %CV for DL-Methionine concentration (AOAC method 994.12).

CHAPTER III

THE EFFECTS OF FEEDING CRACKED CORN AND PELLETED CONCENTRATE PROTEIN PELLETS ON BROILER PERFORMANCE AND FEED MANUFACTURING COSTS

Abstract

Two experiments were conducted to evaluate the effects of feeding cracked corn with a concentrate pellet to broilers from d 0 to 41 was evaluated. A common corn-soybean meal based diet was formulated to meet or exceed all NRC (1994) requirements for broilers during the starter (d 0 to 18), grower (d 19 to 32), and finisher (d 33 to 41) period. Cracked corn (0, 25, 50, 75, or 100%) was used to replace the corn fraction in the diet for all three stages of growth. Cracked corn and a concentrate pellet was blended together to be iso-nitrogenous and iso-caloric between all treatments, so as only feed form would differ. For both experiments, pellet quality increased linearly ($P<.001$) for all three phases of growth as the cracked corn inclusion level increased. Exp 1 diets included a control (0% cracked corn) and four experimental diets (25, 50, 75, or 100%) where cracked corn directly replaced the ground corn fraction. Overall (d 0 to 41) a linear decrease ($P<0.001$) for ADG and ADFI, and a linear increase ($P<0.003$) for F:G was observed as cracked corn levels increased. Gizzard weight and yield increased linearly ($P<0.05$) as cracked corn level increased. In Exp 2, a "step-up" feeding program of cracked corn was evaluated with dietary treatments including: 1) control (0%); 2) 0% cracked corn for d 0 to 17 and 25% for d 18 to 41; 3) 0% cracked corn for d 0 to 17 and 50% from d 18 to 41; 4) 25% cracked corn (d 0 to 41); and 5) 50% cracked corn (d 0 to 41). Overall (d 0 to 41), ADG and ADFI for treatment 1, 2, and 4, was greater than 3 and 5. Feed efficiency was superior for diets 2 and 4 in comparison with other treatments. As in Exp 1, gizzard weight and yield was higher than the control diet. In conclusion, broilers can be fed up to 25% cracked corn in the diet without negatively affecting growth performance.

Introduction

In the livestock production industry, feed is known to represent the highest input cost in an operation. Feed costs are more difficult to see in an integrated operation where no direct returns from feed sales can been observed. An integrated company's monetary earnings are determined by least cost formulation of diets, production efficiency (feed conversion), and feed manufacturing costs. Grinding represents a considerable cost in energy consumption and feed mill throughput, second only to pelleting, if done. Considerable research in particle size reduction on animal performance searching for optimal animal growth has been conducted.

Typically in the US most all integrated poultry operations offer feed in the pelleted form. This constitutes the largest percentage of feed manufacturing expense in an integrated operation, in addition to regulating the capacity of the feed plant. To an integrator benefits would include, improved handling characteristics, improved bulk density for transportation, and decreased loss (spillage) at the feeders. To nutritionists benefits would include a general acceptance animals fed pelleted diets will outperform those fed mash diets. Before pelleting, cereal grains are ground to aid in mixing and in the transporting of the mash to feedstock bins before the pelleting system. Disagreements still occur why benefits happen by pelleting feed (energy partitioning, particle size, feed intake, nutrient uptake).

Extensive research has been conducted on growing and finishing pigs in the area of feed processing. Optimum particle size requirements for grower/finisher diets have been studied extensively (Ivan et al., 1974; Owsley et al., 1981). In addition to the effect of particle size on animal performance, Wondra et al (1995a) calculated the actual

cost of feed manufacturing (grinding). Further research has examined particle size requirements for lactating/gestating sows (Wondra et al., 1995b, c).

Although poultry and swine are monogastric animals, there are obvious significant differences in the anatomy and physiology of the digestive tract. The esophagus contains a crop which stores feed, a proventriculus (the true stomach) following, which leads to the gizzard. The gizzard's function is to grind feedstuffs, typically large cereal grains, to a reduced particle size for further digestion. These differences not only change the nutritional requirements, but feed manufacturing techniques that should take place. During the early 1900's, all poultry producers fed whole grain. Not until research began to surface in the middle 1920's (Kennard and Bethke, 1926) showing improvements on poultry performance, did the desire of grinding cereal grains for poultry emerge.

Today, typical feed manufacturing practices used in the poultry industry include the grinding of all cereal grains. This is done for several reasons. When diets are fed in mash form, it prevents birds from selectively consuming particles larger in size. It is also known in feed processing with a wide distribution of particle sizes, it becomes difficult to mix accurately due to the segregation of small and large particles during the mixing process, in addition to succeeding material handling (Martin, 1983).

Effects of Pelleting on Poultry

Considerable research has shown the effects of pelleting versus mash on the performance in poultry (Hussar and Robblee, 1962; Calet, 1965; Runnels et al., 1976; Proudfoot and Sefton, 1978; Nir et al., 1995). Typically poultry diets, more specifically broilers and turkeys, are pelleted for reasons such as increased digestibility, decreased

ingredient segregation, increased palatability, and reduced energy expenditure during prehension (Behnke, 1996).

Pelleting poultry diets will not guarantee an improvement in bird performance (e.g. feed conversion, breast yield, or weight gain). Scheideler (1995) reported feed conversion was increased by 2.4% when broilers were fed a high quality pelleted diet (75% pellets and 25% fines) in comparison to a poor quality pelleted diet (25% pellets and 75% fines). McKinney et al. (2004) also suggested that pelleting contributes 187 kcal/kg of diet at 100% pellet quality (i.e. no fines) and effective caloric value declines curvilinear as pellet quality decreases.

Whole Grain Feeding Procedures

Within the past decade there has been a considerable increase in the use of whole grains in poultry diets, especially in the European Union. This is done for several reasons, which include: 1) lower trucking costs; 2) increased mill capacity; 3) lower equipment costs; and 4) presumed bird health. Several approaches are utilized for the inclusion of whole grains into a broiler diet: 1) pelleting the whole grains with the mash; 2) choice feeding; 3) sequential feeding; and 4) free choice/onsite blending. Pelleting whole grains with the mash is practiced, however not on a large scale due to minimal savings (e.g. grinding). Choice feeding involves feeding of a whole grain plus a protein concentrate. This method includes two feed troughs (or feed lines) in which one line or trough contains the whole grains and the other contains the protein concentrate. Sequential feeding follows a similar approach, however only one feed trough is used. Whole grains are fed, for example, in the morning, and the protein concentrate is fed in the afternoon/evening. Finally, the most common method of

adding whole grains is blending of the whole grains with the pellets. This can be accomplished at farm while the truck is being unloaded into the storage bin (if the farmer has grain on site) or can be done at the feed mill once the truck is loaded with the pellet portion of the diet, then whole grains are added on top of the load.

All four strategies are significantly different than the common arrangement practiced currently in the United States where, formulas are typically corn-soybean meal based, and all ingredients are pelleted for the broiler industry. Could any of the four whole grain feeding strategies be incorporated into the US broiler industry? If only one were to be chosen, which one? Incorporation of whole grains into the pellet will only reduce a percentage of the grinding costs. Sequential feeding assumes animals will eat to meet all of their nutritional needs and more intense management is required for feeding at each house. Adding whole grains at the farm or at the feedmill would be difficult to integrate as producers do not own their own grain on site to blend and a dilution factor for both situations still exists. A choice feeding system, or modification, would deem to be appropriate. In the US, typical feeding operations are not arranged for dual lines or feeders, so an approach which could be taken, would have the feed mill produce a complete diet satisfactory in nutrients for optimal growth with the whole grain incorporated with a concentrate pellet. In the US, typical cereal grains produced include: 1) corn; 2) wheat; 3) sorghum; 4) barley; and 5) oats. Corn would be considered the predominant choice as wheat is used food production, sorghum is raised predominantly in the Midwest in smaller quantities, and barley/oats are difficult to digest by poultry due to a high fiber content and low metabolizable energy content. Whole corn is larger in particle size in comparison to the pellet and is too large for

consumption by a young broiler. To address this issue, cracking the corn to approximately 2000 μm (or the size of a wheat kernel) by the use of a roller mill would aid in blending of the pellet and corn, in addition to aid in feed consumption by the bird.

The objective of this experiment was to determine the effects of cracked corn inclusion into a broiler diet, blended with an appropriate concentrate pellet as not alter final nutrient content (i.e. iso-caloric and iso-nitrogenous), on animal performance as determined by average daily gain (ADG), average daily feed intake (ADFI), and feed efficiency (FG).

Materials and Methods

Experimental Dietary Treatments

Experiment 1

A corn-soybean meal based diet was formulated for the starter phase (0 to 18 d), grower phase (19 to 31 d), and finisher phase (32 to 41 d; Table 1) to meet or exceed National Research Council (1994) requirements for all nutrients. Experimental treatments included: 1) a complete ground and pelleted diet; 2) a diet with 25% of the corn fraction removed and used as cracked corn; 3) a diet with 50% of the corn fraction removed and used as cracked corn; 4) a diet with 75% of the corn fraction removed and used as cracked corn; and 5) a diet with 100% of the corn fraction removed and used as cracked corn. The cracked corn was sieved and the fines were then returned as part of the corn fraction. The appropriate amounts of cracked corn and supplement pellet were blended together and finally, fat was added. For all three phases of growth and five experimental treatments, fat was added post pellet. After the blending process, all dietary treatments were formulated to be iso-nitrogenous and iso-caloric.

Experiment 2

A corn-soybean meal based diet was formulated for the starter phase (0 to 18 d), grower phase (19 to 31 d), and finisher phase (32 to 41 d); (Table 1) to meet or exceed National Research Council (1994) requirements for all nutrients. Experimental treatments included: 1) a complete ground and pelleted diet; 2) a diet with 25% of the corn fraction removed and used as cracked corn; 3) a diet with 50% of the corn fraction removed and used as cracked corn; 4) animals were fed Treatment #1 for the starter period (0 to18 d) and the switched to Treatment #2 for the balance of the grow out period (19 to 41 d); and 5) animals were fed Treatment #1 for the starter period (0 to18 d) and the switched to Treatment #3 for the balance of the grow out period (19 to 41 d). The cracked corn was sieved and the fines were then returned as part of the corn fraction. The appropriate amounts of cracked corn and supplement pellet were blended together and finally, fat was added. For all three phases of growth and five experimental treatments, fat was added post pellet. After the blending process, all dietary treatments were formulated to be iso-nitrogenous and iso-caloric.

Feed Manufacturing

Corn was ground for the complete pelleted diet and corn in the protein pellets using a 30 HP full circle hammermill (Model P-240, Jacobson Machine Works, Minneapolis, MN) equipped with a 3.175 mm screen to achieve a grind of 507 μm geometric mean particle size (d_{gw}). Hammermill production rate was set to obtain approximately an 80% motor load. Corn was cracked through a three-high roller mill (1:1, 1.5:1, 1.5:1 differential drives; 3.2, 4.7, and 6.3 corrugations per centimeter; and 0, 8.3, and 8.3 cm of spiral per meter of roll, Model K, Roskamp Manufacturing, Cedar Falls, IA) equipped with a 15 hp motor for the top and middle pair of rolls and a 10 hp

motor for the bottom pair of rolls. However, the bottom two rolls were left open, as only the top pair were used. Cracked corn was screened through a # 6 US screen to for removal of debris or whole kernels of corn, and over a #10 US, for removal of the fines. Cracked corn particle size would be noted as - # 6 US (- 3360 μm) and + #10 US (+ 2000 μm) Corn particle size is ASAE (1997b) methods were used for particle size analysis of the ground material. Diets were pelleted using a CPM pellet mill (Master Model HD, series 1000, Crawford, IN) equipped with a 4 mm x 32 mm (5/32" x 1 1/4") pellet die. Prior to pelleting, diets were conditioned to 82° C in a short-term (12-15 s) conditioner. Samples were collected and cooled for approximately 15 minutes in a small batch cooler and used to determine pellet quality, Pellet Durability Index (PDI) (ASAE, 1997a).

Animals and Housing

Experiment 1

Forty day-old male broiler chicks of a slow-feather strain were randomly distributed to each of 52 floor pens (1.47m x 1.93m) in a curtain-sided, positive pressure ventilated house. Four pens were assigned to the control treatment and 12 pens were assigned to each of the other four treatments, utilizing location within the house as blocking criteria. Each pen contained nipple drinkers and a Choretime® feed pan adapted to a hopper. Feed and water were consumed *ad libitum.* Feeders were checked twice daily to ensure constant flow. Birds were maintained on a lighting schedule as suggested by the bird supplier. Mortalities were collected and recorded as they occurred.

Experiment 2

Forty day-old male broiler chicks of a slow-feather strain were randomly distributed to each of 36 floor pens (1.47m x 1.93m) in a curtain-sided, positive pressure ventilated house. Four pens each were assigned to the control treatment (1), and the change over treatments (4 and 5) with 12 pens assigned to each of the other 2 treatments (2 and 3), utilizing location within the house as blocking criteria. Each pen contained nipple drinkers and a Choretime® feed pan adapted to a hopper. Feed and water were consumed *ad libitum.* Feeders were checked twice daily to ensure constant flow. Birds were maintained on a lighting schedule as suggested by the bird supplier. Mortalities were collected and recorded as they occurred. Experimental procedures were approved by Kansas State University Institutional Animal Care and Use Committee (IAUCC 3609).

Gizzard and Intestinal Characteristics

At 41 d of age, 2 birds were randomly selected and removed from 4 pens (*Experiment 1* – Treatment 1; *Experiment 2* – Treatment 1, 4 and 5) or 6 pens (*Experiment 1* – Treatment 2-5; *Experiment 2* – Treatment 2 and 3), harvested by CO_2 gas affixation, and viscera removed. Carcass weight was determined without giblets. Gizzard contents were emptied, adhering fat was removed, and gizzards were weighed for the calculation of gizzard weight as a percent of dress weight. The small intestine was subdivided into two sections (foregut and hindgut) for determination of intestinal strength. Foregut is characterized as from the duodenum loop to Meckle's diverticulum and the hindgut is characterized as from Meckle's diverticulum to the ileocecal junction. Each section was excised at 25 cm and all contents were discarded with

adhering connective tissue and adipose tissue removed prior to intestinal strength analysis. Strength was determined by peak force (Instron model 4201 Canton, Massachusetts USA) required to break samples by securing intestinal sections in clamps and setting cross-head speed at a rate of 100 mm/min.

Statistical Analysis

Experiment 1

Experimental design was a randomized complete block. Pen served as the experimental unit for all analyses. All data was analyzed by the Mixed procedure of SAS (Release 9.1 for Windows, SAS Institute, Cary, NC) by orthogonal contrasts evaluating linear and quadratic responses. Level of significance was fixed at $P<0.05$.

Experiment 2

Experimental design was a randomized complete block. Pen served as the experimental unit for all analyses. All data was analyzed by the Mixed procedure of SAS (Release 9.1 for Windows, SAS Institute, Cary, NC) by means separation. Level of significance was fixed at $P<0.05$.

Results and Discussion

Physical feed characteristics are reported in Table 3. Pellet durability, as described by Pellet Durability Index (PDI); (ASAE, 1997a), in both the grower and finisher phase showed a increasing linear response ($P< 0.001$) as cracked corn inclusion level increased for both PDI and PDI modified. As more corn is removed from the pelleted fraction of the diet, the concentration of protein increases, and results of this experiment are in agreement with Briggs et al. (1999) who stated a there is a direct relationship with protein level and pellet quality. Clark (2004) evaluated the effects of cracked corn inclusion on feed manufacturing efficiency, more specifically, pellet

quality (determined by PDI and % fines), electrical consumption, and production rate, and found similar results in which there was an increase in pellet quality as a fraction of the corn in the diet was removed from the pelleted portion and protein concentration increased. Additional feed characteristics, which were evaluated, included bulk density of the concentrate pellet and finished feed. For the starter phase, concentrate pellet and finished feed bulk density was not different between the treatments.

Broiler Growth Performance

Experiment 1

Broiler growth performance for Experiment 1 is reported in Table 4. Within the starter phase, a linear ($P<0.001$) and quadratic ($P<0.01$) response was found for ADG. A similar response was found for ADFI (linear ($P<0.001$) and quadratic ($P<0.003$). Feed conversion showed a linear response ($P<0.03$) ranging from Treatment 1 (control diet) (1.35) to Treatment 5 (100% of the corn fraction cracked) (1.41). From visual observations, feed selectivity (i.e. feed sorting) potentially could be a reason for this growth response. However, a reduction in feed intake could also have contributed to a reduced growth response. Tucker (2006) stated gut health is critical and the relationship between gut health and growth performance is crucial, especially in the young bird. If feed intake is depressed, gut development is hindered, allowing for increased endogenous losses and pulling valuable nutrients out of body reserves for development (Tucker, 2006). Kiiskinen (1996) evaluated the effects of adding whole wheat into a broiler diet and found similar results stating daily gain and feed intake was depressed as inclusion levels increased. The addition of whole wheat in European countries has been a common practice for the last decade. However, when these methods are incorporated

into production settings, wheat is added without any adjustment to the pelleted portion of the diet. This results in a dilution of all nutrients, and could account for reduced animal performance. Kiiskinen (1996) also evaluated the blending of whole grains with either a starter pellet or a grower pellet from 12 to 37 d. It was reported that blending of whole grains and a starter pellet resulted in higher animal performance, compared to whole grains and a grower pellet, due to the increased crude protein, mineral, and vitamin concentration levels.

During the grower and finisher period, ADG and ADFI dropped significantly ($P<0.001$) as cracked corn levels increased. For both the grower and finisher period, feed was removed by negative pressure from the feed pan to determine if feed selectivity existed. For both the grower and finisher phase, the apparent consumption of cracked corn increased as cracked corn inclusion level increased, i.e. more pellets were being consumed than cracked corn in the 25%, 50% treatments in comparison to the 75% and 100% treatments. In addition, data suggests there also was a difference within treatment between the grower and finisher phase for the lower cracked corn inclusion level treatments (25%, 50%). The range of apparent consumption difference from 25% inclusion to 100% inclusion for both grower and finisher (21.29% to 3.81% and 28.62% to 2.28%) appears to be significant however, the experiment was not designed to determine if selectivity of the feed was a behavioral or a nutritional response.

Experiment 2

Broiler growth performance for Experiment 2 is reported in Table 6. During the starter phase (0 to 18 d), similar growth performance was observed for all treatments with the exception of 50% inclusion for both ADG and ADFI. However, feed

conversion was statistically similar for all treatments. Treatment 3 (50%) and Treatment 5 (0/50%) had a depressed ADG, yet feed intake remained similar to other treatments. This resulted in a considerable drop in feed conversion during the grower period. One could suspect the animals were not adapted to an instantaneous change of feed form with inclusion of cracked corn at that level. This was a similar response to Experiment 1. For the finisher phase, an apparent response with compensatory gain occurred. Average daily gain returned to levels similar to that of the other treatments. However, ADFI dropped for Treatments 2, 3, and 5 with the feed intake reduction ranging 10 to 30 grams/day. Treatment 5 had a significantly ($P<0.05$) lower feed conversion (1.93) in comparison to all other treatments. For the overall grow out period (0 to 41 d), Treatments 3 and 5 had a lower ADG and a depressed feed intake, which affected feed conversions negatively. Statistically, total individual body weight was similar with the exception of 50% inclusion level. Finally, mortality was noticeably reduced when cracked corn was introduced into the diet. These data would be in agreement with Engberg et al. (2002) who reported, bird mortality was significantly influenced by degree of grind. Birds with coarse ground mash had the lowest mortality in comparison to the highest mortality found in fine ground, pelleted diets.

Gizzard and Intestinal Characteristics

Experiment 1

Live weight and dress weight were statistically similar for all treatments (Table 5). Gizzard weight and gizzard yield was significantly increased ($P<0.04$ and $P<0.008$, respectively) as the level of cracked corn in the diet increased. Adding whole wheat to pelleted feed has been shown to increase gizzard weight in proportion to body weight

(Cumming, 1994; Nir et al., 1994). Svihus et al. (1997) reported larger gizzards of broilers provided diets having whole barley added. Intestinal strength was not affected by the dietary treatments.

Experiment 2

Slight differences were noticed in live weight and dress weight (Table 7). Similar responses to Experiment 1 were recorded for gizzard weight and gizzard yield. Increasing inclusion level of cracked corn in the diet resulted in heavier gizzards and greater gizzard yield percentage. In contrast to Experiment 1, Treatment 2 had slightly lower foregut strength (0.215) and Treatment 4 had slightly higher hindgut strength (0.259) in comparison to other treatments.

Economical Analysis

The objective of this study was to determine if adding cracked corn to a broiler diet would affect animal performance. From the animal performance data, broilers can consume a diet which includes 25% of the corn fraction cracked successfully, without a negative response. There is a depression in animal performance once 50% of the cracked corn fraction is included. Costs typically are being reduced at the feed facility as formulation, animal, and other overhead costs are already at a bare minimum. If, for example, a feed facility is producing 4,400 tons/week, this calculates to approximately 45.8 tons/hr (using a 6 d work week, 2 – 10 hour shifts at 80% efficiency). This results in 96 working hours at the feed mill. The production levels at the feed mill, if 25% of the corn fraction was removed and fed as cracked corn, would be increased. If 4,400 tons is required per week and we assume approximately 64% of the total tons in corn, with 25% of that corn fraction cracked, only 3,696 tons would need to be pelleted. The

pelleting system can still operate at 45.8 tons/hr. The end result is actual working time needed to produce the same 4,400 tons is 81 hours. In an informal survey conducted of feed mill managers, it roughly cost between $200-$400/hr to operate their feed mills. If one were to take an average of $300/hr to operate, this results in a savings of $4,500 per week. These dollars saved are hard dollars, and go directly "into pocket".

Conclusions

These experiments were designed similar to a choice-fed feeding system. It has been stated choice-fed birds will adjust their energy intake in response to climatic fluctuation making ingredients more efficiently utilized in comparison to a complete diet (Cumming, 1992). Emmans (1975) has also stated there are advantages of choice feeding in which birds having different requirements for maintenance and production or growth will adjust accordingly to meet those needs. These results would not agree with these statements however, climate did not vary and many previous experiments only include whole grains up to approximately 30% of the diet.

Cracked corn can be included into a broiler diet up to 25% with out a negative response on animal performance. Considerations could be made to include up to 50% cracked corn in the diet during the finisher phase after the animal has had an adaptation period on a lower inclusion level of cracked corn. Additional considerations for implication would include the installation of a rollermill, as many poultry feed mills do not have one, a sifter to scalp fines of the cracked corn, and an additional bin to hold the cracked corn for blending. These additional pieces of equipment can be purchased for approximately $75,000- $100,000, depending upon size. If cost savings for having 25% of the corn fraction cracked is $4,500/week, this results in a 22-week payoff period.

Future research needs to identify if there is a correct particle size for the cracked corn fraction of the diet and if there are any potential "step-up" programs, which could be utilized to maximize feed mill throughput and not result in negative effects on animal growth. Other potential areas for adapting this feeding method would be for roaster birds, where animal are fed until 60 d, or during the withdrawal period where the diet consists mainly of corn. This concept is drastically different than the current practice applied today.

Literature Cited

American Society of Agricultural Engineers (ASAE). 1997a. ASAE S269.4, Cubes, Pellets, and Crumbles-Definitions and methods for determining density, durability, and moisture. Standards 1997. Am. Soc. Agric. Eng., St. Joseph, MI.

American Society of Agricultural Engineers (ASAE). 1997b. ASAE S319.2 Method of determining and expressing fineness of feed materials by Sieving. Standards 1997. Am. Soc. Agric. Eng., St. Joseph, MI.

Behnke, K. C. 1996. Feed manufacturing technology: current issues and challenges. Animal Feed Science and Technology. 62:49-57.

Briggs, J. L., D. E. Maier, B. A. Watkins, and K. C. Behnke. 1999. Effect of Ingredients and Processing Parameters on Pellet Quality. Poult. Sci. 78: 1464-1471.

Calet, C. 1965. The relative value of pellets versus mash and grain in poultry. World's Poultry Science Journal. 21:23-52.

Clark, P. M. and K. C. Behnke. 2004. Effects of pelleting protein concentrate pellets on feed mill throughput and electrical efficiency. Poult. Sci. 83 (Suppl. 1):170 (Abst.).

Cumming, R. B. 1992. The advantages of free choice feeding for village chickens. *19th World's Poultry Congress*, The Netherlands. 627-630.

Cumming, R. B. 1994. Opportunities in whole grain feeding. Pages 219-222 in Proceeding 9th European Poultry Conference. Vol. 2. WSPA (United Kingdom Branch), Glasgow, Scottland.

Emmans, G. C. 1975. Problems in laying house hens: Can a feeding system on choice solve them? Report of 5th European Poultry Conference. World's Poultry Science Journal. 31:311.

Engberg, R. M., M. S. Hedemann, and B. B. Jensen. 2002. The influence of grinding and pelleting of feed on the microbial composition and activity on the digestive tract of broiler chickens. British Poultry Science 44: 569-579.

Hussar, N., and A. R. Robblee. 1962. Effect of pelleting on the utilization of feeds by growing chicken. Poult. Sci.. 41:1489-1493.

Ivan, M., L. R. Giles, A. R. Alimon, and D. J. Farrell. 1974. Nutritional evaluation of wheat. 1. Effect of preparation on digestibility of dry matter, energy, and nitrogen in pigs. Anim. Prod. 19:359.

Kennard, D. C., and R. M. Bethke. 1926. The all-mash method of feeding chickens. Poult. Sci. 6:190-195.

Kiiskinen, T. 1996. Feeding whole grain with pelleted diets to growing broiler chickens. Agricultural and Food Science in Finland. 5:167-175.

Martin, S. 1983. The effect of particle size on mixing and pelleting quality and production rates. Pages F1-F14 in: First Int. Symposium on Particle Size Reduction in the Feed Industry. Kansas State University, Manhattan, KS.

McKinney, L. J. and R. G. Teeter. 2004. Predicting effective caloric value of nonnutritive factors: I. Pellet Quality and II. Prediction of Consequential Formulation Dead Zones. Poult. Sci. 83:1165-1174.

National Research Council. 1994. Nutrient Requirements of Poultry. 9th ed. National Academy Press, Washington, DC.

Nir, I., R. Hillel, G. Shefet, and Z. Nitsan. 1994. Effect of grain particle size on performance. 2. Grain texture interactions. Poult. Sci. 73:781-791.

Nir, I., R. Hillel, I. Ptichi, and G. Shefet. 1995. Effect of particle size on performance. 3. Grinding pelleting interactions. Poult. Sci. 74:771-783.

Owsley, W. F., D. A. Knabe, and T. D. Tanksley, Jr. 1981. Effect of sorghum particle size on digestibility of nutrients at the terminal ileum and over the total digestive tract of growing-finishing pigs. Journal of Animal Science. 52:557.

Proudfoot, F. G., and A. E. Sefton. 1978. Feed texture and light treatment on the performance of chicken broilers. Poult. Sci. 57:408-416.

Runnels, T. D., G. W. Malone, and S. Klopp. 1976. The influence of feed texture on broiler performance. Poult. Sci. 55:1958-1961.

Scheideler, S. E. 1995. Is pelleting cost effective?. Feed Management. Vol 46, No.1:21-26.

Svihus, B., O. Herstad, C. W. Newman, and R. K. Newman. 1997. Comparison of performance and intestinal characteristics of broiler chickens fed on diets containing whole, rolled, or ground barley. British Poultry Science. 38:524-529.

Tucker , L. 2006. For poultry: Correct nutrient supply for a healthy gut. Feed International. Vol 27, No. 4:14-16.

Wondra, K. J., J. D. Hancock, K. C. Behnke, R. H. Hines, and C. R. Stark. 1995a. Effects of mill type and particle size uniformity on growth performance, nutrient digestibily, and stomach morphology in finishing pigs. J. Ani. Sci. 73:2564-2573.

Wondra, K. J., J. D. Hancock, G. A. Kennedy, K. C. Behnke, and K. R. Wondra. 1995b. Effects of reducing particle size of corn in lactation diets on energy and nitrogen metabolism in second-parity sows. J. Ani. Sci. 73:427-432.

Wondra, K. J., J. D. Hancock, G. A. Kennedy, R. H. Hines, and K. C. Behnke. 1995c. Reducing particle size of corn in lactation diets from 1,200 to 400 micrometers improves sow and litter performance. J. Ani. Sci. 73:421-426.

Table 1. Ingredient and calculated nutrient composition of experimental broiler diets (Exp 1 and 2, as fed basis).

Item	Starter (0 to 18d)	Grower (19 to 32d)	Finisher (33 to 41d)
Ingredient, %			
Corn	60.54	64.61	68.05
Soybean Meal (48% CP)	31.55	27.85	24.80
Meat Meal (Porcine)	3.50	2.50	---
Animal Fat	1.35	1.95	3.60
Limestone (38% Ca)	0.95	1.05	1.15
Monocalcium, (21% P)	1.20	1.15	1.55
Salt	0.34	0.35	0.39
L-lysine HCl	0.03	---	---
DL-methionine	0.25	0.19	0.15
Vitamin/mineral premix[a]	0.25	0.25	0.25
Coccidiostat[b]	0.05	0.05	0.05
Calculated Composition, %			
Crude Protein	22.20	20.12	17.50
Total methionine	0.60	0.52	0.45
Total methionine+cystine	0.96	0.85	0.76
Total lysine	1.23	1.07	0.92
Calcium	0.95	0.90	0.84
Phosphorus-Total	0.73	0.67	0.65
Phosphorus-Available	0.49	0.44	0.43

[a]Provided (per kg of complete diet): 7717 IU vitamin A; 1653 IU vitamin D; 16 IU vitamin E; .83 mg vitamin K; 385 mg biotin; 24 mg of copper; 3.3 mg of iodine; 110 mg of iron; 220 mg of manganese; 27 mg of niacin; 6 mg of pantothenic acid; 6 mg of riboflavin; .3 mg of selenium; 1mg of thiamin.

[b]Provided 60g/ton of salinomycin.

Table 2. Physical finished feed composition fed to broilers for three phases of growth.

Item, %	Concentrate Pellet	Cracked Corn	Fat
Starter			
Control	98.65	--	1.35
25%	83.51	15.14	1.35
50%	68.38	30.27	1.35
75%	53.24	45.41	1.35
100%	38.11	60.55	1.35
Grower			
Control	98.05	--	1.95
25%	81.90	16.15	1.95
50%	65.75	32.30	1.95
75%	49.65	48.40	1.95
100%	33.45	64.60	1.95
Finisher			
Control	96.40	--	3.60
25%	79.38	17.02	3.60
50%	62.37	34.02	3.60
75%	45.36	51.03	3.60
100%	28.35	68.05	3.60

Table 3. Physical characteristics of concentrate pellets and finished feed.

Item,	Concentrate Pellets (LB/FT^3)	Finished Feed (LB/FT^3)	PDI[1]	PDI Modified[2]
Starter				
Control	42.83	47.32	--	--
25%	41.70	46.20	--	--
50%	42.07	46.57	--	--
75%	42.32	47.32	--	--
100%	42.83	46.32	--	--
Grower				
Control	42.34	42.81	83.65	79.00
25%	42.01	41.85	83.79	79.20
50%	41.26	40.62	82.05	76.64
75%	40.76	38.80	88.87	87.03
100%	39.52	34.54	88.44	85.92
Linear	.001	.001	.001	.001
Quadratic	.045	.001	.003	.001
Finisher				
Control	41.07	40.79	87.70	82.73
25%	40.07	37.37	88.67	85.57
50%	40.17	36.43	90.40	87.76
75%	38.96	35.68	94.13	92.75
100%	39.99	33.86	95.53	94.70
Linear	.182	.001	.001	.001
Quadratic	.317	.005	.006	.345

[1]ASAE (1997a).
[2]Addition of 5-1/2" hex nuts.

Table 4. Effects of feeding coarsely cracked corn and concentrate pellets in comparison to a complete pelleted diet on broiler performance from d 0 to 41 (Experiment 1).

	Cracked Corn Inclusion Level[1]						Probability	
Item	0%	25%	50%	75%	100%	SE	Linear	Quadratic
d 0 to 18								
ADG, g	34.31	33.73	32.59	30.27	26.60	1.00	0.001	0.01
ADFI, g	46.06	46.56	44.77	42.33	37.56	1.27	0.001	0.003
F:G, g:g	1.35	1.38	1.38	1.40	1.41	.026	0.030	0.93
d 18 to 32								
ADG, g	87.00	85.85	73.46	71.39	65.69	2.22	0.001	0.85
ADFI, g	135.88	133.59	134.77	125.40	116.68	5.39	0.001	0.11
F:G, g:g	1.56	1.56	1.83	1.77	1.78	.070	0.001	0.09
d 33 to 41								
ADG, g	82.94	82.99	81.08	67.18	64.85	3.84	0.001	0.12
ADFI, g	187.76	176.36	173.24	159.84	153.61	4.75	0.001	0.99
F:G, g:g	2.27	2.13	2.14	2.48	2.38	.153	0.133	0.35
d 0 to 41								
ADG, g	61.91	61.03	56.06	51.56	47.07	1.97	0.001	0.12
ADFI, g	107.75	105.37	104.09	96.77	90.54	2.58	0.001	0.06
F:G, g:g	1.76	1.73	1.85	1.90	1.93	.076	0.003	0.77
Total BW, g	2,740	2,637	2,386	2,192	2,084	109.05	0.001	0.88
Mortality, %	10.63	5.40	6.66	4.32	6.36			

[1]Described as the percentage of corn fraction in the formula which is cracked.

Table 5. Effects of feeding coarsely cracked corn and concentrate pellets in comparison to a complete pelleted diet on carcass and small intestine characteristics from d 0 to 41 (Experiment 1).

	Cracked Corn Inclusion Level[1]						Probability	
Item,	0%	25%	50%	75%	100%	SE	Linear	Quadratic
Live weight, g	2,610	2,850	2,720	2,733	2,687	77.00	0.88	0.11
Dress weight, g	1,995	2,104	1,932	1,976	1,944	61.67	0.21	0.75
Gizzard weight, g	38.75	42.58	41.00	47.17	44.17	2.50	0.04	0.48
Dress yield, %	76.49	73.89	70.88	72.30	72.37	1.28	0.01	0.03
Gizzard yield, %	1.94	2.02	2.12	2.39	2.27	.11	0.008	0.58
Small intestine strength								
Foregut, kg force	0.232	0.215	0.225	0.223	0.246	.024	0.59	0.39
Hindgut, kg force	0.209	0.216	0.219	0.232	0.218	.020	0.56	0.60

[1]Described as the percentage of corn fraction in the formula which is cracked.

Table 6. Effects of feeding coarsely cracked corn and concentrate pellets in comparison to a complete pelleted diet on broiler performance from d 0 to 41 (Exp 2).

	Cracked Corn Inclusion Level[1]					
Item,	0%	0/25%[2]	0/50%[3]	25%	50%	SE
d 0 to 18						
ADG, g	33.69^{ab}	34.99^{a}	34.44^{a}	33.74^{ab}	32.50^{b}	1.22
ADFI, g	45.69^{ab}	48.52^{a}	47.11^{ab}	46.56^{ab}	44.65^{b}	1.74
F:G, g:g	1.35	1.38	1.38	1.38	1.37	.04
d 18 to 32						
ADG, g	86.42^{a}	86.88^{a}	71.59^{b}	85.85^{a}	73.33^{b}	2.65
ADFI, g	135.99	139.72	133.16	133.59	135.16	7.48
F:G, g:g	1.56^{a}	1.60^{a}	1.86^{b}	1.55^{a}	1.83^{b}	0.10
d 33 to 41						
ADG, g	82.94	86.44	83.61	82.99	81.08	5.24
ADFI, g	187.76^{a}	183.95^{ab}	157.06^{d}	176.36^{bc}	173.24^{bc}	6.40
F:G, g:g	2.27^{b}	2.13^{b}	1.93^{a}	2.13^{b}	2.14^{b}	0.12
d 0 to 41						
ADG, g	60.52^{ab}	63.36^{a}	56.04^{c}	61.03^{ab}	55.89^{c}	1.76
ADFI, g	107.65^{ab}	110.60^{a}	101.69^{bc}	105.37^{abc}	104.04^{bc}	3.23
F:G, g:g	1.77^{ab}	1.74^{a}	1.85^{b}	1.73^{a}	1.85^{b}	0.06
Total BW,g	2,740.46^{a}	2,616.79^{a}	2,639.00^{a}	2,637.51^{a}	2,386.27^{b}	107.21
Mortality, %	10.63	6.88	5.00	5.40	6.66	

[1]Described as the percentage of corn fraction in the formula which is cracked.
[2]Animals were fed control diet from 0 to 18 d, then fed 25% of the diet as cracked corn through the rest of the growout period.
[3]Animals were fed control diet from 0 to 18 d, then fed 50% of the diet as cracked corn through the rest of the growout period.
[4]Different letters within row represent significant difference ($P<0.05$).

Table 7. Effects of feeding coarsely cracked corn and concentrate pellets in comparison to a complete pelleted diet on carcass and small intestine characteristics from d 0 to 41 (Experiment 2).

	Cracked Corn Inclusion Level[1]					
Item,	0%	0/25%[2]	0/50%[3]	25%	50%	SE
Live weight, g	2,612[b]	2,838[a]	2,762[ab]	2,850[a]	2,720[ab]	99.15
Dress weight, g	1,994[ab]	2,090[ab]	2,011[ab]	2,103[a]	1,931[b]	85.17
Gizzard weight, g	38.75[b]	63.00[a]	47.00[b]	42.58[b]	41.00[b]	5.18
Dress yield, %	76.41[a]	73.68[ab]	72.80[ab]	73.89[ab]	70.88[b]	2.05
Gizzard yield, %	1.96[b]	3.00[a]	2.35[b]	2.03[b]	2.13[b]	.25
Small intestine strength						
Foregut, kg force	0.228[ab]	0.275[a]	0.238[ab]	0.215[b]	0.226[ab]	.285
Hindgut, kg force	0.217[b]	0.259[a]	0.214[b]	0.215[b]	0.221[b]	.208

[1]Described as the percentage of corn fraction in the formula which is cracked.
[2]Animals were fed control diet from 0 to 18 d, then fed 25% of the diet as cracked corn through the rest of the growout period.
[3] Animals were fed control diet from 0 to 18 d, then fed 50% of the diet as cracked corn through the rest of the growout period.
[4]Different letters within row represent significant difference ($P<0.05$).

Table 8. Apparent cracked corn consumption by broilers when fed a blend of pellets and cracked corn.

Item,	Corn – Theoretical	Corn – Actual	Difference
Grower			
25%	16.47	37.76	21.29
50%	32.94	41.62	8.67
75%	49.36	52.67	3.31
100%	65.88	62.07	3.81
0/25%	16.47	29.37	12.89
0/50%	32.94	43.48	10.54
Finisher			
25%	17.70	46.32	28.62
50%	35.30	51.35	16.05
75%	52.95	65.74	12.79
100%	70.59	72.87	2.28
0/25%	17.70	47.18	29.48
0/50%	35.30	49.26	13.96

CHAPTER IV

THE EFFECTS OF SOYBEAN MEAL INCLUSION LEVEL IN NURSERY PIG DIETS ON GROWTH PERFORMANCE

Abstract

Three experiments were conducted to determine the effects of soybean meal (SBM) inclusion level on growth performance of nursery pigs fed diets with or without animal protein. Experiments were conducted using 516 weanling pigs (Exp 1 n=168; avg BW of 6.89 kg; Exp 2 n=168 avg BW of 6.29 kg; Exp 3 n=180; avg BW of 6.69 kg) in 35-d (Exp 1 and 2; 36-d Exp 3) trial to determine the effects of soybean meal (SBM) inclusion level and diet complexity on growth performance (ADG, ADFI, G:F). Pigs were sorted by sex, ancestry, blocked by BW, and allotted to pens with feed provided *ad libitum*. For Exp 1, diets for d 0 to 7 were a control (0% SBM), and three diets with direct substitution of soybean meal for corn in increasing levels (10, 20, and 30% SBM). The control was formulated to 1.80% lysine, 0.90% Ca, and 0.80% P. A common diet was fed to all pigs from d 7 to 21(1.6% lysine) and d 21 to 35 (1.35% lysine). For d 0 to 7 and d 22 to 35, as SBM concentration increased, feed efficiency (G:F) increased (linear, $P<0.001$ and $P<0.017$, respectively). Similarly, overall (d 0 to 35) G:F (linear, $P=0.009$) increased. For experiment 2, diet complexity (simple or complex) and SBM level (high or low)(2 x 2 factorial) was evaluated to determine the effects on growth performance (ADG, ADFI, G:F). For d 0 to 7, ADG significantly increased when pigs were fed animal proteins compared with no animal proteins ($P<0.0002$) 23% from simple to complex and 17.9% from low to high ($P<0.003$). Overall (d 0 to 35) no differences were found for complexity ($P=0.34$) or concentration ($P=0.30$) in ADG. A tendency ($P<0.06$) was found in an increase of ADFI (d 7 to 21) for SBM concentration. Feed efficiency increased with diet ($P<0.02$) and SBM concentration ($P<0.10$) (d 0 to 7). For Experiment 3, individual ingredients were

directly replaced with soybean meal or corn to determine if negative growth performance is caused by the addition of soybean meal or the removal of a certain ingredient. Experimental diets included: 1) control (no soybean meal); 2) No animal protein source; 3) No whey; 4) 50% reduction in whey and animal proteins; and 5) All ingredients (positive control). Statistical differences were observed ($P<.02$) for ADG for d 0 to 7 contrasting treatments containing soybean meal vs. the control diet. Overall, (d 0 to 36) ADG, ADFI, and feed efficiency was not affected by any of the dietary treatments. In conclusion, addition of SBM did not depress pig performance, rather diet complexity or removal of highly digestible ingredients (whey or animal protein) affected pig performance.

Introduction

Pig producers are continuously seeking to improve animal efficiency. The most notable approach is weanling piglets at 18 to 21 d. In doing so, fixed costs are spread across more animals due to an increased number of sows/crate/year and piglets/sow/year. Unfortunately, with the reduction in age of the weanling pig, several challenges are encountered. Weanling pigs are confronted with several stress factors at weaning. In commercial situations there are complex social changes. These include removal from the sow, change in housing, and separation from littermates and introduction to unfamiliar pigs (Fraser et al., 1998). Diet composition also changes at weaning. The highly digestible liquid milk from the sow is replaced with a dry pelleted feed. Typically, lactose products (i.e. spray-dried whey, dry skim milk, etc.) are included into weanling pig diets in upwards of forty percent to aid in the transition, as weanling pigs are more adapted to utilizing these lactose products versus vegetable proteins such as soybean meal (Nelssen, 1986). Other highly digestible protein sources such as, spray dried blood plasma and fishmeal, have also been incorporated into swine starter formulas. These complex diets have been developed and reported to improve swine starter performance in comparison to simple corn-soybean meal diets (Himmelberg et al., 1985; Graham et al., 1981; and Wilson and Liebholz, 1981). Himmelberg et al. (1985) reported improved average daily gains, feed intake, and feed efficiency with pigs fed complex diets (inclusion of dried skim milk). It was also noted that feeding complex diets containing milk products increased feed intakes and increased nutrient utilization, which subsequently increased average daily gains.

Nelssen (1986) proposed a three phase feeding program to maximize pig performance by adapting the nutritional requirements of the pig for that particular stage of growth. Phase feeding will typically shift protein sources away from milk and other animal products, to increasing levels of soybean meal. These phase feeding practices are still very much a part of swine nutrition today. However, while managers are attempting to reduce fixed costs across a larger number of animals, a situation which surfaces is, cost per ton of feed. The specialty ingredients which are included into the nursery pig diets are expensive. This is a driving factor in getting pigs started quickly, having a healthy pig, then switching the pig to a cheaper corn-soybean meal based diet.

Li et al. (1990) suggested a delayed transient hypersensitivity (DTH) response to soybean meal when pigs were exposed to soybean meal pre-weaning and fed soybean meal post-weaning. A DTH response is an immune response occurring in the small intestine. It is suggested that pigs are not accustomed to the soy protein and the soy is recognized as an antigen. The DTH response results in suppressed average daily gains and feed efficiency (Li et al., 1991). Research conducted by Li et al. (1991) evaluated further processed soy products such as, soy protein concentrate, and their suitability for baby pigs. Moist extrusion of soy protein concentrate tended to increase average daily gains in phase I of growth (d 0 to 14 post-weaning) which could be attributed to increased feed intake levels, thus improved feed efficiency. Li et al. (1991) then discovered pigs fed extruded soy protein concentrate had longer small intestine villi in comparison to pigs fed soybean meal or non-extruded soy protein concentrate. From these observations, it was determined that pigs fed soy protein concentrate had increased villi height, which correlated with increased average daily gain, in

comparison to pigs fed other soy products. Sohn et al. (1994a,b) and Friesen (1992) would also be in agreement with Li (1991) that further processing of soy proteins will increase animal performance to similar levels of milk products in comparison to feeding soybean meal alone.

In conclusion, the young pig faces adversity during the weaning process on several fronts, socially, environmentally, and dietary. It is generally accepted that the inclusion of soybean meal in early weaned pigs reduces animal performance. However, there are other indications stating feed intake can be a significant issue. With data suggesting both theories, are both correct? The objective of the following research experiments is to determine if soybean concentration and ingredient composition affects weanling pig growth performance.

Materials and Methods

Animals and Housing

Experiment 1.

One hundred sixty eight (line 210 boars × C 22 sows, PIC, Franklin, KY) piglets, with an average initial BW of 6.88 kg and average initial age of 21 d, were used in a 35 d growth assay to determine the effects of increasing levels of soybean meal on growth performance and nutrient digestibility. The pigs were weaned, blocked by BW, and allotted to pens based on sex and ancestry. There were six pigs per pen and seven pens per treatment. Treatment diets (Table 1) for Phase 1 were formulated off a complex control Diet 1 (0% SBM) with Diets 2-4 (10%, 20%, and 30% SBM, respectively) having direct substitution of soybean meal for corn in increasing levels (10, 20, and 30%). A common Phase II and III diet was fed to all pigs from d 7 to 21 and d 21 to 35, respectively. Diets were formulated to: 1.8% lysine for Phase I (0% SBM) (d 0 to 7) ; 2.07% lysine for Phase I (10% SBM) (d 0 to 7); 2.34% lysine for Phase I (20% SBM) (d 0 to 7); 2.61% lysine for Phase I (30%SBM) (d 0 to 7); 1.6% lysine for Phase II (d 7 to 21); and 1.35% lysine for Phase III (d 21 to 35) (Table 1) and to meet or exceed all nutrient concentrations suggested by the National Research Council (NRC, 1998).

Experiment 2

One hundred sixty eight (line 210 boars × C 22 sows, PIC, Franklin, KY) piglets, with an average initial BW of 6.28 kg and average initial age of 21 d, were used in a 35 d growth assay to determine the effects of diet complexity and level of soybean meal on growth performance and nutrient digestibility. The pigs were weaned, blocked

by BW, and allotted to pens based on sex and ancestry. There were six pigs per pen and seven pens per treatment. Diets (Table 3) were formulated to: 1.80% lysine in Phase I (Complex Low) (d 0 to 7); 2.61% lysine in Phase I (Complex High) (d 0 to 7); 1.80% lysine in Phase I (Simple Low) (d 0 to 7); 2.61% lysine in Phase I (Simple High) (d 0 to 7); 1.6% lysine in Phase II (d 7 to 21); and 1.35% lysine in Phase III (d 21 to 35) (Table 3), and to meet or exceed all nutrient concentrations suggested by the National Research Council (NRC, 1998). Treatment diets for Phase 1 were formulated off a complex and simple control diet with a direct replacement of soybean meal for corn. A common Phase II and III diet was fed to all pigs from d 8 to 21 and d 22 to 35, respectively.

Experiment 3

One hundred eighty (line 210 boars × C 22 sows, PIC, Franklin, KY) piglets, with an average initial BW of 6.69 kg and average initial age of 21 d, were used in a 36 d growth assay to determine the effects of diet complexity and level of soybean meal on growth performance and nutrient digestibility. The pigs were weaned, blocked by BW, and allotted to pens based on sex and ancestry. There were six pigs per pen and six pens per treatment. Diets (Table 5) were formulated to: 1.80% lysine in Phase I (No animal protein source) (d 0 to 8); 2.11% lysine in Phase I (No Soybean meal); (d 0 to 8); 2.79% lysine in Phase I (No Whey); (d 0 to 8); 2.30% lysine in Phase I (50% reduction in animal products and whey); (d 0 to 8); 2.92% lysine in Phase I (All ingredients); 1.6% lysine in Phase II (d 9 to 22); and 1.35% lysine in Phase III (d 23 to 36) (Table 5), and to meet or exceed all nutrient concentrations suggested by the National Research Council (NRC, 1998). All ingredients which were included or

removed were done at the expense of corn. A common Phase II and III diet was fed to all pigs from d 9 to 22 and d 23 to 36, respectively.

Animal Housing

The pigs were housed in an environmentally controlled building with 1.2-m × 1.5-m pens having woven wire flooring. Room temperature was maintained at 32, 29, 27, and 24° C for d 0 to 7, 7 to 14, 14 to 21, and 21 to 35, respectively, for Experiment 1 and 2 and 32, 29, 27, and 24° C for d 0 to 8, 9 to 15, 16 to 22, and 23 to 36, respectively, for Experiment 3. Each pen had a self-feeder and nipple waterer to allow ad libitum consumption of feed and water. Pigs and feeders were weighed on d 7, 21, and 35 (Experiment 1 and 2) or d 8, 22, and 36 (Experiment 3) to allow calculation of ADG, ADFI, and gain / feed.

Feed Manufacturing

Corn was ground for the diet using a 30 HP full circle hammermill (Model P-240, Jacobson Machine Works, Minneapolis, MN) equipped with a 3.175 mm screen to achieve a grind of 565 μm geometric mean particle size (d_{gw}). All experimental diets were pelleted using a CPM pellet mill (Master Model HD, series 1000, Crawford, IN) equipped with a 4 mm x 32 mm (5/32" x 1 1/4") pellet die. Prior to pelleting, Phase I and II diets were conditioned to 54° C with Phase III diets conditioned to 82° C in a short-term (12-15 s) conditioner.

Statistical Analysis

All data was analyzed by the *Mixed* procedure of SAS (Release 9.1 for Windows, SAS Institute, Cary, NC). Orthogonal contrasts (linear and quadratic) were

used for statistical differences in Exp 1. Experiment 2 was analyzed as a 2 X 2 Latin square (soybean meal concentration X diet complexity). Treatment differences were divided by orthogonal contrasts for experiment 3 (no soybean meal vs. soybean meal; no animal protein vs. animal protein, and no whey vs. whey). Statistical significance was set at $P<0.05$ for all three experiments.

Results

Experiment 1

Inclusion of soybean meal into weanling pig diets did not depress growth performance (Table 2). In contrast, feed efficiency improved linearly as SBM level increased 12% ($P<0.001$) for d 0 to 7. Similar results were also observed during d 22 to 35 for feed efficiency with pigs fed increasing levels of SBM having improved G:F ($P<.02$). In addition, overall (d 0to 35) feed efficiency improved from 0.775 to 0.805 ($P<.01$). No other statistical differences were observed within any other measured growth parameters. However, it should be noted that even though not statistically significant, average daily feed intakes had tendencies to decline ($P<0.17$) for all phases of growth and overall (d 0 to 35).

Experiment 2

The effects of soybean meal concentration and diet complexity on nursery pig growth performance in reported in Table 4. There was no diet x SBM level interaction ($P>0.18$). A diet complexity affect ($P<0.0002$), resulting in a 23% increase, and soybean meal level affect ($P<0.0024$), a 17.9% increase, was observed for ADG (d 0 to 7). Feed efficiency was affected by diet complexity ($P<.02$), while there was a trend for

an increase in feed efficiency as soybean meal level increased (P<.09). For d 7 to 21 ADFI improved (P<0.06) as SBM was increased from 0 to 30%, independent of diet complexity. Overall (d 0 to 35), there were no statistical differences observed for diet or level for ADG, ADFI, or G:F.

Experiment 3

The effects of specialty ingredient sources on nursery pig performance is reported in Table 6. For d 0 to 8, pigs fed diets without SBM had an improved ADG (P<.02). Feed efficiency was also higher numerically than most treatments, with the exception of the dietary treatment with all ingredients included. For d 23 to 36, pigs fed no soybean meal had poorer feed efficiency in comparison to other dietary treatments (P<.05). No other planned contrasts for ADG, ADFI, and G:F for any stage of growth reported any statistical significant differences.

Discussion

In general, weanling pigs were not affected by the inclusion of soybean meal. Pigs appeared to be affected by the removal of certain feed ingredients, i.e. whey and animal proteins. This would be in agreement with Himmelberg et al. (1985); Graham et al. (1981); and Wilson and Liebholz (1981), which stated milk proteins and diet complexity has an affect on nursery pig performance.

Lindemann et al. (1986) and Owsley et al. (1986) stated by increasing feed intakes, there is an increased volume of feedstuffs in the small intestine (SI). This increased volume of feedstuffs in the SI stimulates increased secretions of protease, amylase, and lipase enzymes from the pancreas. Spreeuwenberg et al. (2001) also

stated that diet composition on mucosal integrity is not as important as low feed intakes during the first 4 d postweaning. The hypothesis of an immune response to dietary antigens from soy proteins has been generally accepted. However, not until recently has there been an acceptance of postweaning "lag" being attributed to reduce feed intake. McCracken et al. (1999) reported that inflammatory and villus atrophy correlated with depressed feed intakes and inflammations, which were soy induced, was a secondary event.

It is understood that dietary treatments for all experiments were significantly higher in lysine content than the NRC (1998) recommendations. However, the objective of the research was to determine if animal performance is reduced by SBM inclusion or the removal of other ingredients. For all experiments overall growth performance was not hindered and in most situations it improved. One explanation could include, Mahan et al. (1993) who reported, even with the addition of L-Lysine-HCl, animal performance did not increase until whey was added to the diet, suggesting lysine is not a limiting factor, but whey (lactose). Data reported here would agree with this, as there was an increase in animal performance with increasing lysine levels, with the exception of the dietary treatment with no whey added, which had a numerical reduction in growth performance.

In conclusion, SBM did not detrimentally affect pig performance with inclusions up to 30% of the diet. It appears that other ingredient interactions are occurring with the pig during the weaning process in addition to feed intakes driving animal performance.

Literature Cited

Fraser, D., B. N. Milligan, E. A. Pajor, P. A. Phillips, A. A. Taylor and D. M. Weary. 1998. Behavioural perspectives on weaning in domestic pigs. Progress in Pig Science. 121:138.

Friesen, K. G. 1992. The effect of dietary soybean meal and extrusion processing of soy products on growth performance and immunology in the early-weaned pig. Masters Thesis, Kansas State University, Manhattan, KS.

Graham, P. L., D. C. Mahan, and R. G. Shields, Jr. 1981. Effect of starter diet and length of feeding regimen on performance and digestive enzyme activity of 2-week old weaned pigs. J. Anim. Sci. 53:299.

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

Lindemann, M. D., S. G. Cornelius, S. M. El Kadelgy, R. L. Moser, and J. E. Pettigrew. 1986. Effect of age, weaning and diet on digestive enzyme levels in the piglet. J. Anim. Sci. 62:1298.

Li, D. F., J. L. Nelssen, P. G. Reddy, F. Blecha, J. D. Hancock, G. L. Allee, R. D. Goodband and R. D. Klemm. 1990. Transient hypersensitivity to soybean meal in the early-weaned pig. J. Anim. Sci. 68:1790.

Li, D. F., J. L. Nelssen, P. G. Reddy, F. Blecha, R. D. Klemm, D. W. Giesting, J. D. Hancock, G. L. Allee and R. D. Goodband. 1991. Measuring suitability of Soybean products for early-weaned pigs with immunological criteria. J. Anim. Sci. 69:3299-3307

Mahan, D. C., R. A. Easter, G. L. Cromwell, E. R. Miller, and T. L. Veum. 1993. Effect of dietary lysine levels formulated by altering the ratio of corn:soybean meal with or without dried whey and L-lysine-HCI in diets for weanling pigs. J. Anim. Sci. 71:1848-1852

McCracken, B. A., M. E. Sprulock, M A. Roos, F. A. Zuckermann and H. R. Gaskins. 1999. Weaning anorexia may contribute to local inflammation in the piglet small intestine. J. Nutr. 613-619.

National Research Council. 1998. Nutrient Requirements of Swine, 10th ed. National Academy Press. Washington, DC.

Nelssen, J. L. 1986 High nutrient density diets for weanling pigs. Proceedings 47th Minnesota Nutrition Conference. Pp. 217-230. Minneapolis, MN.

Owsley, W. F., D. E. Orr, Jr., and L. F. Tribble. 1986. Effect of age and diet on the development of the pancreas and the synthesis and secretion of pancreatic enzymes in the young pig. J. Anim. Sci. 63:497.

Sohn, K. S., C. V. Maxwell, D. S. Buchanan, and L. L. Southern. 1994a. Improved soybean protein sources for early-weaned pigs: I. Effects on performance and total tract amino acid digestibility. J. Anim. Sci. 72:622-630

Sohn, K. S., C. V. Maxwell, L. L. Southern, and D. S. Buchanan. 1994b. Improved soybean protein sources for early-weaned pigs: II. Effects on ileal amino acid digestibility. J. Anim. Sci. 72:631-637

Spreeuwenberg, M. A. M., J. M. A. J. Verdon, H.R. Gaskins and M.W.A. Verstegen. 2001. Small intestine epithelial barrier function is compromised in pigs with low feed intake at weaning. J. Nutr. 131:1520-1527.

Wilson, R. H., and J. Leibholz. 1981. Digestion in the pig between 7 and 35 d of age 5. The incorporation of amino acids absorbed in the small intestines into the empty-body gain of pigs given milk or soya-bean proteins. Fr. J. Nutr. 45:359-366.

Table 1. Composition of experimental diets (Exp 1, as-fed basis)[a]

	Phase I[c]				Phase II[d]	Phase III[e]
Item,	0%	10%	20%	30%		
Ingredient, %						
Corn	33.72	23.72	13.72	3.72	43.00	54.81
Soybean meal (48% CP)	--	10.00	20.00	30.00	24.00	36.25
Dried whey	30.00	30.00	30.00	30.00	20.00	--
Soybean oil	4.00	4.00	4.00	4.00	2.00	5.00
Spray-dried wheat gluten	10.00	10.00	10.00	10.00	--	
Spray-dried plasma	10.00	10.00	10.00	10.00	3.00	--
Fish meal (menhaden)	10.00	10.00	10.00	10.00	5.00	--
Monocal (21%P)	0.10	0.10	0.10	0.10	0.30	1.50
Limestone (38% Ca)	0.30	0.30	0.30	0.30	0.66	1.00
L-Lysine·HCl	0.19	0.19	0.19	0.19	0.193	0.15
DL-methionine	--	--	--	--	0.149	0.04
L-threonine	--	--	--	--	0.044	--
Salt	0.20	0.20	0.20	0.20	0.30	0.35
Vitamins[a]	0.25	0.25	0.25	0.25	0.25	0.25
Minerals[a]	0.15	0.15	0.15	0.15	0.15	0.15
Antibiotic[b]	0.70	0.70	0.70	0.70	0.70	0.50
Zinc oxide	0.39	0.39	0.39	0.39	0.25	--
Calculated Analysis						
Total Lysine	1.80	2.07	2.34	2.61	1.60	1.35
Total Ca	0.90	0.93	0.96	0.99	0.80	0.77
Total P Available	0.81	0.85	0.89	0.93	0.70	0.70

[a]Provided (per kg of complete diet): 11,025 IU of vitamin A; 1,654 IU of vitamin D; 44 IU of vitamin E; 4.4 mg of vitamin K (as menadione); 55 mg of niacin; 33 mg of pantothenic acid (as d-calcium pantothen); 10 mg of riboflavin; 0.044 mg of B_{12}; 17 mg of Cu from $CuSO_4$; 165 mg of Fe from $FeSO_4$; 40 mg of Mn from $MnSO_4$; 0.3 mg of Se from sodium selenite; 165 mg of Zn from ZnO; and 0.3 mg of I from Ca iodate.

[b]Provided 108 mg of neomycin and 154 mg oxytetracycline per kilogram of complete diet in Phases I and II and 77 mg of neomycin and 110 mg oxytetracycline per kilogram of complete diet in Phase III.

[c]Phase I fed from d 0 to 7.

[d]Phase II fed from d 8 to 21.

[e]Phase III fed from d 22 to 35.

Table 2. Growth response for weanling pigs fed increasing levels of soybean meal (Exp 1).[a]

	Soybean meal level (%)				Probability, P<0.05		
Item,	0	10	20	30	Linear	Quadratic	SE
d 0 to 7							
ADG, g	353	335	368	362	0.44	0.70	17
ADFI, g	281	270	274	258	0.21	0.85	13
G/F, g/g	1.26	1.24	1.35	1.41	0.001	0.14	31
d 8 to 21							
ADG, g	524	516	513	543	0.39	0.90	17
ADFI, g	638	641	614	612	0.15	0.89	18
G/F, g/g	.821	.809	.836	.830	0.39	0.83	35
d 22 to 35							
ADG, g	673	687	693	701	0.17	0.85	16
ADFI, g	993	1007	988	988	0.69	0.69	21
G/F, g/g	.678	.681	.702	.711	0.02	0.80	37
d 0 to 35							
ADG, g	549	548	556	556	0.48	0.92	11
ADFI, g	709	713	696	692	0.17	0.70	14
G/F, g/g	.775	.769	.800	.805	0.009	0.45	25

[a]Pen served as experimental unit with 6 pigs per pen (n=7).

Table 3. Composition of experimental diets (Exp 2, as-fed basis)

	Phase I[c]				Phase II[d]	Phase III[e]
	Simple		Complex			
Item, %	Low	High	Low	High		
Ingredient						
Corn	30.12	0.12	33.72	3.72	43.00	54.81
Soybean meal (48% CP)	--	30.00	--	30.00	24.00	36.25
Dried whey	30.00	30.00	30.00	30.00	20.00	--
Soybean oil	4.00	4.00	4.00	4.00	2.00	5.00
Spray-dried wheat gluten	15.00	15.00	10.00	10.00		
Spray-dried plasma protein	--	--	10.00	10.00	3.00	--
Fish meal (menhaden)	--	--	10.00	10.00	5.00	--
Monocal (21% P)	0.85	0.85	0.10	0.10	0.30	1.50
Limestone (38% Ca)	1.18	1.18	0.30	0.30	0.66	1.00
L-lysine·HCl	1.01	1.01	0.19	0.19	0.193	0.15
DL-methionine	--	--	--	--	0.149	0.04
L-threonine	0.10	0.10	--	--	0.044	--
Salt	0.20	0.20	0.20	0.20	0.30	0.35
Vitamins[a]	0.25	0.25	0.25	0.25	0.25	0.25
Minerals[a]	0.15	0.15	0.15	0.15	0.15	0.15
Antibiotic[b]	0.70	0.70	0.70	0.70	0.70	0.50
Zinc oxide	0.39	0.39	0.39	0.39	0.251	--
Tryptophan	0.05	0.05	--	--	--	--
Whey Protein Concentrate	5.00	5.00	--	--	--	--
Corn Gluten Meal (60% CP)	11.00	11.00	--	--	--	--
Calculated Analysis						
Total Lysine	1.80	2.61	1.80	2.61	1.60	1.35
Total Ca	0.90	0.99	0.90	0.99	0.80	0.77
Total P	0.80	0.93	0.80	0.93	0.70	0.70

[a]Provided (per kg of complete diet): 11,025 IU of vitamin A; 1,654 IU of vitamin D; 44 IU of vitamin E; 4.4 mg of vitamin K (as menadione); 55 mg of niacin; 33 mg of pantothenic acid (as d-calcium pantothen); 10 mg of riboflavin; 0.044 mg of B_{12}; 17 mg of Cu from $CuSO_4$; 165 mg of Fe from $FeSO_4$; 40 mg of Mn from $MnSO_4$; 0.3 mg of Se from sodium selenite; 165 mg of Zn from ZnO; and 0.3 mg of I from Ca iodate.
[b]Provided 108 mg of neomycin and 154 mg oxytetracycline per kilogram of complete diet in Phases I and II and 77 mg of neomycin and 110 mg oxytetracycline per kilogram of complete diet in Phase III.
[c]Phase I fed from d 0 to 7.
[d]Phase II fed from d 8 to 21.
[e]Phase III fed from d 22 to 35.

Table 4. Effects of diet complexity and soybean meal concentration on nursery pig performance (Exp 2).[a]

	Without Animal Protein		With Animal Protein		Probability, P<0.05			
Item, %	Low	High	Low	High	Diet	Level	D*L	SE
D 0 to 7								
ADG, g	209	278	296	337	0.0002	0.0024	0.40	16
ADFI, g	225	254	256	270	0.13	0.16	0.61	17
G:F, g/g	.965	1.10	1.17	1.32	0.02	0.09	0.94	.10
d 7 to 21								
ADG, g	476	491	473	486	0.73	0.20	0.94	11
ADFI, g	308	350	330	348	0.49	0.06	0.43	18
G:F, g/g	1.56	1.44	1.41	1.44	0.18	0.18	0.40	.05
d 21 to 35								
ADG, g	659	617	623	637	0.70	0.50	0.18	21
ADFI, g	905	895	915	920	0.39	0.91	0.70	20
Gain / feed, g/g	.689	.728	.693	.681	0.30	0.51	0.22	.02
d 0 to 35								
ADG, g	496	498	497	517	0.34	0.30	0.43	10
ADFI, g	530	549	549	561	0.13	0.14	0.74	12
G:F, g/g	.938	.911	.906	.922	0.51	0.71	0.19	.02

[a]Pen served as experimental unit with 6 pigs per pen (n=7).

Table 5. Composition of experimental diets (Exp 3, as-fed basis).

			Phase I			Phase II	Phase III
Item, %	WithoutAnimal Protien	Without SBM	Without Whey	50% Reduction	All Ingredients		
Ingredient							
Corn	30.37	40.37	30.37	30.37	10.37	43.00	54.81
Soybean meal (48% CP)	30.00	--	30.00	30.00	30.00	24.00	36.25
Dried whey	20.00	20.00	--	10.00	20.00	30.00	--
Soybean oil	4.00	4.00	4.00	4.00	4.00	2.00	5.00
Spray-dried wheat gluten	10.00	10.00	10.00	10.00	10.00	--	
Spray-dried plasma	--	10.00	10.00	5.00	10.00	3.00	--
Fish meal (menhaden)	--	10.00	10.00	5.00	10.00	5.00	--
Monocal (21% P)	1.75	1.75	1.75	1.75	1.75	0.30	1.50
Limestone (38% Ca)	0.95	0.95	0.95	0.95	0.95	0.66	1.00
L-lysine·HCl	0.67	0.67	0.67	0.67	0.67	0.19	0.15
DL-methionine	0.22	0.22	0.22	0.22	0.22	0.15	0.04
L-threonine	0.19	0.19	0.19	0.19	0.19	0.04	--
Tryptophan	0.02	0.02	0.02	0.02	0.02	--	0.35
Valine	0.09	0.09	0.09	0.09	0.09	--	0.25
Salt	0.20	0.20	0.20	0.20	0.20	0.30	0.15
Vitamins[a]	0.25	0.25	0.25	0.25	0.25	0.25	0.50
Minerals[a]	0.15	0.15	0.15	0.15	0.15	0.15	--
Antibiotic[b]	0.70	0.70	0.70	0.70	0.70	0.70	--
Zinc oxide	0.40	0.40	0.40	0.40	0.40	0.25	--
Sow add pack	0.05	0.05	0.05	0.05	0.05	--	--
Calculated Analysis							
Total Lysine	1.80	2.11	2.79	2.30	2.92	1.60	1.35
Ca	0.92	1.32	1.26	1.09	1.41	0.80	0.77
P	0.81	1.10	1.14	0.97	1.22	0.70	0.70

[a]Provided (per kg of complete diet): 11,025 IU of vitamin A; 1,654 IU of vitamin D; 44 IU of vitamin E; 4.4 mg of vitamin K (as menadione); 55 mg of niacin; 33 mg of pantothenic acid (as d-calcium pantothen); 10 mg of riboflavin; 0.044 mg of B_{12}; 17 mg of Cu from $CuSO_4$; 165 mg of Fe from $FeSO_4$; 40 mg of Mn from $MnSO_4$; 0.3 mg of Se from sodium selenite; 165 mg of Zn from ZnO; and 0.3 mg of I from Ca iodate.

[b]Provided 108 mg of neomycin and 154 mg oxytetracycline per kilogram of complete diet in Phases I and II and 77 mg of neomycin and 110 mg oxytetracycline per kilogram of complete diet in Phase III.

Table 6. Effects of specialty ingredient sources and soybean meal concentration on nursery pig performance (Exp 3)

Item, %	Without Animal Protein	Without SBM	Without Whey	50% Reduction	All Ingredients	Probability, P<0.05			SE
						No Soy vs. Soy	No Whey vs. Whey	No Animal vs. Animal	
d 0 to 8									
ADG, g	176	224	170	188	180	0.02	0.23	0.44	17
ADFI, g	137	158	128	154	126	0.14	0.31	0.74	13
G:F, g/g	1.34	1.45	1.37	1.23	1.51	0.58	0.90	0.78	.20
d 9 to 22									
ADG, g	484	481	505	496	459	0.87	0.41	0.98	27
ADFI, g	606	608	628	627	587	0.88	0.44	0.81	24
G:F, g/g	0.79	0.79	0.81	0.80	0.78	0.96	0.73	0.98	.04
d 23 to 36									
ADG, g	624	612	670	703	619	0.26	0.41	0.46	39
ADFI, g	835	969	962	928	852	0.07	0.10	0.03	35
G:F, g/g	0.76	0.65	0.70	0.76	0.73	0.05	0.54	0.26	.05
d 0 to 36									
ADG, g	472	473	493	508	457	0.66	0.45	0.58	18
ADFI, g	590	640	643	639	584	0.31	0.23	0.15	22
G:F, g/g	0.80	0.74	0.77	0.80	0.78	0.10	0.57	0.25	.02

[a]Pen served as experimental unit with 6 pigs per pen (n=7).