Diet mixing time affects nursery pig performance[1]

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ABSTRACT: The objective of this study was to determine the effects of mixing time (mixer efficiency) of diets containing several low-inclusion ingredients (crystalline AA, ZnO, a medication, and vitamin and trace mineral premixes) on growth performance of nursery pigs. In a pilot study, mixing efficiency of a 1,360-kg capacity, horizontal ribbon mixer was evaluated with salt of different particle sizes (440, 730, 2,000, and 3,000 μm). Sample preparation was evaluated by analyzing diet samples as collected (unground) or by grinding the entire sample to approximately 400 μm in particle size (ground). Diets (907 kg) were mixed, and samples were collected after 0, 30, 60, 120, 210, 330, 480, and 630 s of mixing. The coefficient of variation among 10 samples for each mixing time was used to measure mixer efficiency as determined by Cl concentration. A salt particle size × sample preparation × mixing time interaction was observed ($P = 0.04$). Samples with 2,000- or 3,000-μm salt particle size (unground or ground) never reached the desired mixing efficiency of a 10% CV. Using 440-μm salt (unground or ground) or 730-μm salt particle sizes (ground) was necessary to accurately achieve a mixing efficiency of a <10% CV within 330 and 630 s, respectively. Next, 180 weanling pigs (PIC, 6.31 ± 0.84 kg of BW, 21 ± 3 d of age) were fed diets in 2 phases (d 0 to 14 and d 14 to 28). Treatments consisted of mixing diets for 0, 30, 60, 120, or 330 s (440-μm salt particle size). Samples were collected in the mixer, and then each bag of feed (22.5 kg) was labeled (first to last as-manufactured) and sampled to determine the mixing efficiency. An individual bag of feed was fed to a single pen of pigs, and when finished, the next sequential bag was used. As mixing time increased, mixer CV were 178, 38, 26, 21, and 5% for phase 1 and 172, 79, 60, 48, and 26% for phase 2. As mixing time increased, bag CV values were 26, 20, 16, 11, and 7% for phase 1 and 56, 45, 40, 33, and 12% for phase 2. From d 0 to 14, increasing mixing time increased ADG (linear, $P < 0.01$) and G:F (quadratic, $P = 0.03$). From d 0 to 28, increasing mixing time increased ADG (quadratic, $P < 0.01$) and G:F (linear, $P = 0.04$). These data demonstrate that inadequate diet mixing (CV > 12%) reduces nursery pig performance.

Key words: growth, mixer efficiency, nursery pig, particle size, salt

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INTRODUCTION

The goal of diet mixing is to evenly distribute all ingredients and nutrients throughout the entire batch of feed. A uniform mixture will supply the animal with a balanced diet, ensuring proper nutrient consumption and maximizing performance (McCoy et al., 1994). A mixing efficiency test can be used to evaluate diet uniformity (McCoy, 1994). The test involves selecting an ingredient, nutrient, or tracer that can be easily analyzed, then collecting 10 diet samples and determining the CV for the nutrient selected (ASAE 2001a,b).

Salt is the most common ingredient used to evaluate mixer efficiency. The chloride in salt can be analyzed with Quantab chloride titrators (Environmental Test Systems, Elkhart, IN) or laboratory analyses. Quantab analysis is comparable to a salt meter test and laboratory analysis (Wilcox and Unruh, 1986). A CV of 10% or less among 10 samples is considered excellent for a mixer (Herrman and Behnke, 1994). However, few studies are available to support the 10% CV recommendation.

McCoy et al. (1994) suggested a CV of 20%, which is twice the industry standard, as being a sufficient mixing efficiency in broiler chick diets. Traylor et al. (1994)

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observed decreased ADG in nursery and finishing pigs fed diets with a CV greater than 28.4 and 14.8%, respectively. Typical diets contain greater quantities of low-inclusion ingredients such as crystalline AA, ZnO, medications, and concentrated vitamins and trace mineral premixes than the diets used by Traylor et al. (1994). Greater use of low-inclusion ingredients such as crystalline AA, feed additives, and premixes would be expected to increase the need for thorough mixing.

Therefore, the objective of this study was to evaluate the effects of mixer efficiency on growth performance of nursery pigs.

MATERIALS AND METHODS

Experiment 1. Pilot Study

The mixing efficiency of the Kansas State University Animal Sciences and Industry Feed Mill's horizontal ribbon mixer was evaluated using salt of different particle sizes (440, 730, 2,000, and 3,000 μm). Sample preparation before analysis was also tested by evaluating diet samples as collected (unground), or the entire sample was ground to approximately 400-μm particle size (ground; ASAE, 1983). Diets (907 kg) were mixed in a 1,360-kg-capacity horizontal ribbon mixer (DS30, Davis & Sons Manufacturing Company, Bonner Springs, KS). A total of 8 batches of feed were made, 2 for each salt particle size. Each batch of feed collected was also analyzed as collected (unground) or after being ground to approximately 400 μm in a coffee grinder (Model 168940, General Electric, Fairfield, CT). All samples were collected from a basic swine diet that contained 67.3% sorghum (680 μm particle size), 30% soybean meal (700 μm), 1.00% limestone (180 μm), 0.90% monocalcium phosphate (540 μm), 0.15% L-lysine HCl (680 μm), 0.15% trace mineral premix (320 μm), 0.15% vitamin premix (300 μm), and 0.35% salt, as-fed.

Particle size analysis was conducted according to ASAE (1983) procedures. Ten samples were collected from the mixer at 8 mixing times (0, 30, 60, 120, 210, 330, 480, and 630 s), resulting in a total of 80 samples/batch. The 80 individual samples were then split, and one-half was analyzed as-is and the other half was ground. This procedure was replicated twice for each of the 4 particle sizes. For sample collection throughout the 630-s period, the mixer was stopped and then restarted. All samples (approximately 0.50 kg) were collected using a grain probe from the 10 predetermined locations in the mixer (Herman and Behnke, 1994).

Coefficient of variation was used to measure mixer efficiency and was determined by analysis of Cl concentration in the diet using Quantab Cl titrators (low range 0.005 to 0.1% as NaCl; Environmental Test Systems; McCoy, 1994). Ten grams of the collected sample were placed into a 120-mL sample cup. Ninety milliliters of 100°C distilled water were poured over the feed in the 120-mL sample cup. The sample was stirred for 30 s, let stand for 60 s, and then stirred for an additional 30 s. A folded, circular, fast flow, 12.5-cm filter paper (Quantitative Q8, Pittsburgh, PA) was placed inside the 120-mL sample container, and the Quantab chloride titrator was placed inside of the filter paper. The solution was allowed to completely saturate the wick of the titrator. The reaction was completed when the yellow wick turned completely black. The titrator was removed from the solution, read, and recorded. The reading was converted to percentage salt using the calibration table provided with the titrators. Coefficient of variation was calculated. All data was analyzed using PROC MIXED (SAS Inst. Inc., Cary, NC).

Experiment 2

The experimental protocol used in this study was approved by the Kansas State University Institutional Animal Care and Use Committee. A total of 180 weanling pigs (PIC, 6.31 ± 0.84 kg BW, 21 ± 3 d of age) were fed diets in 2 phases (d 0 to 14 and d 14 to 28). Six pigs per pen and 6 pens per treatment were randomly assigned and blocked by BW. Treatments included diet mixing times of 0, 30, 60, 120, or 330 s, with 440-μm salt particle size. Diets in both phases contained high levels of synthetic amino acids (Table 1). Phase 1 diets also contained 3.75% fish meal; 15% dried whey, as-fed; and 2,500 ppm of zinc from zinc oxide. All diets were fed in meal form and were manufactured at the Kansas State University Animal Science Feed Mill in the same mixer used in the pilot study.

Each batch of feed was manufactured following a step-by-step diet mixing procedure. Corn was added to the mixer, and the mixer was turned on to distribute the corn across the bottom of the mixer. The mixer was then turned off for additional ingredients. Soybean meal was then added, followed by the remaining ingredients based on their inclusion rate (largest to smallest). The microadditions (inclusion rates below 3%) were all preweighed into a barrel and added after all of the other ingredients. The mixer was then turned on for 0, 30, 60, 120, or 330 s. To determine mixing efficiency, 8 samples from phase 1 diets (because of a relatively small batch size) and 10 samples from phase 2 diets were collected from the mixer using a grain probe at the completion of the respective mixing time for each batch of feed. The batch was then discharged from the mixer and conveyed to a bagger. The discharge time was approximately 65 s for phase 1 and 100 s for phase 2. The discharge time was not included in the experimental treatment mixing time (0 to 330 s).

There were 272 kg of the phase 1 diet and 500 kg of the phase 2 diet mixed. The feed was discharged via a screw conveyor for approximately 2.5 m, gravity dropped to the bucket elevator leg, elevated to approximately 29.5 m, and then dropped approximately 11 m into a bin. The feed was then carried horizontally approximately 11 m via a round-bottom drag conveyor, dropped into the sac-off serge bin, and bagged. At the bagger, each 22.5-kg bag was labeled sequentially and

Table 1. Ingredient and chemical composition of diets, as-fed basis[1]

Item, %	d 0 to 14	d 14 to 28
Ingredient		
Corn	52.25	65.36
Soybean meal, 46.5% CP	25.26	29.97
Monocalcium phosphate, 21% P	1.00	1.60
Limestone	0.50	1.00
Fine mixing salt[2]	0.30	0.35
Vitamin premix[3]	0.25	0.25
Trace mineral premix[4]	0.15	0.15
Neoterramycin 10/10	0.70	0.70
Zinc oxide	0.25	—
L-Threonine	0.12	0.13
L-Lysine HCl	0.30	0.35
DL-Methionine	0.18	0.15
Menhaden fish meal	3.75	—
Spray dried whey	15.00	—
	100.00	100.00
Calculated analysis[5]		
Total lysine, %	1.45	1.35
ME, kcal/kg	3,272	3,276
CP, %	20.36	19.49
Ca, %	0.78	0.80
P, %	0.75	0.73
Available P, %	0.48	0.41
Lysine:calorie ratio, g/Mcal	4.43	4.12

[1]Dietary treatments consisted of mixing the diet for 0, 30, 60, 120, or 330 s in a horizontal ribbon mixer.
[2]Fine mixing salt (440-μm particle size) was used to aid in mixer efficiency analysis.
[3]Provided (per kilogram of diet): 11,025 IU of vitamin A; 1,654 IU of vitamin D_3; 44 IU of vitamin E; 4.4 mg of vitamin K (as menadione sodium bisulfate); 55.1 mg niacin; 9.9 mg of riboflavin; and 0.044 mg of B_{12}.
[4]Provided (per kilogram of the diet): 39.7 mg of Mn (oxide); 165.4 mg of Fe (sulfate); 165 mg of Zn (oxide); 16.5 mg of Cu (sulfate); 0.30 mg of I (as Ca iodate); and 0.30 mg of Se (as Na selenite).
[5]Nutrient values based on the NRC (1998).

then sampled using a grain probe to determine the degree of mixing that occurred as the feed was conveyed from the mixer to the bagger. Bags of feed were distributed to a pen of pigs in the order bagged (1, 2, 3, etc.); therefore, an individual bag of feed was assigned to a single pen of pigs. As feed was needed, the next sequential bag of feed was added to the feeder. The feeding procedure was designed to reproduce a situation similar to that in which an auger system used in commercial production would distribute feed to the feeders.

Samples of each of the 5 dietary treatments collected from the mixer at the conclusion of mixing and collected from the bags after discharge from the mixer were analyzed for mixing efficiency with Quantab chloride titrators (Environmental Test Systems; Table 2). Two CV values were generated for each diet in each phase of feeding, a mixer CV and a bag CV. The CV was calculated for 12 bag samples for phase 1, and 22 bag samples for phase 2. Crude protein was analyzed using a Leco nitrogen analyzer (Leco Corporation, St. Joseph, MI; AOAC 990.03, 1995) on each sample collected from the bags (Tables 3 and 4).

Table 2. Sample coefficients of variation[1]

	Mixing time, s				
Item	0	30	60	120	330
d 0 to 14					
Mixer[2]	178	38	26	21	5
Bag[3]	26	20	16	11	7
d 14 to 28					
Mixer[2]	172	79	60	48	26
Bag[4]	56	45	40	33	12

[1]Quantab Cl titrators (Environmental Test Systems, Elkhart, IN) were used to determine the CV for all samples.
[2]Coefficient of variation was determined from 8 samples for d 0 to 14 diets and 10 samples for d 14 to 28 diets collected from the mixer for each batch of feed.
[3]The bag CV for each mixing time was determined from 12 samples (1 sample collected from each bag at the bagger).
[4]The bag CV for each mixing time was determined from 22 samples (1 sample collected from each bag at the bagger).

Statistical Analysis

Statistical analysis was performed using the MIXED procedure (SAS Inst. Inc., Cary, NC.). Data from Exp. 1 were analyzed using a repeated measures analysis of variance using the MIXED procedure. The model included main effects of salt particle size, mixing time, and ground vs. unground, and their interactions. The fixed effects were salt particle size and mixing time. The repeated measure was the effect across mixing time within batch. In Exp. 2, the data were analyzed as a complete randomized block, with initial weight as the blocking factor. Pen was used as the experimental unit. Contrasts for linear, quadratic, and cubic polynomial effects of mixing time were also included in the analysis. There were no significant cubic effects observed.

Table 3. Crude protein analysis (%, as-is) for each bag fed on d 0 to 14[1]

	Mixing time, s				
Bag number	0	30	60	120	330
1	8.4	14.2	18.3	19.6	21.1
2	10.1	16.9	20.0	19.9	21.7
3	17.5	22.7	21.2	20.8	21.2
4	24.1	23.9	22.6	21.2	21.3
5	25.5	24.5	20.5	22.4	21.8
6	26.0	19.9	22.4	21.4	21.6
7	24.5	23.3	21.1	20.6	21.1
8	25.3	22.2	21.3	22.3	20.3
9	26.4	22.9	21.6	21.3	21.5
10	26.0	22.5	22.0	21.6	21.4
11	24.7	23.1	23.0	20.7	21.4
12	23.5	23.4	21.9	21.3	20.8
Mean CP	21.8	21.6	21.3	21.1	21.3
SD	6.3	3.1	1.3	0.8	0.4
CP CV, %	29.0	14.3	6.1	4.0	2.0

[1]Crude protein was determined for each bag (1 sample collected from each bag at the bagger).

Table 4. Crude protein analysis (%, as-is) for each bag fed on d 14 to 28[1]

	Mixing time, s				
Bag number	0	30	60	120	330
1	11.2	12.2	12.6	14.1	18.3
2	13.0	13.8	14.0	15.5	18.7
3	17.1	15.6	14.3	16.3	20.6
4	17.5	19.4	19.4	20.4	18.8
5	18.6	20.9	22.0	21.0	20.2
6	22.1	21.5	21.8	23.2	19.5
7	21.8	21.1	22.3	21.8	20.2
8	22.3	22.5	22.1	23.5	20.2
9	20.7	22.5	23.0	22.9	20.8
10	21.1	22.7	23.9	22.3	18.9
11	22.7	22.4	23.9	18.2	20.0
12	22.7	21.7	23.2	21.9	19.9
13	20.9	23.2	22.3	22.1	20.2
14	20.1	21.4	22.3	22.8	19.8
15	19.8	21.3	21.0	22.0	19.9
16	22.4	20.9	19.8	21.3	19.0
17	22.0	19.2	21.6	17.4	19.7
18	19.9	19.6	22.6	21.4	19.7
19	20.5	20.2	16.5	20.1	20.6
20	17.5	21.6	18.0	19.9	19.9
21	20.2	20.3	20.6	20.3	20.2
22	21.8	21.6	21.0	21.5	19.8
Mean CP	19.8	20.2	20.4	20.4	19.8
SD	3.0	2.9	3.3	2.6	0.7
CP CV, %	15.2	14.1	16.1	12.7	3.3

[1]Crude protein was determined for each bag (1 sample collected from each bag at the bagger).

RESULTS

Experiment 1. Pilot Study

A salt particle size × sample preparation × mixing time interaction ($P = 0.04$) was observed (Figure 1). As salt particle size decreased and mixing time increased, CV decreased. When samples were ground before Quantab analysis, CV decreased when compared with unground samples. Differences between ground and unground samples decreased as salt particle size decreased. There was no difference in mixer CV between ground and unground samples containing 440 μm of salt. The samples containing 440 and 730 μm of salt (ground) reached a CV less than 10% within 330 and 630 s, respectively, indicating a uniform mixture (Herrman and Behnke, 1994). All other treatments failed to reach a CV of 10% or less within 630 s.

Experiment 2

Increasing mixing time improved mixer efficiency (Table 2) and CP uniformity (Table 3 and 4) of the sample. Mixer efficiency CV decreased to 7 and 12% for phase 1 and 2, respectively, at the longest mixing time of 330 s. Crude protein CV also decreased to 2.0 and 3.3% for phase 1 and phase 2, respectively. Crude protein was lower in the first bags collected and increased in subsequent bags, indicating that the first bags contained ingredients low in CP, such as corn.

From d 0 to 14 increasing mixing time increased ADG (linear, $P < 0.01$, quadratic $P = 0.10$) and G:F (quadratic, $P = 0.03$; Table 5). Gain:feed increased from 0 to 60 s mixing time with relatively small improvements thereafter. From d 14 to 28, ADG and ADFI increased (linear, $P < 0.01$) with increasing mixing time. Gain:feed was not affected by mixing time. From d 0 to 28, increasing mixing time increased ADG (quadratic, $P < 0.01$), ADFI (linear, $P < 0.01$), and G:F (linear, $P = 0.04$, quadratic $P = 0.10$). Increasing mixing time from 0 to 30 s improved ADG with a smaller improvement in ADG observed as mixing time increased from 30 to 330 s. Final BW increased (linear, $P < 0.01$) with increased mixing time. Pigs fed the diet mixed for 330 s had the greatest (linear, $P < 0.01$) BW at d 28 when compared with pigs fed diets with the other mixing times. The salt mixing efficiency CV at 330 s was 7 and 12% in phase 1 and 2, respectively, and corresponded to the greatest growth performance observed in the experiment.

DISCUSSION

Each type of mixer has a different optimal mixing time. For example, horizontal mixers generally tend to have a shorter optimal mixing time than vertical mixers. As mixer ribbons and augers wear with use, mixing time needs to be increased to meet adequate mixing standards. Diets containing low bulk density ingredients may also require extra time to achieve the desired mixture uniformity (McCoy, 1994). The extent to which the mixer is filled relative to its rated capacity will also influence optimal mixing time. Therefore, evaluation of mixer efficiency should be conducted for individual mixers on a regular basis to ensure proper mixing times are used. The actual mixing times used in our study to reach the appropriate CV will not be applicable to other mixers; however, the diet CV should be applicable across different mixer types.

Differences in salt particle size and sample preparation are potential concerns in mixer efficiency analysis. Samples were analyzed ground and unground to make certain that large salt particles did not influence mixer efficiency results. The pilot study samples analyzed as collected (unground) often resulted in overestimation of mixer efficiency when compared with samples that were ground before analysis. These results are due to the distribution of the salt within the sample collected from the mixer and then the 10-g sample used in the analysis. However, use of a fine (440 μm) salt resulted in similar mixer efficiencies (CV values) for the ground and unground samples, indicating that mixer efficiency analysis should be conducted with fine mixing salt.

The collection site of feed samples, and the nutrient used to evaluate mixing efficiency are also potential variables. As shown in our study, movement of feed through conveyers and bins decreases diet CV. Therefore, sampling feed at the final delivery stage, or even

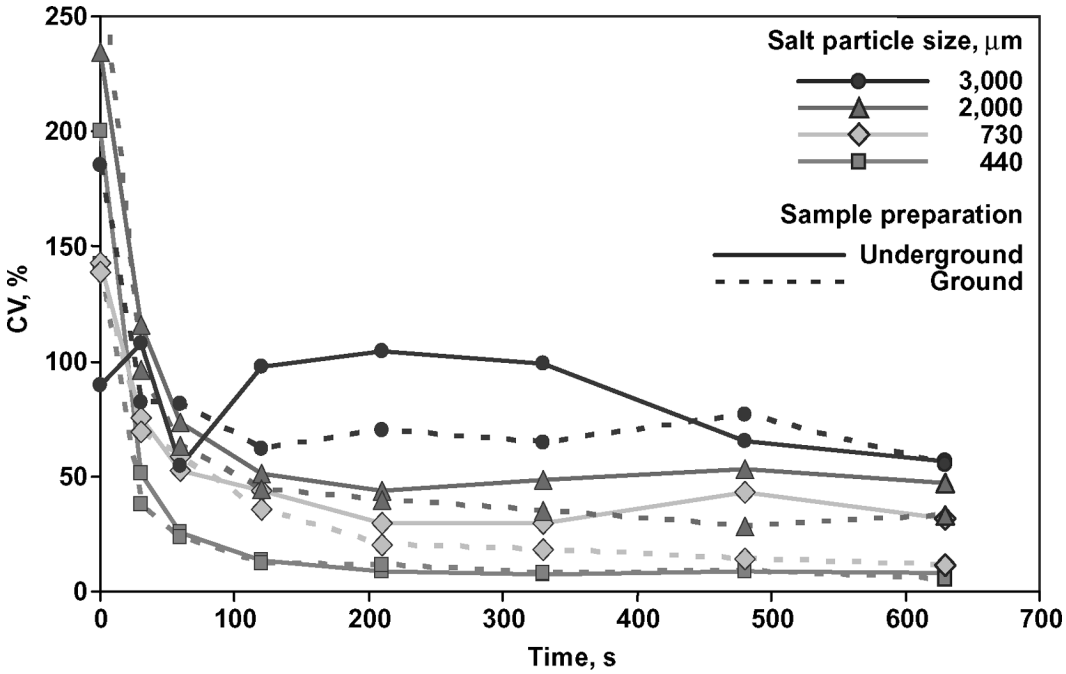

Figure 1. Effects of salt particle size, mixing time, and sample preparation on feed uniformity (CV). A particle size × sample preparation × mixing time interaction ($P < 0.04$) was observed. The mixing efficiency of the Kansas State University Animal Sciences and Industry Feed Mill's horizontal ribbon mixer was evaluated using salt of different particle sizes (440, 730, 2,000, and 3,000 μm). Ten samples were collected from the mixer at 8 mixing times (0, 30, 60, 120, 210, 330, 480, and 630 s), resulting in a total of 80 samples/batch. The 80 individual samples were then split, and one-half was analyzed as-is and the other half was ground.

from feeders, may provide a better estimate of diet CV. We tried to simulate collection of the feed at the final stages of delivery by sampling bags of feed and providing each pen of feed with its own bag of feed rather than distributing a bag of feed across several pens. Our results also suggest that analyzing for Cl provides more accurate determinations of mixer efficiency because of its lower inclusion rate relative to nutrients such as CP.

Particle size of ingredients can affect the time needed to adequately mix feed. Particle sizes of all ingredients should be similar in size to insure proper dispersal throughout the feed. Herrman and Behnke (1994) showed that grain ground to 1,200 and 1,500 μm reduced the probability of achieving a uniform mixture. These results were similar to those of the pilot study in that as particle size of salt increased, time needed

Table 5. Effects of diet mixing time on nursery pig performance[1,2]

	Mixing time, s						*P*-value	
Item	0	30	60	120	330	SE	Linear	Quadratic
d 0 to 14								
Initial wt, kg	6.30	6.35	6.30	6.30	6.30	0.16	0.42	0.65
ADG, g	190	249	245	256	280	23.25	0.01	0.10
ADFI, g	253	298	275	292	314	19.04	0.03	0.49
G:F	0.71	0.83	0.89	0.88	0.90	0.05	0.03	0.03
d 14 to 28								
ADG, g	473	562	569	595	646	48.50	0.01	0.12
ADFI, g	687	822	793	841	889	56.14	0.01	0.17
G:F	0.66	0.68	0.72	0.71	0.73	0.03	0.11	0.32
d 0 to 28								
ADG, g	331	405	407	426	463	35.04	0.01	0.01
ADFI, g	470	560	534	566	601	35.89	0.01	0.19
G:F	0.67	0.72	0.76	0.75	0.77	0.03	0.04	0.10
Final wt, kg	15.6	17.6	17.7	18.3	19.3	1.2	0.01	0.89

[1]A total of 180 weanling pigs (average initial BW of 6.31 kg), with 6 pigs/pen and 6 pens/treatment.
[2]No cubic responses ($P > 0.05$) were observed.

to achieve a uniform mixture also increased. Because of the potential variability in ingredient particle sizes, ingredient selection is an important factor impacting mixing efficiency. Selection of ingredients with similar particle sizes should improve mixing efficiency and result in a more uniformly mixed end product.

Traylor et al. (1994) conducted a 21-d growth assay evaluating effects of mixing time on growth performance of nursery and finishing pigs and produced similar results to the current study. Traylor et al. (1994) demonstrated that increasing mixing time decreased mix CV and improved growth performance. However, their results indicated a greater diet CV was adequate for optimal pig growth. One of the primary differences between the 2 studies is diet complexity. The diets used in the current study contained almost twice the number of ingredients with an inclusion rate of 2% or less than did those of Traylor et al. (1994). In recent years the greater use of low-inclusion ingredients, such as crystalline AA, ZnO, medications, and concentrated vitamins and trace mineral premixes has dramatically increased. Arguably, the mixer efficiency CV value becomes more important with increased use of low-inclusion ingredients. Traylor et al. (1994) observed little improvement in nursery and finishing pig performance above 30 s mixing with diet CV of 28.4 and 14.8%, respectively. In our study we used diets with a greater number of low-inclusion ingredients and observed improved ADG, ADFI, and G:F at the longest mixing time (330 s) in both phases (CV of 7 and 12% for phase 1 and phase 2, respectively). This also indicates that, compared with results of Traylor et al. (1994), growth performance might be improved further with lower mixer efficiency CV. It is clear that inadequate mixing negatively affects nursery pig performance.

McCoy et al. (1994) also evaluated diet uniformity in broiler chicks. In one experiment, there were no differences in ADG or carcass CP, fat, and ash content with diet CV ranging from 43 to 10.8%. However in a second experiment when diets were formulated to 80% of the estimated nutrient requirements, decreasing diet CV from 40.5 to 12.1% improved ADG and G:F. They concluded that a CV up to 20% may be adequate for maximum growth performance. These data demonstrate that if diets are over-formulated, the response to mixing uniformity may be diminished.

In conclusion, our studies suggest that using a fine mixing salt in mixer efficiency tests will lead to more accurate determinations of the appropriate mixing time for a mixer. If a coarser salt is used, grinding the sample to a uniform particle size before analysis may give a better indication of mixer performance. The improvements in ADG observed in our study indicate a low CV (7 to 12%) is ideal for maximizing nursery pig growth performance. With greater use of low-inclusion ingredients such as synthetic amino acids and concentrated feed additives in swine diets, uniform mixing becomes more important to ensure that proper nutrients are supplied to the pig.

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