

Variability in mixing efficiency and laboratory analyses of a common diet mixed at 25 experiment stations^{1,2}

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ABSTRACT: An experiment involving 25 experiment stations in the North Central and Southern regions (NCR-42 and S-288, respectively) was conducted to assess the degree of uniformity of diet mixing among stations and to assess the variability among station laboratories in chemical analysis of mixed diets. A fortified corn–soybean meal diet was mixed at each station using a common diet formula (except for vitamin and trace-mineral additions). The diet was calculated to contain 14% crude protein (CP), 0.65% Ca, 0.50% P, and 125 ppm Zn (based on 100 ppm added Zn). After mixing, samples were collected from the initial 5% of feed discharged from the mixer, after 25, 50, and 75% was discharged, and from the final 5% of discharged feed. The five samples were sent to the University of Kentucky, finely ground, and divided into subsamples. Each set of five subsamples from each station was distributed to three randomly selected stations for analysis of CP, Ca, P, and Zn (i.e., each station analyzed five diet subsamples from three other stations). In addition, two commercial and two station laboratories analyzed composites of the five subsamples from each of the 25 mixed diets. Based on the laboratories that analyzed all diets, means were 13.5, 0.65, and 0.52%, and 115 ppm for CP,

Ca, P, and Zn, respectively. Ranges of 11.8 to 14.6% CP, 0.52 to 0.85% Ca, 0.47 to 0.58% P, and 71 to 182 ppm of Zn were found among the 25 diet mixes. The coefficients of variation among the 25 diet samples for CP, Ca, P, and Zn were 4.3, 9.3, 4.1, and 17.4%, and among the 25 laboratories were 3.6, 12.5, 10.7, and 11.1%, respectively. Overall analyses of the five subsamples were, respectively, CP: 13.4, 13.6, 13.4, 13.5, and 13.4% ($P < 0.06$); Ca: 0.66, 0.67, 0.67, 0.66, and 0.67%; P: 0.50, 0.51, 0.51, 0.50, and 0.50%; and Zn: 115, 116, 112, 113, and 120 ppm ($P < 0.001$). Diets were not uniformly mixed at all stations (station \times sample No. was $P < 0.08$ for Ca and $P < 0.01$ for CP, P, and Zn). Among stations, the range of the five samples, expressed as a percentage of the mean and averaged for CP, Ca, P, and Zn, varied from $\pm 1.1\%$ (i.e., 98.9 to 101.0%) to $\pm 12.9\%$ (84.6 to 110.4%), with an overall average of $\pm 5.2\%$. Neither type nor volume of mixers was related to mixing uniformity. The results suggest that uniformity of diet mixes varies among experiment stations, that some stations miss their targeted levels of nutrients (especially Zn), and that the variability among experiment station laboratories in analysis of dietary Ca, P, and Zn in mixed diets is quite large.

Key Words: Chemical Analysis, Feed Mixing

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Introduction

A previous study conducted by the North Central Regional Committee on Swine Nutrition indicated that

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samples of corn and soybean meal collected from various locations in the Midwestern United States over a 3-yr period varied in their DM, CP, Ca, P, Se, and AA composition (Cromwell et al., 1999). This committee also reported that samples of wheat middlings collected from different locations in the Midwestern United States also varied in their nutrient composition (Cromwell et al., 2000). Others have reported similar findings (Watson and Ramstad, 1987; Sprague and Dudley, 1988), especially with respect to Se concentration (Ulrey, 1974). Surprisingly, in the two regional studies, there was as much or more analytical variability for most of the assays (except CP and Se) among the experiment station and commercial laboratories that analyzed the samples than there was among sources of ingredients from various locations in the United States.

Excellent blending of diets is essential in nutrition experiments. However, most experiment stations have little information on how uniformly they are able to blend their diets. Therefore, this study was conducted to assess the degree of uniformity of diet blending at 25 experiment stations that are commonly involved in swine nutrition research, and also to determine the analytical variability among experiment station laboratories in analysis of complete mixed diets.

Materials and Methods

Representatives of two regional research committees, the North Central Regional Committee on Swine Nutrition (NCR-42) and the Southern Regional Committee on Nutritional Systems for Swine to Increase Reproductive Efficiency (S-288) participated in a cooperative study to assess the uniformity in the mixing of a common diet at 25 experiment stations and to assess the analytical variability among 25 experiment station laboratories in chemical analysis of the mixed diets. Experiment stations from the NCR-42 committee that participated in the study were Iowa State University, University of Illinois, Purdue University, Kansas State University, University of Kentucky, Michigan State

Table 1. Composition of diets, as fed basis (%)^a

Item	Composition	
Ground corn	83.15	81.40
Dehulled soybean meal (48% CP)	14.50	—
Conventional soybean meal (44% CP)	—	16.25
Dicalcium phosphate (24% Ca, 18.5% P)	1.10	1.10
Ground limestone (38% Ca)	0.90	0.90
Salt	0.25	0.25
Vitamins ^b	+	+
Trace minerals ^b	+	+
Total	100.00	100.00

^aCalculated to contain 14.0% CP, 0.65% Ca, 0.50% P, and 125 ppm Zn.

^bEach station used its own vitamin and trace mineral premixes. The trace mineral premix was added at a level to provide 100 ppm of Zn.

University, University of Minnesota, University of Missouri, University of Nebraska, USDA Meat Animal Research Center, The Ohio State University, South Dakota State University, and University of Wisconsin. Experiment stations from the S-288 committee that participated were Auburn University, University of Florida, University of Georgia, Louisiana State University, Mississippi State University, Oklahoma State University, Clemson University, University of Tennessee, Texas A&M University, Virginia Polytechnic Institute and State University, and the Tidewater Agricultural Experiment Station of the Virginia Polytechnic Institute and State University. The stations were coded 1 to 25. Each station had the same code number for its diet mix and for its laboratory analysis contribution.

A fortified corn–soybean meal diet was mixed at each experiment station using the mixer that the station routinely used to mix their experimental diets. There were three basic types of mixers in the study: horizontal ribbon mixers (n = 13), horizontal paddle mixers (n = 5), and vertical screw mixers (n = 7). One of the vertical mixers had a twin-screw configuration; the other vertical mixers were single screw. The capacity of the mixers was 0.23 (n = 1), 0.45 (n = 3), 0.91 (n = 16), 1.36 (n = 1), and 1.82 t (n = 4). Mixers were at capacity when diets were blended.

Each station blended a swine finishing diet from one of two mixing formulas (Table 1) depending on whether they routinely used dehulled or conventional soybean meal. Each station used its own vitamin and trace mineral premixes. The protocol indicated that the trace mineral premix was to be added at such a level to provide 100 ppm of supplemental Zn. Both diets were calculated to contain 14% CP, 0.65% Ca, 0.50% P, and 125 ppm of Zn, based on the content of CP, Ca, P, and Zn listed for the dietary ingredients by NRC (1998).

To determine the uniformity of mixing, the following procedures were followed. After diets were blended, 1-kg samples were obtained from the initial 5% of the feed discharged from the mixer, after 25, 50, and 75% of the feed was discharged, and from the final 5% of discharged feed. These five samples were labeled and

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⁵Administrative advisors during this study were D. K. Layman, Univ. of Illinois, Urbana (NCR-42) and J. A. Boling, Univ. of Kentucky, Lexington (S-288).

⁶At the time of the study, the Southern Regional Committee was S-145.

sent to the study coordinator at the University of Kentucky, where they were finely ground in a mini-hammer mill (Micro sample mill, Summit, NJ) and divided into subsamples. A complete set of five subsamples from each station's mix was then sent to three randomly selected participating stations for chemical analysis of CP, Ca, P, and Zn. Thus, the laboratories at each of the 25 participating stations analyzed five samples from mixes of three other stations, for a total of 15 samples per laboratory. Another set of analyses was performed on each station's mix, in which equal parts of the five subsamples of each station's mix were blended into a single sample. These 25 blended samples were analyzed for CP, Ca, P, and Zn by two commercial laboratories, the University of Missouri Experiment Station Chemical Laboratories (Columbia, MO) and Consolidated Nutrition Laboratories (Decatur, IN), for CP by the University of Kentucky, and for Ca, P, and Zn by Michigan State University (hereafter, the two university laboratories are referred to as the third laboratory). All participating investigators were asked to use the analytical procedures routinely used in their laboratory. Each laboratory analyzed samples in duplicate or triplicate, with the means for each sample reported to the study coordinator.

Each laboratory followed commonly accepted procedures (AOAC, 1990) for most of the analyses. Crude protein was analyzed with Kjeldahl methodology ($N \times 6.25$) or by combustion with a N analyzer. After wet-ashing procedures, Ca and Zn were assayed with atomic absorption spectrophotometry and P was assayed using colorimetric procedures at most of the laboratories or by gravimetric procedures at one laboratory.

Statistical Analysis. The data were compiled and statistically analyzed by variance procedures (Steel and Torrie, 1980) using the GLM procedures of SAS (SAS Inst., Inc., Cary, NC). In the analysis of station mixes

by three laboratories, a random model was assumed that included effects of station (24 df), laboratory (2 df), and station \times laboratory (experimental error, 48 df). To obtain the estimate of variation (CV, $100 \cdot s/\text{mean}$) among station mixes (σ_S), the error variance (σ_E^2) was subtracted from the station variance ($\sigma_E^2 + 3\sigma_S^2$), the result was divided by 3 (No. of laboratories), the square root was determined, and the result was divided by the overall mean and multiplied by 100. In the analysis of analytical values obtained by the 25 laboratories, the model included laboratory (24 df) and replication (station mix) within laboratory (error, 50 df). The CV among laboratories (σ_L) was determined by subtracting the error variance (σ_E^2) from the laboratory variance ($\sigma_E^2 + 3\sigma_L^2$), the result was divided by 3 (No. of station mixes analyzed by each laboratory), the square root was determined, and the result was divided by the overall mean and multiplied by 100. In the analysis of the diet subsamples, the model included station mix (24 df), laboratories within station mix (50 df), sample No. (4 df), sample No. \times station mix (96 df), and sample No. \times laboratory within station mix (200 df, considered as error). Unless stated otherwise, the values in the tables are simple (unadjusted) means.

Results and Discussion

Overall Analyses of Diets. The diets mixed at the 25 stations were calculated to contain 14.0% CP, 0.65% Ca, 0.50% P, and 125 ppm of Zn according to concentrations of these nutrients in corn, soybean meal, dicalcium phosphate, and ground calcitic limestone as listed in NRC (1998). The overall means for CP, Ca, and P in the 25 diets, shown in Table 2, were reasonably close to targeted levels based on the assays of the three laboratories that analyzed all 25 diets, as well as the assays of the station laboratories that analyzed five diet sam-

Table 2. Analyses of 25 diets by laboratories

Item	CP, %	Ca, %	P, %	Zn, ppm
Targeted	14.0	0.65	0.50	125
Laboratories that analyzed all diets ^a				
Laboratory 1	13.4	0.65	0.55	128
Laboratory 2	13.4	0.64	0.49	110
Laboratory 3	13.6	0.66	0.53	106
Mean	13.5	0.65	0.52	115
Mean of 25 station laboratories ^b	13.5	0.67	0.51	115
Laboratory effect, among three laboratories, $P <$	0.05	0.42	0.001	0.001
CV among three laboratories ^c	0.8	— ^d	6.1	10.0

^aMean of three laboratories that analyzed the complete diet mix from 25 stations. Laboratories 1 and 2 are for assays conducted at two commercial laboratories (University of Missouri Experiment Station Chemical Laboratories and Consolidated Nutrition Laboratories, respectively). Laboratory 3 represents assays that were conducted at the University of Kentucky (CP) or Michigan State University (Ca, P, and Zn).

^bEach laboratory analyzed five subsamples of each of three mixes from three other stations.

^cCalculated as follows: the error mean square was subtracted from the laboratory mean square, the result was divided by 25 (No. of station mixes), the square root was determined, and the result was divided by the overall mean and multiplied by 100.

^dUsing the procedure described in footnote "c," the laboratory mean square was less than the error mean square, thus a CV among laboratories could not be calculated.

ples from three other randomly selected laboratories. However, Zn levels were slightly less than the targeted levels. The three laboratories were relatively consistent in their assays for CP and Ca, but assays for P varied from 0.49 to 0.55%, and from 106 to 128 ppm for Zn among the three laboratories.

Variation Among Diet Mixes. Table 3 gives the levels of CP, Ca, P, and Zn in the diets mixed at the 25 stations as determined by the three laboratories that analyzed all diets. Considerable variation occurred in the nutrient concentration among the diets mixed at the 25 stations. The CP levels varied from 11.8 to 14.6% ($P < 0.001$), Ca varied from 0.52 to 0.85% ($P < 0.001$), and P ranged from 0.47 to 0.58% ($P < 0.001$). Zinc had the greatest range in values, from 71 to 182 ppm ($P < 0.001$). The variation in CP among station diets may have been due to differences in CP content of corn and/or soybean meal, as we found in previous studies (Cromwell et al., 1999) and has been reported by others (Watson and Ramstad, 1987; Sprague and Dudley, 1988). It is possi-

ble that variation in Ca and P content of corn and soybean meal may have contributed to some of the variation in Ca and P among mixes, although our earlier study indicated that these ingredients do not vary appreciably in Ca and P content (Cromwell et al., 1999), except in cases where Ca may be elevated in soybean meal due to addition of ground limestone to improve flow characteristics. A more plausible explanation is that the feed-grade dicalcium phosphate used in the diets may have varied in Ca and P content. For example, feed-grade dicalcium phosphate can vary from 21 to 24% Ca depending on the proportion of mono- and dicalcium phosphate in the blend (NRC, 1998). The nearly twofold range in Zn concentration among diets was largely due to two stations (No. 2 and 24) that had 182 and 71 ppm of Zn, respectively, in their diets. The next highest and lowest Zn levels were 137 (station No. 5) and 94 ppm (stations No. 11, 12, and 20), respectively. There is no evidence that Zn varies enough among the major ingredients used in the diets to account for the exceptionally high and low levels of Zn in the two extremes, so the disparity was more likely related to the

Table 3. Analyzed composition of a common diet mixed at 25 stations as analyzed by three laboratories^a

Station mix	CP, %	Ca, %	P, %	Zn, ppm
1	13.5	0.62	0.53	117
2	14.0	0.72	0.54	182
3	13.5	0.69	0.54	137
4	13.5	0.58	0.52	114
5	12.5	0.64	0.52	110
6	12.5	0.60	0.52	112
7	13.4	0.67	0.53	128
8	13.9	0.67	0.52	112
9	14.2	0.62	0.54	125
10	13.5	0.59	0.54	118
11	13.2	0.69	0.51	94
12	13.1	0.85	0.58	94
13	13.8	0.71	0.55	132
14	14.4	0.57	0.54	96
15	13.8	0.65	0.51	110
16	13.8	0.70	0.51	116
17	13.3	0.65	0.51	132
18	13.3	0.62	0.52	123
19	11.8	0.56	0.47	108
20	14.0	0.62	0.53	94
21	13.5	0.52	0.49	103
22	12.8	0.73	0.56	118
23	13.4	0.65	0.48	125
24	14.6	0.61	0.53	71
25	13.6	0.65	0.52	102
Mean	13.5	0.65	0.52	115
Range				
Low	11.8	0.52	0.47	71
High	14.6	0.85	0.58	182
Station effect, $P <$	0.001	0.001	0.001	0.001
CV of model	2.8	7.7	3.2	6.1
CV among station mixes ^b	4.3	9.3	4.1	17.4

^aEach station's diet (composite of five subsamples) was analyzed by three laboratories.

^bCalculated as follows: the error mean square was subtracted from the station mean square, the result was divided by 3 (No. of laboratories), the square root was determined, and the result was divided by the overall mean and multiplied by 100.

Table 4. Analysis of three diet mixes by 25 experiment station laboratories^a

Station laboratory	CP, %	Ca, %	P, %	Zn, ppm
1	12.9	0.59	0.51	95
2	12.9	0.52	0.45	123
3	12.1	0.61	0.52	78
4	14.1	0.68	0.54	109
5	14.6	0.70	0.51	111
6	14.5	0.67	0.51	134
7	14.1	0.74	0.56	90
8	12.8	0.36	0.44	170
9	12.8	0.68	0.49	108
10	13.3	0.72	0.55	113
11	13.1	0.66	0.42	91
12	13.2	0.68	0.56	102
13	13.0	0.59	0.41	104
14	14.2	0.73	0.44	128
15	13.8	0.73	0.48	116
16	13.5	0.92	0.51	136
17	13.0	0.71	0.66	108
18	14.0	0.59	0.50	119
19	13.2	0.44	0.44	84
20	15.2	0.82	0.57	153
21	13.7	0.67	0.53	117
22	12.6	0.82	0.51	105
23	13.3	0.70	0.58	172
24	13.7	0.66	0.52	116
25	12.7	0.66	0.43	101
Mean	13.5	0.67	0.51	115
Range				
Low	12.1	0.36	0.41	78
High	15.2	0.92	0.66	172
Laboratory effect, $P <$	0.001	0.001	0.001	0.001
CV of model	4.4	15.2	7.3	22.5
CV among laboratories ^b	4.7	14.8	10.8	15.8

^aEach laboratory analyzed five subsamples of diets mixed at three other stations.

^bCalculated in a manner similar to that described in Table 3, footnote b.

trace mineral premix used in the diets. Possible factors may have been a low inclusion rate of the Zn premix at those stations prevented the Zn from being mixed uniformly, the Zn concentration in the premixes used at those stations may have been higher or lower than shown on the label, or the correct amount of the Zn premix may not have been added to the diet at those stations.

Variation Among Laboratories in Diet Analyses. A summary of the CP, Ca, P, and Zn concentrations in the diets that were analyzed by the 25 station laboratories is shown in Table 4. The differences in analytical values obtained by the laboratories were substantial ($P < 0.001$). The range in values was especially large for Ca (0.36 to 0.92%) and Zn (78 to 172 ppm), representing twofold or more in the extremes. The CV among laboratories was quite high for these two assays (14.8 for Ca and 15.8 for Zn). The range in analytical values among laboratories was less for CP (12.1 to 15.2%; CV = 4.7) and intermediate for P (0.41 to 0.66%; CV = 10.8).

Because each station laboratory analyzed samples from three other stations selected at random, an estimate of how effective each laboratory was at analyzing diets accurately may have been confounded by the accuracy with which the three diets were mixed at the other three stations. Therefore, to minimize this possible bias, the results of the individual laboratories' analyses were expressed as a percentage of the values for those mixes that the laboratories analyzed, with the "values" determined by the three laboratories that analyzed all 25 station mixes. These unbiased estimates of laboratory-to-laboratory variability in analytical precision are shown in Table 5. Analyses of CP, Ca, P, and Zn were different among laboratories ($P < 0.001$), with rather large ranges in analytical results, especially for Ca and Zn (60 to 127% and 70 to 142% of the three-laboratory mean, respectively). The CV among laboratories was lower for CP (3.6%) than for Ca, P, and Zn (10.7 to 12.5%). Although the CV among laboratories, when expressed as a percentage of the values analyzed by the

Table 5. Analysis of three diet mixes by 25 experiment station laboratories, expressed as a percentage of the values determined by the three laboratories that analyzed the composited subsamples of the station mixes^a

Station laboratory	CP, %	Ca, %	P, %	Zn, %
1	92	92	94	87
2	101	91	93	109
3	93	97	102	71
4	103	108	102	99
5	106	106	97	113
6	105	102	97	121
7	101	127	108	87
8	95	60	84	142
9	98	98	90	102
10	97	113	106	103
11	101	95	77	85
12	94	110	106	99
13	96	90	79	82
14	100	107	83	102
15	102	116	91	102
16	100	123	93	98
17	98	108	125	95
18	104	89	97	94
19	100	68	85	70
20	111	119	105	107
21	100	110	101	102
22	96	121	100	99
23	99	107	112	135
24	106	107	100	105
25	100	111	84	96
Mean	100	103	96	100
Range				
Low	92	60	77	70
High	111	127	125	142
Laboratory effect, $P <$	0.001	0.001	0.001	0.001
CV of model	4.4	14.8	7.3	20.9
CV among laboratories ^b	3.6	12.5	10.7	11.1

^aEach laboratory analyzed five subsamples of diets mixed at three other randomly selected stations. To reduce confounding effects, the analyses by each laboratory are expressed as a percentage of the value for the specific diets that they analyzed. Those "values" were determined by the three laboratories that analyzed all diets from all stations.

^bCalculated in a similar manner as described in Table 3, footnote b.

Table 6. Analyses of subsamples of a common diet mixed by 25 experiment stations and analyzed at experiment station laboratories^a

Item	CP	Ca	P	Zn	Mean
Targeted level	14.0%	0.65%	0.50%	125 ppm	
Analysis of subsamples, % or ppm					
1 ^b	13.4	0.66	0.50	115	
2	13.6	0.67	0.51	116	
3	13.4	0.67	0.51	112	
4	13.5	0.66	0.50	113	
5	13.4	0.67	0.50	120	
Differences					
Among subsamples, <i>P</i> <	0.06	0.95	0.51	0.001	
Station × subsamples, <i>P</i> <	0.001	0.02	0.002	0.001	
CV of model	3.3	14.4	7.2	10.3	
Variation among samples, % of sample means					
1 ^b	99.6	99.6	100.0	100.1	99.8
2	100.7	100.2	100.3	100.2	100.4
3	99.9	99.6	101.0	97.5	99.5
4	100.4	99.9	99.5	98.9	99.7
5	99.4	100.7	99.3	103.2	100.7
Differences					
Among subsamples, <i>P</i> <	0.09	0.99	0.62	0.02	0.74
Station × subsamples, <i>P</i> <	0.001	0.08	0.002	0.001	0.001
CV of model	3.4	14.6	7.4	10.2	6.0

^aBased on diets mixed at 25 stations. Each diet was analyzed by three other station laboratories.

^bSubsamples 1 to 5 were from the initial 5% of discharged feed, after 25, 50, and 75% of the feed was discharged, and from the last 5% of discharged feed, respectively.

three laboratories (Table 5), were slightly less than when they were expressed as dietary concentrations (Table 4), overall trends were the same.

A possible reason for the large variation among laboratories in Ca, P, and Zn analyses may have been due to certain laboratories not routinely conducting mineral assays. In general, these results agree with our previous studies, which indicated that the variation in analysis of Ca, P, and several other nutrients (except CP or Se) among laboratories is as great as, or greater than, the variation in nutrient content among ingredients (Cromwell et al., 1999; 2000).

Uniformity of Diet Mixing. The overall efficiency of mixing the common diet at the 25 stations is represented by the analyses of the five diet subsamples, shown in Table 6. In general, the differences among the five subsamples were quite small and not significant (*P* > 0.05) for CP, Ca, and P, but the variation among subsamples in Zn concentrations was larger, ranging from 112 to 120 ppm (*P* < 0.001). Similar trends occurred when the variation among subsamples was expressed as a percentage of the total sample, ranging from 99.4 to 100.7 for CP, 99.6 to 100.7 for Ca, 99.3 to 100.3 for P, and 97.5 to 103.2 for Zn (Table 5). These differences were not significant for CP, Ca, or P (*P* > 0.09), but they were significant for Zn (*P* < 0.001 on ppm basis, *P* < 0.02 on percentage of total basis). The reason for the higher concentration of Zn in the final 5% of the feed taken from the mixers is unclear. The mean percentages of the five subsamples averaged across the four nutrients ranged from 99.5 to 100.7.

Uniformity of Diet Mixing Among Stations. The overall difference among nutrient concentrations among the five subsamples of the diets was not significant when averaged across all stations (*P* = 0.74), but there was a large station × subsample interaction (*P* < 0.001; Table 6). To investigate this interaction, the overall means of the five subsamples (averaged across CP, Ca, P, and Zn), expressed as a percentage of the total sample, were

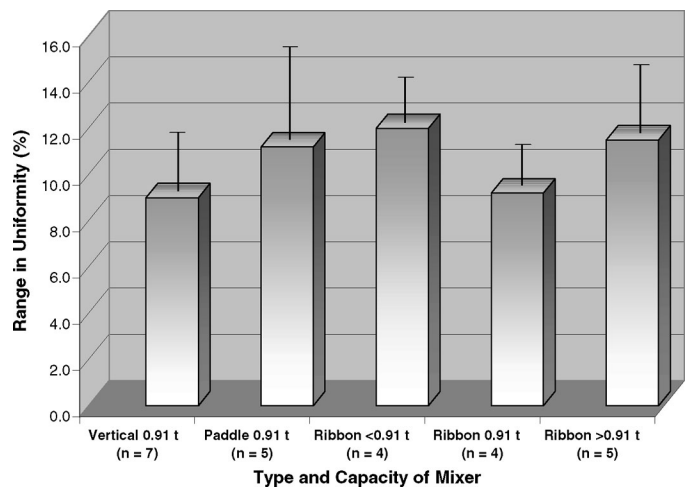


Figure 1. Relationship of uniformity of mixing to type and batch size of mixer. A range of 10% means that the lowest and highest analytical means for CP, Ca, P, and Zn in five subsamples taken from the mixer were 95 and 105% of the mean. Bars represent standard errors.

Table 7. Uniformity of mixing efficiency of a common diet mixed at 25 experiment stations and analyzed at experiment station laboratories (percentage of sample mean)^a

Station	Mixer type	Mixer capacity, t	Subsample no. ^b					Range ^c
			1	2	3	4	5	
22	Vertical ^d	0.91	99.9	98.9	101.0	100.4	99.9	2.1
14	Paddle	0.91	98.8	98.5	100.1	100.6	101.8	3.3
17	Ribbon	1.82	97.8	101.4	99.2	101.8	100.0	4.0
21	Vertical	0.91	97.8	98.3	101.6	100.0	102.3	4.5
12	Ribbon	0.91	99.8	102.6	101.5	98.3	97.7	4.9
15	Vertical	0.91	102.8	96.8	100.4	97.3	102.6	6.0
8	Paddle	0.91	101.6	102.1	95.9	99.7	100.9	6.2
1	Vertical	0.91	102.3	103.7	99.3	96.1	98.4	7.5
9	Ribbon	0.91	94.6	100.9	101.2	102.4	101.0	7.8
6	Ribbon	1.36	96.7	99.0	102.4	97.3	104.5	7.8
10	Paddle	0.91	103.9	103.3	97.2	100.4	95.2	8.7
5	Ribbon	0.45	97.8	102.7	103.3	94.6	101.8	8.7
23	Ribbon	0.23	104.8	99.8	99.7	101.3	94.5	10.3
3	Vertical	0.91	104.4	99.7	94.9	105.3	95.8	10.4
19	Vertical	0.91	94.6	105.0	98.2	102.8	99.4	10.4
7	Ribbon	0.45	99.2	100.9	94.5	99.7	105.9	11.4
18	Ribbon	1.82	94.7	96.4	102.9	106.4	99.8	11.7
16	Ribbon	0.91	106.5	103.5	96.2	94.6	99.2	11.9
20	Ribbon	1.82	102.7	105.6	97.7	100.4	93.6	12.0
24	Paddle	0.91	95.8	94.1	100.6	103.2	106.2	12.1
13	Ribbon	0.91	94.2	106.5	99.5	99.5	100.4	12.3
4	Ribbon	0.45	105.4	91.7	93.5	109.1	100.3	17.4
25	Ribbon	1.82	89.5	90.9	101.1	107.3	111.3	21.8
11	Vertical	0.91	110.5	97.0	104.8	88.5	99.2	22.0
2	Paddle	0.91	99.3	110.4	100.9	84.6	104.7	25.8
Mean of all stations ^e			99.8	100.4	99.5	99.7	100.7	1.2
Mean of station ranges								10.4

^aAverage of the means for CP, Ca, P, and Zn analyses with each expressed as a percentage of the sample mean (see last column in Table 6), ranked from the most uniform to least uniform mixing.

^bSubsamples 1 to 5 were from the initial 5% of discharged feed, after 25, 50, and 75% of the feed was discharged, and from the last 5% of discharged feed, respectively.

^cRepresents the highest minus the lowest value among the five subsamples.

^dVertical twin screw mixer; all other vertical mixers were single screw.

^eNo differences among subsamples ($P = 0.74$); station \times subsample interaction ($P < 0.001$); CV of model = 6.0.

determined for each station. These percentages, which reflect uniformity of diet mixing by the 25 stations, are shown in Table 7. The data in Table 7 show stations ranked from lowest to highest according to their overall range in analytical values.

Stations varied from a 2.1 to 25.8% range among subsamples, with a mean range of 10.4%. Expressed another way, stations ranged from $\pm 1.1\%$ to $\pm 12.9\%$ of the mean, with an overall average of $\pm 5.2\%$ of the mean for the five subsamples. Five stations had ranges among the five subsamples that were $< 5.0\%$, seven stations were within the range of 5 to 10%, nine stations were in the range of 10 to 20%, and three stations had ranges of $> 20\%$. Other than the fact that the best mixing efficiency was at the only station with a twin-screw vertical mixer, type of mixer was not a major contributing factor in this study (Figure 1). Similarly, the capacity of the ribbon mixers in this study did not seem to be a contributing factor in mixing efficiency (Figure 1). The apparent similarity of mixing efficiencies among the three

types of mixers used in this study agrees with the findings of Wilcox and Unruh (1986), who concluded that mixing time, mixing speed, fullness of mixers, and wear and tear on ribbons, paddles, and screws had greater effects on mixing efficiency than did mixer type or capacity.

In summary, the results of this study indicate that nutrient analyses of diets by experiment station laboratories are quite variable. This conclusion is in agreement with previous findings involving nutrient analyses of individual ingredients such as corn, soybean meal, and wheat middlings (Cromwell et al., 1999; 2000). The study also shows that in some instances, researchers were unable to achieve a specific level of a nutrient (especially Zn) in their diets. Finally, the study shows that some stations were able to mix experimental diets uniformly, whereas other stations were less able to mix diets uniformly. In this study, neither mixer type nor mixer capacity affected blending uniformity.

Implications

This study indicates that the variation among chemical analyses of diets by experiment station laboratories is quite large, especially with respect to zinc analysis. The study also provides evidence that researchers are not always able to achieve a targeted level of a nutrient, such as zinc, that is supplied in the form of a premix. Some stations apparently mix experimental diets quite uniformly while other stations do not. Mixer type or capacity does not seem to affect the efficiency of which diets are uniformly blended. The results raise the possibility that, in some experiments, variation in animal performance across dietary treatments could be due to mixing error rather than animal variation. Care must be taken in nutrition experiments to minimize mixing errors in order to avoid drawing erroneous conclusions regarding dietary treatment effects.

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