

Effects of the Pelleting Process on Diet Formulations with Varying Levels of Crystalline Amino Acids and Reducing Sugars on Nursery Pig Growth Performance¹

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Summary

Pelleting swine feed and the use of crystalline amino acids and by-product ingredients can potentially create ideal conditions that further facilitate the Maillard browning reaction. The Maillard reaction combines an amino group of a free amino acid and a carbonyl group of a reducing sugar (RS), making the amino acid less available. The objective of this study was to determine the effects of pelleting swine diets containing free amino acids and reducing sugars at high temperatures on nursery pig growth performance. A total of 360 pigs (initially 25.0 lb; Line 200 × 400; DNA, Columbus, NE) were used in a study evaluating the effect of crystalline AA, reducing sugars, and feed form on growth performance of nursery pigs. Treatments were arranged in a 2 × 2 × 2 factorial with main effects of crystalline AA concentration (low vs. high), reducing sugars (RS; low vs. high), and diet form (mash vs. pellet). Diets were formulated with low or high crystalline AA and low or high reducing sugars provided by co-product ingredients, DDGS and bakery meal. Diets were pelleted to a conditioning temperature of 187.5°F. When pigs weighed approximately 25 lb, they were weighed, and pens were randomly assigned treatments. There were 9 replications per treatment and 5 pigs per pen. There were no 3-way or 2-way interactions. For the main effect of form, there was no evidence of difference in ADG, and ADFI increased ($P = 0.001$) in pigs fed mash diets compared to pellets. Feed efficiency and caloric efficiency improved ($P = 0.001$) in pigs fed pelleted diets compared to mash diets. For the main effect of crystalline AA, there was no evidence of difference in ADG or F/G; however, pigs fed high crystalline AA had increased ($P = 0.024$) ADFI compared to those fed low crystalline AA diets. For the main effect of RS inclusion, pigs fed low RS diets had increased ($P < 0.041$) ADG and ADFI compared to pigs fed high RS inclusion diets. There was an improvement ($P = 0.019$) in F/G and caloric efficiency for pigs fed high RS inclusion diets compared to those fed low RS diets. There was no evidence of difference in IOFC for form, crystalline AA, or RS. In conclusion, there was no evidence of interactions

¹ Appreciation is expressed to the National Pork Board for partial financial support of this study.

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between diet types, indicating that increasing amounts of crystalline AA and RS did not increase the Maillard reaction or reduce growth performance when pelleting diets by using the reported conditions. Pigs fed pelleted diets had similar ADG and an 8% improvement in F/G compared to those fed mash diets. Pigs fed the high RS diets had reduced feed intake, which resulted in reduced gain and improved feed and caloric efficiency. Additionally, pigs fed high AA diets had increased feed intake.

Introduction

Pelleting swine feed is commonly used to improve feed efficiency, feed handling characteristics, and bulk density while decreasing feed wastage. The combination of pelleting feed and current swine diet formulation trends that include a combination of crystalline AA and co-product ingredients, such as DDGS and bakery meal, could create ideal conditions for the Maillard browning reaction. The Maillard reaction is a non-enzymatic browning reaction between an amino group in amino acids, peptides, or proteins and a carbonyl group of reducing sugars such as glucose, fructose, or lactose. Variables optimizing the Maillard browning reaction include high temperatures and moisture levels, which can occur during feed processing. Thus, pelleting diets containing crystalline amino acids and co-products with reducing sugars may increase the risk for reduced amino acid availability and, consequently, impaired growth performance. Therefore, the objective of this experiment was to test the hypothesis that effects of pelleting swine diets containing free amino acids and reducing sugars at high temperatures will reduce nursery pig growth performance.

Materials and Methods

The Kansas State University Institutional Animal Care and Use Committee approved the protocol used in this experiment. The study was conducted at the Kansas State University Swine Teaching and Research Center (Manhattan, KS). Pigs were housed in 4 × 4-ft pens containing a three-hole dry self-feeder and one cup waterer to provide *ad libitum* access to feed and water.

A total of 360 pigs (initially 25.0 lb; Line 200 × 400; DNA, Columbus, NE) were used in an 18-d growth study. Pigs were weaned at approximately 21-d of age, weighed, and assigned to pens in a completely randomized design with 5 pigs per pen with 3 barrows and 2 gilts or 3 gilts and 2 barrows. When pigs weighed approximately 25 lb, each pen was randomly assigned to 1 of 8 dietary treatments from 4 formulations provided in mash or pelleted form (Table 1).

Dietary treatments were arranged in a 2 × 2 × 2 factorial with main effects of crystalline amino acid level (AA; low vs. high); reducing sugars (RS; low vs. high); and diet form (mash vs. pellet; Table 1). For crystalline amino acid treatments, diets were considered low or high based on the inclusion of crystalline AA, with high crystalline AA diets having increased concentrations of lysine, threonine, and tryptophan compared with low crystalline AA diets. Valine and isoleucine were included as needed in the high crystalline AA diets. Reducing sugars were naturally occurring in ingredients (corn and soybean meal-based diets; low) or increased by adding DDGS and bakery meal (20 and 15%, respectively; high). Diets were manufactured at the North Carolina State Feed Mill Education Unit (Table 2; Raleigh, NC). Whole grain ingredients were ground with a double-high roller mill (Model C128829, RMS, Harrisburg, SD). Feed was mixed in a 126-ft³ Hayes & Stolz counterpoise mixer for a standard time of 270 s

(Model TRDB126-0604, Hayes & Stolz, Fort Worth, TX). Treatments were pelleted using a 1-ton 30-horsepower pellet mill (Model PM1112-2, CPM) equipped with a 11/64 × 1 3/8 in. die (L:D = 8.1) and pelleted to a hot pellet temperature of 187°F. To minimize the effect of pellet quality differences, pellets were passed through a sifter to remove fines before transport. Motor load was recorded every 5 s using a data logger to determine energy consumption (kWh). A sample of cool pellets was collected and analyzed for pellet durability index using the Holmen NHP100.⁴

Chemical analysis

Representative samples of treatment diets were analyzed at the University of Missouri Agricultural Experiment Station Chemical Laboratory (Columbia, MO) for dry matter,⁵ crude protein,⁶ crude fat,⁷ crude fiber,⁸ ash,⁹ complete AA profile,¹⁰ melanoidin,¹¹ available lysine,¹² and protein solubility in potassium hydroxide (KOH)¹³ (Tables 2).

Calculations and statistical analysis

Feeders and pens of pigs were weighed, and feed disappearance calculated on d 0 and 18 of the experiment to determine ADG, ADFI, and F/G. Feed additions were recorded for each individual pen.

Pellet mill energy consumption (kWh/ton) was calculated using average logged motor load divided by 100 times the rated 30 horsepower rating for the pellet mill. Then kWh was determined by multiplying an estimated 75% efficiency. Final energy consumption was determined by kWh divided by production rate.

For economic evaluation, total diet cost for mash diets was the sum of ingredient costs from either November 2020 or June 2021. To calculate economics based on market values from November 2020, the following prices for major ingredients were used to calculate diet cost: corn at \$3.05/bu (\$120/ton), DDGS at \$140/ton, soybean meal at \$280/ton, and bakery meal at \$114/ton (November 2020). To calculate economics based on market values from June 2021, the following prices for major ingredients were used to calculate diet cost: corn at \$6.72/bu (\$264/ton), DDGS at \$260/ton, soybean meal at \$373/ton, and bakery meal at \$269/ton (June 2021). The cost of pelleting was determined using energy cost, estimated boiler fuel usage, and manufacturing and maintenance. Energy cost was calculated using measured energy consumption (kWh;

⁴ Schofield, Eileen K, and American Feed Industry Association. Feed Manufacturing Technology V. (pg. 631). American Feed Industry Association, 2005.

⁵ AOAC Official Method 934.01, 2006.

⁶ AOAC Official Method 990.03, 2006.

⁷ AOAC Official Method 920.39 (A).

⁸ AOAC Official Method 978.10, 2006.

⁹ AOAC Official Method 942.05.

¹⁰ AOAC Official Method 982.30 E(a,b,c), chp. 45.3.05, 2006.

¹¹ Del Castillo, M. D., Ames, J. M and Gordon M.H. (2002). Effect of roasting on the antioxidant activity of coffee brews. *Journal of Agricultural and Food Chemistry* 50, 3698-3703. and Shen, Yanting & Chen, Gengjun & Li, Yonghui. (2018). Bread characteristics and antioxidant activities of Maillard reaction products of white pan bread containing various sugars. *LWT- Food Science and Technology*. 95. 10.1016/j.lwt.2018.05.008.

¹² AOAC Official Method 975.44, chp. 45.4.03, 2006.

¹³ Protein solubility in potassium hydroxide (KOH) method *J. Anim. Sci.*, 69:2918-2924, 1991.

Table 2) at \$0.12/kWh (2020) or \$0.13/kWh (2021) to provide \$/kWh. Estimated pellet mill boiler fuel (natural gas) cost was \$1.95/gallon (2020) or \$3.24/gallon (2021) at approximately 0.93 gallons used to provide \$/gallon of boiler fuel. A flat cost of \$2/ton was used to determine manufacturing and maintenance cost. Therefore, the final cost of pelleting per ton was \$5.00, \$4.86, \$4.99, and \$4.94 in 2020, and was \$6.30, \$6.16, \$6.29, and \$6.24 in 2021 for the low crystalline AA, low RS; low crystalline AA, high RS; high crystalline AA, low RS; and high crystalline, high RS diets; respectively. The total feed cost/per pig was calculated by multiplying the total feed consumed by the cost per pound of feed. Revenue per pig was calculated by multiplying total gain per pig and an assumed live price of \$48.00 per cwt (National Daily Hog and Pork Summary, November 3, 2020) or \$88.78 per cwt (National Daily Hog and Pork Summary, June 15, 2021). To calculate income over feed cost (IOFC), total feed cost was subtracted from pig revenue.

Data were analyzed as a completely randomized design using the GLIMMIX procedure of SAS (SAS Institute, Inc., Cary, NC) with pen as the experimental unit and blocked by gender. Fixed effects included feed form, crystalline AA, and RS inclusion; and the interaction between all three, feed form and crystalline AA, feed form and RS, and crystalline AA and RS inclusion. Least square means were calculated for each independent variable and means were separated using the PDIF statement in SAS. Results will be considered significant at $P \leq 0.05$.

Results and Discussion

Chemical analysis of experimental diets indicated the analyzed CP ranged from 17.02 to 24.70%, with the expected range of 18.1 to 24.3% for both mash and pelleted diets. As expected, the high crystalline AA \times low RS inclusion diets contained the lowest CP, and the low crystalline AA \times high RS inclusion diets contained the highest CP in mash and pelleted diets (Table 2). A late reaction product of the Maillard reaction, melanoidin, was analyzed as evidence of the Maillard reaction. Melanoidin values represent the absorbance of the extract measured using spectrophotometer at 420 nm, where higher values indicate the presence of the late Maillard reaction product. The melanoidin absorbance values increased in diets containing high reducing sugars; however, values did not increase in pelleted diets compared to mash. This can potentially be explained by the increased use of by-products in the diet that were previously processed. The analyzed KOH values ranged from 54.9% in the low crystalline \times high RS inclusion mash diet to 80.5% in the high crystalline AA \times low RS inclusion pelleted diet. Analyzed available lysine content ranged from 1.20 to 1.35%, where the lowest was both of the low crystalline AA \times low RS inclusion and the high crystalline AA \times low RS inclusion pelleted diets, and highest was the low crystalline AA \times high RS pelleted diet.

The experiment was designed to pellet the diets at a conditioning temperature of 190.0°F. However, average conditioning temperature was achieved at 187.5°F with average hot pellet temperature of 194.4°F (Table 2). The pellet durability index (PDI) ranged from 62.5 to 82.2%, with lowest PDI being low crystalline AA \times high reducing sugar diet, and highest PDI was the high crystalline \times low reducing sugar diet. Differences in PDI were alleviated by sifting pellets post-pelleting to remove excessive fines before transport.

There was no evidence of a 3-way interaction of feed form × crystalline AA inclusion × RS inclusion. There was no evidence of a 2-way interaction of feed form × crystalline AA, crystalline AA × RS, or feed form × RS. There was no evidence of a main effect of form, crystalline AA, or RS inclusion for d 0 or d 18 BW (Table 4). For the main effect of form, there was no evidence of difference in ADG, but ADFI increased ($P = 0.001$) in pigs fed mash diets compared to pellets. Thus, F/G and caloric efficiency improved ($P = 0.001$) in pigs fed pelleted diets compared to mash diets. For the main effect of crystalline AA, there was no evidence of difference in ADG or F/G; however, pigs fed high crystalline AA had increased ($P = 0.024$) ADFI compared to those fed low crystalline AA diets. For the main effect of RS inclusion, pigs fed low RS diets had increased ($P < 0.041$) ADG and ADFI compared to pigs fed high RS inclusion diets. There was an improvement ($P = 0.019$) in F/G and caloric efficiency for pigs fed high RS inclusion diets compared to those fed low RS diets.

Income over feed cost was calculated based on economic values from November 2020 and June 2021 to demonstrate changes in market values. While there were no differences in IOFC within year, numerical differences between years were nearly double in June 2021 compared to November 2020; however, this did not influence the response to treatment.

In conclusion, this experiment was designed to determine if pelleting different swine diets can differentially influence growth performance. Diets were formulated with low or high crystalline AA and low or high reducing sugars provided by co-product ingredients, DDGS and bakery meal, to increase the chances of binding lysine via the Maillard reaction. Diets were pelleted to a conditioning temperature of 187.5°F and average hot pellet temperature of 194.4°F. There was no evidence of interactions between diet types, indicating that increasing amounts of crystalline AA and RS did not increase the Maillard reaction enough to reduce growth performance when pelleting diets by using the reported conditions. Diets formulated with 20% DDGS and 15% bakery (high RS) resulted in decreased growth performance and caloric efficiency compared with the corn-soybean meal-based diets. Pigs fed pelleted diets had improved feed intake and F/G.

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Table 1. Diet composition (as-fed basis)^{1,2}

Ingredient, %	Crystalline AA:	Low	Low	High	High
	Reducing sugars:	Low	High	Low	High
Corn		61.45	30.82	70.81	42.41
Soybean meal		33.55	27.92	24.07	16.34
DDGS		---	20.00	---	20.00
Bakery meal ³		---	15.00	---	15.00
Poultry fat		1.55	3.08	0.85	2.25
Calcium carbonate		0.68	0.83	0.73	0.85
Monocalcium P, 21% P		1.50	1.10	1.60	1.23
Sodium chloride		0.60	0.60	0.60	0.60
L-Lys-HCl		0.13	0.19	0.43	0.55
DL-Met		0.10	0.05	0.14	0.10
L-Thr		0.05	0.02	0.19	0.17
L-Trp		---	---	0.05	0.07
L-Val		---	---	0.11	0.03
L-Ile		---	---	0.04	0.01
Trace mineral premix ⁴		0.15	0.15	0.15	0.15
Vitamin premix ⁴		0.25	0.25	0.25	0.25
Total		100	100	100	100
Calculated analysis					
Standardized ileal digestible AA, %					
Lys		1.10	1.10	1.10	1.10
Ile:Lys		71	77	60	60
Leu:Lys		144	168	123	143
Met:Lys		35	35	35	35
Met and Cys:Lys		61	63	58	59
Thr:Lys		65	65	65	65
Trp:Lys		21.0	21.0	21.0	21.0
Val:Lys		77	87	72	72
NE, ⁵ kcal/lb		1,159	1,159	1,159	1,159

¹ Dietary treatments were arranged in a 2 × 2 × 2 factorial with main effects of crystalline AA inclusion (low vs. high), reducing sugar inclusion (low vs. high), and diet form (mash vs. pellet).

² Experimental diet was formulated for 25 to 50-lb BW range.

³ Quincy Farm Products, Quincy, IL.

⁴ Provided per lb of diet: 110 ppm Zn, 110 ppm Fe, 33 ppm Mn, 17 ppm Cu, 0.30 ppm I, 0.30 ppm Se, 1,875 IU vitamin A, 750 IU vitamin D, 20 IU vitamin E, 1.5 mg vitamin K, 22.5 mg niacin, 12.5 mg pantothenic acid, 3.75 mg riboflavin, and 0.02 mg vitamin B₁₂.

⁵ To ensure the ability to detect a difference in AA utilization, these diets were formulated to 85% of the recommended SID Lys requirement of pigs (NRC. 2012. Nutrient Requirements of Swine, 11th ed. Natl. Acad. Press, Washington DC).

⁶ AA = amino acids. ME = metabolizable energy. NE = net energy.

Table 2. Chemical analysis of experimental diets (as-fed basis)^{1,2}

Item, %	Mash				Pellets				
	Crystalline AA:	Low	Low	High	High	Low	Low	High	High
	Reducing sugars:	Low	High	Low	High	Low	High	Low	High
DM		87.70	87.76	87.44	87.86	86.72	87.20	86.85	87.07
CP		20.53	24.70	17.02	20.37	22.05	23.74	19.33	20.26
Fat		3.34	6.17	3.09	5.00	3.92	6.12	3.48	5.72
Fiber		2.70	4.09	2.14	3.43	2.25	3.83	2.04	3.77
Ash		5.6	5.45	4.05	5.47	5.39	5.61	5.06	5.10
Melanoidin, abs ³		0.095	0.145	0.087	0.120	0.089	0.125	0.082	0.128
KOH protein solubility		65.71	54.90	76.56	28.03	76.87	72.03	80.50	48.82
Available lysine		1.21	1.34	1.31	1.26	1.20	1.35	1.20	1.28
Total AA		20.03	22.91	19.59	19.17	19.63	23.45	17.18	19.53
Indispensable AA									
Arg		1.32	1.46	1.27	1.09	1.32	1.48	1.08	1.12
His		0.53	0.63	0.51	0.51	0.52	0.64	0.44	0.51
Ile		0.92	1.07	0.88	0.84	0.90	1.06	0.75	0.85
Leu		1.71	2.15	1.67	1.85	1.68	2.18	1.47	1.87
Lys		1.24	1.39	1.33	1.30	1.23	1.39	1.22	1.31
Met		0.40	0.40	0.45	0.39	0.35	0.40	0.35	0.40
Phe		1.02	1.22	0.97	0.97	1.00	1.23	0.84	0.99
Thr		0.79	0.91	0.86	0.89	0.78	0.94	0.79	0.88
Trp		0.24	0.26	0.23	0.25	0.26	0.28	0.25	0.26
Val		0.99	1.20	1.01	1.00	0.97	1.20	0.87	0.98
Feed processing ^{4,5}									
Production rate, ton/h						1.0	1.0	0.95	1.1
Conditioning temperature, °F						187.5	187.5	187.2	187.7
Hot pellet temperature, °F						194.3	192.8	197.5	193.0
Pellet durability index (PDI), % ⁶						71.9	62.5	82.2	74.4
Energy consumption, kWh/ton						9.9	8.8	9.8	9.4

¹ Dietary treatments were arranged in a 2 × 2 × 2 factorial with main effects of crystalline AA inclusion (low vs. high), reducing sugar inclusion (low vs. high), and diet form (mash vs. pellet).

² Samples were analyzed at the University of Missouri Agricultural Experiment Station Chemical Laboratories in Columbia, MO.

³ Melanoidin values represent the absorbance of the extract measured using spectrophotometer at 420 nm.

⁴ Treatments were pelleted using a 1-ton 30-horsepower pellet mill (Model PM1112-2, CPM) equipped with a 11/64 × 1 3/8 in. (L:D = 8.1).

⁵ Pellets were sifted to remove fines to ensure no effect of pellet quality on pig performance.

⁶ A 100-gram pellet sample was agitated with forced air for 60 seconds in the Holmen NHP100 to determine PDI.

Table 3. Main effects of the pelleting process on diet formulations with varying levels of crystalline AA and reducing sugars on nursery pig growth^{1,2}

Item	Form		AA		RS		SEM	P-value ³		
	Mash	Pellet	Low	High	Low	High		Form	AA	RS
BW, lb										
d 0	24.9	25.1	25.1	24.9	25.0	24.9	0.40	0.720	0.719	0.782
d 18	48.3	47.8	48.1	48.1	48.6	47.5	0.58	0.586	0.986	0.191
d 0 to 18										
ADG, lb	1.26	1.26	1.25	1.27	1.29	1.23	0.021	0.878	0.521	0.041
ADFI, lb	2.07	1.98	1.98	2.07	2.11	1.94	0.027	0.001	0.024	0.001
F/G	1.68	1.54	1.59	1.63	1.64	1.58	0.017	0.001	0.073	0.019
Caloric efficiency, NE kcal/lb of gain ⁴	1,949	1,786	1,843	1,893	1,900	1,834	19.5	0.001	0.073	0.019
Economics, \$ ⁵										
2020 IOFC	7.25	7.45	7.32	7.38	7.39	7.31	0.146	0.343	0.754	0.706
2021 IOFC	14.48	14.80	14.74	14.54	14.91	14.37	0.280	0.426	0.632	0.181

¹ A total of 360 pigs (initially 25.0 lb; Line 200 × 400; DNA, Columbus, NE) were used in an 18-d growth trial with 5-pigs/pen with 3 barrows with 2 gilts or 3 gilts with 2 barrows in a completely randomized design.

² Dietary treatments were arranged in a 2 × 2 × 2 factorial with main effects of crystalline AA inclusion (low vs. high), reducing sugar inclusion (low vs. high), and diet form (mash vs. pellet).

³ Probability, *P* < for the main effects of feed form, crystalline amino acid inclusion, or reducing sugar inclusion.

⁴ Caloric efficiency = (ADFI × formulated NE, kcal/lb (1159 kcal/lb))/ADG.

⁵ Income over feed cost (IOFC) = total revenue/pig – feed cost/pig. Based on economic values from November 2020 and June 2021 to demonstrate changes in market values.