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Evaluation of Net Energy, Standardized Ileal Digestible Lysine, and Soybean Meal Content Interactions in Pigs from 25 to 50 lb using a Central Composite Design

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Summary

A total of 4,681 pigs (PIC 337 × 1050; initially 28.7 ± 2.00 lb) were used in a 21-d trial to investigate the interaction of net energy (NE), standardized ileal digestible lysine (SID Lys), and soybean meal (SBM) content on growth performance of nursey pigs. Pigs were housed in mixed-gender pens with 35 pigs per pen and assigned in a randomized complete block design to 15 dietary treatments using a circumscribed central composite design (CCD). Factorial and axial points had seven repetitions, and the central points had a total of 24 repetitions. Eight diets were formulated to various levels of NE, SID Lys, and SBM and blended to create the 15 dietary treatments. The NE ranged from 1,059 to 1,253 kcal/lb, SID Lys from 1.08 to 1.52%, and dietary SBM content from 25.5 to 35.9%. Diets were corn-soybean meal based and soy hulls and soybean oil were added to reduce or increase NE content of the diet. Feed-grade amino acids and SBM were used to adjust SBM and SID Lys content and to maintain SID Thr, Trp, Met, Val, and Ile ratios relative to SID Lys. Increasing NE decreased (linear, $P < 0.10$) ADG and ADFI while F/G became poorer (quadratic, $P < 0.10$) due to a reduction in SID Lys:calorie ratio. There was a significant interaction ($P < 0.10$) observed between SID Lys and SBM for F/G, where SID Lys improved F/G, but maximized F/G when SID Lys and SBM were at 1.52% and 35.9%, respectively. When increasing SID Lys, ADG and F/G improved (quadratic, $P < 0.10$) up to approximately 1.43% with minor benefit thereafter. Increasing SBM content improved (linear, $P < 0.10$) ADG and F/G when included up to 33.8% without additional improvements thereafter. Feed cost per pig increased (linear, $P < 0.10$) as NE and SID Lys concentrations increased. Feed cost per lb of gain increased (quadratic, $P < 0.10$) as NE, SID Lys, and SBM content increased; however, there was an interaction ($P < 0.10$) between SID Lys and SBM where increasing both at the highest inclusion reduced feed cost per lb of gain. Revenue increased (linear, $P < 0.10$) as the SID Lys level and SBM content increased. Income over feed cost (IOFC) increased when increasing SID

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Lys (quadratic, $P < 0.10$) and SBM (linear, $P < 0.10$) levels were fed, and decreased (linear, $P < 0.10$) with increasing NE. In conclusion, using a CCD, increasing SID Lys resulted in a quadratic improvement in ADG and F/G with a greater response observed when SBM also increased in the diet.

Introduction

Energy represents a significant proportion of swine diet costs. Pigs between 25 and 50 lb can change performance according to the energy level fed when SID Lys is adequate. Adding fibrous ingredients will decrease the energy content of the diet and negatively affect feed efficiency; however, when fat is added to increase the energy concentration of the diet at this stage, an improvement in feed efficiency is observed. Lysine (Lys) is the first limiting amino acid for pigs' growth. Increasing levels of SID Lys in pigs over 25 lb demonstrated a linear improvement in growth performance when energy was kept constant up to a point where caloric intake becomes deficient.[4] Soybean meal is a widely used vegetable protein source in swine diets due to its concentration of essential and nonessential amino acids. It is typically included in low concentrations in early nursery diets to reduce the incidence of scours in newly weaned pigs; however, when pigs are above 25 lb of BW, SBM could be added at greater than 25%. Cemin et al. (2020)[5] observed that feed efficiency improved when 37.5% soybean meal was fed to pigs between 25 and 55 lb compared to pigs fed 27.5% soybean meal.

The central composite design (CCD) is the most used response surface model (RSM) design. This design comprises first- and second-order models and provides a geometrical representation of a response variable plotted as a function of the independent variable. A three-level factorial design generates a large treatment combination; alternatively, the CCD was developed to reduce the number of treatments required while providing similar information.

The RSM is widely used in the poultry nutrition research field due to accessibility to larger amounts of experimental units; however, it is not commonly used in the swine research field. Therefore, the objective of this study was to evaluate the interaction between five different levels of net energy, SID Lys, and soybean meal in the diet of nursery pigs from 25 to 50 lb and its effect on growth performance using a central composite design.

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 a commercial research-nursery site in southwest Minnesota. The barns were mechanically ventilated with totally slatted floors. Each pen was equipped with a five-hole stainless steel dry self-feeder and a bowl waterer for ad libitum access to feed and water. Daily feed additions to each pen were accomplished using a robotic feeding system (DryExact Pro; Big

[4] Xue, P., N. Lu, C. M. Pilcher, B. Frederick, M. L. McGhee, Q. Li, C. M. Vier, W. R. Cast, U. A. Orlando. 2022. Effects of increasing dietary standardized ileal digestible lysine levels on growth performance of 13 to 23 kg pigs sired by PIC 800 boars. J. Anim. Sci. 100:67–68. doi: 10.1093/jas/skac064.107

[5] Cemin, H. S., M. D. Tokach, S. S. Dritz, J. C. Woodworth, J. M. DeRouchey, and R. D. Goodband. 2020. Effects of soybean meal level on growth performance of 11 to 25 kg nursery pigs. Transl. Anim. Sci. 4:694–707. doi: 10.1093/tas/txaa053.

Dutchman North America, Holland, MI) able to record feed deliveries for individual pens.

Animals and diets

A total of 4,681 (PIC 337 × 1050; initially 28.7 ± 2.00 lb) were used in a 21-d trial to investigate the interaction of NE, SID Lys, and SBM content on growth performance of nursey pigs. Pigs were housed in mixed-sex pens with 35 pigs per pen and assigned in a randomized complete block design to 15 dietary treatments using a circumscribed central composite design (CCD) of response surface methodology (RSM). The treatment structure of CCD consists of 8 factorial points (treatments 1 to 8), 6 axial points (treatments 9 to 14), and a central point (treatment 15). By design, the central point is repeated at least three times more than the factorial and axial point treatments. Eight diets were formulated to various levels of NE, SID Lys, and SBM and blended to create the 15 dietary treatments. The NE ranged from 1,059 to 1,253 kcal/lb, SID Lys from 1.08 to 1.52%, and SBM from 25.5 to 35.9%. Diets were corn-soybean meal based and soy hulls and soybean oil were added to reduce or increase NE content of the diet. Feed-grade amino acids and SBM were used to adjust SBM and SID Lys content and to maintain SID Thr, Trp, Met, Val, and Ile ratios relative to SID Lys. All treatment diets were manufactured at the Hubbard Feeds Feed Mill in Mankato, MN, and were formulated to meet or exceed NRC[6] requirement estimates for 25 to 55 lb pigs (Table 1).

Pens of pigs and feed disappearance were weighed at the beginning and at the end of the study to determine ADG, ADFI, and F/G. Feed cost per pig was calculated as diet feed cost times feed intake per phase divided by pigs placed. Feed cost per lb of gain was calculated dividing total feed cost per pig by total gain per pig. Revenue was calculated by multiplying total gain by a standard carcass yield of 75% and carcass price. Income over feed cost (IOFC) was calculated by subtracting feed cost per pig from revenue.

Statistical analysis

Data were analyzed as a central composite design of response surface methodology using the RSM function from the RSM package in R (version 4.1.1 (2021-08-10), R Foundation for Statistical Computing, Vienna, Austria) with pen considered the experimental unit, treatment as fixed effect, and initial weight as block factor. Data were visualized using the contour and perspective plots of the RSM package in R. The response surface methodology showed an apparent relationship between some of the variables analyzed in the confidence interval between 95% to 90%; therefore, all results were considered significant at $P \le 0.10$.

Results and Discussion

Chemical analysis of complete diets was consistent with the calculated values used in diet formulation (Table 2).

During the 21-d experimental period, increasing NE decreased (linear, $P < 0.10$) ADG and ADFI while F/G became poorer (quadratic, $P < 0.10$) due to a reduction in SID Lys:calorie ratio (Table 3; Figures 1 and 2). There was a significant interaction observed (quadratic, $P < 0.10$) between SID Lys and SBM for F/G, where SID Lys and SBM

[6] National Research Council. 2012. Nutrient Requirements of Swine: Eleventh Revised Edition. Washington, DC: The National Academies Press. https://doi.org/10.17226/13298

improved F/G when fed at 1.52% and 35.9%, respectively. This response was observed due to the increase in some essential and all non-essential amino acids provided by SBM. When increasing SID Lys, ADG, and F/G improved (quadratic, $P < 0.10$) up to approximately 1.43% with little benefit thereafter. Increasing SBM content improved (linear, $P < 0.10$) ADG and F/G when included up to 33.8% without additional improvements thereafter (Table 3). The resulting models using significant terms to predict ADG, ADFI, and F/G were reported in Table 4.

For economics, feed cost per pig increased (linear, $P < 0.10$) as NE and SID Lys concentrations increased. Feed cost per lb of gain increased (quadratic, $P < 0.10$) as NE, SID Lys, and SBM content increased; however, an interaction between SID Lys and SBM where increasing SID Lys reduced ($P < 0.10$) feed cost per lb of gain at the highest inclusion of each. Revenue increased (linear, $P < 0.10$) as the SID Lys level and SBM content increased, with maximum revenue at the maximum inclusion level for both. Income over feed cost increased when increasing SID Lys (quadratic, $P < 0.10$) and SBM (linear, $P < 0.10$) levels were fed, and decreased (linear, $P < 0.10$) with increasing NE (Table 5).

In conclusion, modeling NE content, SID Lys levels, and SBM content in late nursery diets using a CCD resulted in a quadratic improvement in ADG and F/G when increasing SID Lys, with a greater response observed when SBM also increased in the diet. However, no other interactions between the factors evaluated were observed.

Acknowledgments

The authors would like to thank Hubbard Feeds, Mankato, MN for providing partial financial support for these studies. The authors would like to thank Schwartz Farms, Sleepy Eye, MN, for providing technical assistance for these studies.

Table 1. Diet composition (as-fed basis)[1]

Item	Diet 1	Diet 2	Diet 3	Diet 4	Diet 5	Diet 6	Diet 7	Diet 8
Ingredients, %								
Corn	56.48	49.15	58.85	51.24	65.18	55.58	66.79	56.87
Soybean meal, 46.5% CP[2]	25.50	35.57	25.50	35.57	25.50	25.50	25.50	35.57
Soybean hulls	13.30	11.58	12.72	10.94	---	---	---	---
Soybean oil	---	---	---	---	4.29	4.87	4.48	5.08
Calcium carbonate	0.46	0.47	0.48	0.49	0.65	0.66	0.66	0.64
Monocalcium P, 21% P	0.94	0.86	0.94	0.85	0.95	0.95	0.95	0.86
Salt	0.65	0.65	0.65	0.65	0.65	0.65	0.65	0.65
L-Lys HCl	0.87	0.56	0.31	---	0.92	0.36	0.36	0.04
DL-Met	0.42	0.32	0.14	0.05	0.42	0.15	0.15	0.06
L-Trp	0.13	0.07	0.03	---	0.13	0.04	0.04	---
L-Thr	0.44	0.30	0.15	0.01	0.46	0.17	0.17	0.03
L-Val	0.33	0.16	0.02	---	0.35	0.03	0.03	---
L-Ile	0.28	0.11	0.01	---	0.30	0.02	0.02	---
Vitamin and mineral premix[3]	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
Phytase[4]	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
TOTAL	100	100	100	100	100	100	100	100
Calculated analysis								
Standardized ileal digestible (SID) amino acids, %								
Lys	1.52	1.52	1.08	1.08	1.52	1.52	1.08	1.08
Ile:Lys	60	60	60	74	60	60	60	73
Leu:Lys	87	103	124	146	87	102	124	144
Met:Lys	44	41	37	32	44	41	38	33
Met and Cys:Lys	60	60	60	60	60	60	60	60
Thr:Lys	65	65	65	65	65	65	65	65
Trp:Lys	21	21	21	23	21	21	21	23
Val:Lys	70	70	70	84	70	70	70	83
His:Lys	27	33	39	47	27	32	38	46
Total Lys, %	1.68	1.70	1.24	1.26	1.65	1.67	1.21	1.23
NE, kcal/lb	1,059	1,059	1,059	1,059	1,253	1,253	1,253	1,253
SID Lys:NE, g/Mcal	6.51	6.51	4.63	4.63	5.50	5.50	3.91	3.91
CP, %	19.4	22.7	18.2	21.6	18.5	21.9	17.3	20.8
Ca, %	0.55	0.57	0.55	0.58	0.55	0.58	0.56	0.58
Available P, %	0.46	0.46	0.46	0.46	0.46	0.46	0.46	0.46

[1] Fed from approximately 28 to 55 lb.
[2] Crude protein.
[3] Vitamin and trace mineral premix with added Alltech Sel-Plex 600 (Alltech, Nicholasville, KY) at same amount in all the diets.
[4] Quantum Blue 5G (AB Vista, Marlborough, UK) was included at 680 FTU/kg providing an estimated release of 0.14% STTD P.

Table 2. Chemical analysis of experimental diets (as fed-basis)[1]

Diet	DM	CP	Fat	ADF	Ash	Total Lys
		------	------	%	------	------
1	86.3	17.8	3.16	6.7	4.5	1.36
2	85.9	19.7	5.57	3.2	4.2	1.28
3	86.2	19.0	3.41	7.3	4.5	1.53
4	85.5	18.9	5.52	2.8	4.2	1.57
5	85.7	19.6	3.14	6.7	4.6	1.29
6	86.4	20.8	6.13	3.4	4.5	1.37
7	86.5	20.0	3.40	7.2	4.4	1.53
8	86.5	20.7	6.06	3.8	4.6	1.51
9	86.8	18.6	2.36	7.4	4.5	1.43
10	86.4	18.1	7.04	2.4	4.1	1.38
11	86.8	20.6	5.21	4.7	4.4	1.24
12	86.5	19.9	5.35	4.9	4.2	1.64
13	86.6	17.8	4.96	5.9	4.2	1.38
14	86.3	19.9	4.62	5.7	4.4	1.35
15	86.6	19.8	4.63	4.6	4.3	1.40

[1] Values represent means from 15 composite samples. For each treatment, samples were collected from multiple feeders, blended, subsampled, ground, and analyzed (Midwest Laboratories, Inc., Omaha, NE; Ajinomoto Health & Nutrition North America, Inc., Eddyville, IA).

Table 3. Performance of nursery pigs fed five levels of net energy (NE), SID lysine (Lys), and soybean meal (SBM) content using central composite design model[1]

	Nutrient level[2]			Growth performance response			
Diet No.	NE[3]	Lys[4]	SBM[5]	Final BW, lb	ADG, lb	ADFI, lb	F/G
1	1,098	1.17	27.6	52.1	1.19	1.83	1.53
2	1,214	1.17	27.6	50.8	1.14	1.74	1.53
3	1,098	1.43	27.6	53.8	1.29	1.81	1.40
4	1,214	1.43	27.6	53.8	1.28	1.78	1.39
5	1,098	1.17	33.8	52.7	1.21	1.81	1.50
6	1,214	1.17	33.8	52.1	1.18	1.73	1.47
7	1,098	1.43	33.8	54.7	1.31	1.83	1.40
8	1,214	1.43	33.8	55.3	1.33	1.82	1.37
9	1,059	1.30	30.7	54.4	1.30	1.90	1.47
10	1,253	1.30	30.7	53.1	1.23	1.78	1.45
11	1,156	1.08	30.7	51.8	1.16	1.78	1.54
12	1,156	1.52	30.7	54.4	1.33	1.82	1.37
13	1,156	1.30	25.5	52.8	1.24	1.81	1.46
14	1,156	1.30	35.9	54.4	1.29	1.83	1.43
15	1,156	1.30	30.7	53.7	1.28	1.82	1.43

continued

Table 3. Performance of nursery pigs fed five levels of net energy (NE), SID lysine (Lys), and soybean meal (SBM) content using central composite design model[1]

	Nutrient level[2]			Growth performance response			
Diet No.	NE[3]	Lys[4]	SBM[5]	Final BW, lb	ADG, lb	ADFI, lb	F/G
SEM				1.67	0.027	0.044	0.014
R^2				0.059	0.385	0.073	0.670
Adjusted R^2				0.014	0.355	0.029	0.655
P -values[6]							
Linear							
NE				0.546	0.052	0.011	0.047
Lys				0.017	< 0.001	0.210	< 0.001
SBM				0.241	0.039	0.639	< 0.001
Quadratic							
NE × NE				NS	NS	NS	0.005
Lys × Lys				NS	0.044	NS	0.020
SBM × SBM				NS	NS	NS	NS
Interactions							
NE × Lys				NS	NS	NS	NS
NE × SBM				NS	NS	NS	NS
Lys × SBM				NS	NS	NS	0.082
Lack of fit[7]				0.999	0.798	0.923	0.822
Pure error[8]				4.41	0.07	0.12	0.04

[1] A total of 4,681 pigs (PIC 337 × 1050, initially 28.7 ± 2.00 lb) were used in a 21-d experiment using central composite design of response surface methodology. Approximately 35 pigs per pen were used and assigned to 1 of 15 treatments in a completely randomized block design.
[2] Each of the 3 factors NE, SID Lys, and SBM content were tested in five different levels (-α, -1, 0, +1, and +α) calculated based on the central values (0) selected for this period.
[3] Net energy levels (kcal/lb): -α=1,059; -1=1,098; 0=1,156; +1=1,214; and +α=1,253.
[4] SID Lys levels (%): -α=1.08; -1=1.17; 0=1.30; +1=1.43; and +α=1.52.
[5] Soybean meal (%): -α=25.5; -1=27.6; 0=30.7; +1=33.8; and +α=35.9.
[6] Results were considered significant at a *P* value ≤ 0.10. NS = Non-significant.
[7] Indicates how well the model fits the data. The higher the lack of fit p-value indicates a better fitting model for the responses analyzed.
[8] Standard deviation of replicates at the center points. Calculated as √MSE.

Table 4. Regression equations for prediction of nursery pig ADG, ADFI, and F/G in response to net energy (NE), SID lysine (Lys), and soybean meal (SBM) content

Response variable	Regression equation	*P*	Adjusted R^2
Final BW, lb	=53.40502 + (-0.26205 × NE) + (1.04977 × Lys) + (0.51069 × SBM%)	0.059	0.034
ADG, lb	=1.2773418 + (-0.0139748 × NE) + (0.0574957 × Lys) + (0.0148654 × SBM%) + (-0.0144889 × Lys^2)	< 0.001	0.355
ADFI, lb	=1.8100744 + (-0.0301734 × NE) + (0.0146715 × Lys) + (0.0054730 × SBM%)	0.040	0.040
F/G	=1.42648649 + (-0.00732617 × NE) + (-0.05553294 × Lys) + (-0.01322049 × SBM%) + (0.01032657 × NE^2) + (0.00861054 × Lys^2) + (0.00835981 × Lys × SBM)	< 0.001	0.662

Table 5. Economic results of nursery pigs fed five levels of net energy (NE), SID lysine (Lys), and soybean meal (SBM) content using central composite design model[1]

	Dietary treatment[2]			Economics, $/pig placed[6]			
Diet No.	NE[3]	Lys[4]	SBM[5]	Feed cost[7]	Feed cost, $/lb[8]	Revenue[9]	IOFC[10]
1	1,098	1.17	27.6	5.53	0.241	15.48	9.94
2	1,214	1.17	27.6	5.90	0.270	14.76	8.86
3	1,098	1.43	27.6	6.57	0.264	16.77	10.20
4	1,214	1.43	27.6	7.03	0.287	16.55	9.52
5	1,098	1.17	33.8	5.85	0.246	16.05	10.20
6	1,214	1.17	33.8	6.25	0.270	15.60	9.35
7	1,098	1.43	33.8	6.40	0.249	17.36	10.96
8	1,214	1.43	33.8	7.11	0.271	17.64	10.53
9	1,059	1.30	30.7	6.04	0.236	17.22	11.17
10	1,253	1.30	30.7	6.83	0.281	16.40	9.57
11	1,156	1.08	30.7	5.73	0.252	15.37	9.63
12	1,156	1.52	30.7	7.09	0.275	17.34	10.25
13	1,156	1.30	25.5	6.39	0.268	16.09	9.70
14	1,156	1.30	35.9	6.51	0.258	17.03	10.52
15	1,156	1.30	30.7	6.33	0.254	16.79	10.46

continued

Table 5. Economic results of nursery pigs fed five levels of net energy (NE), SID lysine (Lys), and soybean meal (SBM) content using central composite design model[1]

	Dietary treatment[2]			Economics, $/pig placed[6]			
Diet No.	**NE[3]**	**Lys[4]**	**SBM[5]**	**Feed cost[7]**	**Feed cost, $/lb[8]**	**Revenue[9]**	**IOFC[10]**
SEM				0.319	0.003	0.763	0.453
R^2				0.222	0.821	0.127	0.191
Adjusted R^2				0.160	0.807	0.064	0.132
P -values[11]				< 0.001	< 0.001	0.045	0.002
Linear							
NE				0.006	< 0.001	NS	< 0.001
Lys				< 0.001	< 0.001	< 0.001	0.020
SBM				NS	< 0.001	0.095	0.020
Quadratic							
NE × NE				NS	0.011	NS	NS
Lys × Lys				NS	< 0.001	NS	0.070
SBM × SBM				NS	< 0.001	NS	NS
Interactions							
NE × Lys				NS	NS	NS	NS
NE × SBM				NS	NS	NS	NS
Lys × SBM				NS	< 0.001	NS	NS
Lack of fit[12]				0.991	0.820	0.973	0.239
Pure error[13]				0.844	0.007	2.019	1.197

[1] A total of 4,681 pigs (PIC 337 × 1050, initially 28.7 ± 2.00 lb) were used in a 21-d experiment using central composite design of response surface methodology. Approximately 35 pigs per pen were used and assigned to 1 of 15 treatments in a completely randomized block design.

[2] Each of the 3 factors NE, SID Lys, and SBM content were tested in five different levels (-α, -1, 0, +1, and +α) calculated based on the central values (0) selected for this period.

[3] Net energy levels (kcal/lb): -α=1,059; -1=1,098; 0=1,156; +1=1,214; and +α=1,253.

[4] SID Lys levels (%): -α=1.08; -1=1.17; 0=1.30; +1=1.43; and +α=1.52.

[5] Soybean meal (%): -α=25.5; -1=27.6; 0=30.7; +1=33.8; and +α=35.9.

[6] Market prices: Carcass price = $0.90/lb; corn = $5.04/bushel ($180/ton); soybean meal = $460/ton; soybean hulls = $200/ton; soybean oil = $1,500/ton; limestone = $0.04/lb; monocalcium phosphate 21% P = $0.50/lb; salt = $0.08/lb; L-Lys HCl = $1.10/lb; DL-Met = $1.45/lb; L-Thr = $1.02/lb; L-Trp = $5.25; L-Val = $2.50/lb; L-Ile = $8.00/lb.

[7] Feed cost = total feed intake per pig × diet cost per lb.

[8] Feed cost/lb gain = total feed cost per pig divided by total gain per pig.

[9] Revenue = (total gain × carcass yield) × carcass price.

[10] Income over feed cost = revenue – feed cost.

[11] Results were considered significant at a *P* value ≤ 0.10.

[12] Indicates how well the model fits the data. The higher the lack of fit p-value indicates a better fitting model for the responses analyzed.

[13] Standard deviation of replicates at the center points. Calculated as √MSE.

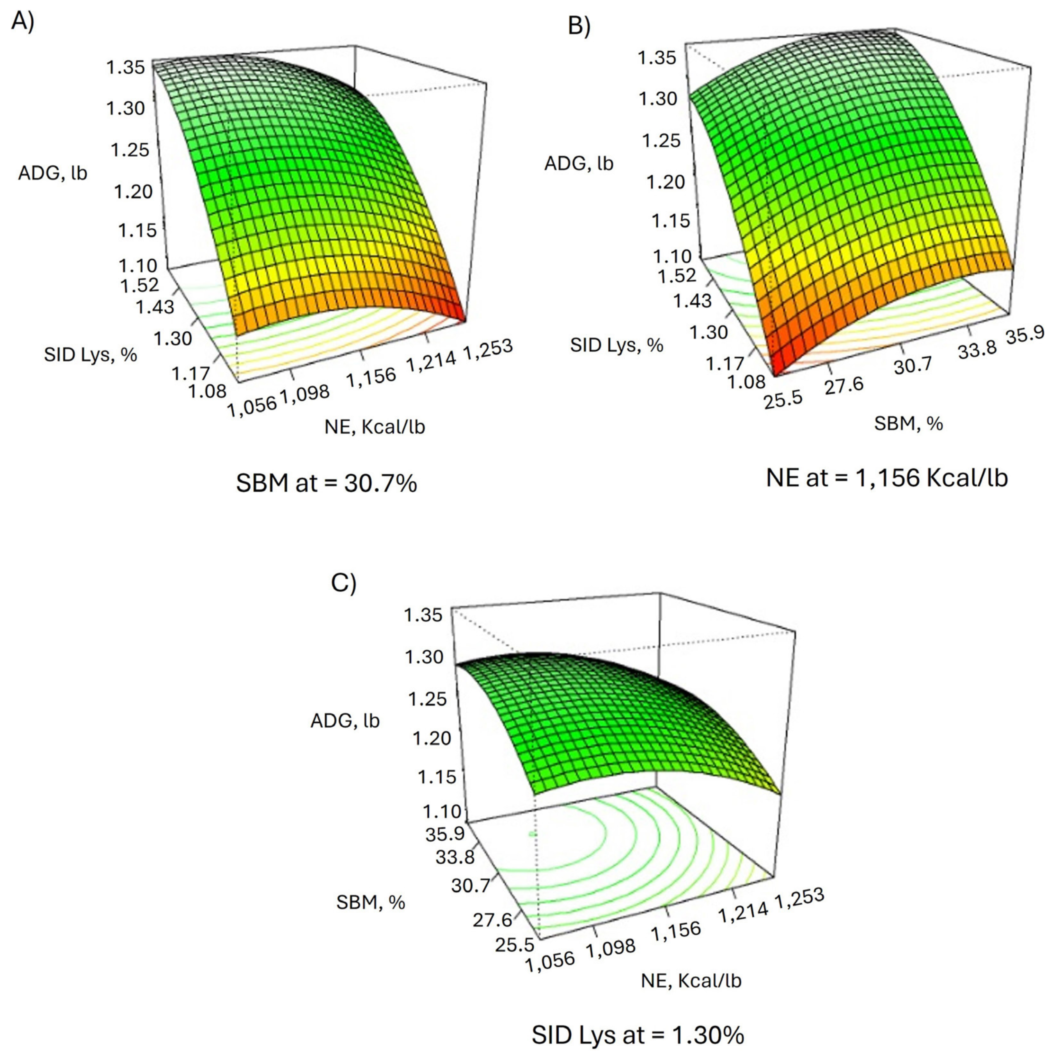

Figure 1. Interaction of NE and SID Lys with SBM at 30.7% (A), SBM and SID Lys with NE at 1,156 Kcal/lb (B), and NE and SBM with SID Lys at 1.30% (C) on ADG in pigs from 25 to 50 lb.

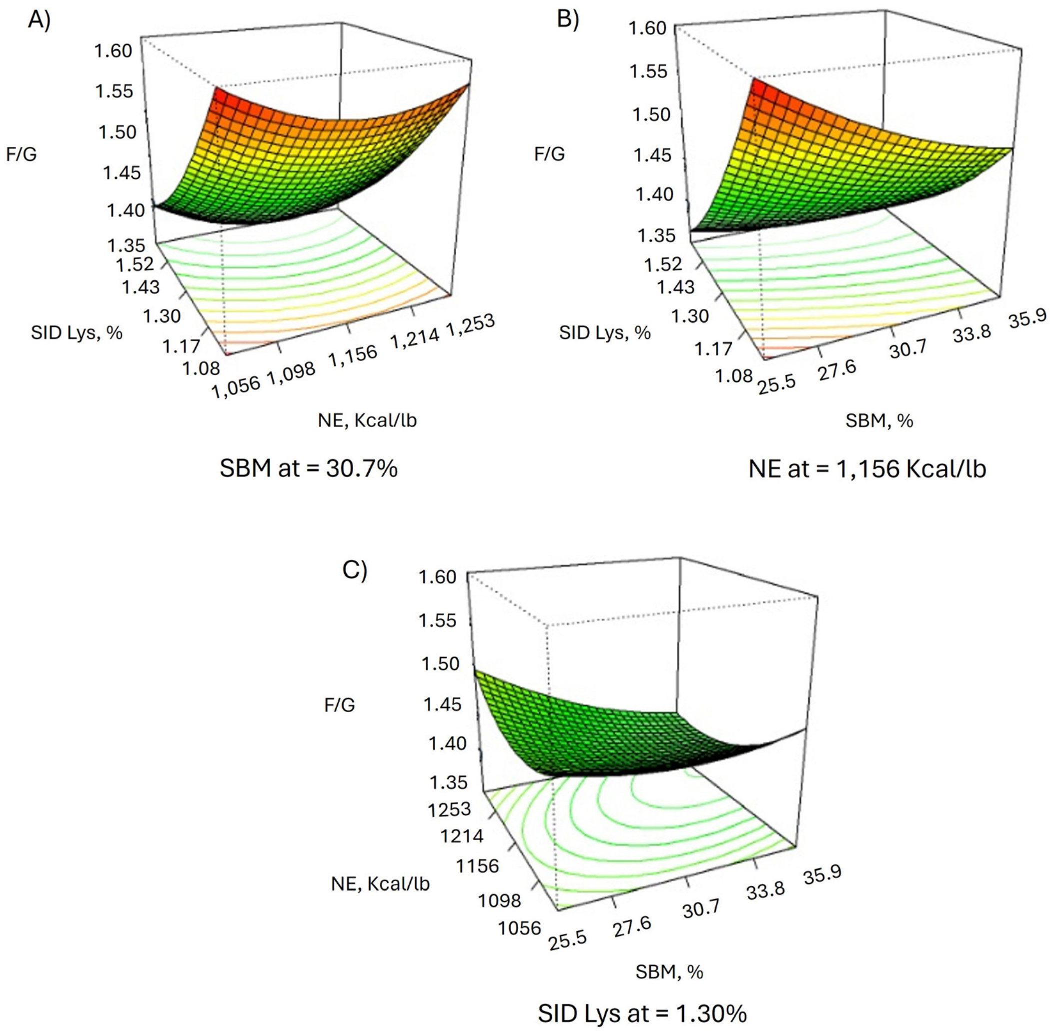

Figure 2. Interaction of NE and SID Lys with SBM at 30.7% (A), SBM and SID Lys with NE at 1,156 Kcal/lb (B), and NE and SBM with SID Lys at 1.30% (C) on F/G in pigs from 25 to 50 lb.