Quantifying the value of soybean meal in poultry and swine diets

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Primary Audience: Nutritionists, Researchers, Feed Mill Managers, Feed Manufacturers, Industry Personnel, Production Managers

SUMMARY

The soybean supply chain incentivizes upstream participants (farmers) to maximize crop yield (volume), while downstream participants (nutritionists) make decisions based on crop quality characteristics such as amino acid concentration and energy content. These parameters tend to decline as soybean yield increases, consequently, the value proposition for soybean meal (**SBM**) is not fully recognized in the market. Furthermore, on a global basis, SBM sales are based primarily on minimum crude protein (**CP**) content, which does not fully account for the true value of SBM to the end user. In this study, a systematic framework was developed to quantify SBM value in both poultry and swine diets using the nutritional attributes (digestible amino acids and energy) that are the primary determinants of end-user value. To demonstrate the application value of soybean meal and its nutrient composition, SBM samples were analyzed for moisture, CP, and 11 amino acids. These values were then regressed to estimate 5 SBM CP concentrations (44.0, 45.0, 46.0, 47.0, and 48.0% CP) and the corresponding energy, and then used in a formulation exercise. Least cost diet formulation software calculated the cost of diets for poultry and swine for the 5 SBM CP concentrations. For each scenario, the only change allowed during the least cost optimization was the individual CP concentration of SBM. Relative SBM value was calculated based on SBM use (kg), total diet costs ($/MT) and current market ingredient prices ($/MT) for the diet formulas. The results showed that for each 1% increase in SBM CP concentration from 44.0 to 48.0% (or each 0.065% increase in total lysine from 2.75 to 3.01%) the SBM value increased on average $10.27 for swine and $12.62 for poultry per metric ton of feed. This analysis ties incremental changes in product nutritional composition (amino acid content and energy) to an increase in value of SBM ($/MT) for swine and poultry diets, and quantifies value from the end-user (nutritionist) perspective, allowing alignment across the value chain.

Key Words: soybean meal value, relative value of soybean meal, poultry diets, swine diets, monogastrics

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DESCRIPTION OF PROBLEM

Soybeans (Glycine max) are a major oilseed commodity, with global production estimated to be 352 million metric tons (**MMT**) in the 2021−2022 marketing year (USDA WASDE, 2022). Approximately 87% of that will be processed into 247.4 million metric tons of soybean meal (**SBM**) and 59.4 million metric tons of soybean oil (USDA WASDE, June 2022). Soybean meal, a co-product of soybean processing, is a primary source of amino acids in livestock and poultry diets (Willis, 2003; Karr-Lilienthal et al., 2004; Stein et al., 2008; Zhang et al., 2013; Cromwell, 2017). The importance of SBM in diets is based on its high crude protein (**CP**) content as an indicator of its concentration of both essential and nonessential amino acids (Bajjalieh, 2012; Banaszkiewicz, 2011). Use of SBM in diets depends on the nutrient composition of the meal, and is affected by the offering and nutrient composition of competing ingredients (Ruiz et al., 2020; Sifri, 2017). Like soybeans, the nutrient composition of SBM is impacted by factors that work both independently and interactively, including geography, environmental and processing conditions, and genetics (Baize, 1999; Grieshop and Fahey, 2001; De Coca-Sinova et al., 2008; García-Rebollar et al., 2016; Ibáñez et al., 2020). Over the past several decades, soybean genotype selections have focused on yield improvements, as measured by weight or volume per area (e.g., bushels per acre in the U.S.) without retaining comparable nutrient composition. This resulted in decreased protein content and decreased concentration of essential amino acids (Chung et al., 2003; Mahmoud et al., 2006; Patil et al., 2017; de Borja Reis et al., 2020; Naeve and Miller-Garvin, 2020) over time. These changes led to a reduction of the amount of SBM used in poultry and swine diets. Such reductions were primarily driven by diets formulated by animal nutritionists. That trend has been accelerated by increased use of crystalline amino acids, distillers dried grains with solubles (**DDGS**), feed enzymes to improve nutrient utilization, and other competitive protein sources in poultry and swine diets (Bregendahl, 2008; Stein and Shurson, 2009; Gacche et al., 2016; Swiatkiewicz et al., 2015).

In addition to protein and amino acid concentrations, the value and use of SBM in poultry and swine diets is also affected by its energy concentration. Recent research (Mateos et al., 2019; Cemin et al., 2020; Lee et al., 2022; Suesuttajit et al., 2021; van Heugten, 2021) has shown that the energy concentration and availability in SBM is higher than that referenced in nutrient requirement guides, including both the 1994 Poultry NRC and 2012 Swine NRC publications. The higher energy concentration than current standard industry practice (Rostagno et al., 2017) led to reviewing, evaluating, and updating SBM maximum use and value in the diet formulation. Consequently, that led to the evaluation of the use and value of SBM in poultry and swine diets, where the SBM contains 44.0 to 48.0% CP (2.75 to 3.01% total lysine). Since end-user evaluation and use of SBM in swine and poultry diets is based on nutritional value, both CP and lysine concentration were reported (lysine concentration as an indicator of amino acid concentration).

This analysis is focused on raising the awareness, understanding, and application of the primary SBM value drivers for end users, thereby improving stakeholder communication by defining and quantifying the primary determinants of end-user value. The analysis aimed to 1) understand the financial value associated with varying amino acid and energy concentrations in SBM for poultry and swine diets, and 2) develop a framework for estimating the economic value of SBM based on protein, amino acids, and energy concentrations. There is an urgent need to align the economic incentives for soybean growers with the key drivers of SBM value (nutritional value) by end-user customers. The first step is to illustrate how end-user nutritionists quantify SBM value while evaluating whether improved nutritional composition increases or decreases soybean meal value. The soybean value chain (Figure 1) is tightly integrated, and includes soybean geneticists, soybean growers, elevator operators, soybean processors, and end-user customers of SBM (animal producers). However, the recognition of value varies within each participant in the value chain. This analysis defines value from the end-user perspective, creating alignment in the value chain so the end-user

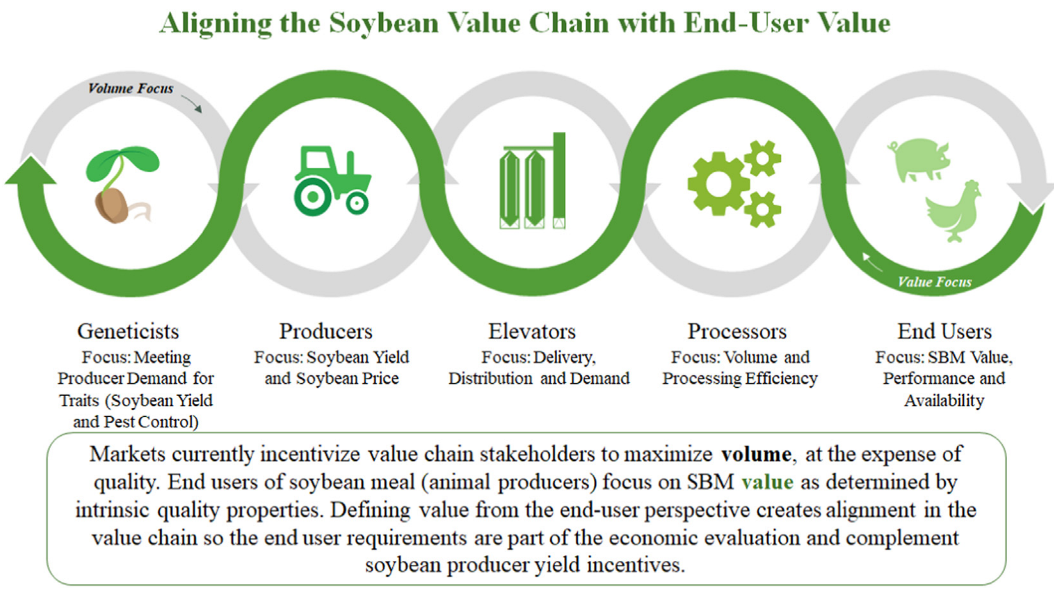

Figure 1. Soybean value chain.

requirements are part of the economic evaluation by all value chain stakeholders.

MATERIALS AND METHODS

SBM Nutrient Profile

Ingredient Sampling. A total of 169 samples of processed SBM were acquired from 2 soybean oil extraction plants in Illinois, United States (Archer-Daniels-Midland [**ADM**] Company in Quincy, IL and Solae Company in Gibson City, IL). Soybeans were processed to meal form by hull removal and oil extraction. Soybean meal samples were acquired by serial sampling during the unloading process of each truckload lot at the feed manufacturing plant (Hanor Company, Greenfield, IL). Truckload lots consisted of 21.78 MT of SBM and originated from either of the 2 processing plants. Each lot was sampled to secure about 1.0 kg samples, which were identified by lot and source, subsampled and ground using a Retsch ultra centrifugal mill with a 0.5 mm sieve (Retsch ZM 200) prior to analysis. Samples of SBM were collected over the course of nine months (April through December 2017) with 52 and 117 samples sourced from Solae and ADM, respectively.

SBM Analyses. Nutritive value was determined by near-infrared spectroscopy (**NIRS**) technology using a Foss Model 5000-II near-infrared spectrophotometer with ISIScan software (FOSS North America, Eden Prairie MN) for dry matter, crude protein, and 11 amino acids. The NIRS machine was housed in a temperature-controlled room with no external traffic to minimize the influence of temperature variation. Since protein and amino acid spectra would be read using Evonik proprietary technology (AMINONIR[R]), an Evonik technician conducted serial scans on-site prior to validating spectra accuracy. This procedure involved 20 ingredient sample standards that were scanned at the Mill Lab with spectra transferred to Evonik Industries AG Lab (Hanau, Germany) to determine machine accuracy and repeatability. This procedure was repeated at midpoint of the test.

The NIRS machine was turned on 30 min prior to operation to warm up. Thereafter, a calibration cell was scanned to verify the accuracy of parameters prior to scanning SBM samples. This cell was scanned at intervals within session runs to verify performance. The NIRS scanned between 1,100 and 2,500 nm in 2 nm steps. Ground SBM sample depth was 2 cm. Spectral scan files were electronically transferred to Evonik to compute dry matter (**DM**), CP, and amino acid (**AA**) concentrations. The

Table 1. Linear and predictive values of amino acids for SBM crude protein concentrations 44.0% to 48.0%.

Amino Acid	Intercept	Slope	*P*-value	R-squared	44%	45%	46%	47%	48%
MET	0.041	0.013	<0.0001	0.790	0.619	0.632	0.645	0.659	0.672
CYS	−0.106	0.018	<0.0001	0.528	0.665	0.683	0.700	0.718	0.735
MET + CYS	0.005	0.029	<0.0001	0.680	1.264	1.293	1.321	1.350	1.379
LYS	−0.168	0.066	<0.0001	0.881	2.745	2.812	2.878	2.944	3.010
THR	0.030	0.038	<0.0001	0.907	1.718	1.757	1.795	1.833	1.872
TRP	0.008	0.014	<0.0001	0.858	0.612	0.626	0.640	0.653	0.667
ARG	−0.629	0.087	<0.0001	0.938	3.193	3.280	3.367	3.454	3.541
ILE	−0.236	0.051	<0.0001	0.902	1.994	2.045	2.095	2.146	2.197
LEU	−0.132	0.078	<0.0001	0.921	3.316	3.394	3.473	3.551	3.629
VAL	−0.117	0.050	<0.0001	0.960	2.089	2.139	2.189	2.239	2.289
HIS	−0.052	0.028	<0.0001	0.887	1.159	1.186	1.214	1.241	1.269
PHE	−0.044	0.051	<0.0001	0.912	2.213	2.264	2.315	2.367	2.418

latter were computed directly from spectra, not indirectly from CP content, based on proprietary relationships that were developed by Evonik (Fontaine et al., 2001) from an extensive database comparing chemical analysis to NIR estimates for each amino acid. Values were standardized to a constant 88.7% DM content.

During the same period, corn, and corn distillers-dried grains with solubles (DDGS) were also sampled to obtain Evonik-assisted NIRS estimates that were necessary for formulation exercises. Estimates for DM, CP and AA concentration were derived using the same protocol for particle size and NIRS scans with file transfer to Evonik to compute estimates. A total of 155 and 220 lot samples of corn and DDGS, respectively, were analyzed. Protein and amino acid concentrations for corn and DDGS were standardized to a constant DM content of 88.7% for use in diet formulation exercises.

Statistical Methods for Deriving Prediction Equations Relating Amino Acids to Crude Protein Content

As CP and total AA concentrations were independently determined by NIRS, the association of AA to CP concentration was computed for SBM (Table 1). The concentration for each AA was regressed on CP concentration over the 43.7 to 48.6% range to derive the equation that best described the association. This relationship was determined to be linear ($P < 0.0001$) for each AA. Equations were derived with accompanying R^2 values. Confidence limits (95%) around the predicted value were also computed. Equivalent information was generated for corn and DDGS, using the PROC GLM procedure of the SAS program (SAS/STAT 9.4, 2016. SAS Institute, Cary, NC).

Calculations for Standardized Ileal Digestible Amino Acids. Conversion of predicted total AA estimates for each increment of SBM CP to SID values was made possible using digestibility coefficients from the Brazil Feed Composition and Nutritional Requirement report for Poultry and Swine (Rostagno et al., 2017). Coefficients for growing pigs were applied to each CP increment over the CP range of 44.0 to 48.0%. The values were equally applied (Table 2) given the relative similarity of coefficients. Different digestibility coefficients (DC) per CP concentration were applied for broilers and layers (Table 3).

Calculations for Net and Metabolizable Energy Values. Net energy (**NE**) estimates were used for growing pigs and metabolizable energy (**ME**) estimates were used for broilers and layers. ME was used for broilers and layers because the NE system has not been adequately developed for those poultry types. Published values were obtained from the Brazilian Tables (Rostagno et al., 2017). They described 4 SBM CP concentrations over the 44.4 to 48.1% range. Since DM and oil content varied among CP concentrations, table values for poultry ME were standardized to 88.7% DM and 1.80% oil. Soybean NE estimates for growing pigs were derived from recent calorimetry (Lee et al., 2022) and growth validation assays (Boyd and Rush, 2020 unpublished data), with estimates being remarkably similar. International reference publications underestimate SBM NE (Lee et al., 2022). NE estimates for

Table 2. SBM net energy and amino acid specifications for swine[1].

	SBM crude protein concentrations				
Crude protein, %	48.0	47.0	46.0	45.0	44.0
Dry matter, %	88.7	88.7	88.7	88.7	88.7
Net energy, kcal/kg	2,218	2,205	2,194	2,165	2,130

	48% CP			47% CP			46% CP			45% CP			44% CP		
Amino acid	Total	DC	SID	Total	DC	SID	Total	DC	SID	Total	DC	SID	Total	DC	SID
LYS, %	3.01	0.91	2.72	2.94	0.91	2.66	2.88	0.91	2.60	2.81	0.91	2.55	2.75	0.91	2.49
THR, %	1.88	0.87	1.63	1.84	0.87	1.60	1.79	0.87	1.56	1.75	0.87	1.52	1.71	0.87	1.48
TRP, %	0.67	0.89	0.59	0.65	0.89	0.58	0.64	0.89	0.57	0.63	0.89	0.55	0.61	0.89	0.54
MET, %	0.67	0.92	0.62	0.66	0.92	0.61	0.65	0.92	0.59	0.63	0.92	0.58	0.62	0.92	0.57
CYS, %	0.73	0.89	0.65	0.72	0.89	0.64	0.70	0.89	0.62	0.69	0.89	0.61	0.67	0.89	0.60
TSAA, %	1.40	0.90	1.27	1.37	0.90	1.24	1.35	0.90	1.21	1.32	0.90	1.19	1.29	0.90	1.16
ILE, %	2.19	0.90	1.97	2.14	0.90	1.92	2.09	0.90	1.88	2.04	0.90	1.83	1.99	0.90	1.79
VAL, %	2.29	0.89	2.03	2.24	0.89	1.98	2.19	0.89	1.94	2.14	0.89	1.89	2.09	0.89	1.85
ARG, %	3.52	0.94	3.32	3.44	0.94	3.25	3.36	0.94	3.17	3.28	0.94	3.10	3.20	0.94	3.02
HIS, %	1.27	0.91	1.15	1.24	0.91	1.13	1.21	0.91	1.10	1.19	0.91	1.08	1.16	0.91	1.05
LEU, %	3.64	0.90	3.28	3.55	0.90	3.21	3.47	0.90	3.13	3.38	0.90	3.06	3.30	0.90	2.98
PHE + TYR, %	4.84	0.91	4.40	4.73	0.91	4.31	4.63	0.91	4.21	4.52	0.91	4.11	4.41	0.91	4.02

[1]Regression equation derived from standardized (88.7% DM, 1.80% Oil). SBM NE in relation to SBM CP concentration is described by: NE, kcal/kg = $-4.4286 \times CP^2 + 429.03 \times CP - 8173.2$; Quadratic, $P = 0.129$ with $R^2 = 0.9858$

Table 3. SBM metabolizable energy and amino acid specifications for poultry[1].

	SBM crude protein concentrations				
Crude protein, %	48.0	47.0	46.0	45.0	44.0
Dry matter, %	88.7	88.7	88.7	88.7	88.7
Metabolizable energy, kcal/kg	2,268	2,235	2,202	2,170	2,137

	48% CP			47% CP			46% CP			45% CP			44% CP		
Amino acid	Total	DC	SID	Total	DC	SID	Total	DC	SID	Total	DC	SID	Total	DC	SID
LYS, %	3.01	0.92	2.78	2.94	0.92	2.69	2.88	0.91	2.61	2.81	0.91	2.55	2.75	0.91	2.49
THR, %	1.88	0.88	1.65	1.84	0.87	1.59	1.79	0.86	1.54	1.75	0.86	1.51	1.71	0.86	1.47
TRP, %	0.67	0.91	0.61	0.65	0.90	0.59	0.64	0.89	0.57	0.63	0.89	0.56	0.61	0.89	0.55
MET, %	0.67	0.94	0.63	0.66	0.93	0.61	0.65	0.92	0.59	0.63	0.92	0.58	0.62	0.92	0.57
CYS, %	0.73	0.86	0.63	0.72	0.85	0.61	0.70	0.85	0.59	0.69	0.85	0.58	0.67	0.85	0.57
TSAA, %	1.40	0.89	1.25	1.37	0.89	1.22	1.35	0.89	1.20	1.32	0.89	1.17	1.29	0.89	1.15
ILE, %	2.19	0.89	1.95	2.14	0.89	1.91	2.09	0.89	1.86	2.04	0.89	1.81	1.99	0.89	1.77
VAL, %	2.29	0.87	2.00	2.24	0.88	1.96	2.19	0.88	1.92	2.14	0.88	1.88	2.09	0.88	1.83
ARG, %	3.52	0.93	3.26	3.44	0.93	3.19	3.36	0.93	3.12	3.28	0.93	3.05	3.20	0.93	2.97
HIS, %	1.27	0.91	1.15	1.24	0.90	1.12	1.21	0.89	1.08	1.19	0.89	1.05	1.16	0.89	1.03
LEU, %	3.64	0.92	3.34	3.55	0.90	3.21	3.47	0.89	3.09	3.38	0.89	3.02	3.30	0.89	2.94
PHE + TYR, %	4.84	0.91	4.42	4.73	0.91	4.31	4.63	0.91	4.20	4.52	0.91	4.10	4.41	0.91	4.00

[1]Regression equation derived from standardized (88.7% DM, 1.80% Oil) ME values in Poultry SBM composition tables (Rostagno et al., 2017) is as follows: ME, kcal/kg = $32.856 \times CP + 691.05$; Linear, $P = 0.089$ with $R^2 = 0.8293$.

the full range of SBM CP (44.0 to 48.0%) were deviated using incremental margins reported by Rostagno et al., 2017. Standardized NE and ME values for growing pigs and poultry, respectively, were regressed on CP to derive predictive equations that best described the association. Predictive estimates of NE and ME were computed for evenly spaced increments in

Table 4. Nutrient specification for nursery, grower, finisher, and lactation swine diets.

Swine diet specification	Lactation	Nursery	Grower	Finisher
Calcium, %, min[1]	0.90	0.85	0.65	0.53
Calcium, %, max[1]	0.95	0.90	0.68	0.56
Available phosphorus, %[1]	0.45	0.45	0.28	0.20
Sodium, %, min[1]	0.40	0.50	0.50	0.50
Sodium, %, max[1]	0.40	0.50	0.50	0.50
SID Lysine, %[2]	1.05	1.31	0.98	0.69
SID Methionine: SID Lysine, %[2]	25.00	28.00	29.00	30.00
SID Methionine + Cysteine: SID Lysine, %[2]	46.00	58.00	58.00	62.00
SID Threonine: SID Lysine, %[2]	59.00	62.00	62.00	65.00
SID Tryptophan: SID Lysine, %[2]	18.00	18.00	18.00	18.00
SID Isoleucine: SID Lysine, %[2]	54.00	55.00	55.00	55.00
SID Valine: SID Lysine, %[2]	75.00	65.00	64.00	65.00
Vitamin and trace mineral pack, %[3]	0.25	0.25	0.25	0.25
Minimum energy, Mcal/kg	3.31	3.31	3.35	3.35

Note: SID is Standardized Ileal Digestibility.

[1]Authors estimate.

[2]Meets or exceeds specifications from the National Swine Nutrition Guide Version 1.2, 2010, Tables 1, 3, 7; National Swine Nutrition Guide, U.S. Pork Center of Excellence, 2010. Iowa State University, Ames IA.

[3]Exceeds specifications from the National Swine Nutrition Guide version 1.2, 2010, Tables 12, 13, 14 and 15; National Swine Nutrition Guide, U.S. Pork Center of Excellence, 2010. Iowa State University, Ames IA.

SBM CP content (44.0, 45.0, 46.0, 47.0, 48.0%), preparatory to diet formulation simulations. The regression step provided a missing estimate (47.0%) and removed probable variation around a SBM concentration based on plant source and experimental procedure. Equations with R^2 and statistical probability are included with predictive estimates in Tables 2 and 3.

Nutrient Specifications for Diet Formulation

Animal diets were formulated based on a variety of factors considered in commercial formulation, including the ingredient contribution to the nutrients required for respective animal and market factors such as ingredient availability and price. Experience-based ingredient limits were set for maximum use in a diet to avoid

Table 5. Nutrient specifications for layer, broiler grower, and broiler finisher diets[1].

Poultry diet specifications	Layer	Broiler grower	Broiler finisher
Calcium, %, min	4.50	0.89	0.81
Calcium, %, max	4.70	1.01	0.94
Available phosphorus, %	0.43	0.40	0.38
Na, % min	0.17	0.22	0.19
Na, % max	0.20	0.31	0.28
SID Lysine, %	0.73	1.20	1.06
SID Methionine: SID Lysine, %	51.00	33.00	32.00
SID Methionine + Cysteine: SID Lysine, %	88.00	64.00	68.00
SID Threonine: SID Lysine, %	79.00	59.00	62.00
SID Tryptophan: SID Lysine, %	21.00	13.00	15.00
SID Isoleucine: SID Lysine, %	78.00	49.00	44.00
SID Valine: SID Lysine, %	89.00	49.00	47.00
SID Arginine: SID Lysine, %	101.00	95.00	97.00
Vitamin and trace mineral pack, %[2]	0.25	0.25	0.25
Minimum energy, Mcal/kg	2.84	3.08	3.13

[1]Source: Ferket, P. 2017. Feedstuffs Poultry Priorities Report 2017, Table 4, page 20, and Table 10 page 24. Feedstuffs Magazine, Bloomington MN.[2]Exceeds specifications (Ferket, 2017), Feedstuffs Poultry Priorities Report, Table 3, page 19.

[2]Ferket, P. 2017. Feedstuffs Poultry Priorities Report. Feedstuffs, March 6, 2017. Feedstuffs.

Table 6. Swine diet ingredient menu, ingredient prices, and maximum ingredient inclusion by phase.

	Price	Nursery	Grower	Finisher	Lactation
Swine diet ingredient constraints	$ US/MT	Maximum inclusion, %			
Soybean meal, 48.0% CP	358.25				
Corn, 8% CP	139.99				
Corn germ meal, 23.2% CP	111.99	5.00	10.00	10.00	5.00
DDGs, 27.4% CP	147.71	10.00	20.00	15.00	10.00
Wheat midds, 16.3% CP	143.30	5.00	10.00	10.00	7.50
Canola meal, 36.7% CP	305.34	7.50	10.00	10.00	10.00
Animal fat (Poultry fat)	617.29				
Choice white grease	655.87	4.75	4.75	4.75	4.75
Calcium carbonate	46.30				
Monocalcium phosphate, 21%	465.17				
Salt	80.47	0.50	0.50	0.50	0.50
L-lysine HCl, 78.6% lysine	1,565.28	0.50	0.50	0.35	0.50
DL-methionine, 98.5%	2,755.78	0.25	0.20	0.20	0.20
L-tryptophan, 98.5%	7,495.71	0.10	0.10	0.10	0.10
L-threonine, 98.5%	1,895.97	0.25	0.20	0.20	0.20
L-valine, 98.5%	8,686.20				
Vitamin & trace mineral pack	2,204.62	0.25	0.25	0.25	0.25
Phytase, 5,000 FTU/g	4,898.67	0.02	0.02	0.02	0.02

dietary intake reduction. Diets were specified for the physiological phases of swine (Table 4) and poultry (Table 5) production. For swine, 4 phases were considered: lactation, nursery, grower, and finisher production. For poultry, 3 phases were specified: layers, broiler grower, and broiler finisher production. Dalex Livestock Solutions, LLC (Los Angeles, CA) least cost formulation software was used for diet formulation.

Formulation Ingredients and Prices

Ingredient menus for each species were developed based on availability and utilization (standard commercial practice in US). Ingredient prices were estimated using the average of 3 marketing years, 2016−2017 through 2018−2019. The US average base price (3 marketing year average) was determined for each ingredient. Regional price variability was also considered to account for different geographic markets in the United States, including the Corn belt, Northeast, South Central, and Southeast regional markets (e.g., prices for the Swine Finisher diet in the Corn belt will be slightly different than prices for a Swine Finisher diet in the Southeast). There was assumed to be no regional price differences between crystalline amino acids. The US average base price and regional price differentials were estimated using both public data from Feedstuffs, an industry recognized source for feed ingredient prices, and feedstuff market reports issued by USDA Agricultural Marketing Service (**AMS**).

Tables 6 and 7 summarize the ingredients that were made available for poultry and swine diet formulations. The tables include the ingredient, US average base price per metric ton and maximum inclusion constraints as a percent of the diet. The tables also include ingredients made available for each production phase in the formulation. Not all ingredients listed were used in the final diets.

Relative SBM Value Calculation

Relative SBM economic value ($/MT) was estimated based on the changes in the nutritional properties of the SBM (amino acids and energy). Market prices for SBM were determined based on trading rules that specify minimum CP content. To estimate the relative SBM value in the diet by CP concentration (44.0−48.0%, or total lysine 2.75−3.01%), differences in formula cost were applied to the SBM based on the amount used per metric ton. In some cases, this may be due to either SBM quantity or other ingredients (e.g., fat) in the formula, while maintaining a constant dietary

Table 7. Poultry diet ingredient menu, ingredient prices, and maximum ingredient inclusion by phase.

Poultry diet ingredient constraints	Price $ US/MT	Broiler grower	Broiler finisher	Layer
		Maximum inclusion, %		
Soybean meal, 48.0% CP	358.25			
Corn, 8% CP	139.99			
DDGs, 27.4% CP	147.71	10.00	10.00	10.00
Wheat midds, 16.3% CP	143.30			15.00
Canola meal, 36.7% CP	305.34			
Poultry by-product meal, 60%CP	292.11			
Animal fat (Poultry Fat)	617.29			
Choice white grease	655.87			
Calcium carbonate	46.30			
Monocalcium phosphate, 21%	465.17			
Salt	80.47			
L-lysine HCl, 78.6% lysine	1,565.28	0.45	0.45	0.45
DL-methionine, 98.5%	2,755.78	0.25	0.25	0.25
L-tryptophan, 98.5%	7,495.71	0.20	0.20	0.20
L-threonine, 98.5%	1,895.97	0.20	0.20	0.20
L-valine, 98.5%	8,686.20	0.20	0.20	0.20
Vitamin & trace mineral pack	2,204.62	0.25	0.25	0.25
Phytase, 2,500 FTU/ g[1]	3,674.00	0.02	0.02	0.02

[1]Different phytase sources were used between poultry and swine diets. These sources were representative of what is commercially available and are reflected in the prices used in the formulation. The impact of price difference was constant and minimal. Across the diets analyzed, phytase was 0.02% of total diet or less than $0.05/MT of total diet cost.

level of energy and nutrients as SBM amount changes.

The 48.0% CP concentration (3.05% total lysine) was assumed to be the base SBM, to which other CP concentrations were compared. The price of 48.0% CP was $358 per metric ton. Equation 1 summarizes the calculation of relative value for each CP concentration 44.0 to 47.0%, where “Base SBM Price” is the price of 48.0% SBM ($/MT), “TDC” is the total diet cost ($/MT), assuming inclusion of the specified SBM CP concentration (where “CP%” is the CP concentration from 44.0−47.0%), and “SBM” is the amount of SBM included in the diet (kg/MT) assuming inclusion of the specified SBM CP concentration (where “CP%” is the CP concentration 44.0−47.0%)

$$\begin{aligned} &Relative\ Value\ of\ SBM_{CP\%}, \$/MT \\ &= Base\ SBM\ Price,\ \$/MT \\ &\quad - \left[(TDC_{\ CP\%} - TDC_{\ 48\%})/SBM_{CP\%} \times 1,000\right] \end{aligned} \tag{1}$$

Table 8 summarizes variables and calculations for each CP concentration using an example for the swine lactation diet.

The relative value of SBM per each CP concentration was then multiplied by estimated

Table 8. Relative value of SBM calculation.

1 CP % (Crude protein concentration)	*2* SBM, kg/MT (SBM use in diet)	*3* TDC, $/MT (total diet cost)	*4* Difference in TDC to base SBM, $/MT	*5* Estimated vost per MT, $/MT	*6* Relative value of SBM, $/MT	*7* Calculation
44.0%	182.00	226.00	7.00	38.46	319.54	*358 − [(226-219)/182 × 1000]*
45.0%	177.00	224.00	5.00	28.25	329.75	*358 − [(224-219)/177 × 1000]*
46.0%	173.00	222.00	3.00	17.34	340.66	*358 − [(222-219)/173 × 1000]*
47.0%	169.00	221.00	2.00	11.83	346.17	*358 − [(221-219)/169 × 1000]*
48.0%	164.00	219.00	0.00	0.00	358.00	*[Base, to which all others compared)*

total volumes of SBM used for the respective species in the study in the United States to estimate a US “gross relative value.” US SBM consumption data was sourced from USDA for the 2018−2019 marketing year (USDA WASDE 2020). The volume of SBM consumption by species was derived using allocations estimated by Decision Innovation Solutions SBM Demand Assessment (Decision Innovation Solutions, 2020) and applied to USDA’s total US SBM utilization estimates. We only consider the species and phases that were included in this analysis. Poultry includes Broiler Grower, Broiler Finisher, and Layers. Swine includes Lactation, Nursery, Grower, and Finisher. For poultry, the broiler SBM consumption was split evenly between grower and finisher production. For swine, it was allocated a feed share by phase and applied to the total SBM consumed for swine. The feed share was determined by estimating average daily gain (**ADG**) and days on feed.

US gross relative value of SBM used in swine and poultry diets was determined by estimating US total SBM utilization by species and phase for each CP concentration 44.0 to 48.0%. For the baseline, total SBM consumption in the United States was assumed to be 48.0% CP SBM. Therefore, any change in SBM utilization in the diet as the CP concentration changes was compared to 48.0% CP. This differential was calculated for each CP concentration for each species and phase. If SBM utilization in the diet changes as CP content (including amino acids and energy) changes, adjusted SBM usage volumes per CP concentration are estimated in aggregate for the United States. The estimated SBM use (kg per metric ton) per CP concentration compared to 48.0% CP as the base was multiplied by total US SBM consumption by phase to estimate total SBM consumption for each protein concentration. The new consumption total was then multiplied by the relative price of SBM (by CP concentration). This results in an aggregate US estimate of SBM value in US dollars, or US Gross Relative Value, by CP concentration.

Equation 2 includes the calculation of Relative Total US Consumption by phase of production for each CP concentration 44.0 to 48.0%.

$$\begin{aligned} &\textit{Relative Total U.S. Consumption}_{CP\%}, MT \\ &\quad = \textit{Relative Total U.S. Consumption}_{48CP\%}, \\ &\qquad MT \times \textit{Percent Change in Use}_{CP\%} \\ &\qquad \textit{Compared to } 48\%\text{ CP} \end{aligned} \tag{2}$$

Equation 3 includes the calculation for US Gross Relative Value.

$$\begin{aligned} &\textit{U.S. Gross Relative Value}_{CP\%}, \$ \\ &\quad = \textit{Relative Total U.S. Consumption}_{CP\%}, MT \\ &\qquad \times \textit{Relative Value of SBM}_{CP\%},\ \$/MT \end{aligned} \tag{3}$$

RESULTS AND DISCUSSION

Soybean meal is sold and priced based on CP content. However, nutritionists formulate diets based on the nutritional profiles of feed ingredients. Therefore, the 2 most important considerations in formulating diets are digestible amino acids and energy concentration of the ingredients used. The reported results are presented in terms of both SBM CP and total lysine concentration as an indicator of amino acid content in SBM. Although results are expressed in relation to SBM CP content, energy was estimated to increase with each increment of SBM CP (Tables 2 and 3).

SBM Inclusion

Figures 2 and 3 summarize the SBM inclusion in swine and poultry diets for each CP concentration analyzed (or from 2.75 to 3.01% total lysine). Overall, inclusion of SBM in the diet declines as SBM CP, amino acids, and energy increase. The 2 exceptions were swine nursery and swine grower diets. The percent decrease in dietary SBM content from 44.0 to 48.0% CP was 6.2 and 10.9% on average for swine and poultry, respectively. There were 2 apparent anomalies in this trend. The first was for swine nursery diets between 45.0 and 46.0% CP where SBM inclusion increased slightly, replacing corn, lysine, and valine. The second was for swine grower

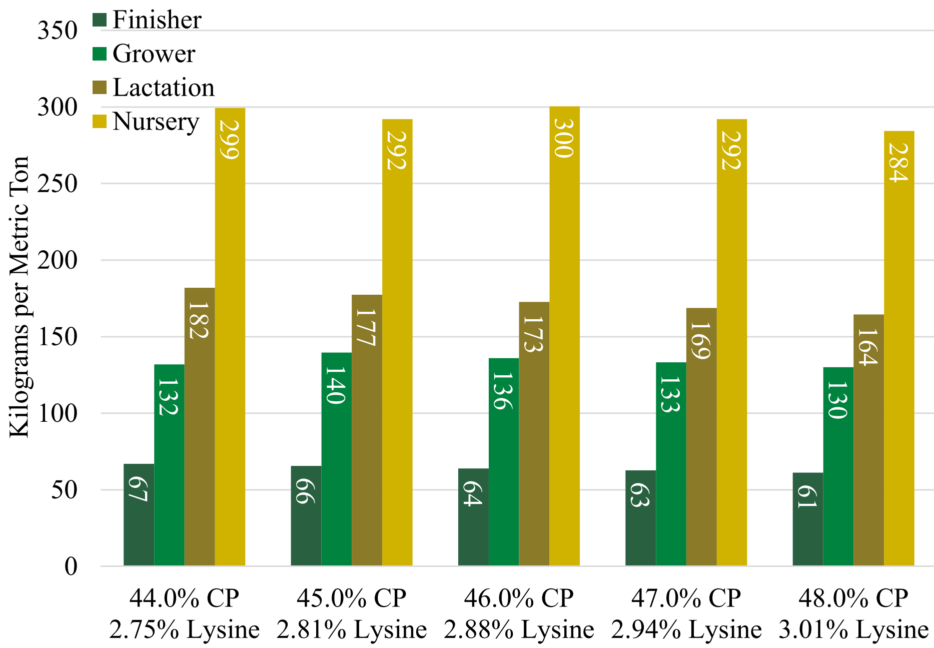

Figure 2. Soybean meal utilization in swine diets, kilograms per metric ton of feed by crude protein (CP) and total lysine (%).

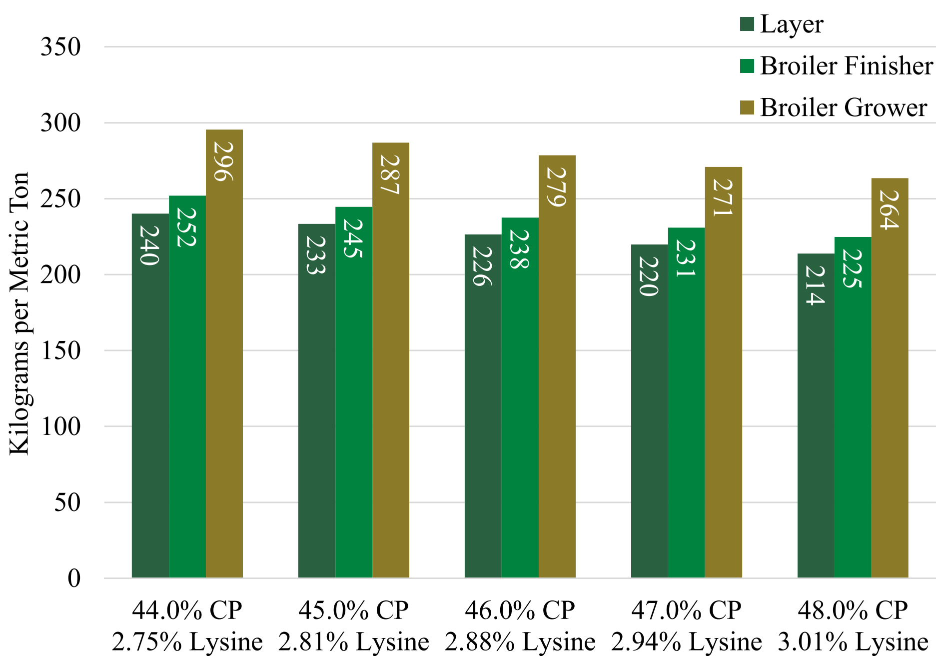

Figure 3. Soybean meal utilization in poultry diets, kilograms per metric ton of feed by crude protein (CP) and total lysine (%).

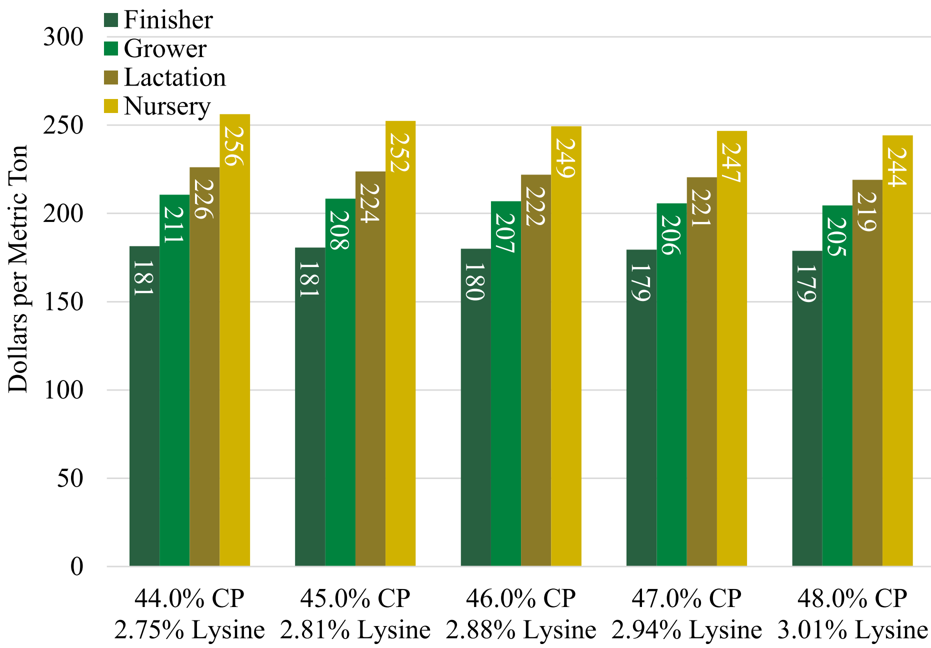

Figure 4. Total diet costs for swine diets, dollars per metric ton by crude protein (CP) and total lysine (%).

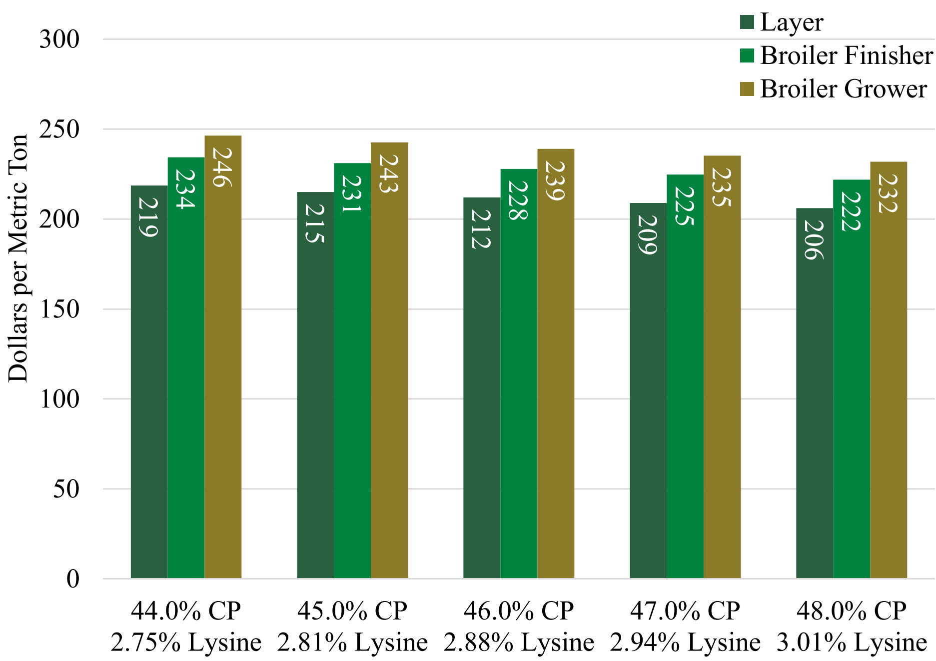

Figure 5. Total diet costs for poultry diets, dollars per metric ton by crude protein (CP) and total lysine (%).

diets between 44.0 and 45.0% CP where DDGs and CWG were replaced by SBM, corn, methionine and threonine. These anomalies were primarily influenced by the least cost optimization related to the nutrient requirements and an inflection point that caused an increase in SBM inclusion due to alternative ingredient prices. The share of SBM in the diet was greatest in nursery diets, comprising about 30% of the total diet across all CP concentrations. Given the prices for

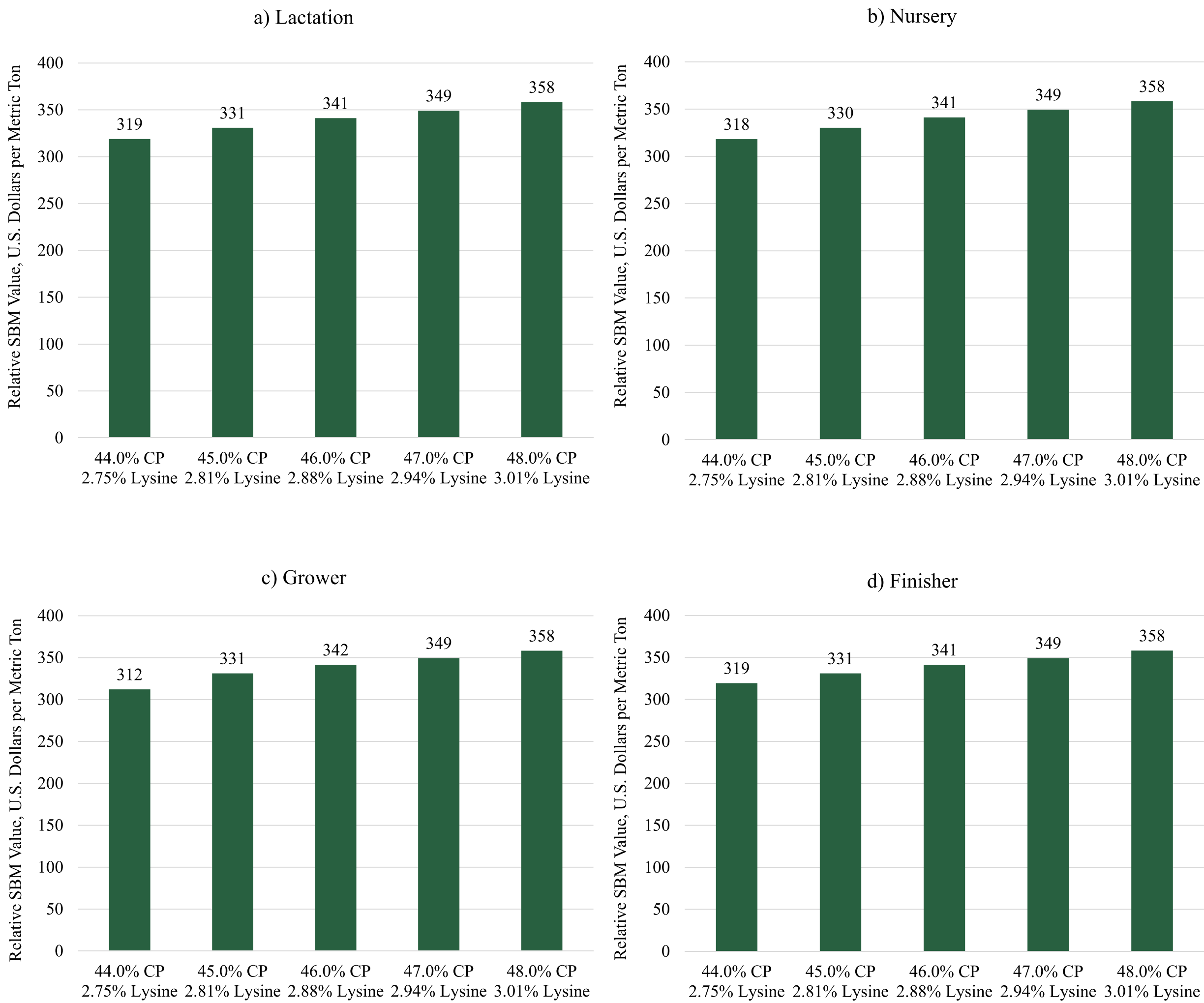

Figure 6. Relative soybean meal value in swine diets, dollars per metric ton by crude protein (CP) and total lysine (%).

all ingredients made available in the formulation (see Tables 6 and 7), SBM, corn, DDGS and wheat midds were utilized across all diets. Canola meal was not utilized in any formulation.

Total Diet Costs

Figures 4 and 5 present the total diet cost (US dollars per metric ton) for all species and phases. Across all species and phases, total diet cost declines as CP increased from 44.0 to 48.0% (or from 2.75 to 3.01% total lysine). The greatest decline in diet cost occurred for swine nursery diets, with a 4.7% decline in total diet cost as the amino acid concentration and energy value of SBM increased.

Relative SBM Value

The following figures summarize the relative value of SBM for each CP concentration. For swine diets (Figure 6) the relative value of SBM increased as the CP increased. The relative value of SBM was similar from 44.0 to 48.0% CP (or 2.75−3.01% total lysine) across all swine phases. SBM with 48.0% CP (3.01% total lysine) had a premium of $39 to $46 per metric ton over 44% CP (2.75% total lysine) across all 4 phases. This translates into an average of $10.27 per metric ton premium for each percentage point increase in CP in the swine diets analyzed.

For poultry diets (Figure 7), the relative value also increased as the CP increased. The data showed that the 48.0% CP SBM (3.01% total lysine) has a premium of $49 to $52 per metric ton over 44.0% CP (2.75% total lysine). This translates into an average of $12.62 per metric ton premium for each percentage point increase in CP. It was also noted that the relative value of SBM was similar across the poultry species.

Overall, as the energy and amino acid (CP) content increased, the value of SBM in the diet increased. Poultry and swine diet costs decline as CP (amino acids and energy) increases. With few exceptions, SBM inclusion in the diet tends to decline as CP increases, but the value proposition of that SBM increases as amino acids and energy increase. Based on the nutrient value of the meal, the economic value ranges between $10.27 and $12.62 per metric ton in swine and poultry, respectively for each 1% increase in CP.

Figure 8 summarizes the results of these SBM values by CP concentration aggregated at the US level. If all SBM used in poultry and swine diets in the United States[1] was 48.0% CP (3.05% total lysine), the gross relative value of US SBM would be $8.459 billion. If all SBM used in poultry and swine diets in the United States was 44.0% CP (2.75% total lysine), the gross relative value is $8.109 billion. This implies that the value of SBM with 48.0% CP is $350 million more than SBM with 44% CP, at the US aggregate level.

Soybean meal is a key ingredient in both poultry and swine diets. The amino acid content of SBM is the primary reason for its use, though its energy composition is also important since energy is the most expensive diet component. Over the past 2 decades, the CP content of SBM has decreased, resulting in alternative feed ingredients replacing SBM in poultry and swine diets. In the United States, DDGS has also become a major competitor to SBM. The combination of crystalline amino acids and DDGS has caused a significant decline in the use of SBM, especially in growing and finishing pig diets. This has increased crystalline amino acid commercialization significantly over the last 20 yr. The value of SBM increases with increasing CP, amino acid, and energy concentration, the primary drivers of SBM use in swine and poultry diets.

The formulation exercises (see Figures 2 and 3) show that there is a slight decrease in SBM inclusion (less SBM, more SBM amino acids) in poultry and swine diets as the CP increases from 44.0 to 48.0% (2.75−3.01% total lysine). With this change, there is a corresponding increase in corn use and a decrease in fat in these diets. The increase in corn used occurs primarily because it has more competitive nutrient composition than other alternatives. These changes result in corresponding decreases in the costs (Figures 4 and 5) of the poultry and swine diets evaluated. Figures 6 and 7 demonstrate the effect of formulating with SBM with higher CP concentrations,

[1] Aggregate U.S. values only consider the swine and poultry phases utilized in this analysis.

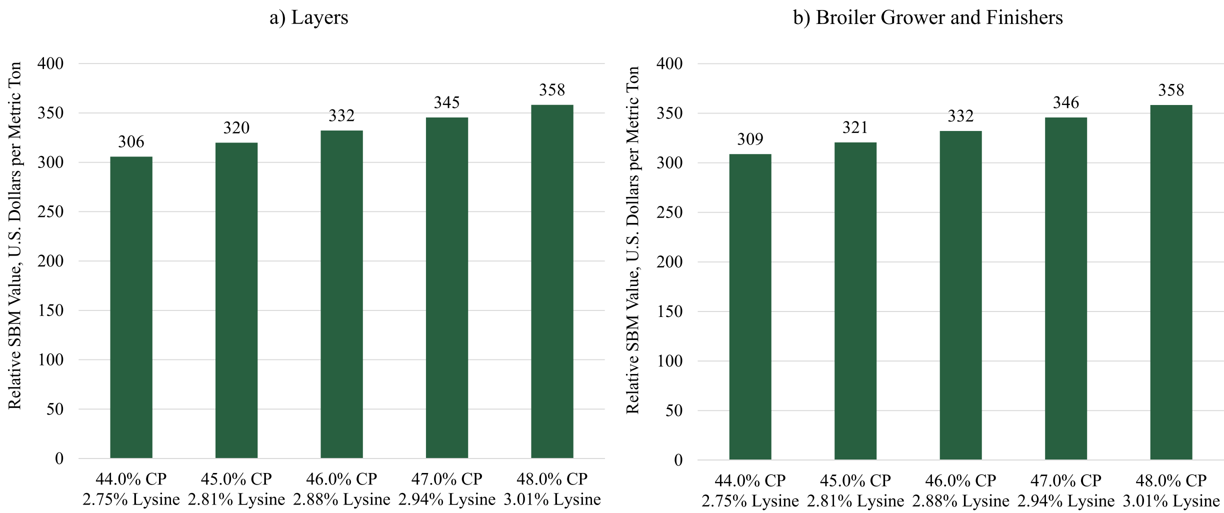

Figure 7. Relative soybean meal value in poultry diets, US dollars per metric ton by crude protein (CP) and total lysine (%).

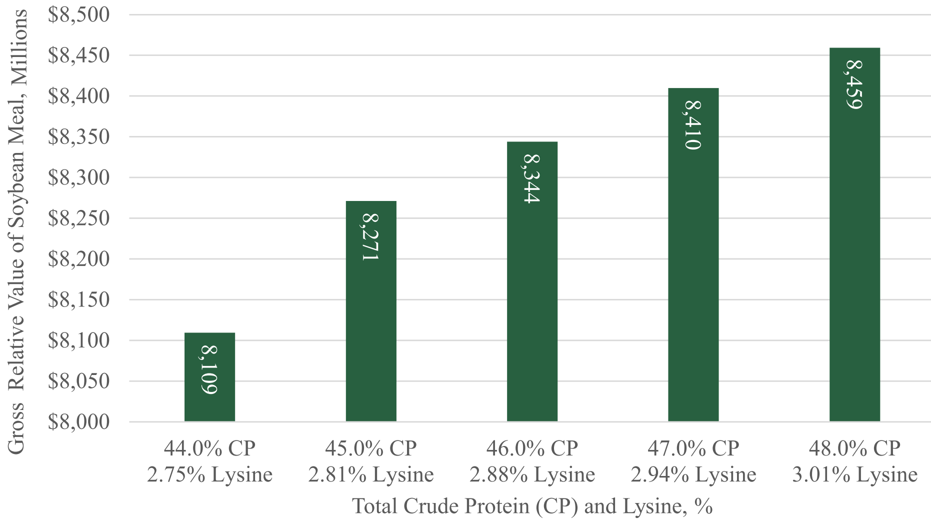

Figure 8. US gross relative value of soybean meal, 2018–2019 marketing year.

which translates into a higher nutrient content. The improved nutrient content of SBM would enable nutritionists to use SBM more effectively in poultry and swine diets. The impact is higher value per metric ton of $10.27 and $12.62 in swine and poultry diets, respectively, for each one percent increase in SBM CP. Stated another way, poultry and swine producers could pay more for a SBM with a higher concentration of CP and still have an overall reduced diet cost. This could offset the concern of soybean producers (fewer bushels of soybeans per acre produced); soybeans would be more valuable in total. As Figure 8 shows, the gross relative value of SBM increases with each one percent increase from 44.0 to 48.0% CP, benefiting multiple segments of the soybean value chain.

An important observation emerged from the formulation calculations. Improved nutritive quality of SBM coincided with increased corn grain demand in diets. Conversely, reduced SBM protein content reduced corn demand in diets. Thus, improved SBM protein content increased corn use volume. The associated need for more corn grain in diets may create additional demand for that product as well, influencing producer decisions when optimizing crop rotation to maximize profit. In addition, the extent that corn displaced competing ingredients (e.g., DDGS) is important from the perspective of diet-sourced greenhouse gas emissions (**GHG**). Feed production and diets comprise approximately 90% of GHG emissions from pig and poultry production (Benavides et al., 2020). This finding potentially expands the value of improved SBM amino acid concentration (and energy) beyond relative value to suggest that high SBM CP content (amino acids, energy) is a means to formulate for reduced GHG, without exacerbating diet cost.

It is anticipated that US SBM production will increase with soybean oil demand for renewable fuels. The projected 2025 US soybean crush (processing) capacity is anticipated to increase SBM volume by 20 to 25% (personal communication, Gordon (Denny, 2022)). In the near-term, soybean cultivars that deliver the greatest amino acid concentration (e.g., 47–49% CP) will compete most effectively because of greater nutrient composition, as compared to lower protein sources (e.g., 45–46% CP). As the nutrient content of SBM increases with improved selection practice, and though there is a corresponding slight decrease in its dietary inclusion in poultry and swine diets, its value increases in these diets. This presents profitability opportunities for soybean growers, soybean processors, and poultry and swine producers, all members of the soybean value chain.

Limitations and Future Considerations

The methods and data utilized in this study relied on best information available at the time of analysis, including estimates of amino acid and energy concentrations attributed to each SBM CP concentration. The formulation exercise utilized ingredient prices estimated from the average of 3 marketing years 2016−2017 through 2018−2019, which were the most recent price series when the original analysis was conducted. While this is now dated, it was during a period of less volatility than has been experienced recently. The authors plan to update the formulation analysis with updated ingredient prices to understand the implication of price sensitivity on the relative SBM values presented here.

CONCLUSIONS AND APPLICATIONS

1. This analysis articulated and quantified the primary determinants of SBM value from the perspective of end-user nutritionists. As the focus was on commercial applications, the analysis quantified the economic value of SBM (and quantity used) with increasing amino acid and energy concentration.
2. Each 1% increase in SBM CP concentration from 44.0 to 48.0% (or each 0.065% increase in total lysine from 2.75 to 3.01%) increases SBM value approximately $10.27 and $12.62 per metric ton in swine and poultry diets, respectively.
3. This additional value represents the additional amount that poultry and swine end users could pay for a higher SBM concentration and still have an overall reduced diet cost.
4. Understanding the relative value of SBM as amino acid and energy concentrations change is critical for economic evaluations and planning at all stages of the soybean supply chain. The results presented here can be used to communicate the true economic value of SBM based on intrinsic product and compositional characteristics.

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DISCLOSURES

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Micah Pope reports financial support was provided by United Soybean Board. Micah Pope reports a relationship with United Soybean Board that includes: consulting or advisory. Bart Borg reports financial support was provided by United Soybean Board. Bart Borg reports a relationship with United Soybean Board that includes: consulting or advisory. R. Dean Boyd reports financial support was provided by United Soybean Board. R. Dean Boyd reports a relationship with United Soybean Board that includes: consulting or advisory. Mamduh Sifri reports financial support was provided by United Soybean Board. Mamduh Sifri reports a relationship with United Soybean Board that includes: consulting or advisory. Editorial Board Member for the Journal of Applied Poultry Research.

SUPPLEMENTARY MATERIALS

Supplementary material associated with this article can be found in the online version at doi:10.1016/j.japr.2023.100337.

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