Raw material nutrient variability has substantial impact on the potential profitability of chicken meat production

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Primary Audience: Poultry Nutritionists, Producers

SUMMARY

Feed accounts for more than 65% of live production costs of poultry production; thus, accurate feed formulation is vital to ensure poultry are receiving an optimal diet and nutrients are not in undersupply or oversupply. However, this is difficult when the nutrient compositions of feed ingredient batches are highly variable. To help reduce the variability in the specified finished feeds, appropriate sampling methodology is critical. Nevertheless, recommended methodology and depth of detail within technical articles varies greatly and does not always reflect the recommendations of the Association of Official Analytical Chemists, a nonprofit scientific association that publishes standardized analytical methods. It is often understood that increased variability in ingredients due to poor sampling technique is detrimental to industry, but the potential economic cost of poor sampling is often not appreciated. Thus, the extent that variation in protein in feed ingredients affects expected performance and profits for the poultry industry was modeled. It was demonstrated that it is possible to incur a 63% reduction in gross margin or a difference of up to $19,053 (USD) in gross margin from one cycle of 30,000 broilers by simply overestimating the nutrient content of feedstuffs. Assuming a poultry company may produce approximately 1,000 broiler cycles per year, this equates to a loss of up to $19 million (USD). Hence, it is clear that identifying the most accurate way to sample, and improving the understanding and implementation of proper sampling methodology, should be a priority.

Key words: sampling, feed, ingredient, variability, poultry

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DESCRIPTION OF PROBLEM

Feed accounts for more than 65% of live production costs of poultry production (Wilkinson, 2018); thus, accurate feed formulation is vital to ensure poultry are receiving an optimal diet and nutrients are not in undersupply or oversupply. However, this is difficult when the nutrient specifications of feed ingredients are highly variable (Moss et al., 2020). Within industry, chemical analyses of feed ingredient samples are impractical owing to the cost and time involved. Consequently, near-infrared (**NIR**) calibrations

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are often used within integrated operations to instantaneously estimate the nutrient composition of feedstuffs to keep up with demand. However, NIR calibrations are only as accurate and representative of the feedstuff as the sample that was taken. This has been an ongoing issue within industry for some time. Lerman and Bie (1975) published a review describing the substantial variation of nutrient composition in feed ingredients—grains and protein meals in particular—and modeled the potential economic cost of this uncertainty. It was concluded that improper sampling technique is a major component of this variability, and correct sampling is vital to ensure the accuracy of diet composition and optimal animal production. Nevertheless, some 45 yr later, few animal nutrition studies report the sampling technique used or the variation caused by inappropriate sampling (Jones et al., 2018). The magnitude of ingredient variation on feed formulation costs and bird responses have been identified in recent years (Jurgens et al., 2012), but they have neither been practically applied in a framework that is useful to producers nor indicate the modern-day economic cost of such uncertainty. Thus, industry still faces the challenge of how to account for this variation in feed formulation (Kleyn, 2013).

In addition, nutritionists within large integrated companies may experience delays in receiving NIR information, and many consulting nutritionists do not have access to an NIR system. Thus, many nutritionists may rely on historical or ‘book’ values. To compensate for any discrepancies between the book values and true nutrient values of the feed, safety margins are applied to formulations in hope that the minimum nutrient requirements of poultry are being met. This is important for commercial feed companies; if nutrients fall below the minimum nutrient contents reported on the label, it may render them legally liable, and in a fully integrated system, bird performance may suffer, causing substantial economic losses to the business (Peña et al., 2009). Safety margins decided by nutritionists are further complicated by the difference between analyses of samples and the actual nutrient content of those ingredients in the feed being manufactured at a given time as multiple batches of a feed ingredient may be delivered to the mill and stored within one silo. However, increasing safety margins raises diet cost, and the size of the safety margin required to avoid nutrient levels falling below the intended level is ambiguous. Therefore, improving the certainty of the specifications used for dietary ingredients and increasing awareness of the variability that may be expected would allow the choice of appropriate safety margins. Improving the estimation of safety margins should also improve the balance of reduced feed costs and economical meat and egg production.

Thus, the industry faces 2 challenges. Where NIR is available, poor sampling technique may affect its accuracy, and delays in receiving information may mean the data are used historically rather than to adjust the present formulations. Where NIR is not available, book values (data published within the literature) are not often provided by the region or season that may help to refine the mean values reported. Book values also rarely include the SD or distribution of the data, which makes the estimation of safety margins inherently inaccurate. If SD was routinely provided, stochastic feed formulation could be used to formulate diets to the particular level of certainty (or probability) the nutritionist is comfortable with, providing a way to calculate safety margins.

Protein is an expensive and crucial macronutrient component of poultry diets, but its methods are relatively short compared with other nutrients, such as starch or fat. Therefore, this review will first model the extent that variation in protein in feed ingredients affects expected performance and profits for the poultry industry and second present options the industry may take to improve the accuracy of feed formulation.

ECONOMIC IMPACT OF IMPROPER SAMPLING AND VARIABILITY OF NUTRIENTS IN BROILER DIETS

Variability in feed ingredients originates from 3 sources: raw ingredient, sampling, and analyses (including normal analytical variability and differences in analytical methodology). Thus, with proper sampling technique used from the feed mill through to the laboratory, this variation may be reduced. The variability in CP of the

Table 1. Typical inclusion of CP-containing feed ingredients to wheat-based broiler starter, grower, finisher, and withdrawal diets used in calculations.

Feedstuff	Approximate proportion of diet (%)	CP level of diet (g/kg)	Protein supplied to diet (g/kg)	Proportionate SD of protein supplied to diet (g/kg)
Starter diet		228		7.40 (CV = 3.25)
Wheat	56.3		62.8	4.28
Soybean meal (origin: Brazil)	33.8		159.6	2.60
Full-fat canola seed	3.0		5.9	0.52
Grower diet		209		7.72 (CV = 3.69)
Wheat	60.2		67.2	4.58
Soybean meal (origin: Brazil)	27.6		130.3	2.13
Canola seed full fat	6.0		11.7	1.02
Finisher diet		191		7.92 (CV = 4.15)
Wheat	64.1		71.5	4.87
Soybean meal (origin: Brazil)	21.9		103.4	1.69
Full-fat canola seed	8.0		15.6	1.36
Withdrawal diet		192		7.92 (CV = 4.13)
Wheat	63.5		70.9	4.83
Soybean meal (origin: Brazil)	22.4		105.8	1.73
Full-fat canola seed	8.0		15.6	1.36

components of wheat-based poultry diets was estimated from the compilation of the nutrient content of feed ingredients (Moss et al., 2020). As variability is not equal among feedstuffs, the overall diet variability will depend on its composition. The proportion of variation in protein from each feed ingredient is calculated in Table 1, the sum of which gives the overall variation in CP content that may be expected within a typical wheat-based poultry diet. From Table 1, it is evident that the SD and coefficient of variation worsen in the finisher and withdrawal diets when increasing levels of full-fat canola seed are incorporated. Nevertheless, in the present exercise, wheat is the single greatest source of variability in CP content of the diets. This is important and should be routinely considered as it is arguably the most used feed ingredient for poultry within Australia, Western Canada, and Europe. The high variability in the finisher and withdrawal stages is particularly undesirable as greater amounts of feed are consumed in these periods, meaning there may be great economic impact. Thus, the potential economic impact of variability throughout a broiler production cycle will be modeled to demonstrate its importance.

Materials and methods

Starter, grower, finisher, and withdrawal diets used in the following exercise were formulated to most accurately represent wheat-based broiler diets (Table 2) using EFG Broiler Model software (Rob Gous, KwaZulu-Natal, South Africa) (EFG Software, 2020). Once the SD and mean of a dietary component is known, assuming normality, simulations can be performed to estimate the likelihood a diet mixed to optimal specifications may in fact fall below recommendations. This was performed for the following example using Excel 2016, NORMINV function, with 10,000 individual simulations per diet. To simulate the economic cost ($USD), the median, highest, and lowest dietary CP levels possible identified by the Excel simulation for the starter, grower, finisher, and withdrawal diets were modeled using EFG Broiler Model software (EFG Software, 2020). To formulate the diets, the CP level of feed ingredient and the diet nutrient specification were adjusted to give the desired low or high dietary CP level with essentially the same proportions of feed ingredients and diet costs. The simulation was based on a growth curve to mimic Ross 308 genetics (2019), set to 30,000 birds per cycle, placed at an initial stocking density of 15 birds/m^2, with estimated variable costs (chicks, vaccination, catching, cleaning, processing, and so on) totaling 164 cents/bird/cycle (all prices in $USD) and fixed costs (labor, insurance, repairs, and so on) totaling $28.5/m^2/year. The break period between cycles was set to 10 d and estimated flock mortalities set to 5% over the 42 d production. Environmental conditions were set to the Ross 308 guidelines,

Table 2. Composition and nutrient specifications of wheat-based starter (0–10 d after hatch), grower (11–24 d), finisher (25–37 d), and withdrawal (38–42 d) diets formulated to the mean intended CP level.

Ingredient (g/kg)	Starter	Grower	Finisher	Withdrawal
Wheat	578.8	621.3	656.8	655.4
Soybean meal	319.1	258.0	205.1	207.8
Full-fat canola seed	30.0	60.0	80.0	80.0
Oil (soy)	15.0	24.1	26.1	25.9
Tallow	13.6	-	-	-
Limestone (38% Ca)	13.4	12.0	10.6	10.6
Salt	1.93	1.75	1.77	1.77
Dicalcium phosphate	8.60	6.80	4.98	4.95
Sodium bicarbonate	2.98	2.68	2.66	2.66
Betaine	1.30	1.30	1.30	1.30
L-lysine sulfate	4.76	4.42	3.93	3.81
DL-methionine	3.45	2.91	2.49	2.46
L-threonine	1.67	1.39	10.75	1.04
Choline chloride (75%)	0.25	0.25	0.20	0.20
Vitamin and mineral premix[1]	4.50	2.50	2.50	1.5
Xylanase	0.25	0.25	0.25	0.25
Phytase	0.30	0.30	0.30	0.3
Nutrient (g/kg; unless specified)				
AMEn (MJ/kg)	12.55	12.97	13.39	13.39
CP	228.0	209.0	191.0	192.0
Lysine[2]	12.8	11.50	10.2	10.2
Methionine[2]	6.28	5.58	5.00	4.98
Methionine + cystine[2]	9.5	8.70	8.00	8.00
Cysteine[2]	3.21	3.11	3.00	3.01
Threonine[2]	8.6	7.70	6.80	6.80
Tryptophan[2]	2.59	2.38	21.8	2.19
Glycine [2]	7.67	7.04	6.45	6.49
Arginine[2]	13.18	11.81	10.53	10.61
Serine[2]	7.67	7.04	6.45	6.49
Histidine[2]	4.91	4.49	4.08	4.11
Isoleucine[2]	8.33	7.53	6.78	6.83
Leucine[2]	14.26	12.97	11.76	11.84
Valine[2]	9.05	8.31	7.59	7.64
Phenylalanine[2]	9.39	8.48	7.65	7.70
Ash	52.62	47.36	42.13	42.26
Crude fat	56.73	63.08	72.17	72.02
Calcium	9.60	8.70	7.80	7.80
Total phosphorus	5.44	4.94	4.42	4.43
Avail. phosphorous	4.80	4.35	3.90	3.90
Sodium	19.5	1.80	1.80	1.80
Chloride	2.00	1.90	1.90	1.90
Potassium	9.55	8.70	7.91	7.96
Electrolyte balance (mEq/kg)	272.7	247.3	227.0	228.3
Choline (mg/kg)	1,839.3	1,783.9	1,684.0	1,691.9
Cost ($USD)	322.56	311.45	305.96	298.15

[1] The appropriate vitamin and mineral premix (starter, grower, finisher, and withdrawal) was substituted within each formulation.

[2] Available.

and 2 cropping cycles were set over the total42-day grow-out period. Estimated sales were set at 30% sold dressed ($3.20, dressed weight and $2.71, downgraded) and 70% sold processed (breast, $5.34; thigh, $3.35; drum, $2.85; wing, $3.49).

Results and discussion

Simulations were performed for starter, grower, finisher, and withdrawal diets (Figures 1A–1D, respectively) to estimate the likelihood a diet mixed to optimal specifications

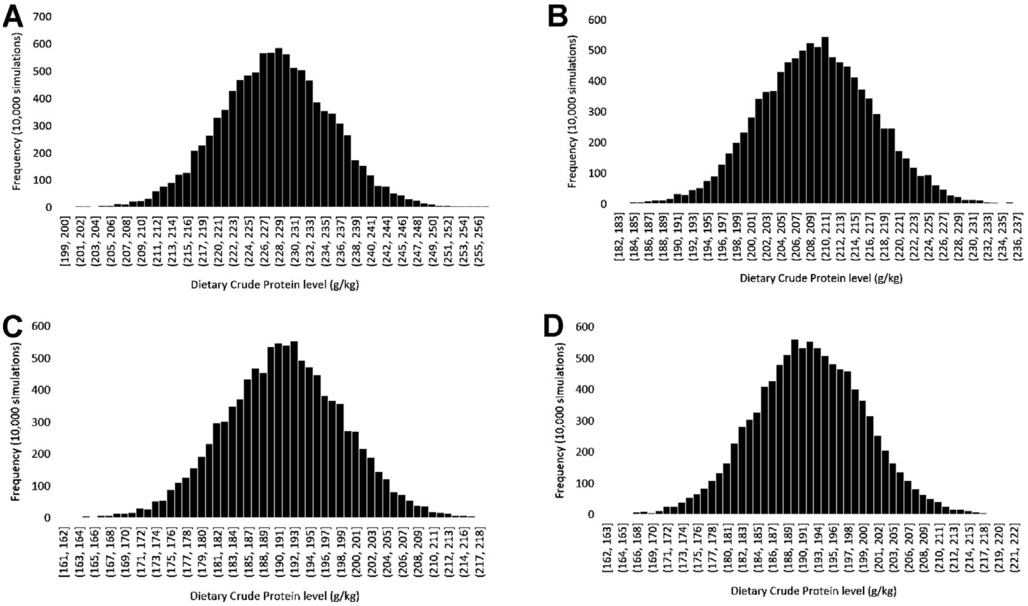

Figure 1. Frequency plot displaying the dietary CP level in 10,000 simulations for a standard wheat-based (A) starter, (B) grower, (C) finisher, and (D) withdrawal diet.

may in fact fall below recommendations. Within withdrawal diets formulated to 192 g/kg of CP from book values, there is approximately a 10% probability (or one in 10 diets) that it will fall below 182 g/kg of CP. However, the potential impacts of overall dietary CP variability are substantially attenuated if the variability of CP in wheat is reduced. For example, suppose sampling and laboratory techniques were improved and wheat CP content was able to be estimated with greater accuracy, reducing the variability of CP in wheat by 10%. This gives an SD of 6.8 for wheat or a total withdrawal diet SD of 7.41. Simulating this change reveals that there is only 8.7% probability that a withdrawal diet pelleted with these ingredients will fall below 182 g/kg of CP. Let us now assume sampling and laboratory techniques were improved to a greater extent, reducing variability of CP by 25% for each ingredient (from the original values), giving an overall total withdrawal diet SD of 5.94 g/kg of CP. Simulating this change reveals that there is now <5% probability that a withdrawal diet will fall below 182 g/kg of CP. Thus, reducing ingredient variability will help increase the odds that the final pelleted diet meets the specified requirements. Given that poultry feed accounts for 65% of total production cost, how much could poor sampling technique and high ingredient variability be costing the poultry industry?

Gross profit is best measured as a margin per unit of area over time. In the simulation (Figures 2 and 3), birds were processed at 42 d after hatch with a 10-day downtime, resulting in 7.019 cycles (or placements) per year. Thus, a comparison of margin/m^2 of shed (or barn) floor space between the various simulations has been used because all time periods in this instance are equal (Table 3). However, if the target response per broiler is based on a set live weight, then variable cycles ensue and time periods become relevant. The EFG broiler growth simulation using the median protein values returned the greatest financial gross margin of \$15.14/m^2, while the return on the minimum dietary protein was 63% lower (5.61/m^2) and the maximum dietary protein was 21% lower (\$12.02/m^2). EFG simulation predicted the greatest total estimated profits (Table 3), weight gain (Figure 2), and most efficient feed conversion ratio (Figure 3) from the diets with CP formulated to median levels. Thus, it is possible to incur a difference of up to \$19,053 in gross

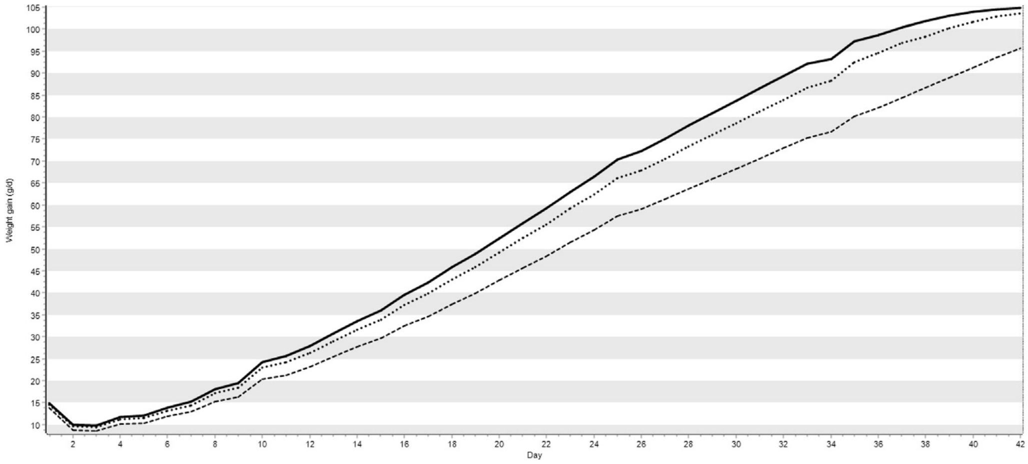

Figure 2. Simulation of diets formulated to reflect the effect of the mean (solid) intended crude protein level and the possible extreme low (dash) and high (dot) crude protein levels calculated from the variability of crude protein within wheat-based starter (0-10 days post-hatch), grower (11-24 days post-hatch), finisher (25-37 days post-hatch) and withdrawal (38-42 days post-hatch) diets on weight gain (g/bird/day).

margin from one cycle of 30,000 broilers by simply overestimating the nutrient content of feedstuffs. Therefore, sampling error has the possibility to generate large financial consequences, with the overestimation of the nutrient content of feed ingredients (i.e., feed ingredients being lower in nutrient content than their perceived value) representing the largest potential cost.

It is also important to also note that while the highest calculated CP level had less of an impact to profits than the low CP level, it may have a larger environmental impact. Nitrogen excretion was highest on day 42 for birds fed with high-CP diet at a dose of 4,329 mg/bird/day than those fed with medium (3,293 mg/bird/day)- or low (2,492 mg/bird/day)-CP diets. Thus, although the cost impact may not be as great in the high-CP diet than in the low-CP diet, environmental impacts are of a greater extent.

POSSIBILITIES TO IMPROVE THE ACCURACY OF FEED FORMULATION

Clearly, as demonstrated previously, sampling error has the potential to have large impacts on the profitability of a poultry enterprise. Thus, it is important to minimize error wherever possible. Some practical possibilities to improve the accuracy of feed formulation within the poultry industry are discussed in the following sections, including NIR systems, improving the descriptive information provided within book values, feed formulation strategies, and, importantly, improving sampling methodology.

Near-Infrared Systems

Real-time/In-line Systems. In-line and real-time NIR systems installed within the entrances to silos may relay information to the nutritionist about the incoming feed ingredients to the mill. One anecdotal issue with a real-time system is that feed mills do not have the capacity to store deliveries of wheat separately, and thus, different batches of the same ingredient must be combined together in a silo. Although the nutritionist would not be certain of the exact composition of which batch of ingredient was present in the silo, it should still provide a more accurate estimate of the silo's contents than book values. In addition, assigning 2 silos to one ingredient within the mill to allow segregation of above- and below-average samples has been shown to be an effective way of reducing the variability of CP within ingredients by more than 50% compared with storing ingredients in one silo only (Alhotan et al., 2014).

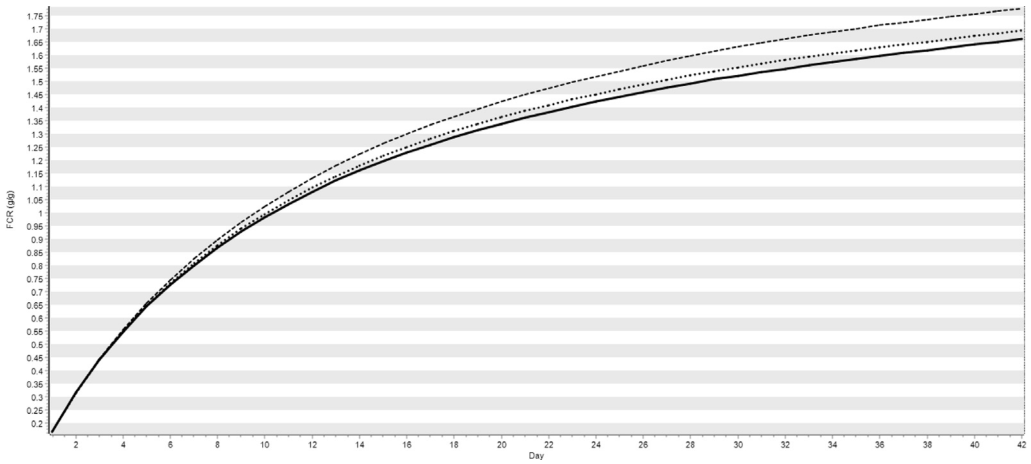

Figure 3. Simulation of diets formulated to reflect the effect of the mean (solid) intended CP level and the possible extreme low (dash) and high (dot) CP levels calculated from the variability of CP within wheat-based starter (0–10 d after hatch), grower (11–24 d after hatch), finisher (25–37 d after hatch), and withdrawal (38–42 d after hatch) diets on FCR (g/g). Abbreviation: FCR, feed conversion ratio.

Hyperspectral Imaging. Hyperspectral imaging combines spectroscopy (such as that of NIR) and further enhances this information with imaging techniques to identify multiple components within a product and the spatial distribution of these components and thus calculate the compositional gradient of a product. By providing spectral and spatial information simultaneously, hyperspectral imaging technology may present a more accurate alternative system than NIR as it accounts for variation across an entire sample (Elmasry et al., 2012; Manley, 2014).

Improvement of Book Value Accuracy and Descriptive Data

Where possible, NIR should be used to determine the nutrient content of the specific ingredient, but for many, this technology is not available. Therefore, enhancing the accuracy and amount of information within databases and ensuring these data are accessible by industry is important. Although many companies provide a good range of data on feed ingredients with quite high sample numbers for some ingredients (Moss et al., 2020), there are still ingredients that lack recent data, and not all sources report important information. For example, in addition to a mean value, the SD and distribution should be provided but is often overlooked. The SD allows the determination of the likelihood that using the mean value will result in a substantial number of the finished feed batches to be below expected nutrient levels as demonstrated previously. The distribution is important as not all nutrients may follow the assumed normal distribution, and in such instances, the median value is a better determination of the true central tendency than the mean (Weiss, 2004). Provision of region- and season-specific data for very common ingredients such as wheat may also prove useful owing to the wide variety of environmental conditions the feedstuff may be grown in.

Table 3. EFG model simulation of economic analysis per batch (cycle) of broilers (total, 30,000), placed at 15 broilers/m^2 and reared to 42 d after hatch in 2,000 m^2 floor space sheds (or barns).

	Gross margin, in $USD					
	Per bird		Per kilogram		Per unit area (m^2)	
Simulation CP level	Per cycle	Per year	Per cycle	Per year	Per cycle	Per year
Minimum	0.37	2.63	0.043	0.30	5.61	39.41
Median	1.01	7.08	0.095	0.67	15.14	106.27
Maximum	0.80	5.62	0.087	0.56	12.01	84.36
Maximum difference	0.64	4.46	0.052	0.36	9.53	66.87

Feed Formulation Techniques to Minimize the Potential Negative Impact of Variability

Once information on the SD of the nutrient content of feed ingredients is attained, it is possible to formulate diets via stochastic means as an alternative to a safety margin. One of the main false assumptions of linear programming is that the parameters are known with certainty, and thus, linear programming models do not account for nutrient variability within feed ingredients (Peña et al., 2009). Safety margins are thus added to either increase the input nutrient requirement of the animal or reduce the input nutrient content of the feed ingredient to provide a 'buffer' to the variation within the feed ingredients. However, this margin is arbitrary and may increase feed cost excessively or lead to environmental pollution.

Stochastic feed formulation is a tool to assure the specified minimum nutrient content of the diet is met by calculating probabilities from the distributions of the nutrients within the ingredients (D'Alfonso et al., 1992). Stochastic feed formulation models have been proven effective in poultry (D'Alfonso et al., 1992), pigs (Peña et al., 2009), and other species (Udo et al., 2011). Within poultry, the stochastic model was shown to meet the nutritional requirements of poultry over a range of confidence levels and consistently resulted in lower feed costs than formulating diets with safety margins included in the study by D'Alfonso et al. (1992). In addition, using a wide variety of ingredients so that you do not rely too heavily on the accuracy of the nutrient content of one ingredient and limiting the use of ingredients with a large SD may also help to reduce the costs associated with variation (Weiss, 2004).

Improving Sampling Methodology

Improving the use of proper sampling methodology will enhance the accuracy of NIR technologies and also book values as careless errors resulting in misleading data will be reduced. Smaller SD relative to the mean nutrient content within an ingredient will reduce the likelihood of nutrients falling below desired levels in feed formulation (Weiss, 2004) and thus reduce the cost of diets formulated via stochastic means. Nevertheless, 45 yr after the review by Lerman and Bie (1975), which identified that the major component of feed ingredient variability was improper sampling technique and correct sampling is vital, variability and uncertainty in feed ingredient specifications is still a large concern for the poultry industry as inaccurate analysis may mean ingredient inclusions in the final diet formulation are underestimated and overestimated (Reese et al., 2017). However, few animal nutrition studies report the sampling technique used or the variation generated by sampling (Jones et al., 2018). Thus, it has been concluded that industry still faces the challenge of how to account for this potential variation in feed formulation (Kleyn, 2013).

Furthermore, aside from the literature highlighted previously, there are very few research articles that identify or demonstrate the importance of proper sampling technique. However, there are some instructive technical documents available and are discussed in the following section.

Industry-Specific Sampling Methodology. Technical bulletins describing sampling procedures for poultry feed are available (Herrman, 2001; AAFCO, 2014; Malomo and Ihegwuagu, 2017; FAO, 2008; Meehan and Sedivec, 2018; U.S. Food and Drug Administration, 2019); however, recommended sampling methodology and depth of detail varies greatly. In addition, the technical bulletins describing sampling techniques (Herrman, 2001, AAFCO, 2014, Meehan and Sedivec, 2018) discuss methods to get a more accurate sample from a hand or bag probe. However, Association of Official Analytical Chemists International has identified stream sampling as a more effective procedure than probe sampling, whereby small portions are sampled from the stream at periodic intervals and the portions are combined into a large aggregate sample, which can be performed effectively using an automatic cross-cut sampler (Davis et al., 1980). Stream sampling will only be effective for feedstuffs that flow, such as grain. For sampling methodology to be used, it must be practical within an industry setting. For example, within a feed mill, probe samples may be quickly obtained from trucks full of grain as they arrive to the mill to determine if the grain is appropriate to accept. Taking a stream sample at this point is not practical as the grain would need to be unloaded from the truck. However, upon loading the accepted grain into a silo, there may be opportunity to collect stream samples randomly throughout unloading from the auger to more accurately assess the grain's nutrient content for the purpose of feed formulation. While multiple truckloads of grain are often contained within a silo, the data may be aggregated to attain a more accurate approximation of the average nutrient content. However, the high frequency of turnover of certain ingredients may mean that updating the diets with nutrient matrix changes upon each delivery is impractical.

Another important consideration is that the primary sample taken must also be of substantial size and then reduced via material reduction and subsampling techniques to achieve the degree of correlation required (Petersen et al., 2004). Some guidelines of the size of samples to take from various feedstuffs are provided in the study by Malomo and Ihegwuagu (2017). Grab samples are commonly used within industry to subsample for its ease; however, it was reported to generate one of the largest SD and worst representativeness of 17 methods tested in the study by Petersen et al. (2004). In contrast, rolling dividers such as the Boerner Divider were recommended (Herrman, 2001; Petersen et al., 2004) as they divided samples with the greatest accuracy to attain a sample small enough with which to perform analysis.

The Official Journal of the European Union states that methods used for sampling should comply with union rules and provides a comprehensive guide to sample preparation of animal feed stuffs (International Organization for Standardization, 2012), which could prove useful outside the European Union; however, the method is not provided open access, and thus, there are barriers to its use. Nevertheless, a European Union guide describing sampling and mixing techniques and equipment to sample feedstuffs for genetically modified organism analysis is openly accessible and describes many of the acceptable sampling techniques for animal feeds (European Union, 2014).

Grain Trade Australia provides a fact sheet on appropriate sampling equipment and some procedures for static grain sampling from road trucks (Grain Trade Australia, 2018). However, it is identified within the Grain Trade Australia document that the research defining their recommendations "was conducted many years ago," that "studies indicate variability among probe types," and that owing to the variability in probe type, depth of the load, and commodity type, obtaining a representative sampling via their methodology is not always possible. Furthermore, the procedures outlined in this document are likely not applicable to small-scale poultry research facilities. These methods are only for grain feed ingredient samples and do not cover protein meals or pelleted feeds. Within the document, it is stated that, "as there has not been any data provided on the financial loss to industry of inappropriate sampling systems, this research to date has not been considered a high priority." However, as shown previously, the losses are likely substantial, and thus, sampling systems should be a high-priority research theme for the poultry industry and also for many other intensive animal production systems as the challenges described in this article exist within many agricultural industries.

CONCLUSIONS AND APPLICATIONS

1. Misestimating the nutrient content of feed ingredients clearly has the potential to have vast economic consequences for the poultry industry. Thus, improving sampling methods and access of industry and researchers to clear information about sampling techniques and proper reporting is a key priority. Within this example, it was demonstrated that it is possible to incur a 63% reduction in gross margin, or a difference of up to \$19,053 (USD) in gross margin, from one cycle of 30,000 broilers by simply overestimating the nutrient content of feedstuffs. Assuming a poultry company may produce approximately 1,000 broiler cycles per year, and this equates to a loss of up to \$19 million (USD).
2. The global chicken meat industry produces approximately 304.6 million metric ton of feed, which may represent a total cost of more than \$110 billion. Thus, there are potentially considerably large economic

consequences arising from poor sampling methodology and the variability within feed ingredients.

3. Therefore, the effect of variation in feed ingredients on performance and profits for industry nutritionists is of great importance, and it is hoped that this review has highlighted this underestimated issue. Nevertheless, proper sampling methods provided within the literature provide a multitude of differing recommendations.
4. It is also apparent that grab samples are commonly used within industry to subsample for its ease; however, it is reported to generate one of the largest SD and worst representativeness of the 17 methods tested (Petersen et al., 2004). As losses may be substantial, sampling systems and variability within ingredients should be a priority research theme for the poultry industry and likely also for many other intensive animal production systems as the challenges described in this article are met across many industries.
5. Finally, other approaches to help mitigate this risk include the improvement of descriptive data that are provided in book values (e.g., SD and normality of the distribution), adoption of NIR technologies where possible, and the implementation of feed formulation strategies to minimize the impact of variability within ingredients.

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DISCLOSURES

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