FEEDING PROGRAM AND USE OF ADDITIVES IN GROWING-FINISHING PIGS

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1.- SUMMARY

Historically, the grow-finish phase of production received less attention in swine nutrition research. Nursery pig research requires less feed, provides easier replication, and needs fewer days to complete a turn. Conversely, finishing pig research takes considerable time and large numbers of pigs are required to find small, but important, differences in performance. It is much easier to create a 5 to 10% change in nursery performance than finisher performance. However, 75 to 80% of the feed used to produce a pig is consumed in the grow-finish phase of growth. Therefore, the finishing pig phase has huge financial implications for the swine producer.

In reviewing the important areas of concern for finishing pigs, we approach them in terms of how we formulate diets. We first determine the most economical energy level. Then, determine the lysine:calorie ratio for that energy level. The third step is to set the ratio for other amino acids relative to lysine. Fourth, we set the STTD or available P:calorie ratio. Finally, the last step is to set the level of calcium, vitamins, trace minerals, salt, and other ingredients including feed additives. We will briefly discuss each of these areas with emphasis on the feed additives in the last section of this review.
2.- ENERGY RESPONSE, FIBER, AND CARCASS DRESSING PERCENTAGE

The first and most important step in diet formulation is to set the energy concentration. Even though energy is the most expensive component of the diet, the level used in formulation is often based on history or impact on diet cost rather than an in-depth analysis to determine the most economical level. To set the optimal energy level in the diet, we must know how an incremental change in dietary energy affects:

- Diet cost
- Pig performance (ADG, F/G)
- Carcass criteria (dressing percentage, lean percentage)

Additionally, the economic value of these incremental changes are dependent on the market price. Our team has built a model (Soto et al., 2017a) using this information to help calculate the optimal dietary energy level in each phase. The key components of that model are discussed here briefly.

3.- IMPACT OF DIETARY ENERGY ON PIG PERFORMANCE AND CARCASS CRITERIA

Ideally, a production system will know how pigs respond to dietary energy changes in their system; however, this is not always possible. In these cases, information from the literature on historically expected responses is valuable. For example, Nitikanchana et al. (2015) developed regression equations from a meta-analysis to predict the change in growth rate for each incremental change in NE intake. The equation from their work predicts ADG, \( g = 0.1135 \times \text{NE, kcal/kg} + 8.8142 \times \text{Avg BW, kg} - 0.05068 \times (\text{Avg BW, kg})^2 + 275.99 \), provided lysine or other amino acids are not limiting performance. Thus, for every 100 kcal/kg increase in NE, ADG would increase by 113.5 g/d. For feed efficiency, the assumption is that efficiency is linearly related to net energy content of the diet. Thus, a 1% change in net energy will result in a 1% change in feed efficiency (figure 1).

Changes in dietary NE level do not fully account for this negative impact of fiber on carcass weight. Feeding diets with high levels of fiber increase digesta content in the colon and cecum at processing and reduce dressing percentage (Turlington, 1984). The increase in gut fill is a result of the type of fiber in the ingredient. Neutral detergent fiber has been shown to result in the digestive contents to swell by absorbing water thus increasing the fecal volume in the large intestine (Coble et al., 2015). Thus, Soto et al. (2017b) conducted a meta-analysis to determine the impact of neutral detergent fiber in diets fed before slaughter on dressing percentage. The regression analysis yielded the equation: Dressing percentage, \(\% = 0.03492 \times \text{WP (d)} - 0.05092 \times \text{NDF1} (%) - 0.06897 \times \text{NDF2} (%) - 0.00289 \times (\text{NDF2} (%) \times \text{WP (d)}) + 76.0769 \), with the variables being the number of days in the withdrawal period (WP), NDF level in the dietary phase before the final phase (NDF1), NDF level in the withdrawal period before marketing (NDF2), and the interaction between NDF2 and WP. This equation was derived from U.S. raised pigs where dressing percentage is calculated with the head removed. As the equation indicates, high
levels of NDF have a negative impact on carcass yield. Increasing the length of the withdrawal period improved carcass yield; however, the effect of withdrawal period was dependent on the level of NDF in the last diet fed (NDF2), as indicated by the interaction term.

Figure 1.- Predicted ADG response to dietary net energy (from Nitikanchana et al.; 2015, where ADG, g = 0.1135 x NE, kcal/kg + 8.8142 x Avg BW, kg - 0.05068 x (Avg BW, kg)² + 275.99)

Thus, the optimal energy density for the diets fed immediately before market must be determined on a carcass weight basis to include the dressing percentage component.

4.- LYSINE, AMINO ACID RATIOS, AND CRUDE PROTEIN

Once the dietary energy level is determined, the lysine:energy ratio and amino acid concentrations or ratios relative to lysine must be set. Although the lysine requirement is best determined within the production system or modeled from protein accretion data, it can be estimated using growth rate and feed intake data. A simple rule of thumb is that grow-finish pigs require approximately 20 g of standardized ileal digestible (SID) lysine per kg of gain. The requirement is lower in the early grower stage and higher during peak protein deposition phase; however, 20 g/d is a reasonable average of the requirement since growth rate is highly correlated with protein deposition rate. Background on this estimate and supporting data can be found in Rostagno (2017).

Once SID lysine is determined, the ratios of other amino acids are set relative to lysine. Most amino acid ratios are well-established. Ratio estimates used in diet
formulation by our research group are summarized in table 1. Much of the disagreement between nutritionists in optimum ratios is a result of different amino acid loadings in diet formulation software. For example, a 68% valine to lysine ratio using amino acid data from one lab may be similar to a 70 or 72% ratio using data from another lab. A second disagreement in ideal ratios relative to lysine is differences in interpretation of the data. Optimal amino acid ratios are often depicted as a point using breakpoint analysis. In reality, a quadratic shape or diminishing returns model more accurately depicts the response to changing amino acid levels in most group feeding situations. Thus, a model can be used to determine whether the ratio will provide 99 to 95% of the maximum response. This technique allows modeling of the ratio that provides the most economical response for a production system rather than simply the maximum response. An example of this type of modelling is established for the optimal tryptophan:lysine ratio for finishing pigs. Selecting the optimum amino acid ratio is dependent on the value of weight gain and incremental cost to increase the ratio. An economic calculator to determine the optimal tryptophan:lysine ratio can be downloaded from: http://www.lysine.com/en/techinfo/TrpLys.aspx.

Table 1.- Minimum ratios of other amino acids relative to lysine

<table>
<thead>
<tr>
<th>Weight range, kg</th>
<th>25 to 50</th>
<th>50 to 75</th>
<th>75 to 100</th>
<th>100 to 135</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isoleucine</td>
<td>52</td>
<td>52</td>
<td>52</td>
<td>52</td>
</tr>
<tr>
<td>Leucine</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Methionine &amp; Cystine</td>
<td>56</td>
<td>56</td>
<td>56</td>
<td>58</td>
</tr>
<tr>
<td>Threonine</td>
<td>61</td>
<td>62</td>
<td>63</td>
<td>65</td>
</tr>
<tr>
<td>Tryptophan</td>
<td>18 - 21</td>
<td>18 - 21</td>
<td>18 - 21</td>
<td>19 - 21</td>
</tr>
<tr>
<td>Valine</td>
<td>68</td>
<td>68</td>
<td>68</td>
<td>70</td>
</tr>
</tbody>
</table>

*Diets with high leucine (ex. > 140% of Lys) require higher isoleucine (ex. 60% of lysine).

*Optimal tryptophan:lysine ratio depends on value of weight gain.

In many parts of Europe, dietary crude protein maximums are required by law. We do not have these requirements in the US and, thus, diets are often much higher in crude protein than in Europe. We are concerned with minimum crude protein levels, particularly in the diets for heavy weight finishing pigs. Our research continues to indicate that diets for pigs over 100 kg should contain at least 13% crude protein to not limit performance. Although considerable research has been conducted, the reason that dietary crude protein cannot be lowered below 13% is not known.

The optimal number of dietary phases for finishing pigs also has received attention. Increasing dietary phases to more closely match the pigs’ amino acid requirement will reduce nitrogen excretion; however, pig performance is rarely improved by increasing the number of dietary phases. As long as the diets fed prior to pigs being marketed are at or above the pigs’ requirement to allow compensatory gain to occur, pigs will compensate for performance that has been lost due to feeding diets that are slightly below their requirement during earlier phases (Main et al., 2006; Menegat et al., 2017).
5.- STANDARDIZED TOTAL TRACT DIGESTIBLE PHOSPHORUS (STTP) AND CA:P RATIOS

As protein accretion rates increase, the phosphorus requirement also increases (Carter and Cromwell, 1998). Desire to minimize phosphorus excretion have led to diets that are marginal in phosphorus. Recent research indicates that the STTD phosphorus requirement of finishing pigs may be as high as 130% of NRC (2012) estimates. Fortunately, high usage of newer phytase products allow more phosphorus release and allow us to be closer to the phosphorus requirements without excess phosphorus excretion.

The calcium:phosphorus ratio is extremely important in diets that are marginal in phosphorus. Although this ratio can be expressed in many ways, we choose to consider the analyzed calcium to analyzed phosphorus ratio because it can be easily measured. We prefer this ratio to be between 1:1 and 1.3:1 for finishing pigs.

6.- OTHER MINERALS AND VITAMINS

Recommendations for inclusion of other minerals and vitamins can vary considerably (Flohr et al., 2015). Basal levels of vitamins and minerals in the ingredients being fed also should be considered when determining levels of supplementation.

7.- FEED ADDITIVES IN THE FINISHING PHASE

We chose to spend time discussing diet formulation in this paper to emphasize that energy, amino acid, and Ca and P levels are much more important than feed additives that are included in diets to improve performance. There is an exhaustive list of additives available for use in finishing pig diets; however, the list of additives with sufficient research data to justify their use is much shorter.

The question of sufficient data for an additive is an important one. Producers and nutritionists are often tasked with interpreting company information on additives to try to determine which are worthy of testing or including in their diets. Additives often have no production data or data with a few pigs and inadequate replication. How much replication is necessary for a new product? The replication within an experiment depends on the size and consistency of the expected response. Multiple experiments also are needed to demonstrate the consistency across experiments. As a rule of thumb, production nutritionists have advised the need for at least three experiments demonstrating a consistent response before they will test a new product in their system.

The number of replications to find a difference from the control treatment in one of our production research barns is shown in table 2. This facility has approximately 25 pigs per pen. Although there is variation in the standard deviation from one experiment to another, the average for this barn across several experiments is 27 g/d for ADG and 0.09 for F/G. If a feed additive is expected to increase ADG by 2% in the finisher, we would
need 35 replications of each treatment to find the response. For F/G, 40 replications would be needed to find a 2% response. Increasing the response to 3% reduces the number of replications required to 16 for ADG and 18 for F/G. In many experiments, 6 or 8 replications are arbitrarily chosen in designing the experiment. The additive would need to provide at least a 5% response to be able to detect a difference with 6 to 8 replications. If we do the same experiment in our university facilities, where there are fewer pigs pen, the number or replicates required to find responses of the same magnitude are much greater. If a feed additive has a significant response with relatively few replications, I would be skeptical about the repeatability of the response.

### Table 2.- Number of replications required per treatment to find a difference

<table>
<thead>
<tr>
<th>Item</th>
<th>Difference from control to be detected, %</th>
<th>2.0%</th>
<th>3.0%</th>
<th>4.0%</th>
<th>5.0%</th>
<th>7.5%</th>
<th>10.0%</th>
</tr>
</thead>
<tbody>
<tr>
<td>SD for ADG (907 g)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18 g</td>
<td></td>
<td>16</td>
<td>7</td>
<td>4</td>
<td>4*</td>
<td>4*</td>
<td>4*</td>
</tr>
<tr>
<td>27 g</td>
<td></td>
<td>35</td>
<td>16</td>
<td>9</td>
<td>6</td>
<td>4*</td>
<td>4*</td>
</tr>
<tr>
<td>36 g</td>
<td></td>
<td>63</td>
<td>28</td>
<td>16</td>
<td>10</td>
<td>4*</td>
<td>4*</td>
</tr>
<tr>
<td>SD for F/G (2.80)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.08</td>
<td></td>
<td>32</td>
<td>14</td>
<td>8</td>
<td>5</td>
<td>4*</td>
<td>4*</td>
</tr>
<tr>
<td>0.09</td>
<td></td>
<td>40</td>
<td>18</td>
<td>10</td>
<td>6</td>
<td>4*</td>
<td>4*</td>
</tr>
<tr>
<td>0.10</td>
<td></td>
<td>50</td>
<td>22</td>
<td>13</td>
<td>8</td>
<td>4*</td>
<td>4*</td>
</tr>
</tbody>
</table>

Although the list of potential feed additives for use in the finisher phase is exhaustive, we will briefly review the main classes of products and try to provide a few key references for each class. Many new products being tested in the industry are combination products using two or more classes of additives in an attempt to provide a measurable benefit.

### 8.- ENZYMES

Enzymes are proteins that can be used to target different substrates in the diet to accelerate their breakdown. Most typically the enzymes used in swine diets include phytase, protease, β-glucanase, α-amylase, and xylanase. While phytase has been shown to be effective to improve phosphorus digestibility (Jacela et al., 2010a), carbohydrate-degrading enzymes have been less consistent in demonstrating responses (Jacela et al., 2009a). By breaking down dietary phytate, phytase also improves utilization of other dietary nutrients, especially when added to the diet at high concentrations (Dersjant-Li et al., 2015). Field research with xylanase suggests potential benefits in reducing mortality (Zier-Rush et al., 2016). The researchers, led by Dr. Dean Boyd from Hanor Company, propose the mode of action is through breaking down arabino-xylans to smaller, prebiotic, xylo oligomers. The resulting shift in microbiome balance is thought to support beneficial bacteria and butyric acid production to aid intestinal barrier function. Clearly further research is needed to confirm these responses. Limited consistent production benefits have been demonstrated for the other enzymes.
9.- PROBIOTICS

Probiotics are live cultures of organisms supplemented in pig diets that can beneficially affect the host animal by improving the microbial balance in the gut (Fuller, 1989). In a review of 44 published experiments using probiotics, they reported numerical improvements in ADG were observed in over 70% of the experiments reported with only 6.8% of the experiments reporting improvements in ADG that were statistically significant. The inconsistency in responses to probiotics may also be partially explained by the use of different direct fed microbial strains (Simon et al., 2003). Organisms commonly used include lactobacillus acidophilus, enterococci faecium, bacillus species, bifidobacterium bifidum, and the yeast saccharomyces cerevisiae (Simon et al., 2003; Chaucheyras-Durand and Durand, 2010). Four mechanisms have been reported to explain the protective effects of probiotics: 1) antagonism through the production of antimicrobial substances, 2) competition with the pathogen for adhesion sites or nutritional sources, 3) immunomodulation of the host, and 4) inhibition of the production of bacterial toxins (Musa et al., 2009). Another possible mechanism by which a probiotic may exert beneficial effects is through its effect on the permeability of the gut, which may increase nutrient uptake and thus improve growth performance. However, results of growth performance trials with probiotics continue to be inconsistent (Jacela et al., 2010b).

10.- PHYTOGENICS

Phytogenic feed additives include herbs, spices, and essential oils. In a review of trials evaluating phytogenics, available evidence indicates that phytogenic feed additives may have potential benefits (Windisch et al., 2008). While the exact mode of action and physiological effect of plant extracts are not fully understood, most are associated with antimicrobial benefits, increased antioxidant activity, and improved gut function (Jacela et al., 2010b). Additionally, phytogenics can potentially increase diet palatability, which could lead to greater feed intake and growth rates (Windisch et al., 2008; Karaskova et al., 2015). Within the phytogenics classification, the active substances found in the products may vary widely depending upon the plant species, plant part used, harvesting season, and geographical origin. Plant extracts have been predominantly provided through essential oils. Essentials oils, are typically mixtures of secondary plant metabolites and may contain phenolic compounds, terpenes, alkaloids, lectins, aldehydes, polypeptides. The exact mode of action of essential oils has not been established, but the activity may be related to the potential of the hydrophobic essential oils to intrude on the bacterial cell membrane, disintegrate membrane structures, and cause ion leakage (Windisch et al., 2008). This influence on the cell membrane provide phytogenics with a potential synergistic effect when coupled with compounds that can act inside the cell after the membrane is disrupted. A systematic approach is needed to explain the efficacy and mode of action for each of type and dose of active compound, possible interactions with other feed ingredients, and safety of phytogenic compounds used as feed additives for swine.
11.- ACIDIFIERS

Acidifiers have been used for decades, mostly for feed preservation. Acidifiers can be classified as organic acids and their salts, inorganic acids, and blends of acids and salts (Tung and Pettigrew, 2006). Most commonly used acidifiers are formic, propionic, acetic, citric, benzoic, or fumaric acid (Suiryanrayna and Ramana, 2015). Organic and inorganic acid combinations are often used commercially, and products with mixed acids are reported to have better performance responses than single acids due to synergistic effects (Chai et al., 2016). In addition, some commercially available products contain acids coated with lipids and other molecules (Upadhaya et al., 2014), mainly to protect and release the acid in a targeted location to ultimately improve their effectiveness. Several modes of action have been suggested for acidifiers including: 1) reduction of diet pH, 2) antimicrobial effects by disruption of bacterial protein synthesis, 3) disruption of cell membrane integrity in bacterial pathogens, and 4) improvement of nutrient digestibility, mainly crude protein and dry matter. Acidifiers have been shown to improve weight gain and feed efficiency in pigs with the greatest benefit during the first weeks after weaning (Tung and Pettigrew, 2006; Jacela et al., 2009b). Potassium diformate and other acidifiers are also often used in growing-finishing pigs, particularly during periods of transition and higher stress. Tung and Pettigrew (2006) indicated that the addition of acids to the diet can improve performance of growing (3.5%) and finishing pigs (2.7%), and, under stressful or disease conditions, acids appear to be effective measure at reducing scouring rate. Reported improvements in growth performance are highly dependent on dose, combination, and nature of acidifiers (Tung and Pettigrew, 2006), as well as diet composition (Jacela et al., 2009b).

12.- PHARMACOLOGICAL CONCENTRATIONS OF COPPER AND ZINC

Low concentrations of added copper (5 to 10 mg/kg) and zinc (50 to 125 mg/kg) are generally enough to meet the pig’s nutrient requirement. However, in the nursery stages, when fed at pharmacological concentrations (100 to 250 mg/kg for copper and 2,000 to 3,000 mg/kg for zinc), these two minerals are known to exert positive influences on growth rate (Hill and Spear, 2001). Recent research continues to show the benefit of supplemental Cu, fed conventionally as copper sulfate or tribasic copper chloride, on feed intake and growth in growing finishing pigs (Coble et al., 2017). While the exact mode of action for growth promoting effects of copper are unclear, they may be attributed to antibiotic-like activities (DuPont et al., 1994). Possible mechanisms for this effect could be attributed to: 1) disruption of bacterial cell membranes where Cu ions penetrate the cell membrane, altering the permeability and causing ion leakage, 2) lipid oxidation where Cu ions enter the cell, stimulate lipid oxidation and combines with intracellular amino acids, which leads to protein denaturation and cell death, and 3) bacterial cell toxicity at high Cu concentration (Pang and Applegate, 2007). Long term environmental limitations prevent high levels from being fed in many countries, but the use of high Zn (nursery) and Cu (nursery and finishing) is commonly practiced where legally approved.
13.- YEAST DERIVATIVES

The three most widely used yeast-derived products are the yeast cell wall, mannanoligosaccharides (MOS), and β-glucans. The yeast cell wall has been used as a prebiotic and immunomodulator, but their specific modes of action are not fully understood. MOS, commonly referred to as mannans, represent surface polysaccharides that make up 20% of the yeast cell wall and serve to store energy (Che, 2010). MOS potentially enhances resistance to enteric disease and promotes growth by: 1) inhibiting colonization of enteric pathogens by blocking binding sites on cell membranes, and 2) enhancing immune response by influencing the innate and adaptive immunity. β-glucans are glucose polymers that are major structural components of the cell wall of yeast, fungi, and bacteria, but also of cereals like oat and barley (Volman et al., 2008). The effects of β-glucans are highly dependent on the source and structure (Stier et al., 2014). The most observed mode of action of β-glucans are induction of innate and adaptive immune responses such as phagocytosis, oxidative burst, and upregulation of cytokines and chemokines. These compounds have been suggested to contribute to the increased resistance against infections observed after β-glucan enteral and parenteral interventions (Volman et al., 2008; Stier et al., 2014). Several benefits of the use of yeast derivatives have been proposed, but the benefit for animal immunity remains unclear and impacts on pig performance, especially in the finisher stage are unremarkable.

14.- SHORT AND MEDIUM CHAIN FATTY ACIDS

In a review, Liu (2015) discusses the numerous experiments demonstrating the influence of short and medium chain fatty acids (MCFA) on improving intestinal morphology and decreasing diarrhea with most of the research in nursery pigs. Medium chain fatty acids have also been found to be able to inhibit bacteria growth in vitro with the majority of research indicating they are more active against gram positive than gram negative bacteria (Zentek et al., 2011). The same review also cited the anti-viral activity of C8 and C10 fatty acids. Recently, our team has demonstrated the in vitro and in vivo effectiveness of MCFA at protecting pigs from PEDv infection (Cochrane et al., 2017).

Hanczakowska (2017) reviewed the influence of MCFA and medium chain triglycerides (MCT) on growth performance. Although more data is needed, responses appear to be dose dependent with MCFA having greater responses than intact MCT. Data with MCFA is promising, but further research on the response to individual MCFA or combinations of MCFA is needed.

15.- REFERENCES


