# Chapter 4
# Feeding Applications of Corn Fermented Protein Co-Products in Swine Diets

## Introduction

Corn fermented protein (CFP) co-products are attractive feed ingredients for use in weaned pig diets because of their high metabolizable energy (ME) and digestible amino acid and phosphorus content. This high energy and nutritional density allows use of less quantity to supply significant amounts of energy and nutrients in diets with limited "formulation space". Furthermore, weaned pig diets must be formulated to be highly concentrated in energy and amino acids, which can only be achieved by using ingredients that are high in ME and digestible amino acid content because they are more likely to support acceptable growth during a stressful time in the pig's life when feed intake is often low and variable. Because of the spent yeast in CFP, feeding diets containing these co-products to weaned pigs may also provide health benefits when added to diets at relatively high inclusion rates resulting from the mannooligosaccharides, β-glucans, and nucleotides found in yeast cell walls (Shurson, 2018). Therefore, this chapter summarizes the results from several recent studies that have determined the digestible energy (DE), ME, standardized ileal digestibility (SID) of amino acids, and standardized total tract digestibility (STTD) of phosphorus (P) of the three different types of technologies used to produce CFP, and a summary of growth performance results in nursery pig feeding trials.

## Nutritional Profile of Corn Fermented Protein Co-Products for Swine

There are three different types of proprietary processing technologies used to produce corn fermented co-products which include ICM's Advanced Processing Package™ (APP™); FluidQuip's Maximized Stillage Co-Products Technology™ (MSC™); and Marquis ProCap Technology™. Although each of these types of technologies concentrate the protein and yeast in the final co-products, their nutritional profiles are different. Therefore, to optimize energy and nutritional efficiency when including these co-products in swine diets, it is essential to use appropriate ME, SID of amino acids, and STTD phosphorus values during feed formulation. Fortunately, digestibility studies have been conducted to determine the DE and ME content, as well as SID of amino acids for swine for each of these types of CFP co-products.

### Nutritional composition

The protein, lipid, fiber, and ash content of different brands of CFP is shown in **Table 1**. Note that although these CFP co-products contain similar crude protein (CP) concentrations. In contrast, ether extract (crude fat) and acid hydrolyzed ether extract, neutral detergent fiber (NDF), total dietary fiber (TDF), and ash content are highly variable among sources. Like DDGS, the calcium content of CFP co-products is low, and the P content varies from 0.68 to 1.04%. These results indicate that due to the variable nutritional profiles among CFP sources, it is essential for end-users to know the specific source being used in swine feed formulations for optimizing nutritional efficiency and animal performance.

**Table 1**. Comparison of protein, lipid, fiber, and ash composition of corn fermented protein sources (as-fed basis)

| Analyte | ANDVantage 50Y[1] | A+Pro[2] | NexPro[3] | ProCap Gold[4] |
|---|---|---|---|---|
| Dry matter, % | 93.76 | 91.73 | 93.00 | 88.00 |
| Crude protein, % | 51.79 | 50.20 | 50.1 | 49.09 |
| Lys:crude protein | 3.46 | 3.96 | 3.95 | 3.93 |
| Ether extract, % | 9.60* | 4.62 | | - |
| AEE[5], % | 9.90 | - | 5.6 | 9.49 |
| Neutral detergent fiber, % | 27.50* | 24.33 | - | - |
| Acid detergent fiber, % | 20.00* | 4.83 | - | - |
| Soluble dietary fiber, % | 2.8 | - | 3.4 | 1.02 |
| Insoluble dietary fiber, % | 29.2 | - | 24.4 | 21.77 |
| Total dietary fiber, % | 32.0 | - | 27.8 | 22.79 |
| Ash, % | 1.44 | 5.49 | 7.9 | 7.38 |
| Ca, % | 0.01* | 0.04 | - | 0.04 |
| P, % | 0.68* | 0.82 | - | 0.77 |

[1]Unpublished data from Lee and Stein (2021) with permission from The Andersons, Inc.
[2]Published data from Yang et al. (2021).
[3]Published data from Acosta et al. (2021).
[4]Published data from Cristobal et al. (2020).
[5]AEE = acid hydrolyzed ether extract
*Values obtained from supplier nutrient specification sheets provided with permission from The Andersons, Inc.

## Metabolizable energy

Because of the wide ranges in lipid, fiber, and ash content among CFP sources, the DE and ME content also varies from 3,837 and 3,643 kcal/kg, respectively, for A+ Pro to 4,560 and 4,306 kcal/kg, respectively, for ProCap Gold (**Table 2**). However, the ME content of these CFP sources is 117 to 150% of the ME content of conventional DDGS sources. The ME to gross energy (GE) ratio is similar among co-product sources except for ProCap Gold, which has a ratio of 0.84 and indicates a much greater proportion of gross energy is utilized by pigs presumably because of the relatively higher oil and lower fiber content compared with other corn-products.

**Table 2.** Comparison of gross energy (GE), digestible energy (DE), metabolizable energy (ME), and energy ratios of corn fermented protein sources for swine (as-fed basis)

| Analyte | ANDVantage 50Y[1] | A+Pro[2] | NexPro[3] | ProCap Gold[4] |
|---|---|---|---|---|
| Dry matter, % | 93.76 | 91.73 | 93.00 | 88.00 |
| GE, kcal/kg | 5,284 | 4,908 | 4,937 | 5,100 |
| DE, kcal/kg | 4,421 | 3,837 | 4,070 | 4,560 |
| ME, kcal/kg | 4,085 | 3,643 | 3,705 | 4,306 |
| ME:DE | 0.92 | 0.95 | 0.91 | 0.94 |
| DE:GE | 0.84 | 0.78 | 0.82 | 0.89 |
| ME:GE | 0.77 | 0.74 | 0.75 | 0.84 |

[1]Unpublished data from Lee and Stein (2021) with permission from The Andersons, Inc.
[2]Published data from Yang et al. (2021).
[3]Published data from Acosta et al. (2021).
[4]Published data from Cristobal et al. (2020).

## Digestible amino acids

The amino acids profiles of CFP co-products vary, but as expected the greater CP content results in increased concentrations of amino acids (**Table 3**). Amino acid ratios relative to Lys content are improved compared to the amino acid profile of conventional DDGS sources (data not shown), which is a result of the greater spent yeast content and associated amino acid profile (Shurson, 2018). Note that the standardized ileal digestibilities are generally greater than found in conventional DDGS sources but vary among CFP sources. For example, SID of Lys ranges from 61% (A+ Pro and NexPro) to 85% in ProCap Gold. Again, because of these differences, it is essential for end-users to know the specific source being used in swine feed formulations to optimize nutritional efficiency and pig performance.

**Table 3.** Comparison of crude protein and amino acid content, and standardized ileal digestibility of corn fermented protein sources for swine (as-fed basis)

| **Analyte[1]** | **ANDVantage 50Y[2]** | **A+Pro[3]** | **NexPro[4]** | **ProCap Gold[5]** |
|---|---|---|---|---|
| Dry matter, % | 93.76 | 91.73 | 93.00 | 88.00 |
| Crude protein, % | 51.79 (80) | 50.20 (70) | 50.1 (75) | 48.09 (84) |
| Lys:Crude protein | 3.46 | 3.96 | 3.95 | 3.93 |
| Arg | 2.37 (90) | 2.36 (81) | 2.31 (81) | 2.47 (92) |
| His | 1.41 (84) | 1.44 (77) | 1.33 (80) | 1.40 (88) |
| Ile | 2.01 (81) | 2.26 (74) | 2.19 (75) | 2.03 (87) |
| Leu | 6.44 (89) | 6.30 (84) | 5.68 (85) | 5.57 (90) |
| Lys | 1.79 (72) | 1.99 (61) | 1.98 (61) | 1.89 (85) |
| Met | 1.28 (89) | 1.07 (81) | 1.01 (84) | 1.09 (89) |
| Phe | 2.75 (86) | 2.66 (81) | 2.49 (81) | 2.51 (89) |
| Thr | 2.00 (80) | 2.01 (67) | 2.00 (70) | 1.89 (83) |
| Trp | 0.58 (83) | 0.37 (75) | 0.42 (81) | 0.49 (90) |
| Val | 2.54 (82) | 2.94 (74) | 2.83 (74) | 2.84 (85) |
| Ala | 3.82 (86) | 3.75 (78) | 3.47 (79) | 3.41 (86) |
| Asp | 3.49 (78) | 3.57 (67) | 3.55 (69) | 3.38 (82) |
| Cys | 1.12 (81) | 0.98 (70) | 0.87 (73) | 1.00 (84) |
| Glu | 8.87 (87) | 8.15 (82) | 7.39 (83) | 7.52 (89) |
| Gly | 1.96 (81) | 2.00 (56) | 2.01 (65) | 2.06 (76) |
| Pro | 4.17 (100) | - | 3.50 | 3.52 (73) |
| Ser | 2.39 (86) | 2.27 (77) | 2.17 (77) | 2.20 (86) |
| Tyr | 2.32 (90) | 2.04 (83) | 1.98 (82) | 1.90 (90) |

[1]Values in parentheses are standardized ileal digestibility coefficients (%) for amino acids in each co-product sources for swine.
[2]Unpublished data from Lee and Stein (2021) provided with permission from The Andersons, Inc.
[3]Published data from Yang et al. (2021)
[4]Published data from Acosta et al. (2021).
[5]Published data from Cristobal et al. (2020).

## Digestible phosphorus

Corn fermented protein contributes a significant amount of digestible P to swine diets and can be captured by formulating swine diets on a STTD of P basis. The relatively high total P content of corn co-products and high digestibility allows reducing the amounts of inorganic supplements (i.e. monocalcium phosphate) needed to meet the pig's P requirements while reducing P excretion in manure and diet cost. However, only one study has been conducted to determine the STTD of P in CFP co-products. Cristobal et al. (2020) determined and compared the STTD of P and apparent total tract digestibility (ATTD) of calcium (Ca) in reduced-oil DDGS and CFP (ProCap Gold). The STTD of phosphorus in CFP was less than for conventional DDGS but significantly greater than in corn grain (**Table 4**). This result indicates that some phytate remained after fermentation and processing, and that the addition of phytase would be useful to release more P for utilization by pigs. Similarly, the ATTD of Ca in CFP was less than in conventional DDGS, but this is of minimal importance because of the very low total Ca contributed to diets from reduced-oil DDGS and CFP. No studies have been conducted to determine the P digestibility in other CFP sources, but it is presumed that STTD of P is comparable to results obtained with ProCap Gold. However, it is important to note that several ethanol plants add phytase during the fermentation process which further increases the conversion of indigestible phytate to digestible phosphate (Reis et al., 2018). Therefore, it is important for nutritionists to know the source of corn co-products they are using and to determine if phytase is being using during the production process because it affects phosphorus digestibility values.

**Table 4.** Comparison of apparent total tract digestibility of calcium and standardized total tract digestibility of phosphorus between conventional reduced oil DDGS and corn fermented protein (ProCap Gold) for swine (as-fed basis; adapted from Cristobal et al., 2020)

| Measure | Reduced-oil DDGS | Corn fermented protein |
|---|---|---|
| Ca, % | 0.04 | 0.04 |
| P,% | 1.01 | 0.77 |
| ATTD of Ca, % | 83 | 66 |
| STTD of P, % | 81 | 56 |

## Summary of Corn Fermented Protein Feeding Trials with Weaned Pigs

The most appropriate use of CFP co-products is in phase 1 and 2 diets for weaned pigs because of its high ME and digestible amino acid content compared with corn. Highly digestible animal-derived proteins, such as spray-dried animal plasma (SDAP), and plant proteins such as enzyme treated soybean meal, are common additions to nursery pig diets but are expensive. Furthermore, nutritionists want to minimize the amount of soybean meal in phase 1 diets due to the antigenic effects of soy protein upon initial consumption. Therefore, there is considerable interest in using less expensive, highly digestible energy and protein sources as alternatives to soybean meal, enzyme treated soybean meal, and SDAP in newly weaned pig diets.

An initial study was conducted by Martindale et al. (2018) to determine the effects of increasing dietary levels (0, 8, 16, and 24%) of CFP (NexPro) in phase 1 (0 to 14 days post-weaning) and phase 2 (14 to 28 days post-weaning), with a common corn-soybean meal diet fed during phase 3 (days 28 to 35 post-weaning) on growth performance of pigs weaned at 21 days of age. No differences in average daily gain (ADG), average daily feed intake (ADFI), and Gain:Feed (G:F) were observed among dietary treatments during phase 1, but pigs fed the 24% CFP diet during phase 2 had reduced ADG and ADFI compared with pigs fed the control (0% CFP) diet. There were no effects on growth performance during phase 3 and the overall 35-day trial. However, the statistical power to detect differences among dietary treatments in this study is questionable because only 4 replicates (pens) per treatment were used, and each pen contained only 5 pigs which does not represent commercial production conditions. The researchers concluded that adding up to 16% CFP to phase 1 and phase 2 nursery diets does not negatively affect growth performance.

Acosta et al. (2021) evaluated the pig growth performance responses and fecal scores when feeding diets containing various amounts of CFP to partially replace SDAP and enzyme treated soybean meal (ES) during phase 1 and 2 post-weaning (**Table 5**). Feeding the control phase 1 diet containing 5% ES and 2.5% SDAP for the first 7 days after weaning resulted in greater ADG and G:F than feeding diets containing 4.5% ES + 5% CFP and 10% CFP, but there was no significant difference in ADFI among dietary treatments. However, the amount of CFP (0 to 10%) in phase 2 diets, fed from day 8 to 21 post-weaning, had no effect on ADG, ADFI, and G:F. All pigs were fed common corn-soybean meal diets during phase 3 (day 22 to 35 post-weaning) and no differences in subsequent growth performance were observed. These results indicate that adding 5% CFP to phase 1 diets for weaned pigs can provide acceptable growth performance if 2.5% SDAP is also included in the diet but not when 4.5% ES is included in the diet. Adding 10% CFP to phase 1 nursery diets appears to be excessive to support optimal growth performance without addition of SDAP or ES. However, adding 10% CFP to phase 2 diets supports acceptable growth performance comparable to feeding the control diet containing 7.5% ES.

Results from these studies indicate that CFP (NexPro) can be successfully added to phase 1 and phase 2 diets at levels up to 16% depending on the other ingredients used. However, CFP co-products contain high concentrations of leucine (Leu), which negatively affects the utilization and metabolism of valine (Val) and isoleucine (Ile), has been recognized as a nutritional challenge by many researchers (Harris et al., 2004; Cemin et al., 2019; Kwon et al., 2019; Yang et al., 2019). In addition, excess Leu competes with tryptophan (Trp) transport through the blood into the brain which reduces serotonin synthesis and consequently reduces ADFI (Kwon et al., 2019; Yang et al., 2019). Furthermore, the high dietary fiber content in CFP likely increases mucin production and threonine (Thr) losses in the small intestine which may increase the Thr requirement of pigs (Mathai et al., 2016). Therefore, additions of crystalline Thr, Trp, Val, and Ile appear to be required to optimize growth performance of weaned pigs fed diets containing CFP.

**Table 5.** Growth performance of weaned pigs fed diets containing variable amounts of animal plasma protein (PP), enzyme treated soybean meal (ES), and corn fermented protein (CFP; NexPro) during phase 1 and 2 post-weaning (adapted from Acosta et al., 2021)

| **Measure** | **Control – No CFP** | **Low CFP** | **Moderate CFP + ES** | **High CFP** |
|---|---|---|---|---|
| Initial body weight, kg | 5.86 | 6.03 | 6.02 | 6.02 |
| Final body weight, kg | 18.53 | 18.58 | 18.51 | 18.20 |
| **Phase 1 (day 1 to 7)** | **5% ES + 2.5% PP** | **2.5% PP + 5% CFP** | **4.5% ES + 5% CFP** | **10% CFP** |
| ADG, kg | 0.134[a] | 0.106[ab] | 0.088[bc] | 0.074[c] |
| ADFI, kg | 0.162 | 0.146 | 0.147 | 0.136 |
| Gain:Feed | 0.836[a] | 0.731[ab] | 0.604[bc] | 0.538[c] |
| **Phase 2 (day 8 to 21)** | **7.5% ES** | **5% ES + 2.5% CFP** | **1% ES + 7.5% CFP** | **10% CFP** |
| ADG, kg | 0.285 | 0.292 | 0.277 | 0.267 |
| ADFI, kg | 0.433 | 0.430 | 0.418 | 0.404 |
| Gain:Feed | 0.662 | 0.681 | 0.663 | 0.661 |

| Phase 3 (day 22 to 35) – common corn-soybean meal diets | | | | |
|---|---|---|---|---|
| ADG, kg | 0.554 | 0.552 | 0.572 | 0.566 |
| ADFI, kg | 0.837 | 0.848 | 0.851 | 0.859 |
| Gain:Feed | 0.663 | 0.653 | 0.672 | 0.662 |
| **Overall (day 1 to 35)** | | | | |
| ADG, kg | 0.362 | 0.359 | 0.357 | 0.348 |
| ADFI, kg | 0.541 | 0.540 | 0.537 | 0.533 |
| Gain:Feed | 0.673 | 0.666 | 0.666 | 0.656 |

[a,b,c]Values within rows with uncommon superscripts are different ($P < 0.05$).

## Summary of Corn Fermented Protein Feeding Trials with Growing-Finishing Pigs

An unpublished study (data provided with permission from POET) conducted by Clizer et al. at South Dakota State University evaluated the Ile to Lys and Val to Lys ratios in growing-finishing pig diets (59.5 kg to market) containing low dietary concentrations (10 to 15%) of CFP (NexPro). Results from this study showed that an adjustment in the SID Val and Ile levels using soybean meal or crystalline amino acids were required during the early grower phase to overcome the negative effects of excess Leu concentrations contributed from CFP. Although pigs fed the 10 to 15% CFP diets had similar growth performance to those fed corn-soybean meal control diets, providing soybean in the CFP diets to provide greater amounts of Val and Ile resulted in similar overall growth performance compared with pigs fed the corn-soybean meal control diets. Therefore, although the addition of 10% or 15% CFP to growing-finishing pig diets had minimal negative effects on growth performance and carcass composition, soybean meal should be used instead of crystalline amino acids to increase the SID Val and Ile concentrations to mitigate the negative effects of excess Leu.

## Conclusions

Corn fermented protein co-products are a high energy, digestible amino acid and phosphorus ingredients that are best suited for phase 1 and 2 diets for newly weaned pigs. Due to the variability in nutritional profiles among sources, it is essential for end-users to know the specific source being used in swine feed formulations to optimize nutritional efficiency and animal performance. When adding CFP to nursery diets, the Thr, Trp, Val, and Ile concentrations relative to Lys content should be calculated and adjusted using crystalline amino acids to achieve optimal pig growth performance.

## References

Acosta, J.P., C.D. Espinosa, N.W. Jaworski, and H.H. Stein. 2021. Corn protein has greater concentrations of digestible amino acids and energy than low-oil corn distillers dried grains with solubles when fed to pigs but does not affect the growth performance of weanling pigs. J. Anim. Sci. 99:1-12. doi:10.1093/jas/skab175

Cemin, H.S., M.D. Tokach, J.C. Woodworth, S.S. Dritz, J.M. DeRouchey, and R.D. Goodband. 2019. Branched-chain amino acid interactions in growing pig diets. Transl. Anim. Sci. 3:1246-1253. doi:10.1093/tas/txz087

Cristobal, M., J.P. Acosta, S.A. Lee, and H.H. Stein. 2020. A new source of high-protein distillers dried grains with solubles (DDGS) has greater digestibility of amino acids and energy, but less digestibility of phosphorus, than de-oiled DDGS when fed to growing pigs. J. Anim. Sci. 98:1-9. doi:10.1093/jas/skaa200

Harris, R.A., M. Joshi, and N.H. Jeoung. 2004. Mechanisms responsible for regulation of branched-chain amino acid catabolism. Biochem. Res. Commun. 313:391-396. doi:10.1016/j.bbrc.2003.11.007

Kwon, W.B., K. Touchette, A. Simongiovanni, K. Syriopoulos, A. Wessels, and H.H. Stein. 2019. Excess dietary leucine in diets for growing pigs reduces growth performance, biological value of protein, protein retention, and serotonin synthesis. J. Anim. Sci. 97:4282-4292. doi:10.1093/jas/skz259

Martindale, A., M. Trenhaile-Grannemann, S. Barnett, P. Miller, and T. Burkey. 2018. Growth performance of weaned pigs fed a high-protein corn co-product. J. Anim. Sci. 96(Suppl. S3):295.

Mathai, J.K., J.K. Htoo, J.E. Thomson, K.J. Touchette, and H.H. Stein. 2016. Effects of dietary fiber on the ideal standardized ileal digestible thronine:lysine ratio for twenty-five to fifty kilogram growing pigs. J. Anim. Sci. 94:4217-4230. doi:10.2527/jas.2016-0680

NRC. 2012. Nutrient Requirements of Swine, 11th rev. Natl. Acad. Press, Washington, D.C.

Reis, C.E.R., Q. He, P.E. Urriola, G.C. Shurson, and B. Hu. 2018. Effects of modified processes in dry-grind ethanol production on phosphorus distribution in coproducts. Ind. Eng. Chem. Res. 57:14861-14869. https://doi.org/10.1021/acs.iecr.8b02700

Shurson, G.C. 2018. Yeast and yeast derivatives in feed additives and ingredients: Sources, characteristics, animal responses, and quantification methods. Anim. Feed Sci. Technol. 235:60-76. https://doi.org/10.1016/j.anifeedsci.2017.11.010

Yang, Z., A. Palowski, J.-C. Jang, P.E. Urriola, and G.C. Shurson. 2021. Determination, comparison, and prediction of digestible energy, metabolizable energy, and standardized ileal digestibility of amino acids in novel maize co-products and conventional dried distillers grains with solubles for swine. Anim. Feed Sci. Technol. 282:115149. https://doi.org/10.1016/j.anifeedsci.2021.115149

Yang, Z., P.E. Urriola, A.M. Hilbrands, L.J. Johnston, and G.C. Shurson. 2019. Growth performance of nursery pigs fed diets containing increasing levels of a novel high-protein corn distillers dried grains with solubles. Transl. Anim. Sci. 3:350-358. Doi:10.5713/ajas.2010.90513