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Broiler efficiency as affected by dietary protein supply and grain source

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Undergraduate Honors Thesis

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1. Abstract

This experiment was conducted to compare the effects of different diet compositions on performance and carcass yield of male broilers from 15 to 36 days of age. In total, 593 male birds were divided across a randomized design that consisted of 6 dietary treatments, each with 8 replications. The treatments included pelleted diets that varied in grain type and crude protein (CP) value: 3 sorghum-based diets at 20%, 18.75%, and 17.5% CP and 3 corn-sorghum blended diets at the same CP levels. CP amounts impacted only body weight gain and feed conversion rate while feed intake only differed with grain source ($P<0.001$). The highest protein diets resulted in the most body weight gain and lowest feed conversions, while corn diets promoted higher feed intake. In carcass evaluation, CP levels impacted live body weight, carcass yield, breast yield, and fat- with all factors, except fat content which decreased along with, increasing alongside the protein increases. Fat content was also impacted by the interactivity between grain type and protein amounts- creating minute inconsistencies in the previous pattern which indicated that increasing protein levels, decreased fat. Moreover, as CP increased, the grain-protein interactions resulted in leg yield decreases for corn-based diets, but leg yield increases in sorghum-based diets.

2. Introduction and Literature Review

2.1 Significance

Society has continuously influenced food production to utilize increasingly sustainable management practices (Lemme et al., 2019). In poultry production, these efforts center around the reduction of nutrient excretion through dietary alteration (Powers & Angel, 2008); this has been researched extensively with regards to nitrogen reduction to conclude: lowered nitrogen output can be achieved through a reduced CP diet balanced to meet the birds' requirements of energy and amino acids. (Santonja et al., 2017) Aside from the environmental benefits of reduced CP diets, there is also evidence which suggests lower CP for poultry is more economical (Kobayashi et al., 2013) and benefits bird health and welfare (van Harn et al., 2017). Still, due to the complex nature of interactions during starch and protein digestion, additional research is necessary for the optimization of protein and starch balance to improve cost efficiency and to reduce the environmental impact of poultry production.

2.2 Review of Literature

2.2.1 Success of Low Protein Diets

Many studies, investigating the impact of low protein diets, have been conducted with success when supplemented with varied essential amino acids (Berres et al., 2010; Shao et al., 2018). However, there are studies that indicate there is a threshold value of protein reduction before other factors limit production success. For example, it has been shown that a decrease in CP from 210 to 180 g/kg did not negatively impact performance. However, further reduction to 165 g/kg began to impose on bird productivity- which is hypothesized to be the result of reaching a point at which non-essential amino acid limitations take hold (Chrystal et al., 2020).

Moreover, there is the important consideration of fat deposition in birds being fed low CP diets. A common issue found in the carcass characteristics of birds raised on low CP feed is the increased amount of abdominal fat (e.g., peritoneal of leaf fat). One study also found an increase in relative liver weight. With the liver being the site of lipogenesis, this study hypothesizes that a correlation exists with increased lipogenic activity in response to being fed diets with reduced CP (Aletor et al., 2000). This is important to consider as consumer expectations need to be met, otherwise the environmental benefits will be mitigated. As consumers are known to find the visual appearance of fat less appealing, it is in the best interest of producers to aim for the minimization of its deposition (Aletor et al., 2000). Furthermore, excess fat can be removed from birds during processing, but feed calories being used for lipogenesis rather than lean tissue accretion represent an inefficiency. In the U.S., there is a trend to consume more thigh muscle processed parts in broiler chickens. And in thigh meat, fat cannot be removed, even if the thigh is packaged as bone-less and skin-less in the retail market.

2.2.2 Relationship Between Amino Acids and Starches

In working to meet threshold amino acid values, it is important to consider how effectively protein consumption is utilized. In order to do so, starch and protein digestion rates are important considerations. These are what govern nutrient allocation and thus bird productivity. What makes this difficult, is the interactive nature of protein and starch digestion; glucose and amino acids both compete for co-absorption with sodium in transport systems (Liu et al., 2021). Moreover, starch serves roles in both amino acid catabolism and protein synthesis (Liu et al., 2021). Their breakdown determines how fast glucose absorbs and conversely how fast insulin can be released (Weurding et al., 2003). In this sense, slow digesting starches have proven to be beneficial as starches lengthen the insulin response, promoting sustained protein deposition and improving the feed conversion rate of birds (Weurding et al., 2003). These benefits have also been hypothesized to be a result of slow digesting starches providing enough energy for the enterocytes in the lower small intestine, so amino acids, in turn, can be used for muscle growth (Weurding et al., 2003).

This is supported by research on maize diets. Hence, in one study- in agreement with prior research- maize was found to be one of the most rapidly digested starches (Moss et al., 2020)- a quality which has been shown to decrease amino acid digestibility in chickens (Selle & Liu, 2019). Conversely, in the same study, sorghum, though higher in protein than corn and slower digesting, still supported limited amino acid digestion - which the author cites could be the result of karifin and phenolic compound presence in sorghum (Moss et al., 2020). Interestingly, when compared to wheat diets, maize- based diets may be able to withstand larger reductions in dietary CP; in one study birds' growth on 165 g/kg CP maize- based diet exceeded their 222 g/kg fed counterparts with negative impacts only on feed conversion ratios (Chrystal et al., 2021).

Regardless, when comparing sorghum and maize, studies have found maize diets generate higher apparent metabolizable energy (AME) and a more efficient feed conversion (Moss et al., 2020). However, there is evidence that they both act as suitable bases for a diet. One study with a differing variety of sorghum (S.bicolor) has shown success in total or partial replacement of corn with sorghum, with negligible effects only on apparent ileal nutrient digestibility (Putigam et al., 2020). This is in agreement with another study which found that a 50% replacement of corn with sorghum led to improvements in growth (Saleh et al., 2019). Both which are corroborated by a study that found that the inclusion of slow digesting starches in combination with faster ones to be beneficial, in their case a 25% inclusion of pea (slow digesting) starch with 75% wheat (fast digesting) starch prompting the greatest feed efficiency (Herwig et al., 2019).

The type and essentiality of the amino acids are important to consider as well. Depending on the feeding frequency of the birds, the presence of protein-bound versus free amino acids could impact amino acid utilization as these forms are absorbed at different speeds (Liu & Selle, 2015). Moreover, if synthetic amino acids are being utilized, their circulation into the portal system would occur at a more rapid rate than protein-bound amino acids which alters typical protein digestive dynamics. This offers potential benefits when competing with starches for digestion, however, in addition to posing risks of displacing balance between amino acid types at sites of protein deposition (Liu & Selle, 2015).

2.2.3 Feed Processing

Aside from grain source, methods of processing feed can also determine how successful a diet formulation is, as the processes can alter how nutrients are absorbed and utilized. Processes such as griding and pelleting have been tested with various levels of success. Both unground and ground particles present potential benefits in nutrient digestibility (Rubio et al., 2020). This is corroborated by a study comparing bird performance with sorghum inclusions. When substituting corn for two types of whole grain sorghum with the partial inclusion of ground sorghum, similar outcomes in broiler performance were observed- the only resulting difference being higher gizzard weights for birds fed the larger particles (Putigam et al., 2020). Overall, indicative that there was not a large enough discrepancy to definitively favor one over the other in terms of nutrient digestibility.

Similarly, the benefit of pelleting which is believed to create a more balanced concentration of nutrients, ensuring they can be more completely consumed (Behnke, 1996), displays discrepancy among feedstuffs. In a wheat, oat, soy diet, both AME and energy retention seemed to be unaffected (Hussar & Robblee, 1962). Meanwhile, in a study on a pelleted wheat diet, nitrogen-corrected apparent metabolizable energy (AMEn) displayed decreasing values, (Amerah et al., 2007). Conversely, when considering maize and sorghum, pelleting has shown potential improvements. For instance, in one trial which tested the pelleting of multiple grain-based diets, AMEn values increased for all, with the largest positive increases for maize and sorghum (Khalili et al., 2021).

2.3 Future Considerations

Food production requires a balance of both consumer and producer satisfaction. With feed accounting for a major percentage of poultry production cost, diet formulations have been widely studied in order to continuously improve upon cost efficiency for the benefit of the producers. At the same time, consumer demand for an environmentally conscious but still desirable product, increases the need for production practices that are sustainable yet allow for maintenance of the standards set for carcass characteristics. Due to the difficulty in understanding the complex mechanisms behind digestive dynamics and the influence nutrient utilization plays on carcass fat and protein characteristics, there is still work to be done in testing different diet compositions to further isolate combinations of ingredients and processes that will further improve industry practices.

This study aims to further the progress already accomplished in this realm by testing six diets in an effort to observe any potential benefits posed by the combinations of protein and starch feedstuffs in these test formulations.

3. Materials and Methods

3.1 Experimental Facility and Bird Husbandry

A total of 593 Cobb 500 male broiler chicks were hatched (Cobb-Vantress, Inc., Siloam Springs, AR), sexed, then transported to the University of Arkansas Broiler Research Farm. The birds were housed in a tunnel-vented facility, divided amongst 48 (3 x 4 feet) pens equipped with bedding, nipple drinkers, and hanging feeders. For days 1-14, the birds were provided a common feed complete with nutrients to meet the minimum feed requirements. They were checked multiple times throughout the day to ensure feed access, raise water lines, and account for bird loss. To begin the experimental trial, on day 15, the birds were weighed by pen in groups of twelve. If there were too few or too many birds in a pen, they were randomly reallocated accordingly. Remaining starter feed was dumped from the feeders, the empty feeders were weighed, then refilled with 1 of 6 experimental diet feeds. For the remainder of the trial, the birds continued to be monitored as above. On day 36, remaining feed and pen weights were recorded. Four broilers per pen were randomly selected and tagged for processing. On day 37, the tagged birds were transported to the University of Arkansas Pilot Processing Plant in order to evaluate carcass traits. Birds were processed using an inline commercial system and manually eviscerated. Fat pads were removed and weighed, carcass weight was recorded, and then breast (*Pectoralis major* and *minor*, bone-less and skinless) and leg weights (bone-in and skin-on) were measured from the deboned carcass.

3.2 Experimental Diets

Six experimental diets were offered to the birds from 15 to 35 days of age. Prior to diet formulation, an amino acid analysis was conducted for the sorghum. As displayed in Table 1, following its characterization, four diets were formulated. Two 20% CP and two 17.5% CP diets were formulated, one each for both a corn-based diet and a corn-sorghum blended diet. Intermediate 18.75% CP corn and corn-sorghum diets were then created by mixing those of 20% and 17.5% CP for each grain (starch) source diet respectively.

3.3 Statistics

The trial followed a 2 x 3 factorial design. Each of the six experimental treatments were replicated in eight pens, the pen functioned as the experimental unit. The treatments were randomly assigned to pens. Broiler performance and carcass yields were analyzed by ANOVA using Proc GLM of SAS 9.4 (SAS Institute, 2012). Statistical significance was set at $P \leq 0.05$ and means were separated by a repeated *t*-test.

4. Results

4.1 Performance

As displayed in Table 2, dietary protein levels had no impact on feed intake ($P > 0.05$) but resulted in differences for body weight gain and feed conversion ($P < 0.001$). The higher protein diet resulted in the largest weight gain and lowest feed conversion while the lowest protein diet resulted in the lowest and largest response, respectively. Conversely, grain type only had an impact on feed intake ($P < 0.05$), with birds being fed corn-only diets consuming more feed than those on the blended diet. In terms of the interactive influence of both protein and grain type on bird performance, there was no significant difference in any of the qualities.

4.2 Carcass Traits

As displayed in Table 3, dietary protein levels resulted in differences in body weight, fat pad, carcass, and breast yields ($P < 0.05$), with all qualities improving as protein inclusion increased. On the other hand, grain type had no impact on any carcass trait quality. Meanwhile the combined effect of protein content and grain type only influenced fat percentage and leg yield. In terms of fat content- when comparing sorghum diets to corn diets, there is not a large difference in terms of the weights. However, individually- corn diets are consistent in that as protein values increase, the fat content decreases. Whereas with sorghum diets, the diet containing an intermediate amount of protein resulted in the least fat, while the diet with the lowest protein resulted in the greatest fat yield. Similarly, leg yield for both corn-based diets and sorghum-based diets are similar in value but also differ in pattern. As protein is increased in corn-based diets, leg yield decreases. Meanwhile, as protein increased in sorghum-based diets, the leg yield increased.

5. Discussion

5.1 Impact of Protein Level

Considering the variation in results amongst prior completed studies and the specific nature of how proteins and carbohydrates interact, the achieved results are as expected. There is prior research that indicates success when feeding low crude protein diets supplemented with amino acids. In one study, CP could be reduced by up to 6% with amino acid fortification while still maintaining broiler performance (Badawi et al., 2019). This indicates success in protein reduction up to a particular threshold, an idea which has been upheld through more recent research. In a more current study, between two different levels of protein reduction, it was found that the initial instance had no impact on performance. Only at a greater reduction of protein did the variation in values become significant enough to indicate higher protein diets might be more effective (Chrystal et al., 2021). When looking at these results, it does appear as if low CP diets have the potential to be as effective as regular diets. However, the results of this research alone indicate the opposite. In this case, it appears that the addition of more protein results in improvements in both bird performance and carcass traits. As such, any reduction in the protein level appears to not support adequate bird development. However, because the results from the prior experimentation had such precise threshold levels, the lack of success in this experiment could be due to the differences in proportion of protein reduction; the threshold requirements needed for a low CP diet to be successful could've been surpassed in the first reduction, thereby making it seem as if any reduction would be unsuccessful. This could be a product of the competition of starches and proteins during digestion and absorption. Since the amino acids were all balanced it is likely that the lower protein diets didn't provide enough CP to compete with the starch sources for priority in digestion. If the starches are more quickly broken down and utilized, insulin spikes would be shorter lasting- in effect, decreasing the rate of protein deposition. The variation in insulin spikes could also explain the higher feed conversion values for birds fed the low protein diet. If the nutrients aren't being affectively allocated, then they would have to consume more to attain the desired growth.

5.2 Impact of Grain Type

The results of this study suggest that grain source only influences feed intake. This is in contrast with another study in which inclusions of pea versus tapioca with corn-based diets had no impact on feed intake (Weurding et al., 2002). In that study, only feed conversion rates and weight gain were impacted, overall demonstrating that the inclusion of slow digestible starches improved protein utilization. Those results corroborate similar studies which indicate that the partial addition of slow digesting starches improves feed conversion rates. Moreover, in a separate study comparing maize and sorghum as diet bases, the corn diets were effective in improving feed conversion rates (Moss et al., 2020). This not only contradicts the aforementioned studies' propositions that slower digesting starches pose benefits for feed conversion but also differs from the study at hand in that feed intake remained unaffected. Based on the case of this trial, none of the previous research is supported. However, the outcome may be explained by the fact that maize is one of the quickest digesting starches. Because the starches are being utilized more quickly, the feeling of satiety may take longer to reach prompting the birds to continue eating.

5.3 Interactive Impact Grain Type and Protein Level

As aforementioned, the only qualities impacted by grain type interacting with protein amount were fat percentage and leg yield. Notably, the abdominal fat yield was the highest in the birds fed the blended diets containing the lowest protein amount. This appears as a common result in carcass traits of birds fed low protein diets. The results of one past study corroborate this, its outcomes demonstrating a pattern of increased body fat for birds being offered low CP feed (Aletor et al.,2000). In a prior study, it was found that this could be negated via the inclusion of L-carnitine to aid in the prevention of excess abdominal fat; an effect of L-carnitine's ability to reduce body fat storage by improving energy and fatty acid use, while decreasing triacylglycerol storage and esterification (Badawi et al., 2019). This is a direction that could be beneficial to explore in the future in conjunction with the combined interactions of protein and grain inclusions.

6. Conclusion

The outcomes of this study indicate the inability of reduced crude protein diets to meet the needs of broilers for adequate performance and carcass development. Also, in this case, the impact of grain type wasn't significant enough to indicate the need to use one grain type over another. Therefore, in terms of grain usage, whichever grain is most economically favorable from the two options tested, considering that the birds fed corn only diets had a higher feed intake, could be used without compromising bird performance.

Considering low CP diets moving forward, there appears to be a high potential for success. Although in this trial, bird performance was overly compromised, the results do aid in further expansion of available literature on possible points of concern for low CP diets. With how important it is for the industry to continually work to please consumers, trials similar to this will need to be done in order to work towards further improvements and success in formulating a diet that satisfies environmental, economic, and societal concerns.

References

Aletor, V.A., Hamid, I., Neib, E., Pfeffer, E. (2000). Low-protein amino acid-supplemented diets in broiler chickens: effects on performance, carcass characteristics, whole-body composition and efficiencies of nutrient utilization. *Journal of the Science of Food and Agriculture*, *80*(5), 547-554. https://doi.org/10.1002/(SICI)1097-0010(200004)80:5<547::AID-JSFA531>3.0.CO;2-C

Amerah, A.A., Ravindran, V., Lentle, R.G., & Thomas, D.G. (2007). Influence of Feed particle Size and Feed Form on the Performance, Energy Utilization, Digestive Tract Development, and digesta Parameters of Broiler Starters. *Poultry Science, 86*(12), 2615-2623. https://doi.org/10.3382/ps.2007-00212

Badawi, M.E., Ali, A.H., El-Razik, W.M.A., Soliman, M.H. (2019). Influence of Low Crude Protein Diets on Broiler Chickens Performance. *Advances in Animal and Veterinary Sciences, 7*, 26-33. http://dx.doi.org/10.17582/journal.aavs/2019/7.s2.26.33

Behnke, K.C. (1996). Feed manufacturing technology: current issues and challenges. *Animal Feed Science and Technology, 62*(1), 49-57. https://doi.org/10.1016/S0377-8401(96)01005-X

Berres, J., Vieira, S.L., Dozier III, W.A., Cortes, M.E.M., de Barros, R., Nogueira, E.T., & Kutschenko, M. (2010). Broiler responses to reduced-protein diets supplemented with valine, isoleucine, glycine, and glutamic acid. *Journal of Applied Poultry Research, 19*(1), 68-79. https://doi.org/10.3382/japr.2009-00085

Chrystal, P.V., Greenhalgh, S., Mclnerney, B.V., McQuade, L.R., Akter, Y., de Paula Dorigam, J.C., Selle, P.H., & Liu, S.Y. (2021). Maize-based diets are more conducive to crude protein reductions than wheat-based diets for broiler chickens. *Animal Feed Science and Technology, 275*, 114867. https://doi.org/10.1016/j.anifeedsci.2021.114867

Chrystal, P.V., Moss, A.F, Khoddami, A., Naranjo, V.D., Selle, P.H., & Liu, S.Y. (2020). Impacts of reduced-crude protein diets on key parameters in male broiler chickens offered maize based diets. *Poultry Science, 99*(1), 505-516. https://doi.org/10.3382/ps/pez573

Herwig, E., Abbott, D., Schwean-Lardner, K.V., & Classen, H.L. (2019). Effect of rate and extent of starch digestion on broiler chicken performance. *Poultry Science, 98*(9), 3676-3684. http://doi.org/10.3382/ps/pey580

Hussar, N., & Robblee, A.R., (1962). Effects of Pelleting on the Utilization of Feed by the Growing Chicken. *Poultry Science, 41*(5), 1489-1493. http://doi.org/10.3382/ps.0411489

Khalili, M.M., Abdollahi, M.R., Zaefarian, F., & Ravindran, V. (2021). Influence of feed form on the apparent metabolisable energy of feed ingredients for broiler chickens. *Animal Feed Science and Technology, 271*, 114754. https://doi.org/10.1016/j.anifeedsci.2020.114754

Kobayashi, H., Nakashima, K., Ishida, A., Ashihara, A., & Katsumata, M. (2013). Effects of low protein diet and low protein diet supplemented with synthetic essential amino acids on meat quality of broiler chickens. *Animal Science Journal, 84*(6), 489-495. https://doi.org/10.1111/asj.12021

Lemme, A., Hiller, P., Klahsen, M., Taube, V., Stegemann, J., & Simon, I. (2019). Reduction of dietary protein in broiler diets not only reduces n-emissions but is also accompanied by several further benefits. *Journal of Applied Poultry Research, 28*(4), 867-880. https://doi.org/10.3382/japr/pfz045

Liu, S.Y., Macelline, S.P., Chrystal, P.V., & Selle, P.H. (2021). Progress towards reduced- crude protein diets for broiler chickens and sustainable chicken-meat production. *Journal of Animal Science and Biotechnology*, *12*, 1-13. https://doi.org/10.1186/s40104-021-00550-w

Liu, S.Y., Macelline, S.P., Toghyani, M., Cao, Y., Selle, P.H. (2021). The involvement of branched-chain amino acids in digestive dynamics. In M.T. Kidd (Ed.), *Branches-Chain Amino Acids: Metabolism, Benefits and Role in Disease.* Nova Scientific Publishers, New York, USA.

Liu, S.Y., Selle, P.H. (2015). A consideration of starch and protein digestive dynamics in chicken-meat production. *World's Poultry Science Journal, 71*(2). 297-310. https://doi.org/10.1017/S0043933915000306

Moss, A.F., Khoddami, A., Chrystal, P.V., Sorbara, J.O.B., Cowieson, A.J., Selle, P.H., & Liu, S.Y. (2020). Starch digestibility and energy utilization of maize- and wheat- based diets is superior to sorghum- based diets in broiler chickens offered diets supplemented with phytase and xylanase. *Animal Feed Science and Technology, 264*, 114475. https://doi.org/10.1016/j.psj.2021.101066

Powers, W., & Angel, R. (2008). A Review of the Capacity for Nutritional Strategies to Address Environmental Challenges in Poultry Production. *Poultry Science, 87*(10), 1929-1938. https://doi.org/10.3382/ps.2008-00090

Puntigam, R., Brugger, D., Slama, J., Inhuber, V., Boden, B., Krammer, V., Schedle, K., Wetscherek-Seipelt, G., & Wetscherek, W. (2020). The effects of a partial or total replacement of ground corn with ground and whole-grain low-tannin sorghum (*Sorghum bicolor* (L.) Moench) on zootechnical performance, carcass traits and apparent ileal amino acid digestibility of broiler chickens. *Livestock Science, 241*, 104187. https://doi.org/10.1016/j.livsci.2020.104187

Rubio, A.A., Hess, J.B., Berry, W.D., Dozier III, W.A., & Pacheco, W.J. (2020). Effects of corn particle size on broiler performance during the starter, grower, and finisher periods. *Journal of Applied Poultry Research, 29*(2), 352-361. https://doi.org/10.1016/j.japr.2019.11.009

Saleh, A.A., Abudabos, A.M., Ali, M.H., & Ebeid, T.A. (2019). The effects of replacing corn with low-tannin sorghum in broiler's diet on growth performance, nutrient digestibility, lipid peroxidation and gene expressions related to growth and antioxidative properties. *Journal of Applied Animal Research, 47*(1), 532-539. https://doi.org/10.1080/09712119.2019.1680377

Santonja, G.G., Georgitzikis, K., Scalet, B.M., Montobbio, P., Roudier, S., & Sancho, L.D. (2017). Best Available Techniques (BAT) Reference Document for the Intensive Rearing of Poultry or Pigs. Publications Office of the European Union. doi:10.2760/020485

SAS Institute, 2012. SAS Proprietary Software. Release 9.4. SAS Inst. Inc., Cary, NC, USA.

Selle, P.H., & Liu, S.Y. (2019). The Relevance of Starch and Protein Digestive Dynamics in Poultry. *Journal of Applied Poultry Research, 28*(3), 531-545. https://doi.org/10.3382/japr/pfy026

Shao, D., Shen, Y., Zhao, X., Wang, Q., Hu, Y., Shi, S., & Tong, H. (2018). Low-protein diets with balanced amino acids reduce nitrogen excretion and foot pad dermatitis without affecting the growth performance and meat quality of free-range yellow broilers. *Italian Journal of Animal Science, 17*(3), 698-705. https://doi.org/10.1080/1828051X.2017.1400414 van Harn, J., Dijkslag, M.A., & van Krimpen, M.M. (2019). Effect of low protein diets supplemented with free amino acids on growth performance, slaughter yield, litter quality, and footpad lesions of male broilers. *Poultry Science*, *98*(10), 4868-4877. https://doi.org/10.3382/ps/pez229

Weurding, R.E., Enting, H., & Verstegen, M.W.A. (2003). The effect of site of starch digestion on performance of broiler chickens. *Animal Feed Science and Technology*, *110*(1), 175-184. https://doi.org/10.1016/S0377-8401(03)00219-0

Weurding, R.E., Enting, H., & Verstegen, M.W.A. (2003). The Relation Between Starch Digestion Rate and Amino Acid Level for Broiler Chickens. *Poultry Science*, *82*(2), 279-284. https://doi.org/10.1093/ps/82.2.279

Tables

Table 1. Composition of diets.

Ingredient %	Diet 1	Diet 3	Diet 4	Diet 6
Corn	57.24	65.40	31.50	32.00
Whole sorghum	—	—	15.73	16.22
Cracked sorghum	—	—	15.73	16.22
Soybean meal	21.68	8.19	25.65	6.11
Dried Distillers Grains	15.00	20.00	5.00	22.00
Poultry Fat	2.79	0.50	3.04	1.74
Limestone	1.26	1.39	1.07	1.39
Dicalcium phosphate	0.68	0.68	0.92	0.67
Sodium bicarbonate	—	0.55	—	0.42
Potassium carbonate	—	—	—	0.14
Sodium Chloride	0.32	—	0.36	0.83
L-Lysine HCl	0.39	0.76	0.36	0.35
DL- Methionine	0.21	0.31	0.26	0.30
L-Threonine	0.11	0.27	0.11	0.48
L-Arginine	0.10	0.42	0.07	0.05
L-Tryptophan	0.01	0.05	0.00	0.24
L-Valine	0.03	0.23	0.02	0.21
L-Isoleucine	—	0.20	—	0.19
L-Phenylalanine	—	0.41	—	—
L-Tyrosine	—	0.20	—	—
L-Histidine	—	0.10	—	0.11
Glycine	—	0.15		0.17
Choline Cl	0.05	0.05	0.05	0.05
Minerals[1]	0.08	0.08	0.08	0.08
Vitamins[2]	0.05	0.05	0.05	0.05
Phytase[3]	0.01	0.01	0.01	0.01

[1]The mineral premix contributed (per kg of diet): manganese, 96 mg; zinc, 58 mg; copper, 2.7 mg; iodide, 1.9 mg; selenium, 0.16 mg.
[2]The vitamin premix contributed (per kg of diet): vitamin A, 9,259 IU; vitamin D_3, 6,614 ICU; vitamin E, 66 IU; niacin, 46 mg; d-pantothenic acid, 12 mg; riboflavin, 8 mg; pyridoxine, 3 mg; thiamine, 2 mg; menadione, 2 mg; folic acid, 1 mg; biotin, 0.1 mg; vitamin B_{12}, 0.02 mg.
[3]Optihos

Table 2. Influence of diet cereal grain and CP on broiler performance for a 15 to 35 d grower period

Treatment				
Grain[1]	CP[2]	BWG	FI	FCR
Interactive effects of Grain and CP (n=8)				
C	H	2.026	3.238	1.624
C	M	1.863	3.202	1.737
C	L	1.842	3.230	1.761
S	H	1.913	3.082	1.642
S	M	1.914	3.209	1.690
S	L	1.805	3.154	1.766
	SEM	0.0338	0.0418	0.0145
Main effect of Grain (n=24)				
C		1.910	3.223	1.707
S		1.877	3.148	1.700
	SEM	0.0195	0.0242	0.0084
Main effect of CP (n=16)				
	H	1.969[a]	3.160	1.633[c]
	M	1.889[ab]	3.205	1.713[b]
	L	1.823[b]	3.192	1.764[a]
	SEM	0.0239	0.0296	0.0103
P-value				
Grain		0.238	0.034	0.513
CP		<0.001	0.539	<0.001
Grain × CP		0.064	0.162	0.073

[1]C = corn; S = sorghum

[2]H = high CP; M = moderate CP; L = low CP

BWG = body weight gain; FI = feed intake; FCR = feed conversion rate

Table 3. Influence of diet cereal grain and CP on broiler performance for a 15 to 35 d grower period

Treatment			Yield (%)					
Grain[1]	CP[2]	Live BW (kg)	Fat	Carcass	Breast	Tender	Wing	Leg
Interactive effects of Grain and CP (n=8)								
C	H	2.544	1.36[ab]	73.30	18.99	3.65	8.06	22.92[a]
C	M	2.391	1.53[ab]	73.31	18.33	3.59	8.18	23.24[a]
C	L	2.334	1.62[a]	72.31	17.27	3.52	8.19	23.53[a]
S	H	2.419	1.50[ab]	73.15	18.22	3.59	7.93	23.47[a]
S	M	2.447	1.35[b]	73.02	18.32	3.64	8.16	23.15[a]
S	L	2.324	1.59[ab]	72.55	17.80	3.56	8.18	22.94[a]
	SEM	0.0502	0.063	0.234	0.289	0.067	0.093	0.220
Main effect of Grain (n=24)								
C		2.423	1.50	72.98	18.20	3.59	8.14	23.23
S		2.396	1.48	72.91	18.12	3.60	8.09	23.18
	SEM	0.0290	0.037	0.135	0.167	0.039	0.054	0.127
Main effect of CP (n=16)								
	H	2.482[a]	1.43	73.22[a]	18.61[a]	3.62	8.00	23.19
	M	2.419[ab]	1.44	73.17[a]	18.33[a]	3.61	8.17	23.19
	L	2.329[b]	1.60	72.43[b]	17.54[b]	3.54	8.18	23.23
	SEM	0.0355	0.045	0.166	0.204	0.047	0.065	0.156
P-value								
Grain		0.519	0.707	0.719	0.731	0.826	0.483	0.802
CP		0.015	0.014	0.002	0.002	0.436	0.089	0.979
Grain × CP		0.202	0.047	0.523	0.089	0.665	0.809	0.045

[1]C = corn; S = sorghum

[2]H = high CP; M = medium CP; L = low CP