Final Report **Summary**

Formulating broiler diets based on protein and starch digestive dynamics

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AgriFutures® Chicken Meat

Background

In meat chicken diets there is a mandatory requirement for crude protein, ranging from 180 to 230 g/kg. When dietary energy density is not limiting, the quality and quantity of dietary crude protein dictates the chickens' growth performance. The digestibilities of protein and amino acids are key to the quality of the inclusion of any feedstuff in diets for chicken meat production. However, a series of studies have demonstrated that feed conversion efficiency is determined by the post-enteral, bilateral bioavailability of protein/amino acids and starch/glucose (Moss et al. 2019; Liu et al. 2020; Macelline et al. 2020). The digestive dynamics of these macronutrients are more indicative of feed efficiency and protein deposition than the extent of digestion by itself (Liu et al. 2013b; Liu and Selle 2015; Truong et al. 2017).

The rationale is that at least 20% of incoming dietary energy is consumed by the gastro-intestinal tract for nutrient digestion and absorption (Cant et al. 1996). Watford et al. (1979) suggested either glutamic acid/glutamine or glucose are catabolised to fuel enterocytes in the avian digestive tract. Starch is digested faster than protein (Liu et al. 2013a); therefore, it was hypothesised that rapidly digestible protein, such as whey protein and non-bound amino acids, may present amino acids to the proximal sites of the small intestine where glucose is abundant, thereby reducing amino acid catabolism, and enhancing nitrogen retention and muscle protein deposition. The same result may also be achievable via slowly digestible starch supplying glucose to the distal small intestine as an alternative energy substrate. This hypothesis was supported by a meta-analysis of sorghum-based diets (Liu and Selle 2015) and a subsequent study in wheat- and maize-based diets (Liu et al. 2014).

Given the importance of digestive dynamics to broiler growth performance, Liu and Selle (2017) defined digestive dynamics of starch and protein as the digestion of starch and protein absorption of glucose and amino acids from the gut lumen and their transition across enterocytes to enter the portal circulation. This broad definition considers the extent, rate and site of nutrient digestion along the small intestine and the bilateral, post-enteral bioavailability of glucose and amino acids. Feed conversion efficiency may be improved by rapidly digestible protein or slowly digestible starch, and the impact of protein digestion is more pronounced than starch (Liu and Selle 2015). Dietary optimisation for balanced starch and protein digestion, and glucose and amino acid absorption, cannot be explored fully without appreciating rates of nutrient digestion in various feed ingredients. Therefore, seven studies were completed to determine starch, protein and amino acid digestion and absorption rates in common feedstuffs used in Australia (Liu et al. 2019a; Macelline et al. 2020). The possibility of optimising dietary digestion rate via selecting feed ingredients and manipulating their inclusions was also evaluated (Liu et al. 2020).

Starch digestion rates in cereal grains (Study 1-2)

In the first two feeding studies, 20 starch-rich ingredients, including sorghum (n = 7), wheat (n = 4), maize (n = 2), barley (n = 3), triticale (n = 2), oats and cassava, were evaluated. The amino acid and mineral contents were quantified, and the apparent digestibilities of starch and protein (N) at four sites of the small intestine were determined where digestion rates were predicted.

The details of these two studies are included in Selle et al. (2020); the summary of digestive dynamics of cereal grains in meat chickens is shown in Table 1. It is interesting but not surprising that the rate of starch digestion in wheat were numerically higher than sorghum and maize. Sorghum, in fact, had the lowest starch digestion rate in comparison to other cereal grains. This could be due to phytate, non-tannin phenolic compounds and kafirin protein bodies in sorghum grains (Liu et al. 2015).

Table 1: Effects of diets based on commonly used feed grains on predicted potential digestible starch (PDS, g/g) and starch digestion rate (SDR, min-1) and growth performance from 21 to 28 days post-hatch

	Starch parameters		Growth performance		
Feed grain (number of samples)	**PDS** (g/g)	**SDR** (min^{-1})	**Weight gain** (g/bird)	**Feed intake** (g/bird)	**FCR** (g/g)
Sorghum (7)	0.850	0.075	631ab	1023	1.649
Wheat (4)	0.849	0.117	669c	1032	1.549
Maize (2)	0.854	0.086	681c	1031	1.518
Barley (3)	0.861	0.104	607a	1006	1.667
Triticale (2)	0.951	0.093	650bc	1035	1.601
SEM	0.0152	0.0136	13.37	10.89	0.0385
Significance (P =)	0.988	0.128	0.004	0.440	0.052
LSD (P < 0.05)	-	-	37.5	-	-

abcMeans within columns not sharing a common superscript are significantly different at the 5% level of probability

Protein and amino acid digestion rates in protein-rich ingredients (Study 3-5)

Three studies were conducted to evaluate protein and amino acid digestive dynamics in protein-rich feedstuffs, including canola meals (5), canola seed, soybean meals (3), full fat soy, blood meal (3), meat and bone meal (8), poultry meal, cottonseed meal, peas and lupins. The details of these studies are reported in Macelline et al. (2020) and Toghyani et al. (2020). Examples of protein and amino acid digestion rates in selected ingredients are given in Table 2. The variation was smaller between similar ingredients processed with different methods than from different sources. The studies detected more variations in jejunal amino acid and protein digestibilities than in ileal digestibilities. There were no significant differences in amino acid digestion rates among feedstuffs, which could be due to the large variation of jejunal digestibilities within treatment. Jejunal digestibilities of individual amino acids are more likely to be influenced by endogenous nitrogen flow (Liu et al. 2013b). There was a significant difference in protein digestion rate; the blood meal had the highest digestion rate. This emphasises that both the extent and rate of protein digestion need to be considered as indicators of protein quality.

Table 2: Examples of protein and amino acid digestion rates in selected ingredients.

Ingredients	Essential amino acids								
	Arg	His	Ile	Leu	Lys	Met	Phe	Thr	Val
Blood meal	0.172	0.22	0.178	0.194	0.185	0.186	0.195	0.189	0.19
Cold-press canola meal	0.040	0.042	0.022	0.028	0.014	0.054	0.03	0.025	0.026
Expeller canola meal	0.021	0.02	0.013	0.016	0.008	0.036	0.016	0.012	0.013
Lupins	0.131	0.107	0.066	0.073	0.052	0.022	0.072	0.061	0.053
Peas	0.141	0.084	0.052	0.061	0.102	0.016	0.067	0.045	0.049
SBM high protein	0.176	0.187	0.159	0.163	0.15	0.042	0.164	0.179	0.156
SBM low protein	0.051	0.055	0.045	0.051	0.031	0.037	0.051	0.049	0.043
SEM	0.073	0.071	0.071	0.07	0.073	0.051	0.07	0.072	0.071
P-value	0.562	0.358	0.523	0.472	0.489	0.343	0.466	0.411	0.461

Ingredients	Non-essential amino acids							
	Ala	Asp	Glu	Gly	Pro	Ser	Tyr	Protein
Blood meal	0.199	0.188	0.177	0.185	0.187	0.184	0.139	0.124^{a}
Cold-press canola meal	0.026	0.025	0.043	0.027	0.037	0.021	0.002	0.023^{bc}
Expeller canola meal	0.015	0.012	0.023	0.013	0.016	0.012	0.001	0.015^{c}
Lupins	0.051	0.088	0.121	0.076	0.087	0.084	0.029	0.062^{b}
Peas	0.057	0.1	0.112	0.061	0.067	0.07	0.01	0.051^{bc}
SBM high protein	0.178	0.195	0.202	0.184	0.194	0.189	0.145	0.066^{b}
SBM low protein	0.047	0.055	0.063	0.05	0.054	0.054	0.013	0.029^{bc}
SEM	0.072	0.071	0.072	0.072	0.071	0.072	0.077	0.021
P-value	0.380	0.392	0.504	0.441	0.429	0.418	0.63	0.033

^{abc}Means within columns not sharing a common superscript are significantly different at the 5% level of probability

Starch and protein digestive dynamics in complete broiler diets (Study 6-7)

Two more studies were conducted to evaluate the influence of starch, protein and lipid digestion rates on growth performance and feed conversion efficiency, and to apply the previously determined starch and protein digestion rates in least-cost feed formulation. The Box-Behnken response surface design was used in Study 6 to include wheat, whey protein and tallow (poultry) at three different levels in a sorghum-soybean meal-soybean oil-based diet. It was hypothesised that wheat + xylanase would supply rapidly digestible starch; whey protein would supply rapidly digestible protein; and tallow would provide slowly digestible lipid. Surprisingly, the hypothesis was rejected because increasing whey protein inclusion did not improve feed conversion efficiency (Figure 1). This was due to the lack of impact of whey protein inclusion levels on protein digestion rate at the anterior sites of the small intestine. It is not clearly understood why increasing whey protein inclusion from 0 to 100 g/kg did not increase protein digestibilities in the proximal and distal jejunum. Increasing wheat inclusion improved feed conversion efficiency, and tallow had little impact on feed conversion compared to starch and protein. For reference, another two published studies by our team also investigated the interactions between protein and energy digestive dynamics in meat chickens (Khoddami et al. 2018; Liu et al. 2019b).

The seventh study was done to validate the relevance of starch and protein digestive dynamics in meat chickens offered diets based on common feedstuffs with pre-determined starch and protein digestion rates. Six diets were formulated to contain six ratios of starch-to-protein digestion rate (1.567–2.453),

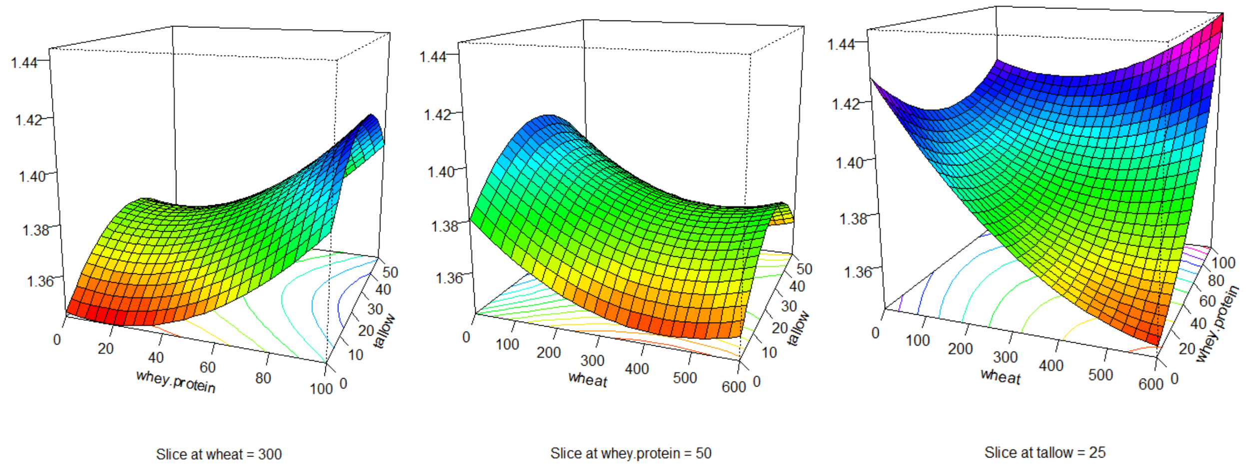

Figure 1: Response surfaces demonstrating the influence of wheat, whey protein, and tallow inclusions (g/kg) on feed conversion ratio (FCR).

but similar amino acid and energy densities, and were offered to meat chickens from 7 to 35 days post-hatch. There were quadratic relationships ($P < 0.01$) between starch and protein digestion rates, and their ratios, with feed conversion ratio (FCR). A predicted optimal 1.446 FCR was attained with a starch digestion rate of 3.31 min-1 (Figure 2). An optimal FCR of 1.450 was predicted with a protein digestion rate of 2.02 min-1 or with a starch:protein digestion rate ratio of 1.663. Increasing protein digestion rate, or decreasing starch digestion rate, or narrowing starch and protein digestion rate ratios tended to improve feed conversion efficiency. There were no significant differences in feed intake, weight gain and FCR between the dietary treatments. The present study confirmed the importance of starch and protein digestive dynamics in practical meat chicken diets, and demonstrated the possibility of incorporating starch and protein digestion rates into least-cost feed formulations.

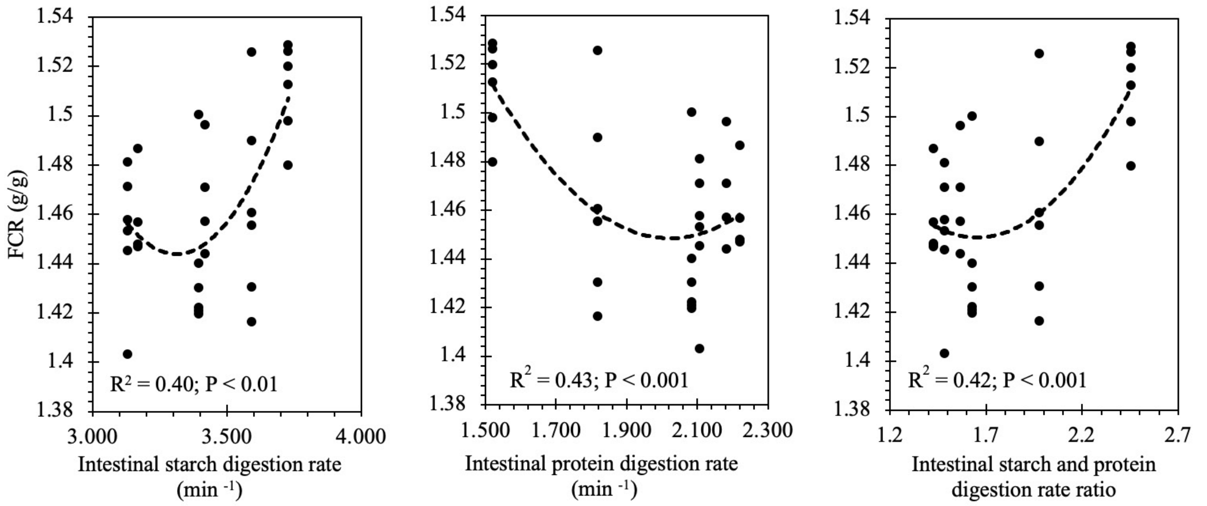

Figure 2: The correlations between FCR and starch, protein digestion rate and starch: protein digestion rate ratios in broiler chickens from 7 to 35 days post-hatch.

Outcomes

This project generated the preliminary database of protein and starch digestion rates in common Australian feed ingredients. As a consequence, nutritionists will be better positioned to predict and improve the efficiency of feed conversion and nutrient utilisation in meat chickens.

Implications

The consideration of digestive dynamics between amino acid and glucose, non-bound and protein-bound amino acids, is necessary and important when the supplementation of synthetic and crystalline amino acids increase largely in reduced crude protein diets.

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Publications arising from PRJ-010216

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