Feed Grain Partnership
TECHNOTE

[Sorghum TechNote PRF 4-14]

Digestive dynamics of starch and protein
Why it is important in sorghum-based broiler diets?

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Introduction

Poultry production in Australia has increased on average by around 4 percent a year over the past 20 years, and this is projected to reach 1030 kilo tonnes by 2014-2015 (Fell, 2010). Feed cost is around 60 percent of total production cost in the poultry industry, and about 90 percent of feed volume is grains and/or oilseeds. Sorghum is used as part, or sometimes as the entire, cereal grain base in diets for pigs and poultry. Sorghum, like other cereals, is rich in starch (~700 g/kg) and has a protein concentration from 115 to 137 g/kg; sorghum has a nitrogen corrected apparent metabolisable energy (AMEn) ranging from 13.5 to 17.7 MJ/kg (Selle *et al.*, 2010).

Black *et al.* (2005) suggested that one reason for the inferiority of sorghum relative to wheat was a lack of synchrony in starch and protein digestion. Starch granules are surrounded by kafirin protein bodies and both are embedded in a glutelin protein matrix in the sorghum endosperm, and because of their close proximity, kafirin and glutelin may impede starch digestion. Anti-nutritive factors, including non-tannin phenolic compounds and phytate may also interfere with starch and protein digestion. Therefore, determination of the relevance of digestive dynamics to broiler performance in sorghum-based diets is necessary.

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The rate, site and extent of digestion

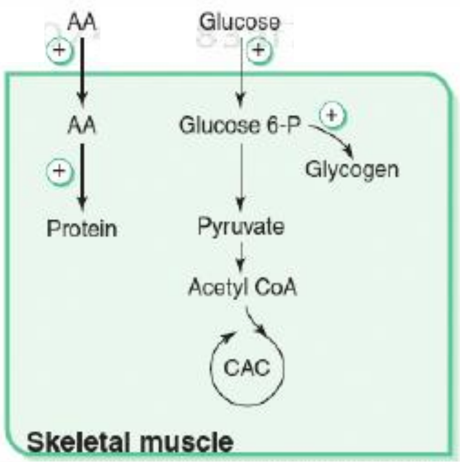

Figure 1. skeletal muscle protein deposition uses both glucose and amino acids (Pelley and Goljan, 2011)

Generally, the gastrointestinal tract of pigs and poultry consumes ~20% of dietary energy density for the digestion and absorption of nutrients (Cant *et al.*, 1996). The majority of energy is derived from protein/amino acids (glutamic acid/glutamine) rather than starch/glucose (Fuller and Reeds, 1998). This means that relatively more glucose is absorbed into the bloodstream than amino acids. Changes in blood glucose concentrations trigger pancreatic secretions of insulin, which influences both amino acid catabolism and protein synthesis (Grizard *et al.*, 1999). Skeletal protein deposition requires both glucose and amino acids (Figure 1); therefore, the balance of starch and protein digestion dynamics is critical for efficient net protein deposition.

In practice, broilers have unrestricted access to feed and *ad libitum* feeding regime is often thought to accommodate any differences in rates of digestion/absorption of nutrients. However, ad libitum feeding does not equate with continuous feeding because birds fed pelleted diets spent less than 5% of illuminated time eating under a '12 hours-on' lighting pattern (Jensen *et al.*, 1962). Thus despite unrestricted access to feed it does appear that consumption patterns still provide scope for asynchronies in digestion and absorption to impact on broiler performance.

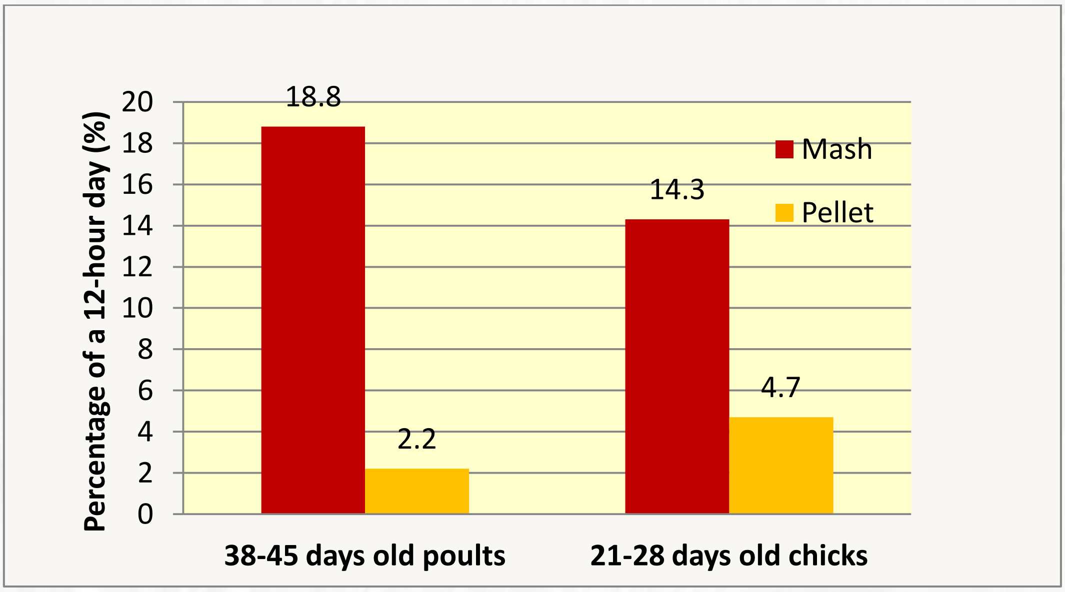

Figure 2. The percentage of time poultry spent on eating under a '12 hours-on' lighting pattern (Jensen *et al.*, 1962)

Digestive dynamics, in this context, are defined to embrace the digestion of nutrients in the gut lumen, absorption of end-products into the gut mucosa, and their entry into the systemic circulation. Conventionally, apparent digestibility coefficients report the extent of nutrient digestion. It is a common indicator of feed quality but it is a static measurement normally taken at the end of small intestine. Digestive dynamcis involve both static and kinetic components and ileal digestibility coefficients may be employed to investigate the kinetics of digestion and absorption. That is the amount, site and rate of absorption of glucose and amino acids along the small intestine. The amount of a nutrient absorbed at the terminal ileum (g/bird) or another intestinal segment is a simple function of feed intakes, dietary concentrations and digestibility coefficients. The site of absorption may be defined as one of four small intestinal segments; the proximal and distal jejunum and the proximal and distal ileum, and the amounts of starch or protein that apparently disappeared or were absorbed may be calculated. The rate of digestion may be deduced by fitting apparent digestibility coefficients and mean retention times in intestinal segments into an exponential mathematical model. Thus the kinetic parameters hinge on static digestibility coefficients but may represent a valuable and instructive extension of the underlying static data.

Sorghum as a dietary model

Previous studies, which investigated the relationship of synchrony of starch and protein digestion with growth performance (Van der Meulen *et al.*, 1997, Weurding *et al.*, 2003), used diets providing extreme fast or slow digestion rates which would not be applied in practical poultry diets. Usually, starch is digested more rapidly and completely than protein. Thus it is a challenge to select a relatively slow digestible starch source with more allowance to manipulate starch digestion rates.

Giuberti *et al.* (2012) reported that sorghum had the lowest rapidly digestible starch (119 g/kg), potential digestible starch (70.4 g/100g dry starch) and the highest resistant starch (275 g/kg). The authors also showed that sorghum had very low starch digestion rate (0.018/min) which is the same as high amylose maize (0.017/min) and the lowest predicted glycaemic index (Table 1). This is consistent with the findings of Weurding *et al.* (2001) where different starch digestion rate in the small intestine of broiler chickens differs among feed ingredients and sorghum had the lowest and slowest starch digestion rate (Table 2). As discussed in other sorghum Technotes, there are several possible factors causing slow and incomplete starch digestion in sorghum-based broiler diets, including kafirin, phytate and phenolic compounds. Sorghum-based diets are appropriate so as to avoid artificial experimental diets and examine the importance of starch and protein digestive dynamics in practical broiler diets. Therefore, a series of studies in broiler chickens offered sorghum-based diets were conducted in Poultry Research Foundation to investigate the relevance of digestive dynamics of starch and protein on broiler performance and nutrient utilisation.

Table 1. Starch fractions and digestion rates of starch in various cereal grains (Giuberti *et al.*, 2012)

Item	Rapidly digested starch (g/kg DM)	Slowly digested starch (g/kg DM)	Resistant starch (g/kg DM)	Potential digestible starch (g/100g dry starch)	Rate of starch digestion (/min)	Predicted Glycaemic index
Maize	147	367	191	95.0	0.017	39.5
Barley	151	264	143	88.6	0.024	51.1
Wheat	181	379	53	92.8	0.035	65.8
Triticale	201	296	139	88.7	0.036	71.4
Rice	355	269	142	87.7	0.057	80.0
Sorghum	119	342	275	70.4	0.018	15.9
Oats	217	166	99	79.3	0.042	65.8
Low-amylose maize	301	270	197	96.1	0.035	67.6
Low-amylose barley	239	263	81	85.5	0.045	77.2

Table 2. starch digestion characteristics in the small intestine of broilers fed diets containing different sources of starch (Weurding *et al*., 2001)

Starch source	Jejunal digestibility	Ileal digestibility	Potential digestible starch (%)	Starch digestion rate (h^{-1})
Wheat	0.882	0.944	93.9	2.51
Corn	0.888	0.969	96.8	2.55
Sorghum	0.837	0.953	95.4	1.81
Barley	0.898	0.981	98.5	2.51
Peas	0.574	0.804	85.3	1.03
Potato starch	0.198	0.329	38.4	0.55

Rate of starch and protein digestion in sorghum-based broiler diets

Given feed conversion ratios (FCR) is an important parameter to the sustainability of the chicken meat industry, the relevance of digestive dynamics and digestibility coefficients to FCR was compared in six published sorghum studies (Liu *et al*., 2013a, Liu *et al*., 2013b, Liu *et al*., 2013c, d, Selle *et al*., 2014, Liu *et al*., 2014). This included 33 dietary treatments with different varieties of sorghum, different feed forms (raw mash, intact pellet and reground mash), hammer-mill screen sizes, steam-pelleting conditioning temperatures, without and with feed enzymes and a reducing agent. The following equation describes ($P < 0.05$) the relationship between starch (k_{starch}) and protein ($k_{nitrogen}$) digestion rates and FCR and experimental variations did not contribute to this model as the experimental leverage was not significant ($P = 0.345$).

$$\mathrm{FCR} = 1.719 - 0.272 \times \log(k_{\mathrm{nitrogen}}) + 0.0864 \times \log(k_{\mathrm{nitrogen}}) \times \log(k_{\mathrm{starch}})$$

The equation indicates that 76% of variation in FCR can be attributed to starch and protein (N) digestion rates along the small intestine. Additionally, there was an interaction between starch and protein digestion rates indicating that coupling slowly digested starch with rapidly digested protein is advantageous for feed conversion efficiency (Figure 3).

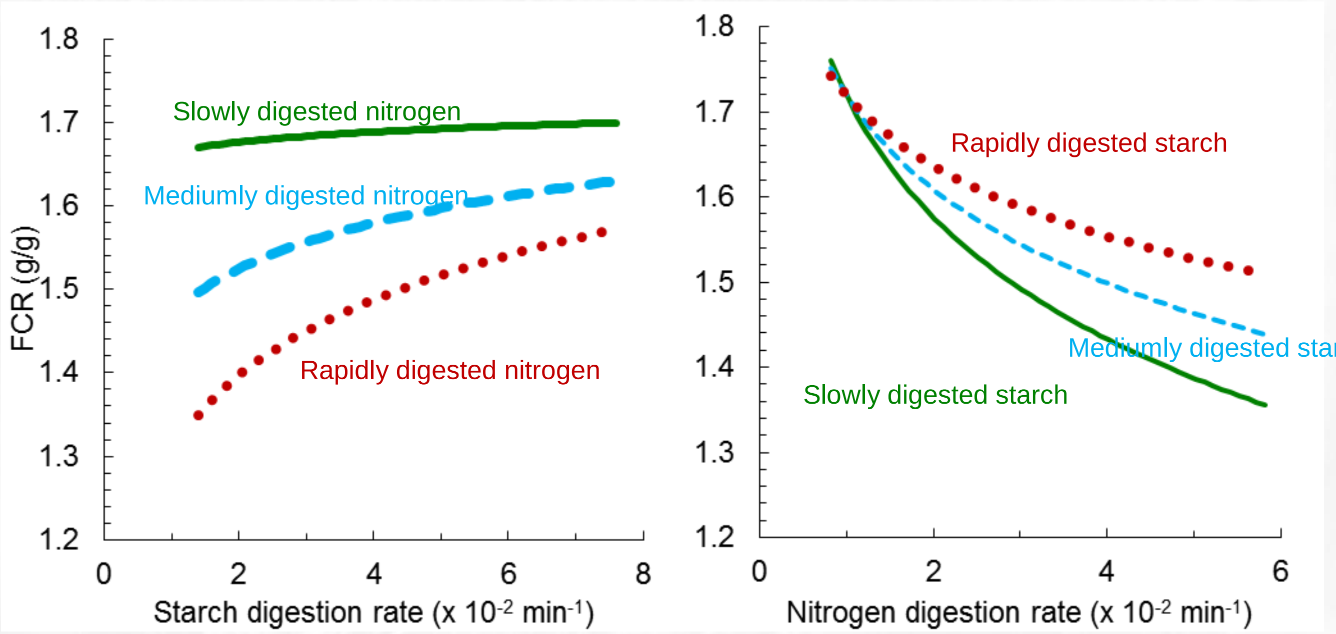

Figure 3. The relationship of FCR and digestion rates of starch and protein (N) in sorghum-based broiler diets

The gastrointestinal tract consumes in the order of 20% of incoming dietary energy for digestive and absorptive processes (Cant *et al.*, 1996) and according to Fleming *et al.* (1997), starch/glucose and glutamic acid/glutamine are approximately equally important energy substrates for small intestinal mucosal cells in the rat. However, net adenosine triphopshate (ATP) production from glucose was greater than glutamine by a two-fold factor (120.0 versus 57.1 µmol/g/minute) and net ATP production with both substrates present was 155.5 µmol/g/minute. This suggests glucose is a more efficient energy source for small intestinal mucosa. It follows that glucose from rapidly digested starch sources would be depleted in the upper small intestine, effectively forcing mucosal cells in the lower small intestine to oxidise amino acids to provide energy. Thus slowly digested starch sources would provide more glucose to the lower small intestine thereby sparing protein from oxidation and energy generation from glucose would be substantially more efficient than from amino acids.

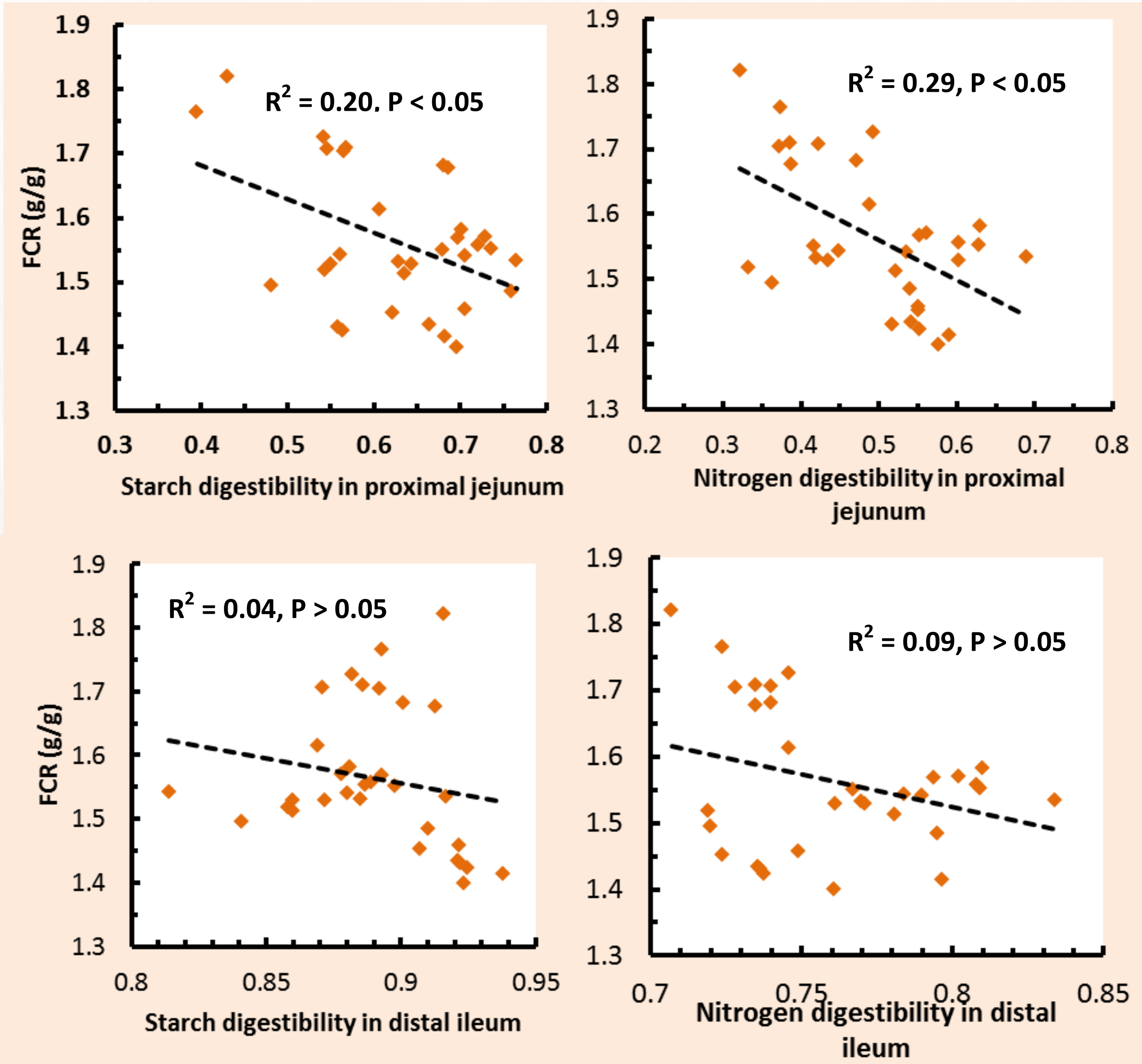

Figure 4. The relationship of FCR and apparent digestibility coefficients of starch and protein (N) in proximal jejunum and distal ileum

More interestingly, FCR was not correlated with starch digestibility coefficients but was correlated with nitrogen digestibility coefficients in the distal jejunum and proximal jejunum but the contribution of experimental variation was significant. These findings demonstrate that static, individual digestibility coefficients of starch and nitrogen are not highly indicative of feed conversion efficiency and nutrient utilisation in broiler chickens. The fact that sorghum has relatively slow starch digestion rate, if possible, coupled with enhanced protein digestion, may benefit growth performance in broiler chickens. Strategies to improve protein utilisation in sorghum-based broiler diets are discussed in other sorghum Technotes.

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