The importance of digestive dynamics in broiler chicken nutrition

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Digestive dynamics

- Digestion (starch and protein)
- Absorption (transition across the enterocytes of the gut mucosa)
- Post-absorption metabolism and utilisation

And more…..

Jejunum is the major site of glucose and AA absorption

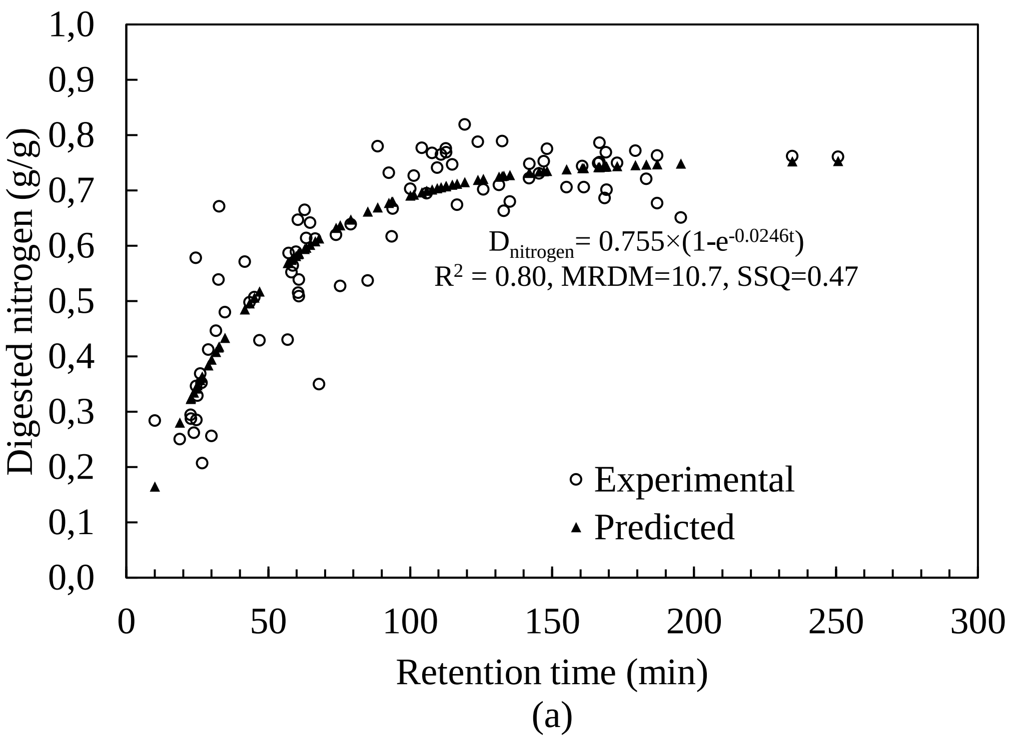
Apparent digestibility coefficients of starch and protein (N) in broiler diets based on maize, sorghum and wheat

	Starch					Protein (N)			
Basis of diet	Proximal jejunum	Distal jejunum	Proximal ileum	Distal ileum		Proximal jejunum	Distal jejunum	Proximal ileum	Distal ileum
Maize	0.827	0.905	0.947	0.950		-0.098	0.701	0.813	0.837
Sorghum	0.798	0.827	0.867	0.877		-0.119	0.547	0.758	0.795
Wheat	0.774	0.869	0.911	0.884		-0.090	0.643	0.715	0.761

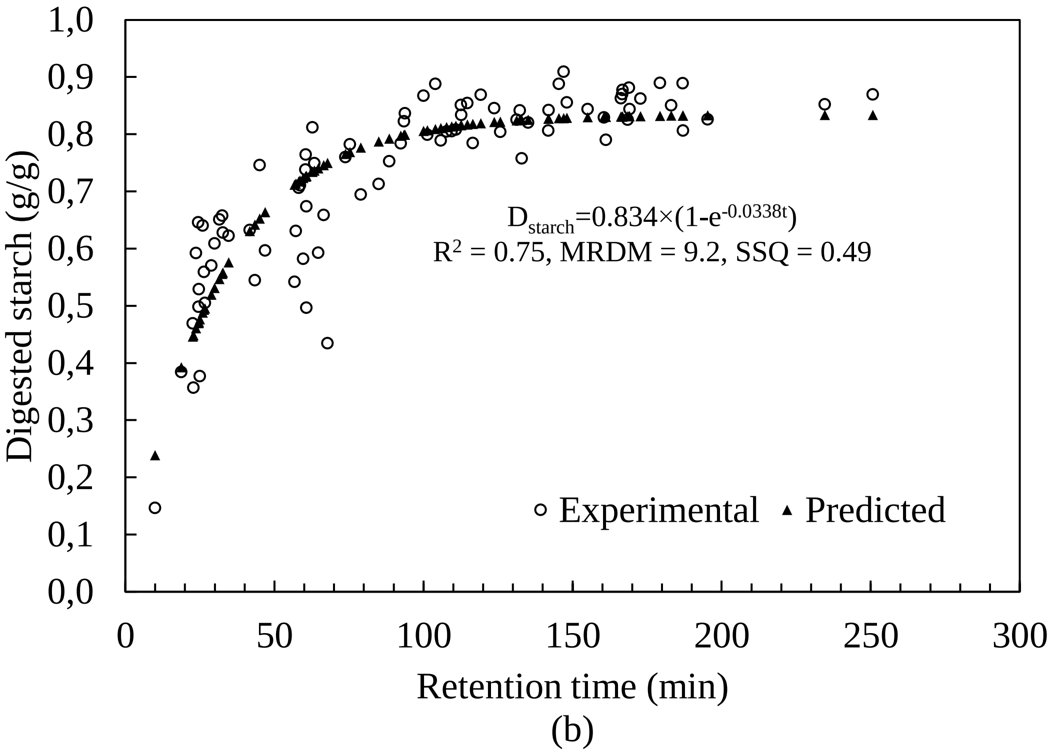
96% digestible starch and 79% digestible protein has been digested by the end of jejunum

Liu, SY, Cadogan, DJ, Péron, A, Truong, HH, Selle, PH (2014) *Animal Feed Science and Technology* **197**, 164-175.

Experimental and predicted digestion curve of protein (nitrogen, a) and starch (b)



(a)



(b)

Starch digestion rates were more rapid than that of protein by nearly 40% (3.38 versus 2.46 $\times 10^{-2}$ min^{-1})

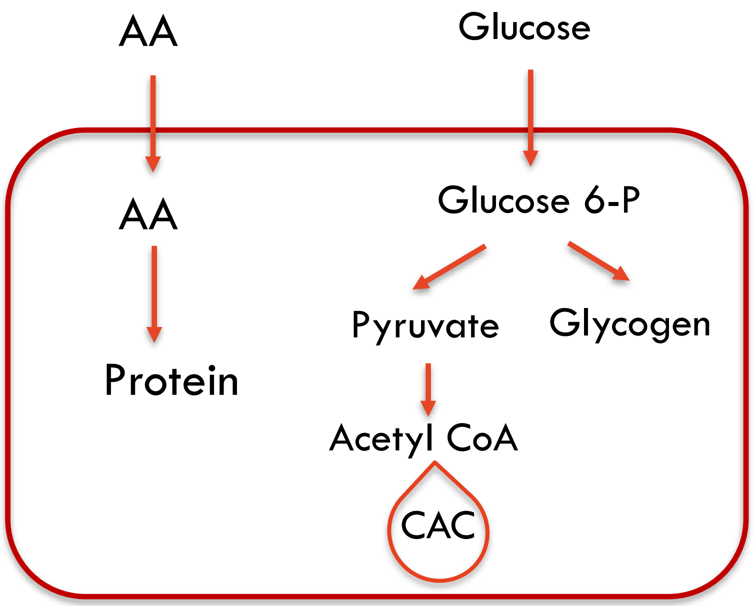
Liu SY, Selle PH, Cowieson AJ (2013) *Animal Feed Science and Technology* **185,** 85-93.

- Starch digestion is more rapidly than apparent protein digestion.

- The synthesis of 1 gram of protein in chicks requires an energy input of 5.35 kJ (or the synthesis of 1 lbs of protein in chicks requires an energy input of 580 kcal) (Aoyagi *et al.*, 1988)

- Starch provides most of the dietary energy; therefore, the presence of both glucose and amino acids at sites of protein synthesis is a prerequisite for skeletal muscle protein deposition.

Skeletal Muscle



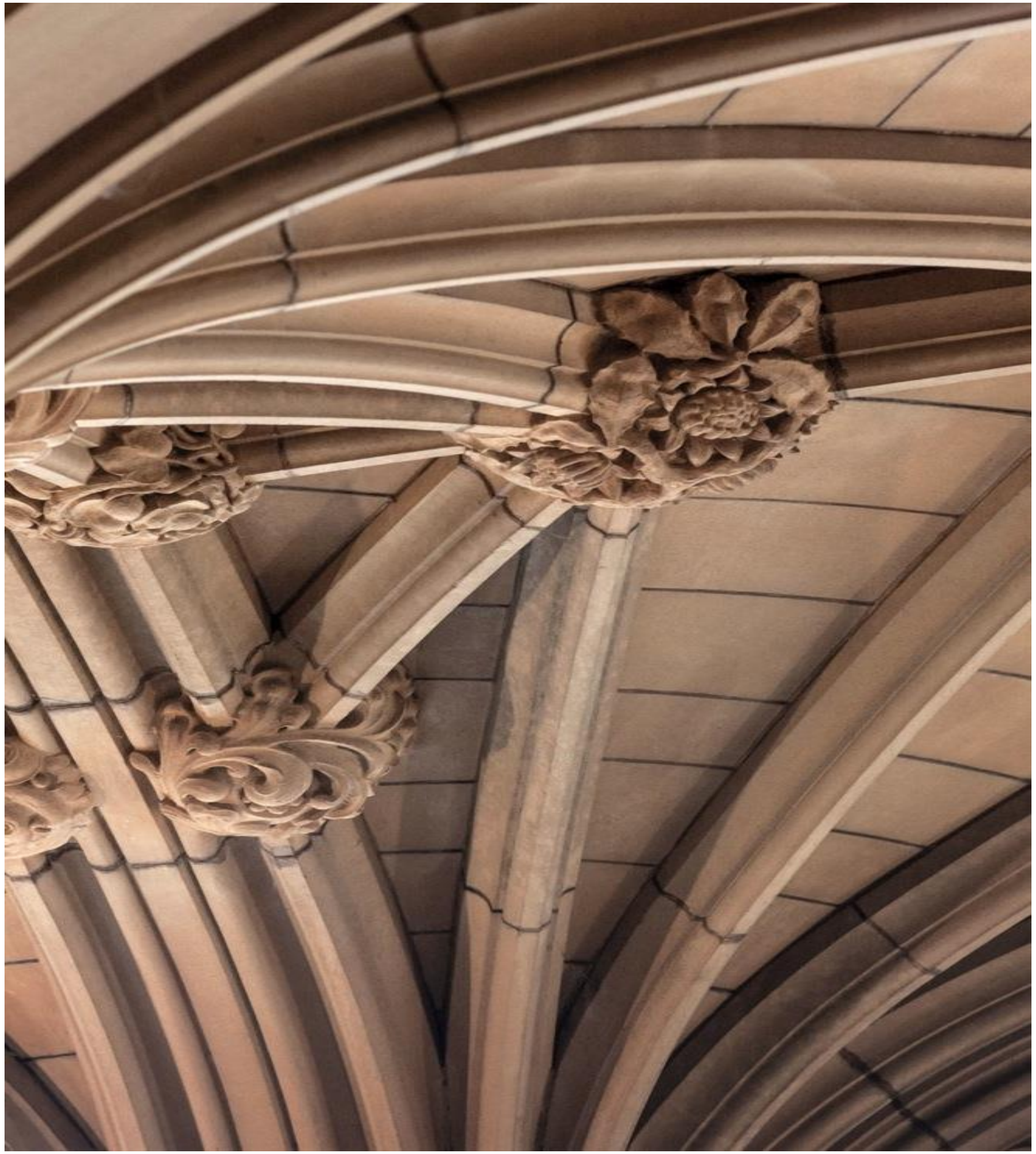
Liu et al., (2013)
Pelley (2009)

Rapidly digestible protein

- Feed conversion efficiency may be improved by rapidly digestible protein and slowly digestible starch; more importantly, **protein digestion rate had the more pronounced impact on feed conversion efficiency.**

In conventional diets!

Digestive dynamics in practice?



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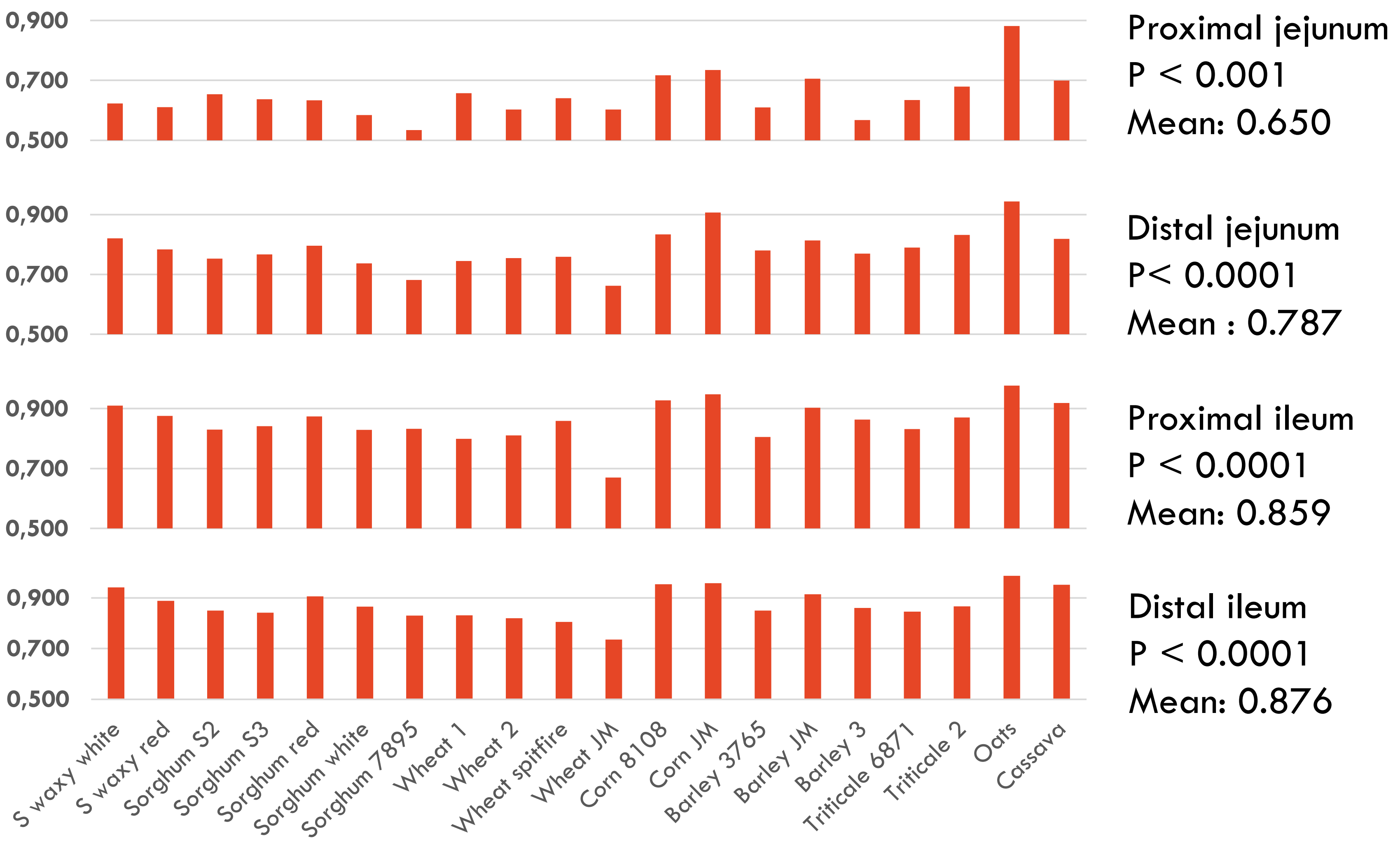
Protein digestion rates were different in protein-rich feed ingredients

	Apparent protein digestibility coefficients (N)					Protein digestion rate	Potential digestible protein
Ingredients	Proximal jejunum	Distal jejunum	Proximal ileum	Distal ileum		(min^{-1})	(g/g)
Blood meal (1)	0.568^{a}	0.516^{b}	0.717^{bcde}	0.761^{bcd}		0.124^{a}	0.678^{b}
Plasma meal (2)	0.256^{b}	0.486^{b}	0.892^{a}	0.937^{a}		-	-
Cold-press Canola Meal (3)	0.229^{b}	0.485^{b}	0.619^{e}	0.684^{d}		0.023^{bc}	0.771^{b}
Expeller Canola Meal (4)	0.246^{b}	0.470^{b}	0.627^{de}	0.704^{cd}		0.015^{c}	0.859^{ab}
Lupins (5)	0.446^{ab}	0.771^{a}	0.826^{ab}	0.834^{b}		0.062^{b}	0.851^{ab}
Peas (6)	0.400^{ab}	0.639^{ab}	0.788^{abc}	0.791^{b}		0.051^{bc}	0.841^{ab}
SBM HCP (7)	0.460^{ab}	0.564^{ab}	0.762^{abcd}	0.765^{bcd}		0.066^{b}	0.804^{ab}
SBM LCP (8)	0.277^{b}	0.586^{ab}	0.678^{cde}	0.773^{bc}		0.029^{bc}	0.921^{a}
SEM	0.074	0.045	0.031	0.030		0.021	0.049
P-value	0.004	0.002	<.001	<.001		0.033	0.016

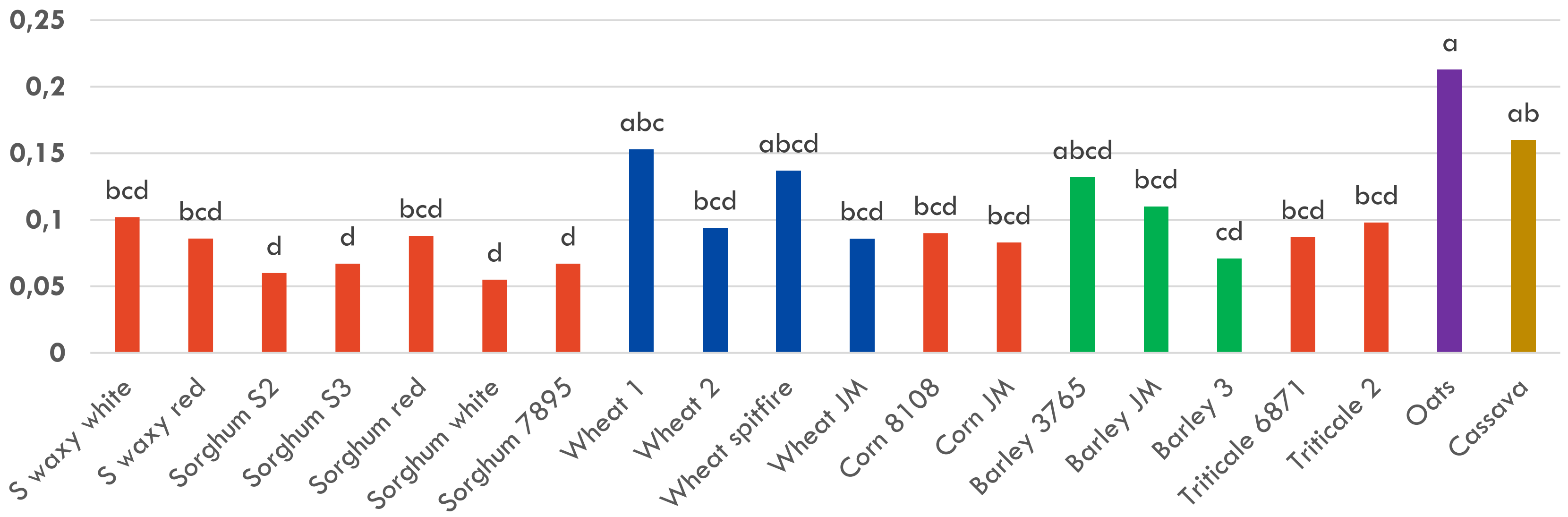
Toghyani et al., (2020) *Plos One* ***15, e0239156.***

Apparent starch digestibility in starch-rich feed ingredients



Liu, et al. (2019) *Proceedings, Australian Poultry Science Symposium* **30**, 15.

Starch digestion rates



Starch
P = 0.048

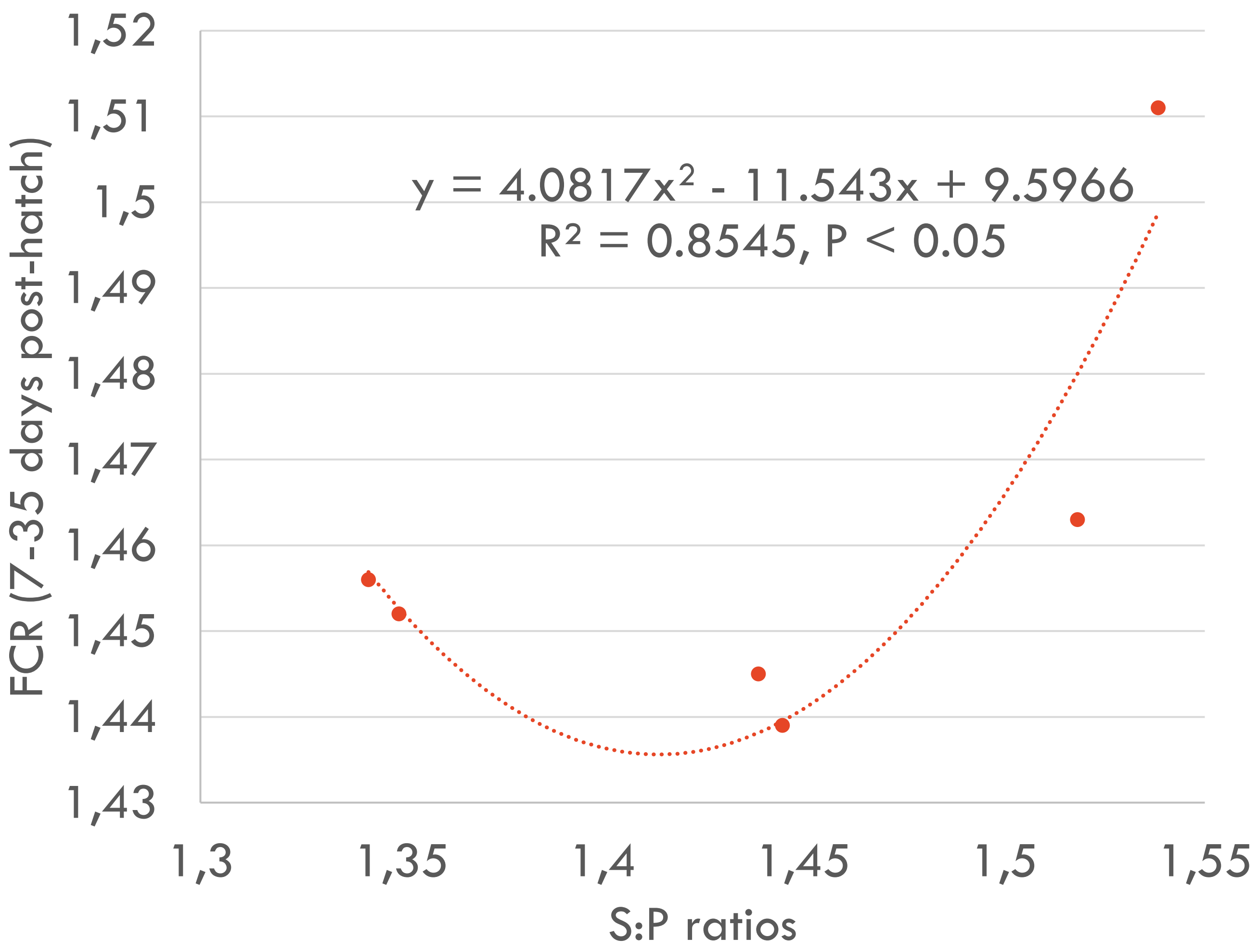
Selle et al., (2021) *Animal Nutrition* ***7, 450-459.***

Digestion rate in feed formulation ?

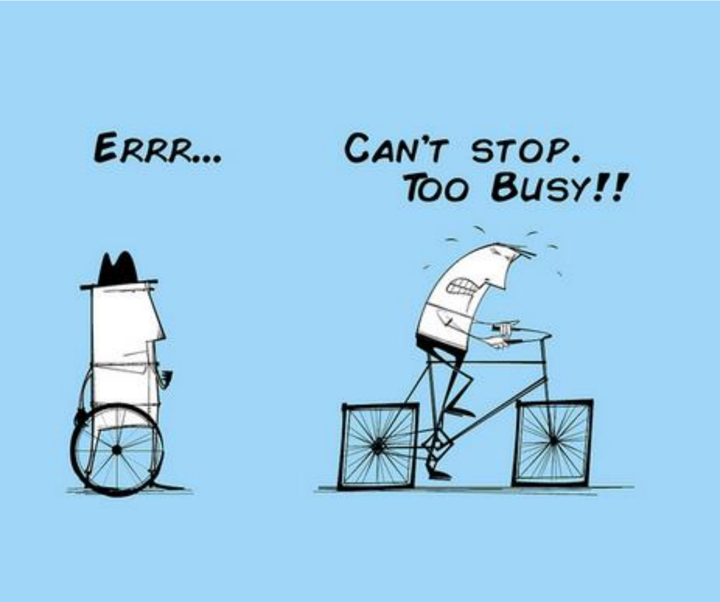
Diet	1	2	3	4	5	6
Wheat	411	262	200	200	200	200
Red sorghum	100	276	385	435	479	510
Canola seed	50.0	50.0	50.0	30.0	30.0	30.0
Soybean meal	243	234	272	257	213	165
Canola Meal	100	100	19	0	0	0
Soybean oil	35.6	27.2	19.2	18.0	11.3	10.0
L-Lys HCl	2.21	2.51	2.81	3.80	5.09	6.54
DL - Met	2.14	2.27	2.78	3.19	3.56	4.01
L-Thr	0.97	0.99	1.17	1.61	2.16	2.81
L-Trp	0.00	0.00	0.00	0.00	0.00	0.01
L-Val	0.10	0.04	0.22	0.73	1.39	2.19
L-Arg	0.00	0.00	0.02	0.92	2.16	3.57
L-Ile	0.05	0.00	0.00	0.40	1.06	1.85
L-His	0.00	0.00	0.00	0.00	0.00	0.32
Others	55.08	45.47	47.18	48.58	50.86	63.71
Starch digestion rate ($x10^{-2}$ min^{-1})	5.56	5.14	5.23	5.60	5.93	6.17
Protein digestion rate ($x10^{-2}$ min^{-1})	3.86	3.81	3.90	3.88	3.91	4.01
S:P digestion rate ratio	1.44	1.35	1.34	1.44	1.52	1.54

FCR and calculated S:P digestion rate

The optimal ratio is 1.414 which gives the optimal FCR = 1.436



Limitations and opportunities

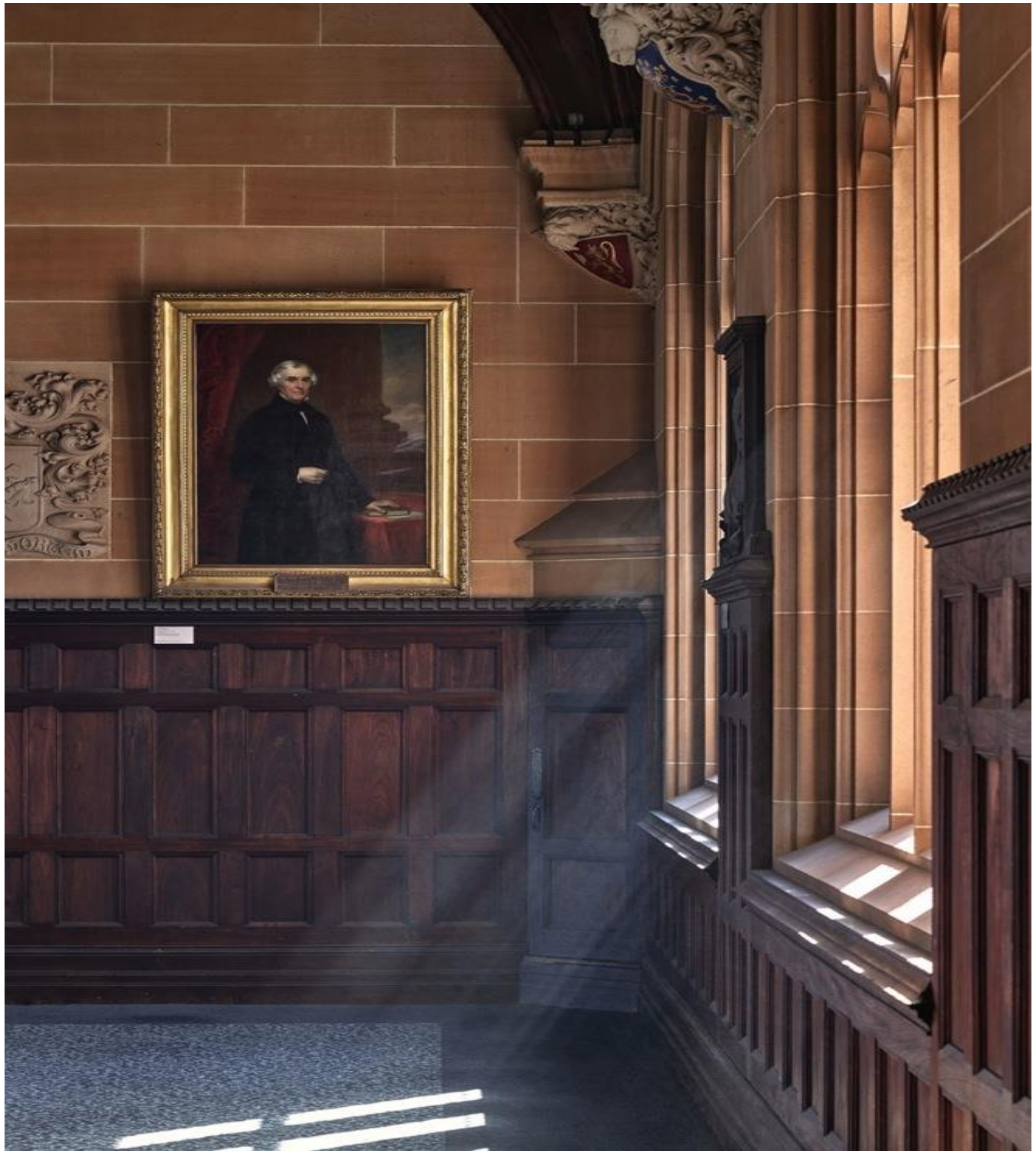


- More comprehensive raw material database is needed
- More application in the field and validation is needed (age, environment, lighting and feeding program)
- Rapid in vitro estimation for digestion rates is needed (wet chemistry or NIR)
- Non-linear feed formulation ?!

Please remember – in conventional diets:
The extent of digestion is still the top priority
Then performance may be improved by optimising digestive dynamics

Protein-bound *versus* non-bound amino acids

challenges in low protein diets



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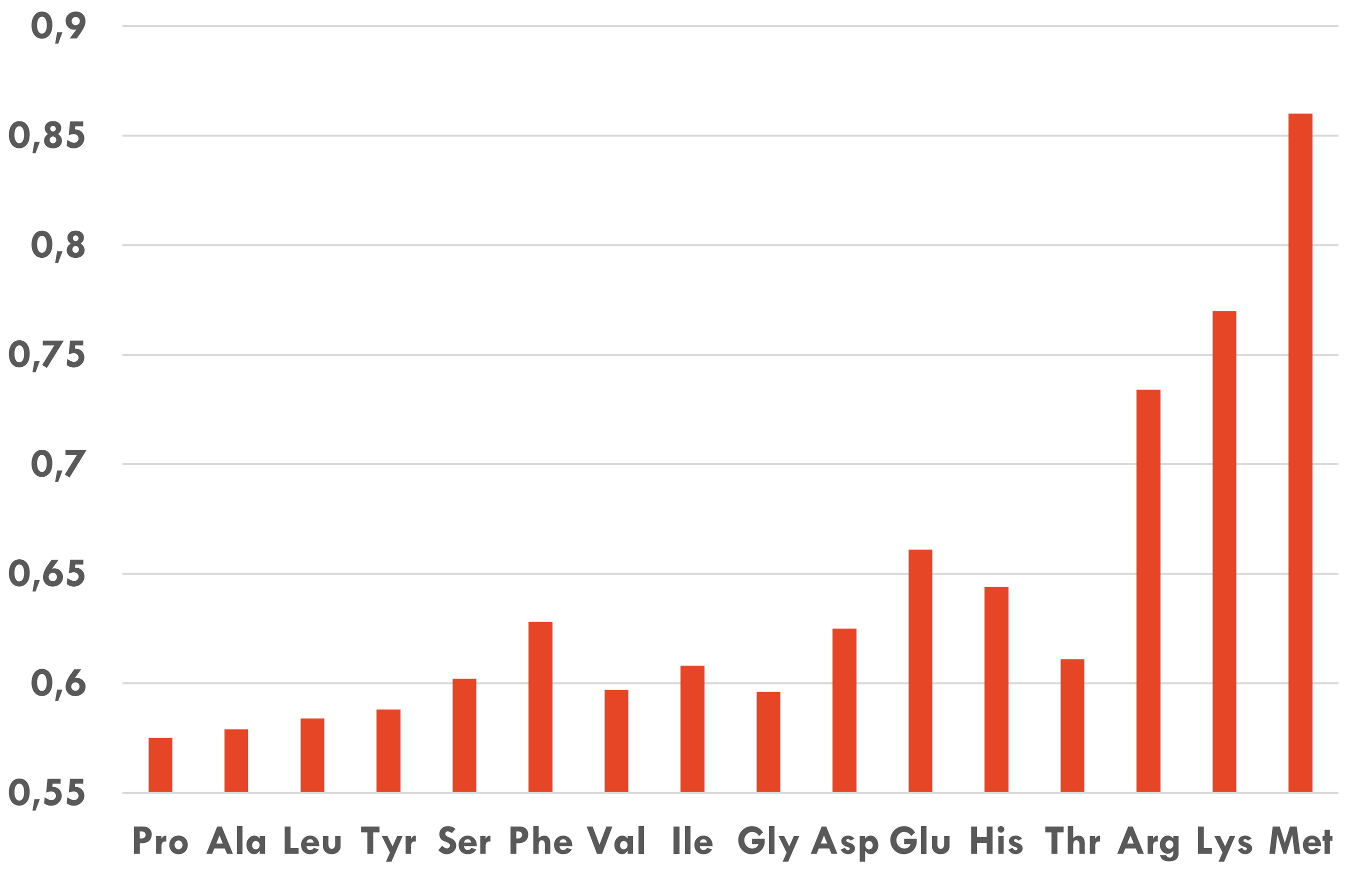
Amino acid digestion rates (× 10^{-2}/min) in typical sorghum-based diet



Liu, et. al, (2013) *Animal Feed Science and Technology* **183**, 175-183.

– The diets contained 4.8 g/kg lysine HCl, 3.4 g/kg *d,l*-methionine (and 1.3 g/kg *l*-threonine)

– Methionine (5.51×10^{-2} min^{-1}) and lysine (4.14×10^{-2} min^{-1}) were the most rapid and comfortably exceeded the mean digestion rate constant of 13 protein-bound amino acids (2.35×10^{-2} min^{-1}).

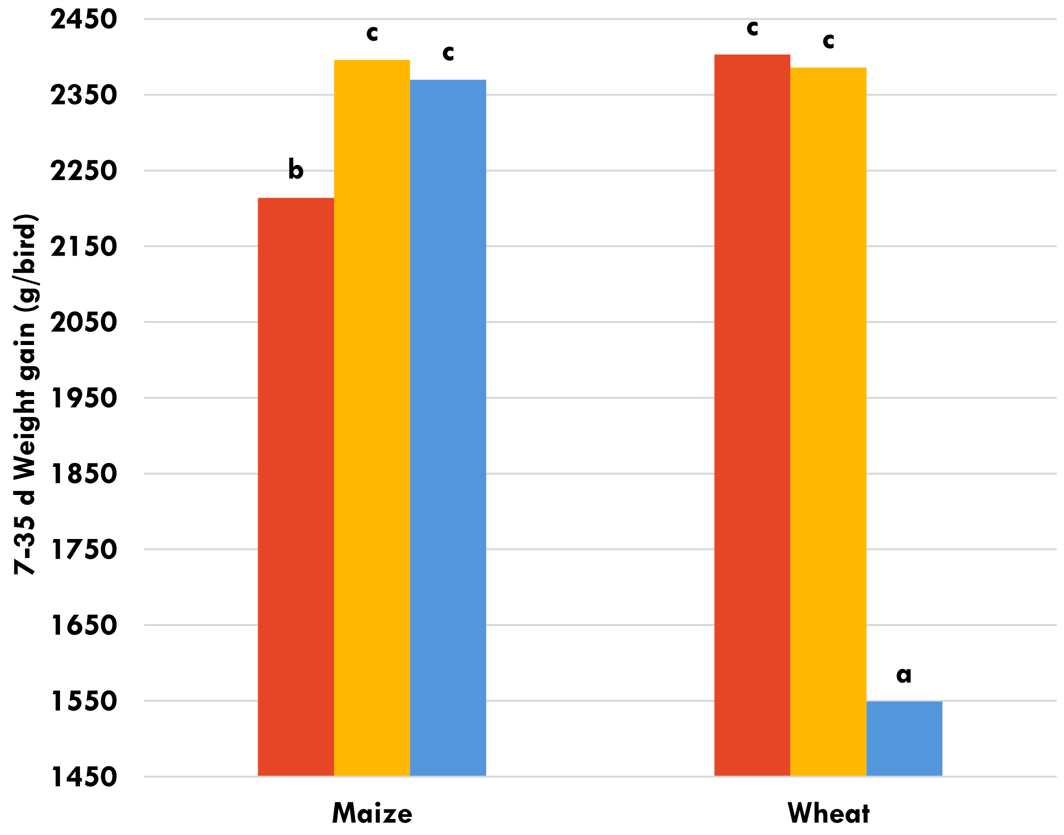
– Digestive kinetics of protein-bound amino acids as opposed to non-bound amino acids are inherently different, simply because non-bound amino acids do not require prior digestion and can be absorbed immediately (Wu, 2009).

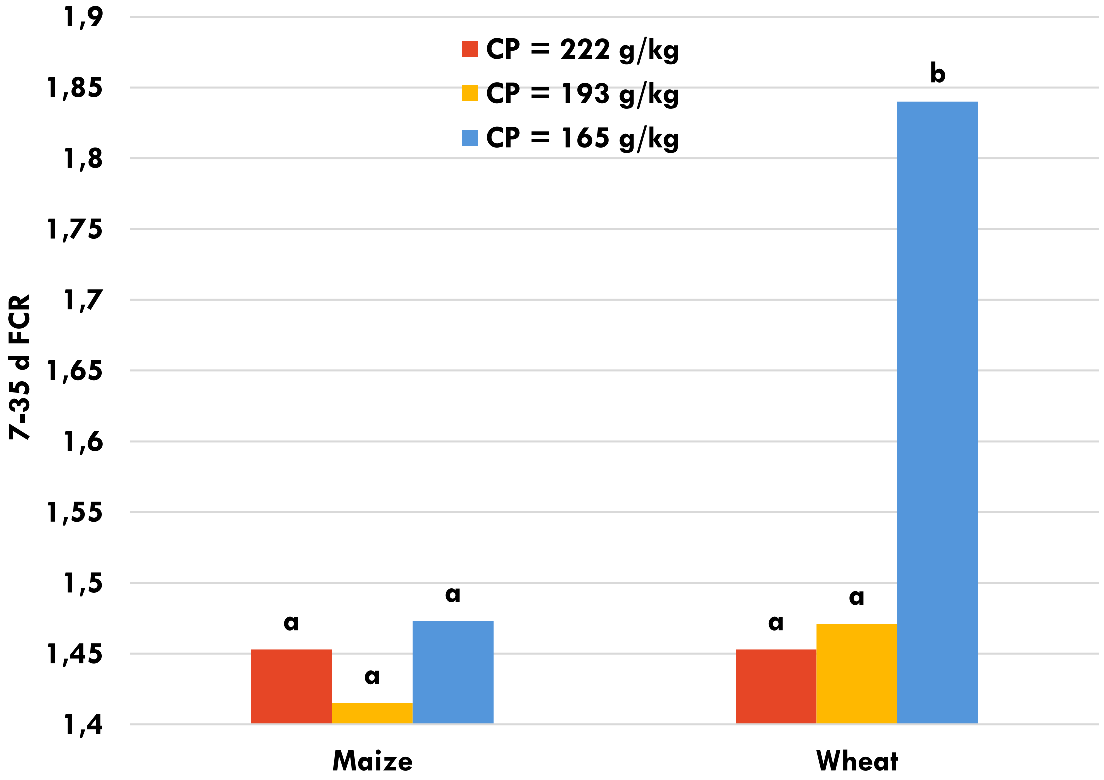
Chrystal, et al. (2021) *Animal Feed Science and Technology* 275, 114867.

Composition of experimental diets[1].

Feed ingredient (g/kg)	Diet 1A	Diet 2B	Diet 3C	Diet 4D	Diet 5E	Diet 6 F
Wheat (107 g/kg CP)	–	–	–	525	637	751
Maize (81 g/kg CP)	511	615	721	–	–	–
Canola seed	60	60	60	60	60	60
Soybean meal (483 g/kg CP)	334	228	113	300	177	48
Soy oil	35	18	–	52	36	20
l-lysine HCl (790)[2]	1.60	4.69	8.12	2.36	5.93	9.72
d,*l*-methionine (990)	2.67	3.54	4.53	2.75	3.74	4.81
l-threonine (985)	1.18	2.56	4.10	1.59	3.21	4.93
l-tryptophan (980)	–	0.15	0.79	–	0.02	0.67
l-valine (965)	1.80	1.93	3.88	0.47	2.47	4.61
l-arginine (900)	–	2.45	5.77	–	3.36	6.99
l-isoleucine (904)	–	1.50	3.46	0.01	2.01	4.15
l-leucine (985)	–		1.41	–	1.91	5.39
l-histidine (900)	–		0.81	–	0.37	1.55
Glycine (985)	0.32	1.86	3.57	0.41	2.12	3.95
l-serine (985)	0.01	1.82	3.84	0.43	2.52	4.76
Crude protein (g/kg)	**222**	**193**	**165**	**222**	**193**	**165**
Dig Lys (g/kg)	11.50	11.50	11.50	11.50	11.50	11.50
Total NBAA (g/kg)	**7.58**	**20.5**	**40.28**	**8.02**	**27.66**	**51.53**

Grain type (CP, AA contents; starch and protein digestive dynamics)





Diets were balanced with Dig Lys, TSAA, Thr, Val, Ile, Arg, His, Trp and Gly_{equi}

Chrystal, et al. (2021) *Animal Feed Science and Technology* **275**, 114867.

Wheat vs maize and sorghum

- Because of its high protein content (12-16%), more NBAAs are included in wheat-based diets
- More starch and less oil in wheat-based diets
- The starch digestion rate of wheat is more rapid than maize or sorghum which has been demonstrated under *in vitro* (Giuberti et al., 2012) and *in vivo* (Selle et al., 2021) conditions.

Feed grain[1]	Starch parameters	
	PDS, g/g	SDR, min^{-1}
Sorghum (7)	0.850	0.075
Wheat (4)	0.849	0.117
Maize (2)	0.854	0.086

- Imbalanced glucose and AA digestive dynamics???
- True protein level in wheat is different

Selle et al. (2021) *Animal Nutrition* **7**, 450-459.

Other pieces of puzzles

Glucose *versus* amino acids

– Geiger (1950) contended that protein synthesis is dependent not only upon the simultaneous presence of essential amino acids, but also upon the speed with which non-essential amino acids are made available.

– Apparent digestibility coefficients of starch were negatively correlated with 9 amino acids in distal jejunum, 12 amino acids in proximal ileum and 11 amino acids in distal ileum in broilers Moss et al. (2018).

– There was mutual inhibition between sugars and amino acid for intestinal absorption, this suggests that glucose and amino acids compete for co-absorption with sodium *via* either SGLT-1 or Na^+-dependent amino acid transporters, respectively, which disrupts intestinal uptakes of glucose and amino acids Vinardell (1990) .

Energy to power the gut

- The gastrointestinal tract requires around 20% of dietary energy for nutrient digestion and absorption (Cant et al., 1996).

- In young pigs (Stoll et al., 1999), enteral (15%) and arterial (29%) glucose contributed to CO_2 poduction by the portal-drained viscera but this was exceed by glutamate/glutamime with enteral and arterial contibutions of 36% and 19%, respectively. These researchers concluded that dietary glutamate is the most important single contributor to mucosal oxidative energy generation in pigs.

- Oxidation of additional substrates including fatty acids and ketone bodies could also happen (Van der Schoor et al., 2001)

- Glucose, glutamine and glutamate are the preferred energy substrates by the gut mucosa in broiler chickens (Watford et al. 1979) and Porteous (1980) found them to be the only individual substates to stimulate oxidation in avian enterocytes.

Can we manipulate the catabolic ratio to spare amino acids?

Amino acid or oligopeptides?

- Most amino acids are absorbed as oligopeptides (Krehbiel and Matthews, 2003) and their intestinal uptakes via Pept-1 are both rapid and energetically efficient (Daniel, 2004).

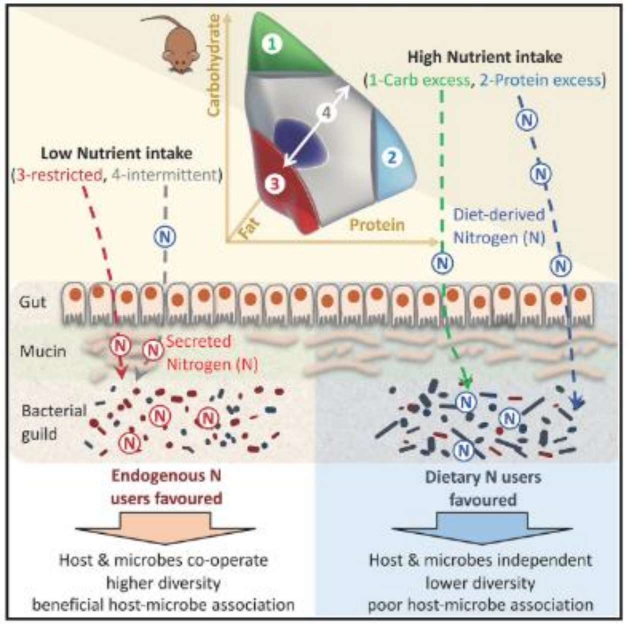
- The cumulative absorption of lysine derived from a lysine-glycine dipeptide exceeded that of non-bound lysine by a factor of 2.35 (30.30 versus 12.88 umol) collectively at 30 and 60 minutes post administration (Li et al. 1999).

Article

Cell Metabolism

Diet-Microbiome Interactions in Health Are Controlled by Intestinal Nitrogen Source Constraints

Graphical Abstract



Highlights

- Gut microbes show a dichotomy in ecological strategy for access to nitrogen
- Beneficial microbes are overrepresented in the endogenous N source guild

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In Brief

Diet interactively impacts the performance of animals and their microbes. Systematic analysis of intake across 25 defined diets in mice showed that microbial community assembly is fundamentally shaped by the relative amount of dietary nitrogen, providing a common factor for how different diets influence healthy host-microbiome outcomes.

Interaction between accessibility of carbohydrate and protein sources shapes the symbiosis between gut microbes and animals.

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Enhancing poultry performance