Reduction in crude protein content and amino acid supplementation in piglet diets

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Content

Key challenges which can be tackled by lowering CP levels in pig diets

Climate change

- Environmental pollution
- Stricter regulation (N, P)

include EU, China

Sustainable Food supply

- Population growth
  7.9 (today) to 9.8 billion in 2050

High feed cost

- low margin (loss)
- over/under meat supply

Animal health / welfare

- diseases (e.g. ASF)
- Stress (immune, heat stress)
- AGPs-free is current focus

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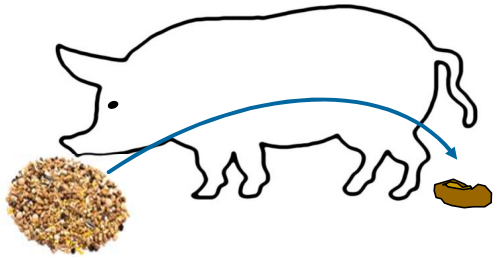
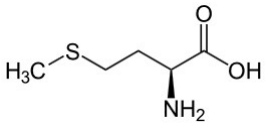
Nutrients in the feed are not completely available to the animals

Not all nutrients are digested and available
Quality of a protein source is affected by its AA availability
Needs nutrient availability estimates



SID of AA in a CAA mixture in pigs

Item	AA[d]
Nitrogen	96.0
Indispensable AA	
Lysine	99.3
Tryptophan	97.9
Threonine	98.2[e]
Methionine	99.2
Histidine	99.3
Leucine	97.2[e]
Isoleucine	100.1[e]
Valine	98.5[e]
Phenylalanine	99.4
Arginine	100.5
Mean	99.0



SID of AA

- good indication of AA availability in ingredients
- used as estimates of available AA in practice by swine nutritionists (AMINODat 6.0; NRC, 2012).

	SID of Met (%; AMINODat 6.0)					
DL-Met	Corn	Wheat	Barley	Soybean meal	DDGS	Wheat bran
~100	87	89	83	92	83	82

- Crystalline AA are proven to be completely (100%) digestible
- CAA: higher availability compared with intact protein sources

Chung and Baker (1992; JAS 70:3781-3790)

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Low protein diet – an old concept but still relevant today

EFFICACY OF SUPPLEMENTAL LYSINE, METHIONINE AND ROLLED OATS FOR WEANLING PIGS FED A LOW-PROTEIN CORN-SOYBEAN MEAL DIET

R. S. Katz, D. H. Baker, C. E. Sasse[1], A. H. Jensen and B. G. Harmon

University of Illinois at Urbana-Champaign, Urbana 61801

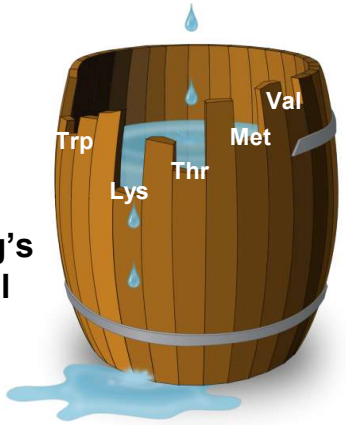
Katz et al., 1973 -J. Anim. Sci.

- CP level of corn-SBM diets reduced from 19 to 16% without reducing performance of weaned pigs by adding L-Lys.HCl.

Low protein diet

- Reducing dietary CP content by replacing a portion of protein bound AA with crystalline AA
- Balancing adequate level of all AA and energy
- Maintaining the same pig performance

Liebig's barrel



Synergy:

Progress of nutritional concepts:

1st limiting	2nd limiting	3rd limiting	4th limiting	5th limiting
Lysine	Lysine Threonine	Lysine Threonine Methionine	Lysine Threonine Methionine Tryptophan	Lysine Threonine Methionine Tryptophan Valine

principle of the "next limiting amino acid"

- Protein synthesis is "**all or nothing**".
- **Lys is the first limiting AA** in typical pig diets (before Thr, Met and Trp, Val and Ile)

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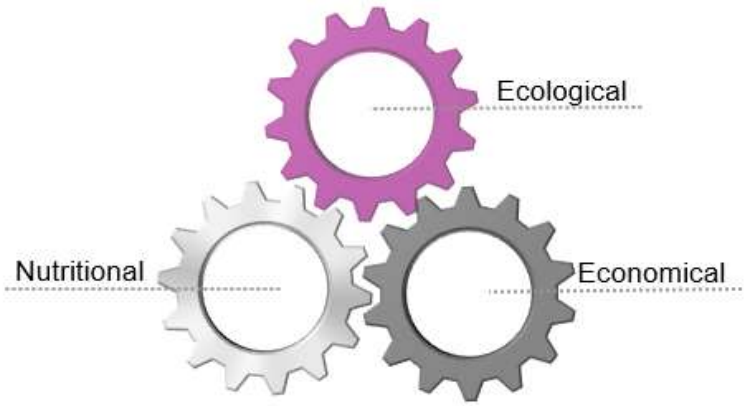
Advancement in feeding concepts for swine

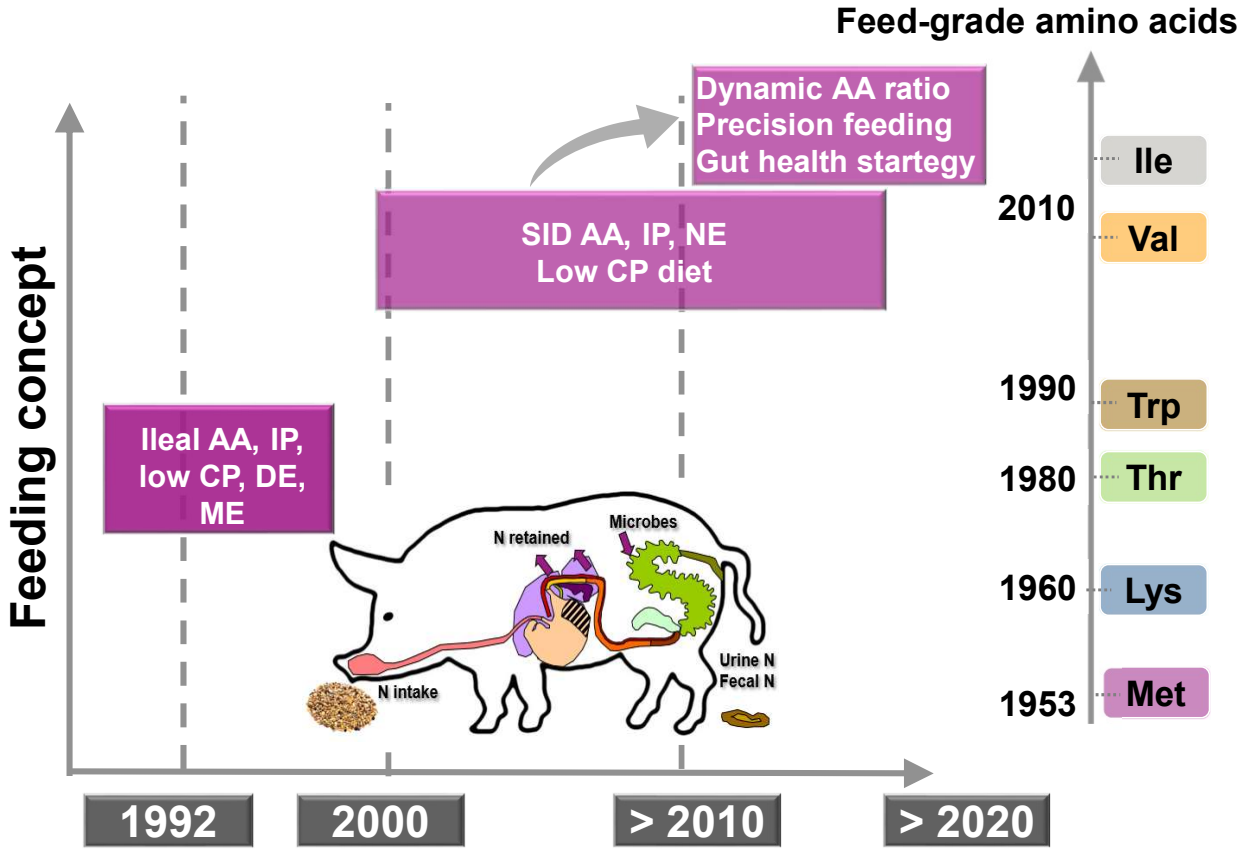
Brazilian Tables for Poultry and Swine

NUTRIENT REQUIREMENTS OF SWINE

Recommendations for Swine
amino acids and more.

- Advances in ileal AA digestibility and requirements of AA for pigs
- Formulating diets on the basis of SID AA in combination with ideal protein concept and NE allows lowering CP level
- Increased availability of CAA such as Lys, Met, Thr, Trp, Val and Ile (Arg, His)





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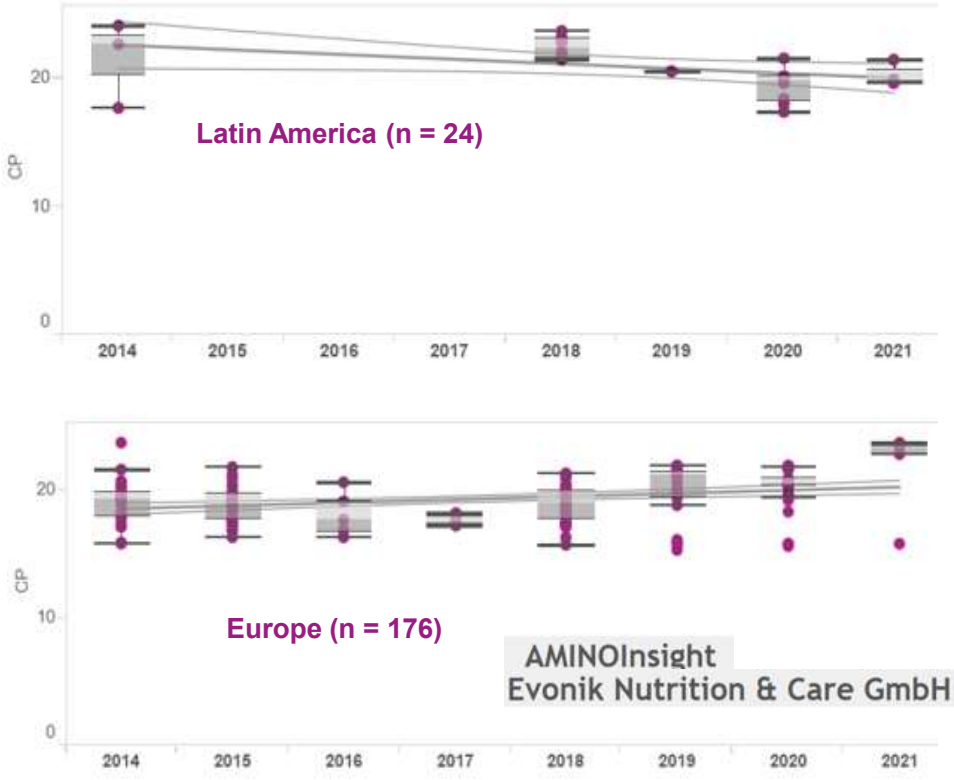
Uncertainty about the formulation of low CP diets?

- Reduced pig performance when the dietary CP level was reduced more than 4%-points with increased CAA (Figueroa et al., 2002).
- Uncertainty about the availability of CAA compared with conventional intact protein sources (SBM)
- How much can we lower dietary CP level in pig diets?
- Any potential benefits of Low CP diets beyond N excretion?

How do CP levels in commercial piglet diets look like?

	NRC, 2012	Brazilian Table, 2017	GBT (Chinese)
Pre-starter		(5-9 kg)	
SID Lys, %	1.50	1.45	1.42
CP, %	22.7	21.4	21.0
SID Lys:CP, %	6.6	6.8	6.8
Starter 1		(7-11 kg)	
SID Lys, %	1.35	1.35	
CP, %	20.6	19.9	
SID Lys:CP, %	6.6	6.8	
Starter 2		(11-25 kg)	(8-25 kg)
SID Lys, %	1.23	1.12	1.22
CP, %	18.9	18.1	18.5
SID Lys:CP, %	6.5	6.2	6.6

Analyzed CP level – Pre-starter commercial piglet feed



- In Europe often nursery pig diets are formulated to contain only 17–18% CP to avoid PWD (Stein, 2002).
- There is still room to reduce CP level in commercial piglet feed.

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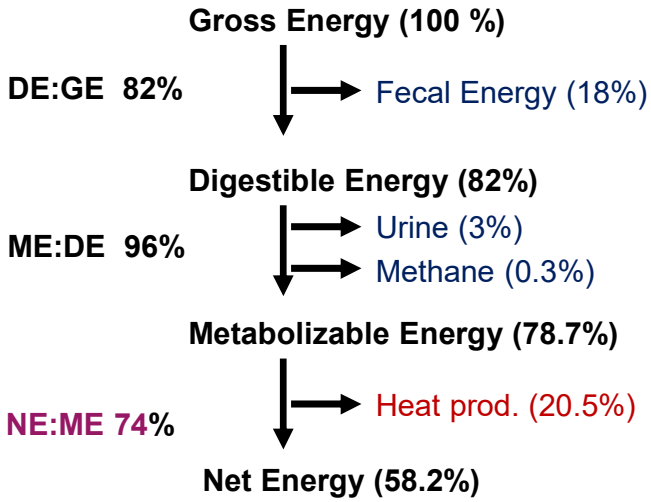
4. Advances on low protein diet concept to enhance intestinal health and microbiota
5. Conclusions

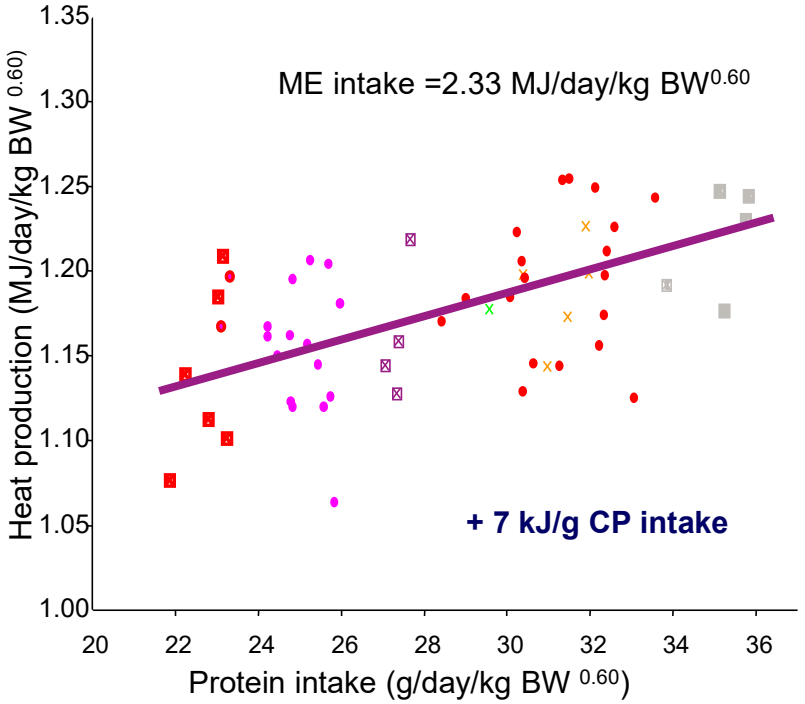
Lowering CP level improves energy utilization efficiency

Noblet et al. (1994)



Efficiency of metabolic utilization of ME for NE			
	Protein, Fiber	Starch	Fat
NE:ME, %	60	82	90

Le Bellego et al. (2001)



Increased fat deposition can be prevented by balancing the same SID Lys:NE.

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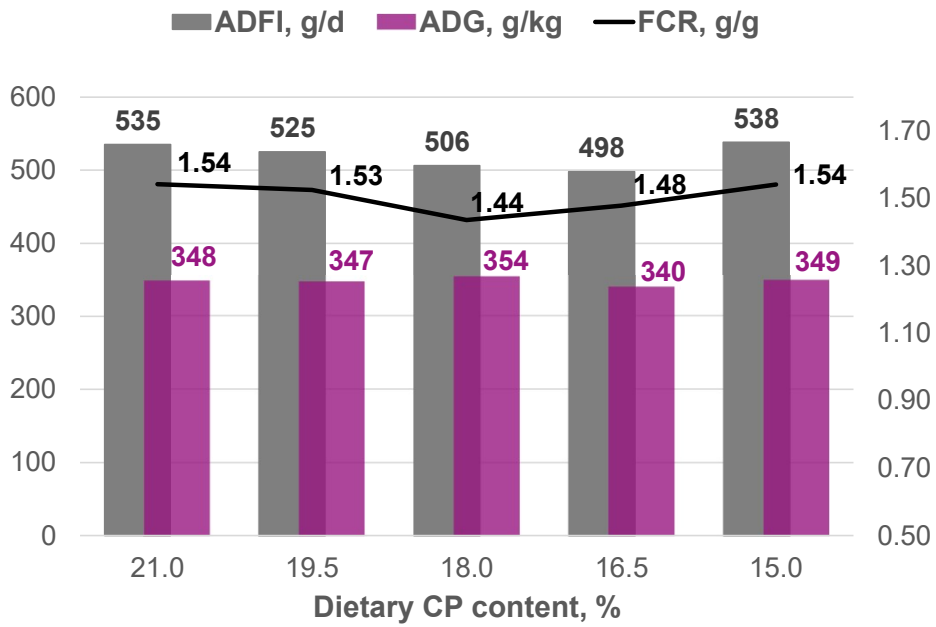
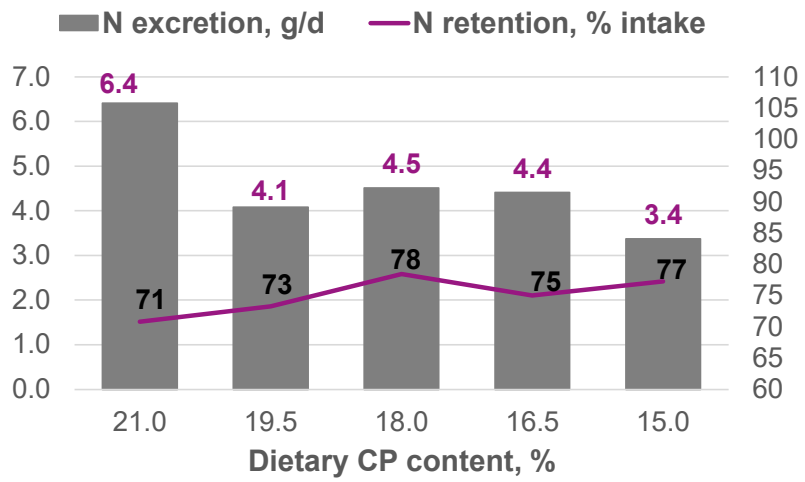
Reduction of dietary CP (6%-unit) on performance and N excretion in weaned pigs

Animals	120 pigs for growth trial (initial BW 6 kg; 28 d) 20 barrows for N-balance (initial BW 10.8 kg)
Treatments	5 CP levels (21, 19.5, 18, 16.5, 15%)
Diets	Corn, SBM, skim milk,Lys, Thr, Met, Trp, Val, Ile
Formulation	Same SID AA, ME and electrolyte balance





Toledo et al. (2014; R. Bras. Zootec.)

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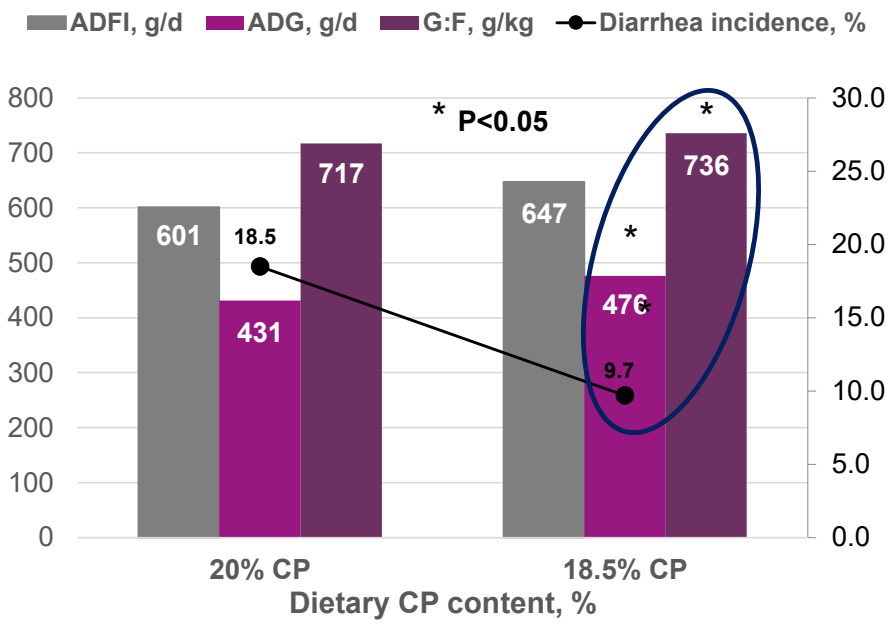
Effect of lowering CP and balancing with CAA on performance of weaned pigs

Corn, **SBM**, Whey diets; 20% CP (5 CAA); 18.5% CP (6 CAA); same SID AA (1.23% Lys), piglets (8-20 kg); 4 wk



	20% CP	18.5% CP
Initial BW, kg (d 1)	**8.1**	**8.1**
Pig price, EUR/kg*	20	20
Final BW, kg (d 28)	**20.2**	**21.4**
Pig price, EUR/kg*	12	12
Revenue per pig, EUR/kg	**80.40**	**94.80**
FCR	**1.39**	**1.36**
Feed intake per pig, kg	16.88	18.07
Feed cost, EUR/kg*	0.376	0.375
Feed cost per pig, EUR	**6.35**	**6.78**
IOFC, EUR/pig	**74.05**	**88.02**
Extra value with LCP, EUR/pig		**13.97**

* Price of ingredients and pigs in China (Sep, 2020; eFeedlink)

Zhou et al. (2019; Anim Sci J. 90(2):237-246)

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Effect of reducing CP (replacing fish meal with CAA) on performance of 7-13 kg weaned pigs (d 0-14)

CP, %	Fish meal*	ME, MJ/kg	SID Lys, %	SID EAA	EAA added	NEAA added	SID Lys:CP, %	Lys:CP, %
21.1	4.5	**14.10**	1.30	Adeq.	6	-	6.2	6.8
20.9	3.6	**14.08**	1.30	Adeq.	6	Gln, Gly	6.2	6.8
20.8	2.7	**14.07**	1.30	Adeq.	6	Gln, Gly	6.3	6.9
20.6	1.8	**14.05**	1.30	Adeq.	6	Gln, Gly	6.3	6.9
20.5	0.9	**14.04**	1.30	Adeq.	6	Gln, Gly	6.3	6.9
20.3	0.0	**14.02**	1.30	Adeq.	6	Gln, Gly	6.4	7.0

Fish meal, %	**4.5**	**3.6**	**2.7**	**1.8**	**0.9**	**0.0**
CP, %	**21.1**	**20.9**	**20.8**	**20.6**	**20.5**	**20.3**
Feed intake, g/d	528	517	537	525	531	546
ADG, g/d	376	372	389	378	380	380
G:F	0.713	0.720	0.730	0.719	0.715	0.698

Nemechek et al. (2014) ; JAS 92:1548-1561

Lowering dietary CP level directly impact N utilization and excretion in 12-27 kg pigs

Animals	32 pigs for growth trial (initial BW 12 kg; 22 d)
Treatments	4 CP levels (22.4, 20.4, 18.4, 16.9%); replacing SBM with CAA (6); 1.01g SID Lys/MJ NE
	Electrolyte balance, mEq/kg (250, 212, 173, 171); Performance + N balance (wk 1)

	Dietary CP, %				
	22.4	20.4	18.4	16.9	P-value
ADG, g/d	642	661	690	663	Linear **
FCR, g/g	1.50	1.58	1.54	1.58	ns
BW (d 22), kg	26.0	26.8	27.2	26.8	Linear **
Total N excretion (g/d)	10.7^{a}	9.4^{a}	6.8^{b}	5.1^{c}	Linear **
Water intake, g/d	1941	1887	1867	1645	Linear *
Urine, g/d	757	643	625	481	Linear *

ns: not significant; * P <0.05; ** P < 0.01

1 %-pt CP reduction ➔ - 9% N output; - 3% water need

Le Bellego and Noblet; 2002 (Liv Prod Sci)

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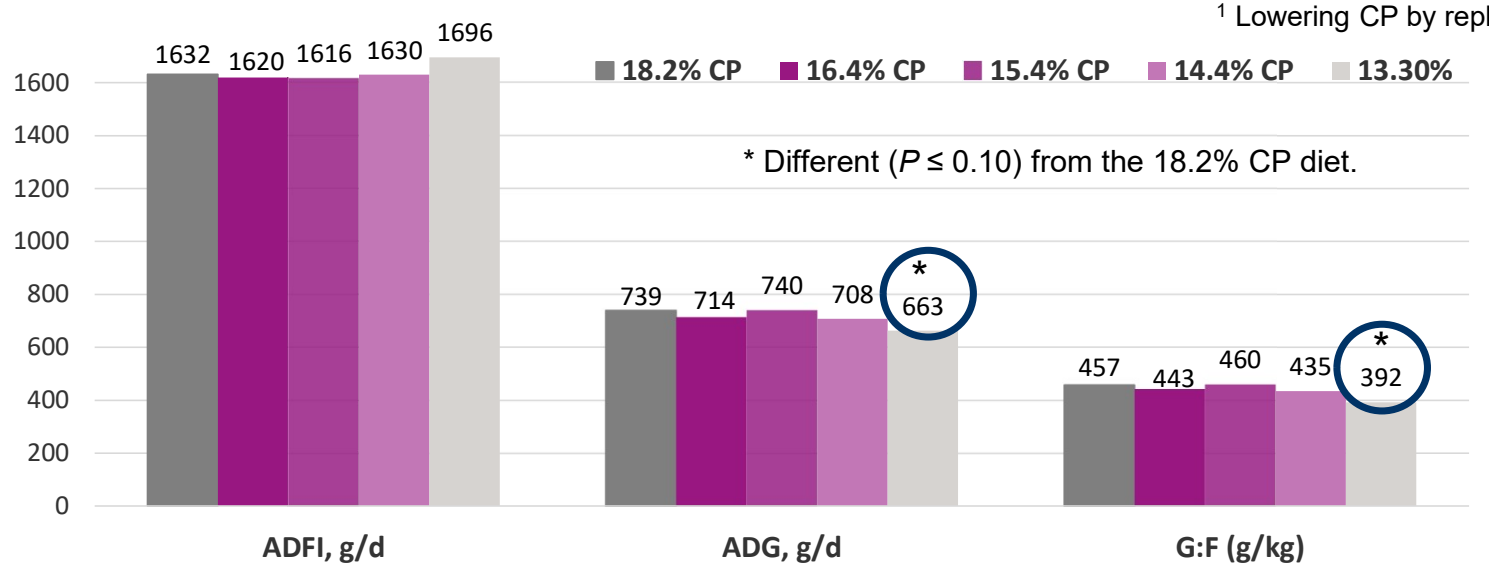
4. Advanced low CP diet concept as a dietary strategy to enhance intestinal health
5. Sustainability?
6. Conclusions

Effect of reducing CP (using up to 4 CAA) on growth performance of 20-45 kg pigs

CP, %[1]	ME, Mcal/kg	SID Lys, %	CAA added	4 EAA level	Val:Lys, %	Ile:Lys, %	Lys:CP, %
18.2	3.24	0.83	0	Adeq.	89	80	5.3
16.4	3.24	0.83	3	Adeq.	79	70	5.7
15.4	3.24	0.83	4	Adeq.	73	64	6.1
14.4	3.24	0.83	4	Adeq.	67	58	6.5
13.3	3.24	0.83	4	Adeq.	61	52	6.9

[1] Lowering CP by replacing SBM with free AA.



- Reducing CP > 4%-pt reduced ADG and G:F.
- Due to deficient in next limiting AA.

Roux et al. (2011; JAS 89:2415–2424)

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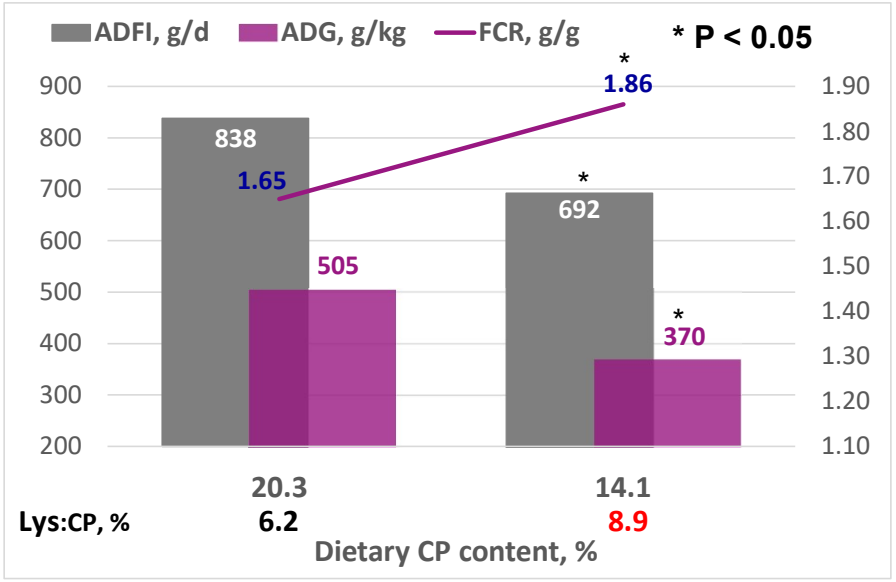
Reduction of dietary CP (6%-unit) on performance and plasma urea N and selected AA in 14-35 kg pigs

CP, %	14.14		20.27	
Lys:CP, %	8.9		6.2	
Lys	1.26	ratio, %	1.26	Ratio, %
M+C	0.63	50	0.63	50
Thr	0.76	60	0.76	60
Trp	0.2	16	0.2	16
Arg	0.71	56	1.09	87
His	0.30	24	0.44	35
Ile	0.46	37	0.71	56
Leu	1.11	88	1.52	121
Phe	0.56	44	0.81	64
Val	0.54	43	0.72	57

Nutrient composition# [% in dry matter]

Crude protein	14.14	20.27
Lysine	1.26	1.26
Methionine + cysteine	0.63	0.63
Threonine	0.76	0.76
Tryptophan	0.20	0.20
Arginine	0.71	1.09
Histidine	0.30	0.44
Isoleucine	0.46	0.71
Leucine	1.11	1.52
Phenylalanine	0.56	0.81
Valine	0.54	0.72

Animals	36 crossbred piglets (initial BW 10.1 kg; 45 d)
Treatments	2 CP levels (20.3, 14.1%) Lys:CP ratio (6.2, 8.9%)
Diets	Corn, SBM, whey, FM, 4 EAA
Formulation	Same SID AA, NE



Luo et al. (2015); Archives of Animal Nutrition

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Effect of reducing CP on performance and gut morphology of 7-10 kg pigs (14 d)

CP, %	Ingredient	ME, MJ/kg	SID Lys, %	EAA level	EAA	EAA:NEAA	SID Lys:CP**, %
23.1	Corn, SBM, whey	13.9	1.30	Adeq.	-	44:56	5.6 (6.3)
18.9	Corn, SBM, whey	13.9	1.30	Adeq.	4	44:56	6.9 (7.5)
17.2	Corn, SBM, whey	13.9	1.30	Adeq.	8	46:54	7.6 (8.1)

*Lowering CP by replacing of SBM with EAA; total Lys:CP in parenthesis.

	Dietary CP, %		
	23.1	**18.9**	**17.2**
Feed intake, g/d	357	342	307
ADG, g/d	266^{a}	252^{ab}	209^{b}
FCR, g/g	1.35^{a}	1.36^{a}	1.49^{b}
PUN (d 14), mg/L	139^{a}	80^{b}	61^{c}
Villus height, µm			
duodenum	454^{a}	457^{a}	433^{b}
jejunum	436^{a}	419^{a}	393^{b}
cecum	399	395	386
Proximal jejunum			
Protein, mg/g mucosa	55.9	54.2	51.8
Lactase, µmol/g protein	39.7^{a}	35.6^{a}	29.5^{b}
Sucrase, µmol/g protein	54.2^{a}	50.7^{a}	43.7^{b}

Yue and Qiao (2008) Livestock Sci

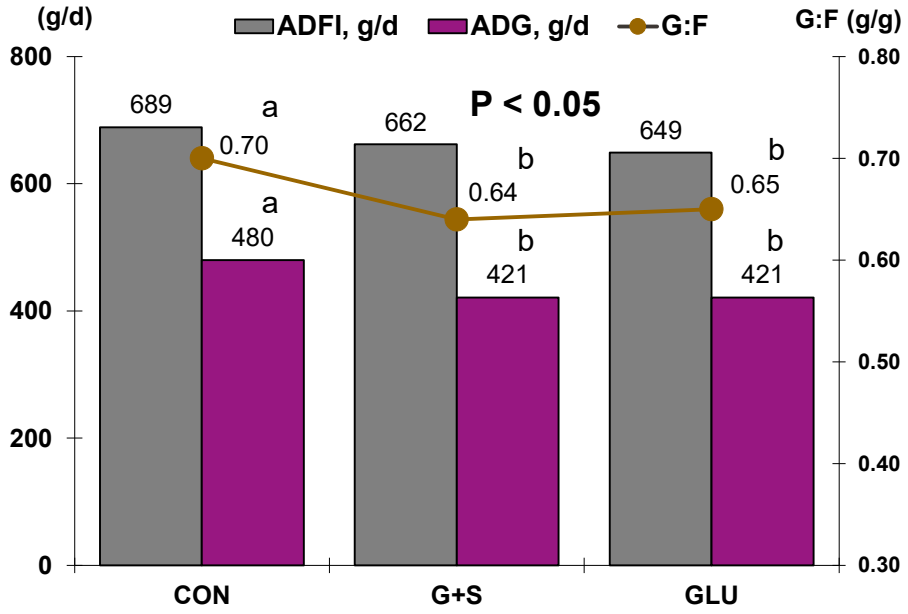
^{a,b,c} Within a row, values with different letters are different ($P < 0.05$).

Reducing dietary at > 8% Lys:CP may be deficient in NEAA affecting performance of 6-23 kg pigs (35 d)

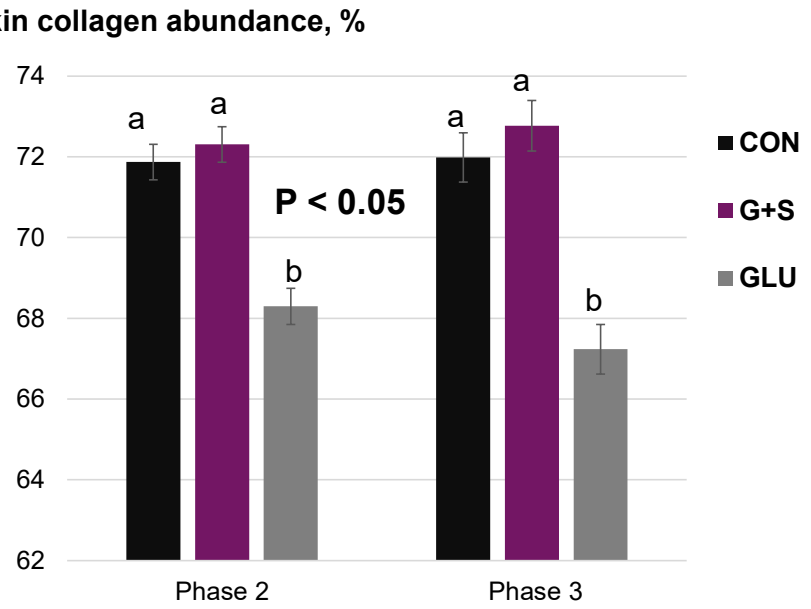
104 weaned pigs (initial BW 6.3 kg; 35 d; 3 phases); 24 pigs were euthanized to collect skin samples (collagen)

3 diets (CON high CP; Low CP[1] (12 CAA + Gly+Ser); Low CP[1] (12 CAA + Glu); similar NE and EAA N:total N (0.48)

[1] Lowering CP by replacing SBM with free AA.



CP, %	**22.3**	**17.0**	**17.0**
SID Lys:CP, %	**6.3**	**8.3**	**8.3**



NEAA (N source) was insufficient in the Low CP diets)

Silva et al. (2020; JAS doi:10.1093/jas/skaa023)

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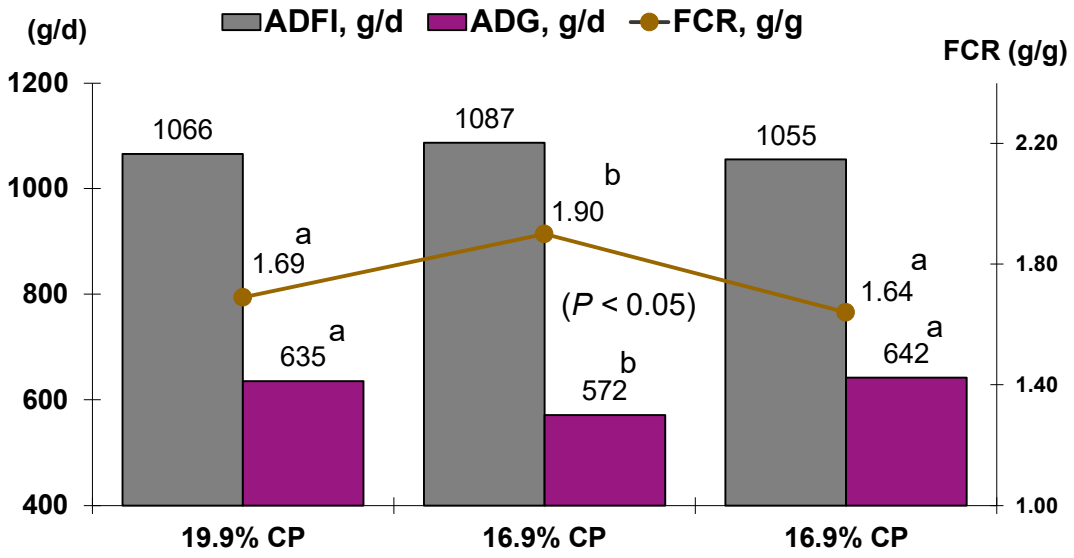
Reducing dietary CP and SID Lys levels reduced performance of 9-32 kg pigs (45 d)*

*Lowering CP by replacing fishmeal with CAA.



SID Lys, %	**1.24**	**1.04**	**1.24**
SID Thr, SAA, Trp	**---------- Same ratios to Lys ----------**		
NE, kcal/kg	**---------- 2,500 ----------**		
Total Lys:CP, %	**6.23**	**6.14**	**7.23**

- Adequate Lys supply in low CP diet maintains pig performance.

Liu et al. (2019; Anim Nutri 5:115-129)

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Effect of reducing dietary CP and supplemental AA on growth of 12-22 kg pigs (21-d)

CP, %[1]	NE, MJ/kg	SID Lys, %	EAA level	EAA added	NEAA added[2]	EAA:NEAA	SID Lys:CP[3], %	Elec. balance, mEq/kg
17.4	10.25	0.96	Adeq.	**4**	-	46:54	5.5 (6.2)	**180**
15.3	10.30	0.94	Adeq.	**5**	-	46:54	6.1 (6.7)	**180**
13.4	10.30	0.92	Adeq.	**9**	-	49:51	**6.9 (7.4)**	**180**
11.6	10.33	0.89	Adeq.	**9**	-	53:47	**7.7 (8.2)**	**180**
12.5	**10.55**	**0.92**	**Adeq.**	**10**	**3**	**46:54**	**7.4 (7.8)**	**180**
13.4	10.77	0.93	Adeq.	**10**	**3**	42:58	6.9 (7.3)	**180**

[1]**Diets 1-4**: Grains-SBM-AA based; **Diets 5-6**: Grains-AA diets; [2]**Glu, Gly, Pro;** [3]Lys:CP in parenthesis.

	Grains-SBM-free AA diets				Grain-free AA diets	
CP, %	**17.3**	**15.3**	**13.4**	**11.6**	**12.5**	**13.4**
Final BW, kg	22.2 [a]	22.2 [a]	21.9 [a]	↓ 20.1 [b]	21.8 [a]	22.3 [a]
Feed intake, g/d	766	775	779	734	810	782
ADG, g/d	450 [a]	454 [a]	442 [a]	↓ 358 [b]	420 [a]	451 [a]
G:F	0.59 [a]	0.59 [a]	0.57 [a]	0.49 [b]	↓ 0.52 [b]	0.58 [a]

- NEAA (N) can limit >4% CP reduction
- **SID Lys:CP ~ 6.9%**

[a,b] Within a row, values with different letters are different ($P < 0.05$).

Gloaguen et al. (2014; JAS 92:637-644)

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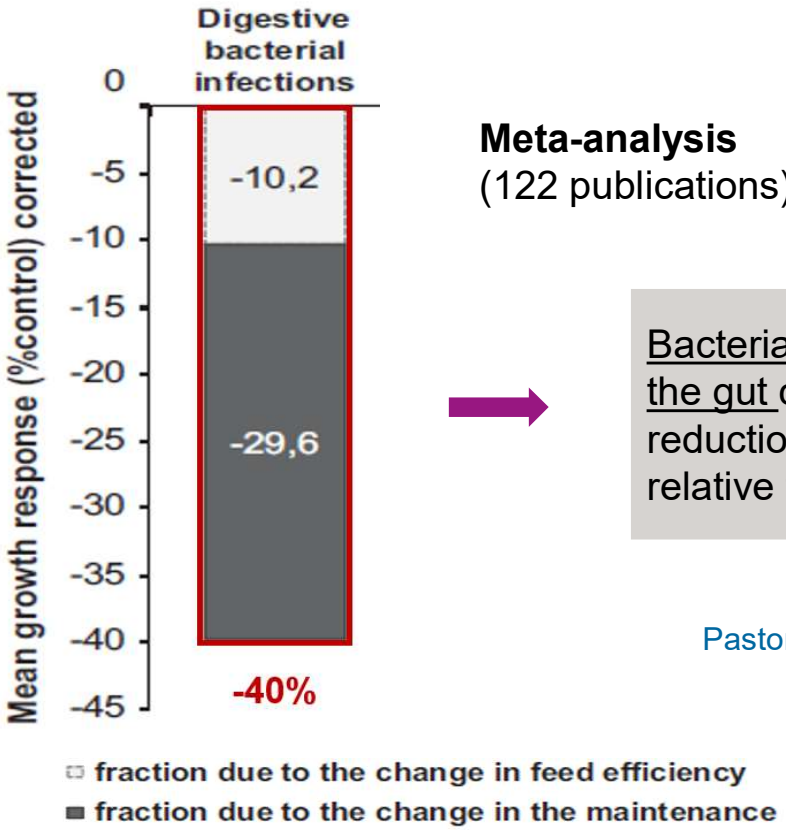
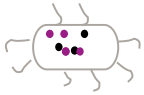
Post-weaning diarrhea is a major gut health challenge for pigs



Meta-analysis
(122 publications)



Bacterial infections of the gut causes 40% reduction in BW gain relative to healthy pigs

Pastorelli et al. (2012)

Enterotoxigenic *E. coli* **(F4, F18)**: main cause of **PWD** in piglets

- due to F4: 65% (USA)
- due to F18: 34% (USA)

Zhang et al. (2007)

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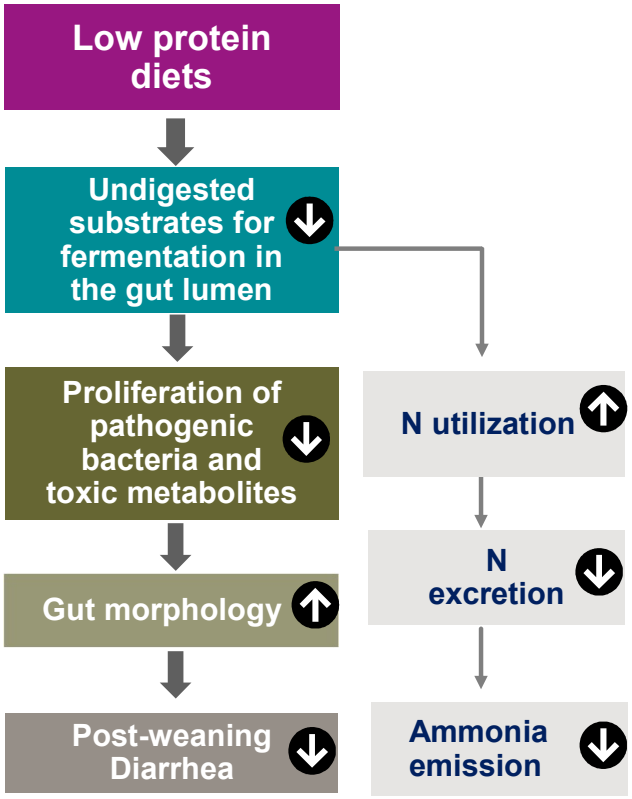
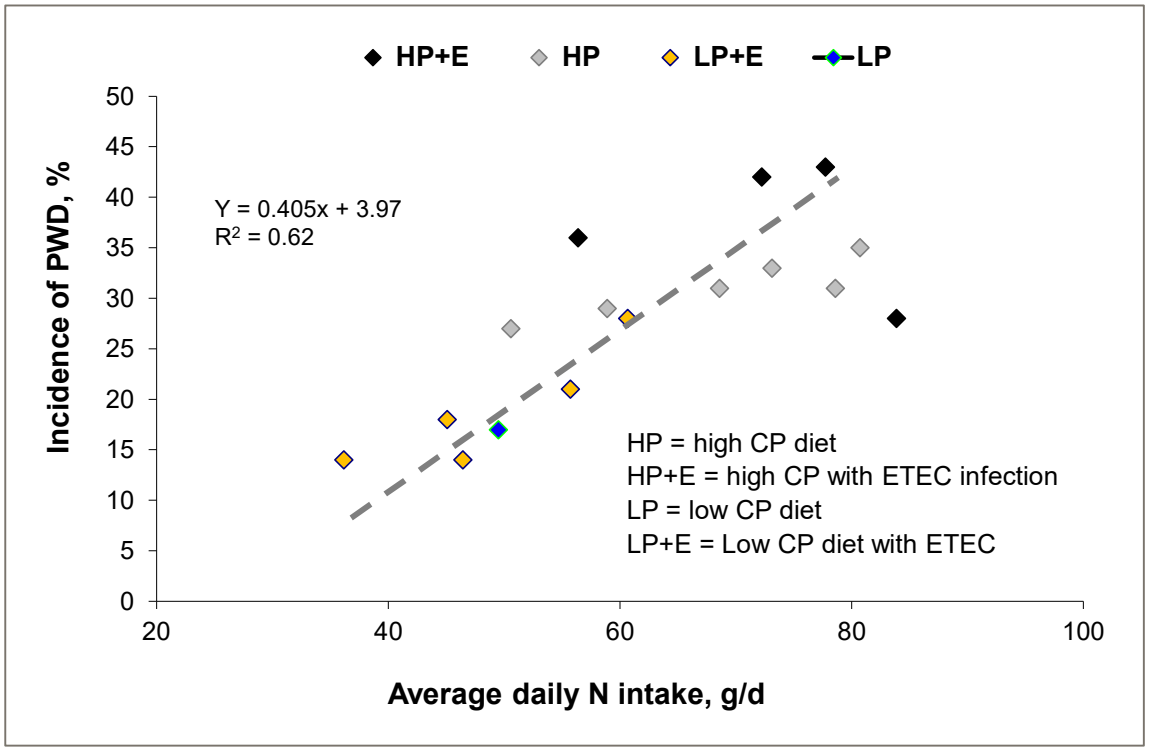
Lowering dietary CP level directly impact gut health and diarrhea incidence



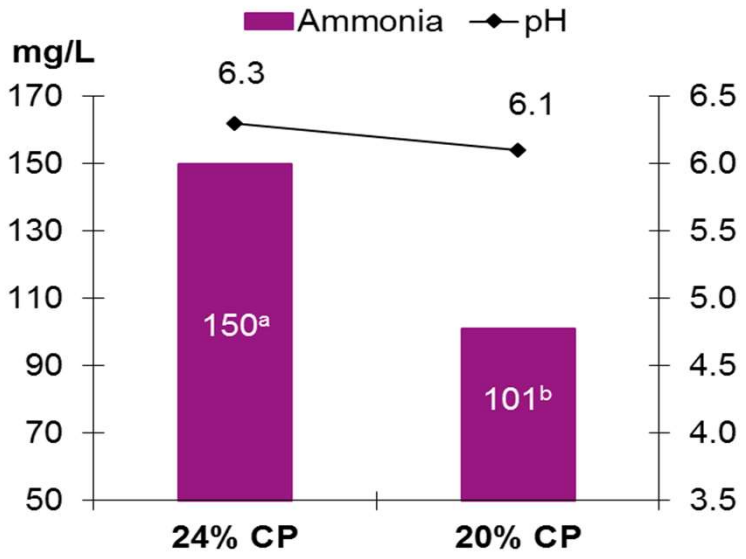


Heo (2010)

EVONIK Leading Beyond Chemistry

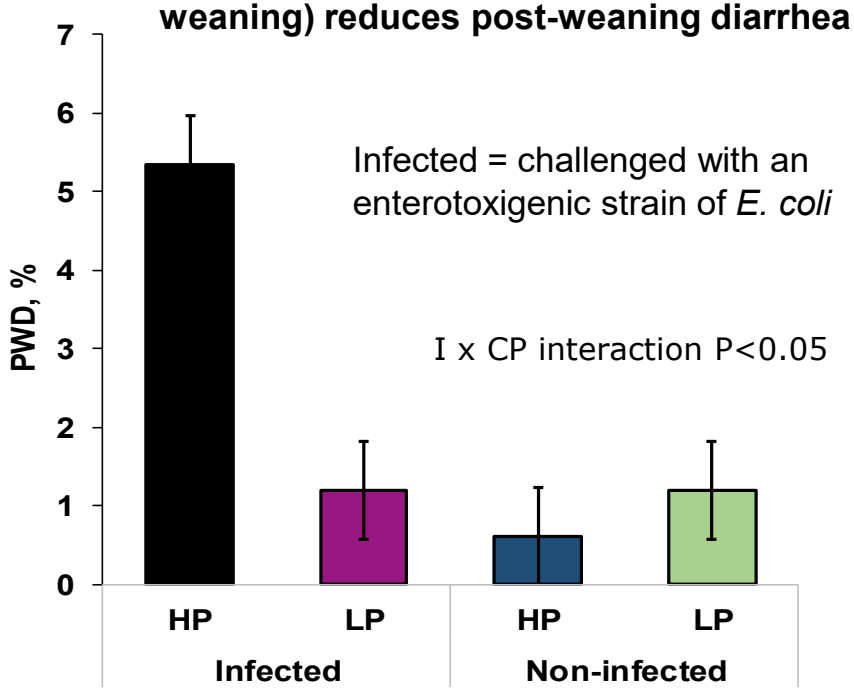
Lowering dietary CP reduces hindgut ammonia concentration and diarrhea incidence in piglets

Effect of diet CP content on ammonia and pH in cecum



Htoo et al. (2007)

Reducing dietary CP from 24 to 18% (2 wk post-weaning) reduces post-weaning diarrhea



Heo et al. (2010)

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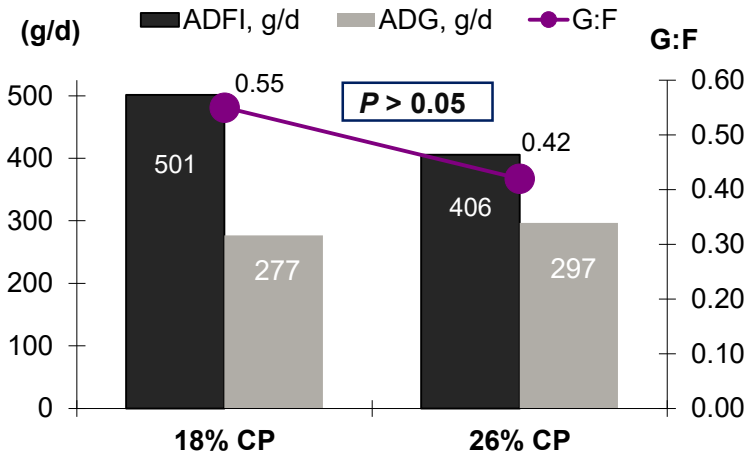
Feeding a low CP diet improves intestinal function and reduces diarrhea and intestinal inflammation without affecting performance of weaned pigs (d 0-12)

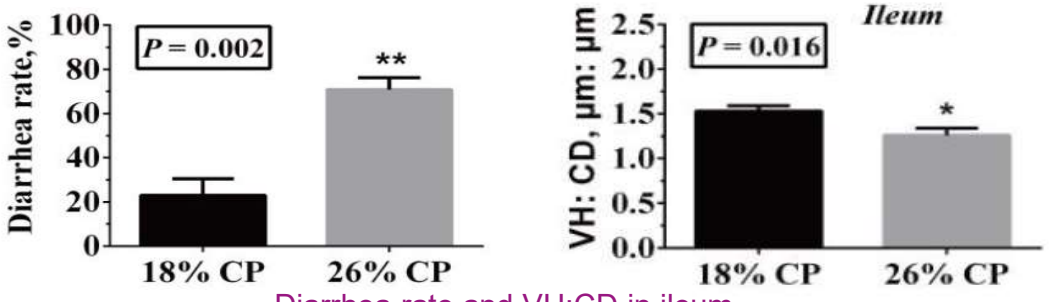
16 Duroc × (Landrace × Yorkshire) weaned pigs (9.7± 0.11 kg BW; 8 pigs/trt; fed 4 times/day; 12-d)

1) **26% CP** (corn, soy, 7% FM, whey; without CAA; AA-adeq); 2) **18% CP** (4 CAA; 3% FM; AA-adeq; same Lys, NE)

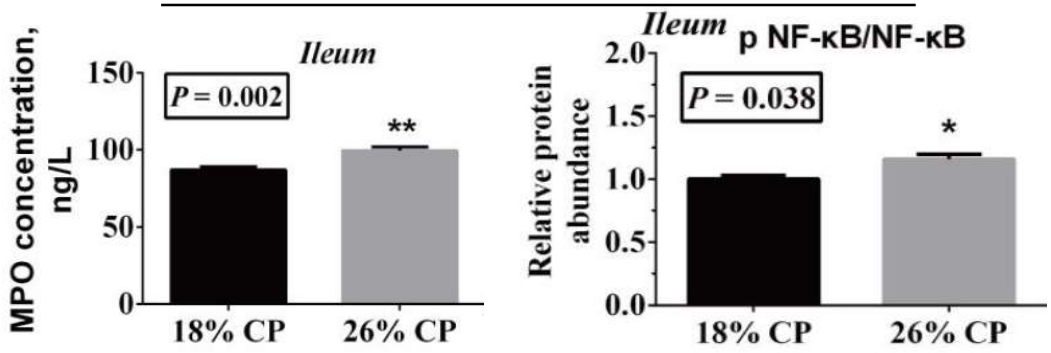
Yin et al. (2021)
Anim Nutr



Piglets fed low CP diet had lower diarrhea through enhanced morphology which may be due to decreased activation of NF-κB signaling to induce intestinal inflammation.



Diarrhea rate and VH:CD in ileum



Myeloperoxidase (MPO) and phosphorylation of NF-κB:NF-κB ratio in ileum

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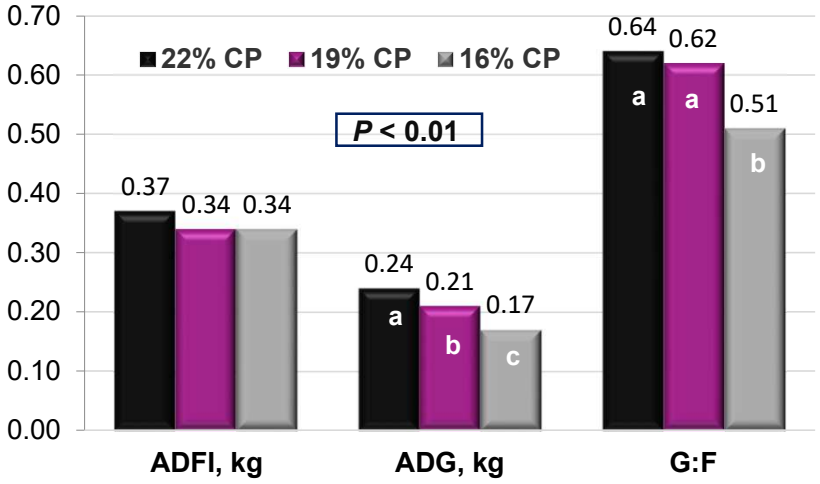
Effect of dietary CP level on growth performance and indicators of intestinal health in weaned pigs (d 0-28)

180 mixed-sex weaned pigs (5.5 ± 0.88 kg BW; 12 rep pens/trt; 5 pigs/pen; 28-d; 2 phase feeding)

3 diets: **22% CP** (corn, soy, FM, whey; 3 CAA; AA-adeq); 2) **19% CP** (corn, soy, FM, whey; 7 CAA; AA-adeq; 3) **16% CP** (corn, soy, FM, whey; 3 CAA; AA-def (lower Lys); NRC (2012) basis.

Limbach et al. (2021) J Anim Sci



- Piglets fed low CP-AA adeq diet maintain performance and improve fecal score and gut morphology
- Piglets fed low CP-AA def diet reduces performance and impairs gut morphology

Fecal scores and blood characteristics of pigs affected by dietary CP levels

	22% CP	19% CP	16% CP	*P*-value
Blood urea N, mg/dL(d 27)	9.33^{c}	5.25^{ab}	4.83^{a}	0.01
IgG, mg/mL (d 27)	4.41	4.65	4.70	0.98
Haptoglobin, mg/mL (d 27)	0.70	0.37	0.88	0.43
Fecal score (d 1-28)	1.52^{a}	1.36^{ab}	1.19^{b}	0.02

Intestinal morphology of pigs affected by dietary CP levels

	22% CP	19% CP	16% CP	*P*-value
Ileum				
Villous height, µm	278^{b}	328^{a}	301^{ab}	**
Crypt depth, µm	213	192	210	ns
VH:CD	1.44^{b}	1.85^{a}	1.54^{ab}	**
Jejunum				
Villous height, µm	242	207	248	ns
Crypt depth, µm	200^{a}	161^{b}	172^{b}	***
VH:CD	1.22	1.30	1.37	ns

ns: not significant; ** P <0.05; *** P < 0.001

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Effect of dietary CP level on intestinal pH, ammonia, VFA and indicators of intestinal health in weaned pigs

pH, ammonia and VFA of pigs affected by dietary CP levels (d 12)

Limbach et al. (2021)
J Anim Sci

	22% CP	19% CP	16% CP	*P*-value
pH				
Stomach	2.90	2.97	3.43	ns
Ileum	7.07^{a}	6.99^{ab}	6.68^{b}	**
Colon	6.70^{a}	6.52^{b}	6.69^{a}	*
Ammonia, mg/g				
Cecum	0.20	0.17	0.19	ns
Colon	0.34	0.31	0.31	ns
Total volatile fatty acids, mg/g				
Cecum	131	118	137	ns
Colon	120	120	118	ns

ns: not significant; * P <0.10; *** P < 0.05

- Piglets fed low CP-AA adeq diet maintain performance and improve fecal score and gut morphology
- Piglets fed low CP-AA def diet reduces performance and impairs gut morphology

Gene expressions of major cytokines in ileal mucosa of pigs (d 12)

	22% CP	19% CP	16% CP	*P*-value
Pro-inflammatory				
TNF-α	1.04	1.15	1.19	ns
IL-8	0.87^{ab}	1.07^{a}	0.69^{b}	**
IFN-γ	1.46^{a}	1.04^{ab}	0.69^{b}	**
Anti-inflammatory				
IL-10	0.84^{a}	0.94^{b}	0.98^{b}	*
TGF-β	0.86^{a}	0.92^{ab}	1.09^{b}	*
Gut-protective proteins				
OCLN	1.08^{a}	1.09^{a}	0.63^{b}	**
ZO-1	0.96^{ab}	1.01^{a}	0.88^{b}	*
MUC2	1.23^{a}	1.27^{a}	0.73^{b}	**

TGF-β, transforming growth factor-beta*; IFN*-γ, interferon gamma; *OCLN*, occludin; *ZO-1*, zonula occludens-1; MUC2, mucin 2.

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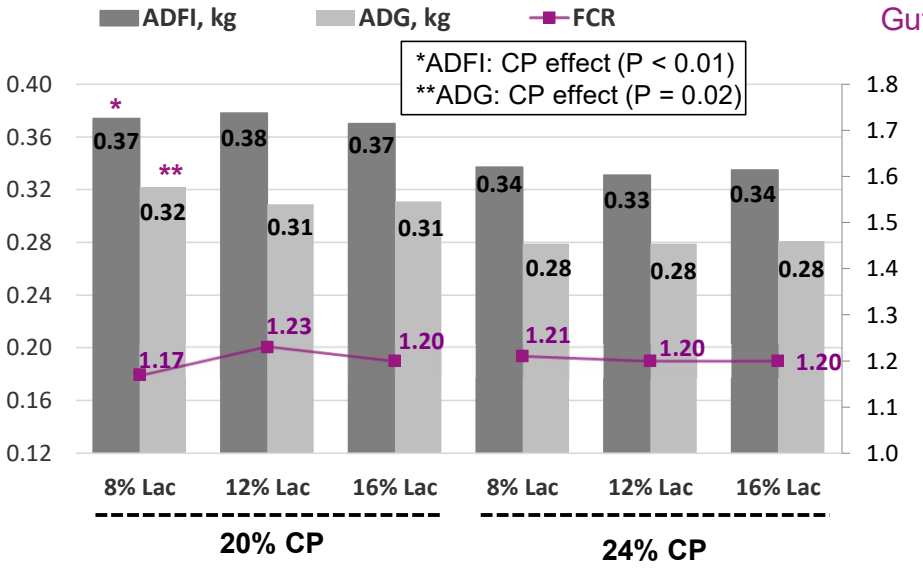
Effect of dietary CP and lactose levels on growth performance and intestinal morphology of weaned pigs (d 0-14)

144 mixed-sex weaned pigs (7.2± 0.97 kg BW)

2 x 3 factorial; 2 CP (20 vs 24%) and 3 lactose level (8, 12 and 16%); 8 rep/trt; 3 pigs/pen; 14-d)

[24% CP (without CAA); 20% CP (4 CAA); lactose was replaced with starch; same SID Lys and ME; 0.3% ZnO]

Soares et al. (2020)
Anim Sci



Gut morphology and tight junction proteins in jejunum of pigs at 14 d post-weaning)

	20% CP			24% CP			P-values		
	Lactose, %			Lactose, %					
Item	8	12	16	8	12	16	CP	LAC	CP x LAC
Villous height:crypt depth (VH:CD), µm									
Duodenum	1.99	2.38	2.40	1.94	2.41	2.37	ns	***	ns
Jejunum	2.56	2.71	2.86	2.24	2.64	2.74	**	***	ns
Ileum	2.74	2.43	2.55	2.23	2.62	2.69	ns	ns	***
Gene expression of tight junction proteins in the jejunum									
Occludin	2.29	3.46	3.04	2.33	3.10	2.77	ns	**	ns
ZO-1	1.74	2.15	2.13	1.21	2.27	1.79	ns	**	ns

ns: not significant; ** P <0.05; *** P < 0.001

Feeding low CP diet increase feed intake and BW gain of weaned pigs.
Inclusion of lactose at 12% may improve intestinal morphology and integrity.

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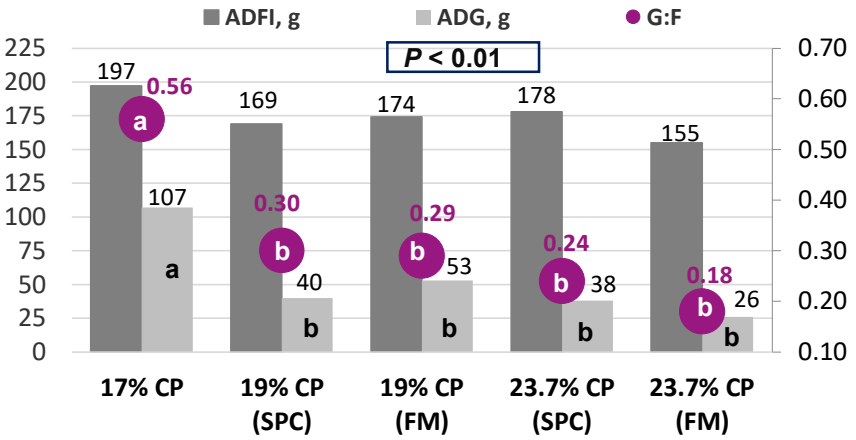
Effect of source and level of protein on performance and intestinal morphology of weaned pigs fed AGP-free diets (d 0-14)

150 barrow weaned pigs (6.0 ± 0.14 kg BW)

5 diets: 1) **LCP** (17% CP; corn, SBM, 3% FM, whey; 8 CAA; AA-adeq); 2) **19% CP** (adding 7.4% SPC*; 6 CAA); 3) **19% CP** (7.4% FM**; 6 CAA; 4) **24% CP** (adding 13.4% SPC; 1 CAA); 5) 24% CP (16.2% FM; no CAA)

Wu et al. (2015) Anim Sci

*SPC, soy protein concentrate; **FM, Fish meal



Diarrhea rate , plasma urea N and gut morphology of pigs at 14 d post-weaned)

Item	CP, %					*P*-values		
	17	19 (SPC)	19 (FM)	23.7 (SPC)	23.7 (FM)	Diets	Source	Level
Diarrhea rate, %	25^{c}	47^{b}	40^{b}	54^{a}	56^{a}	***	ns	***
PUN, mM	1.9^{c}	3.7^{b}	3.7^{b}	5.0^{a}	5.1^{a}	***	ns	***
Villous height: crypt depth								
Duodenum	2.01^{a}	1.32^{c}	1.59^{b}	1.21^{c}	1.31^{c}	***	***	***
Jejunum	2.25^{a}	1.39^{bc}	1.71^{b}	1.16^{c}	1.15^{c}	***	§	***
Ileum	1.73	1.46	1.58	1.40	1.41	ns	ns	ns

Pro-inflammatory cytokines and tight junction proteins in jejunum (d 14 d post-weaned)

Item	CP, %					*P*-values		
	17	19 (SPC)	19 (FM)	23.7 (SPC)	23.7 (FM)	Diets	Source	Level
IL-1β	1.00^{a}	1.36^{ab}	1.37^{ab}	2.28^{a}	2.19^{a}	**	ns	**
IFN-γ	1.00^{c}	3.01^{ab}	2.401^{b}	3.57^{a}	3.40^{ab}	***	§	**
ZO-1	1.00^{a}	0.46^{c}	0.77^{ab}	0.37^{c}	0.56^{bc}	***	***	*
Occludin	1.00^{a}	0.46^{b}	0.71^{ab}	0.32^{b}	0.41^{b}	***	§	*

ns: not significant; * § = 0.07; * P < 0.05; ** P < 0.01; *** P < 0.001

AGP-free diets, feeding 17% CP diet increase performance and decrease incidence of diarrhea of weaned piglets compared to higher (19 or 23.7%) CP groups regardless of protein sources.

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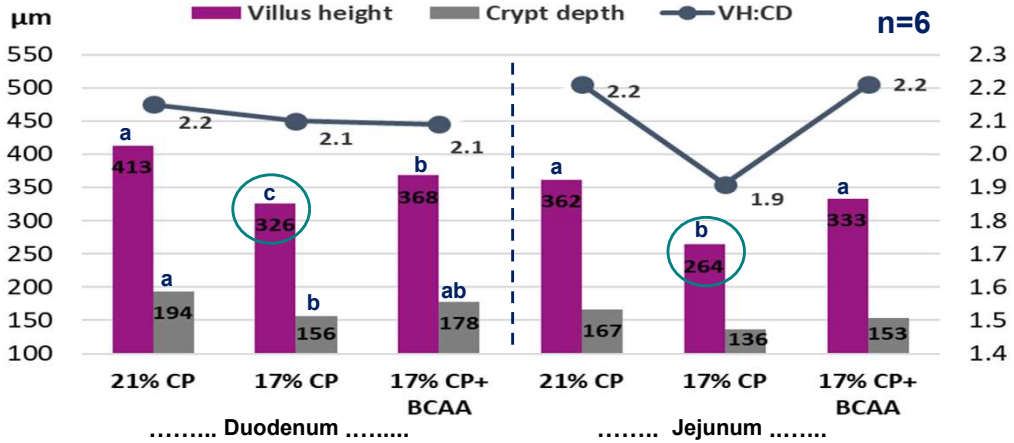
Supplementation with BCAA to a low CP diet improves intestinal function and regulates intestinal expression of AA transporters in weaned pigs

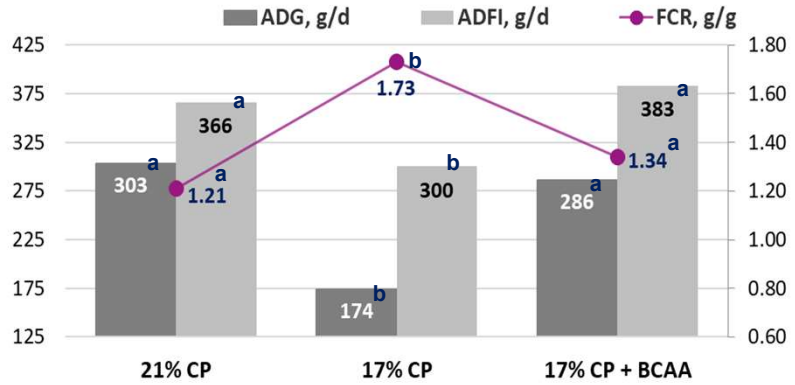
108 weaned pigs (8.0 kg BW; 6 pigs/pen; 6 pens/trt; **14-d**)

3 diets (21% CP (AA-adeq) ; 17% CP (BCAA-def) ; 17% CP + 0.19% L-Ile, 0.10% L-Leu, 0.34% L-Val (AA-adeq.)

Ile/Leu/Val:Lys ratios: 58/100/73%

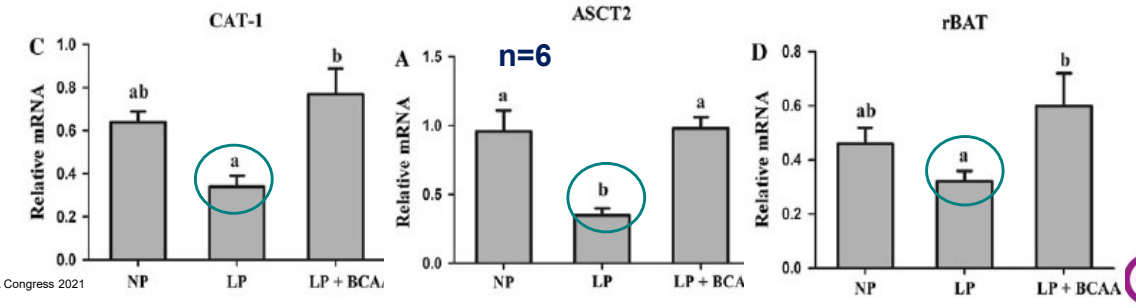
Zhang et al. (2013)





Combined supplementation of BCAA maintains intestinal development and AA absorption by regulating expression of intestinal AA transporters.

Selected AA transporter mRNA expression in jejunum (after 14-d)

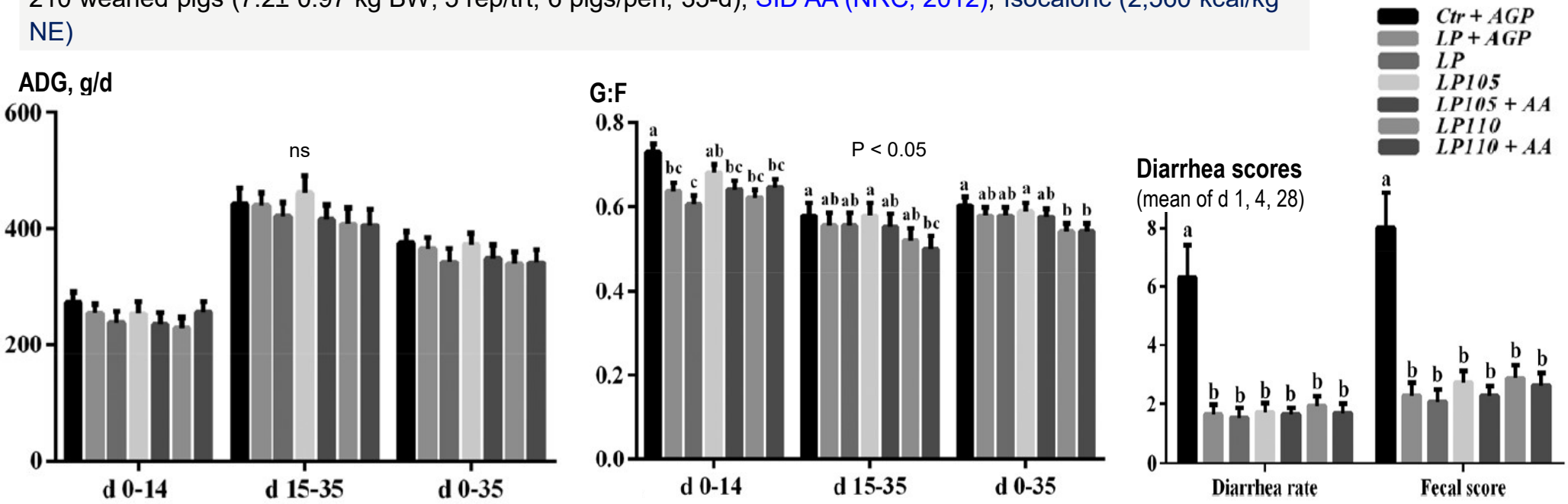


EVONIK Leading Beyond Chemistry

Effect of antibiotic-free, low-protein diets with specific AA levels on growth and fecal scores of weaned pigs

	Ctr+AGP	LP+AGP	LP	LP105	LP105+AA	LP110	LP110+AA
Essential AA				+5%	(+6% M+C, Thr, Trp)	+10%	(+6% M+C, Thr, Trp)
SID Lys (CP), %	**1.29 (21)**	**1.30 (17)**	**1.30 (17)**	**1.37 (17)**	**1.37 (17)**	**1.43 (17)**	**1.43 (17)**

210 weaned pigs (7.2± 0.97 kg BW; 5 rep/trt; 6 pigs/pen; 35-d); SID AA (NRC, 2012); Isocaloric (2,560 kcal/kg NE)



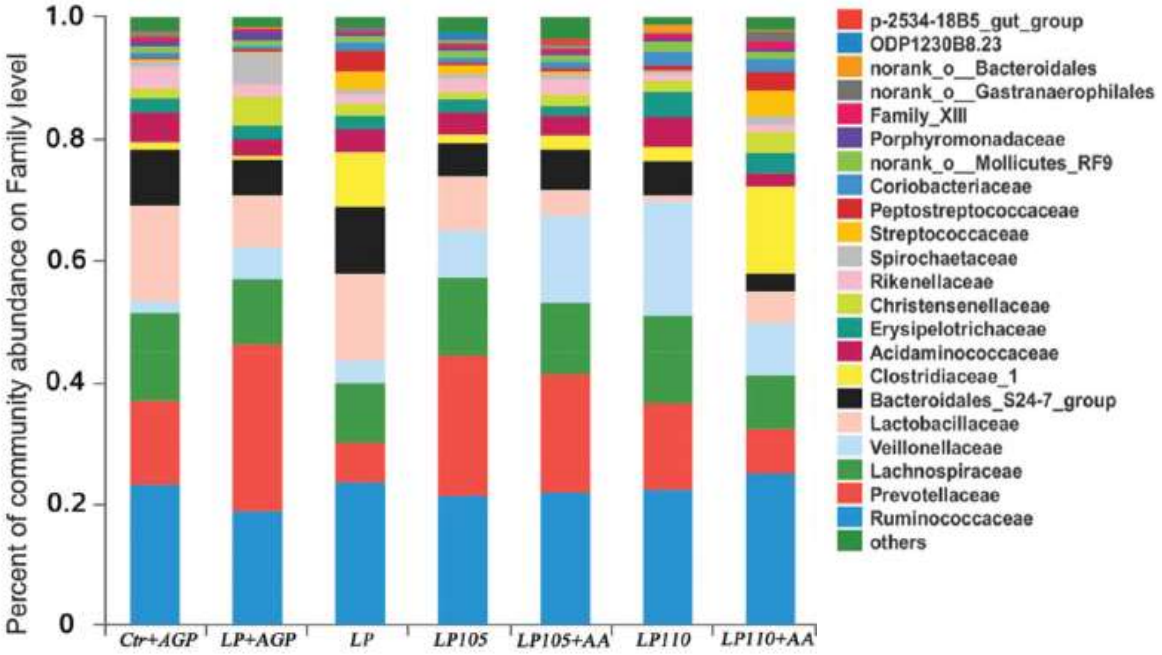
Zhou et al. (2020); *Food Funct.*

EVONIK Leading Beyond Chemistry

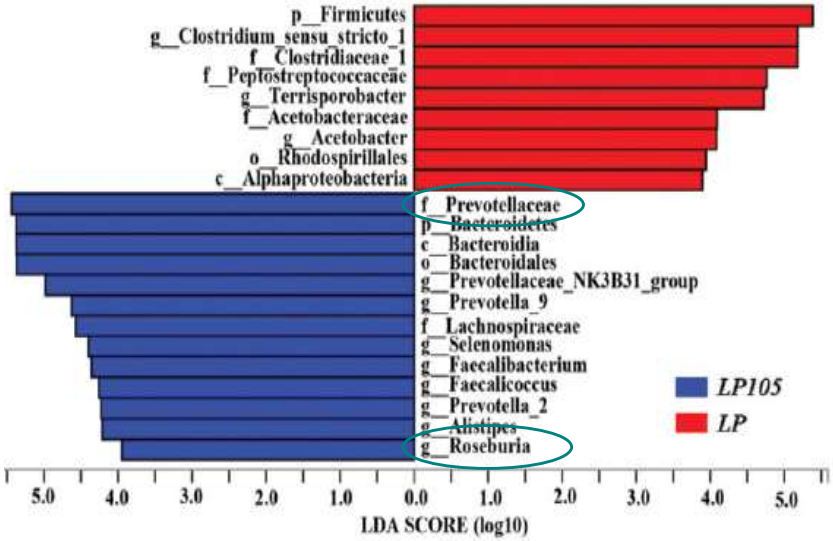
Effect of antibiotic-free, low-protein diets with specific AA levels on composition of fecal microbiota in weaned pigs (16S RNA sequencing)

Fecal bacterial community at the family levels in piglets

Zhou et al. (2020); Food Funct.



Linear discriminant analysis of fecal microbiota
(LP vs LP105 treatment)



LP105 group had increased abundances of Prevotellaceae (positive effects growth performance and immune response; Amat et al. 2020) and Roseburia (butyrate-producing bacteria).

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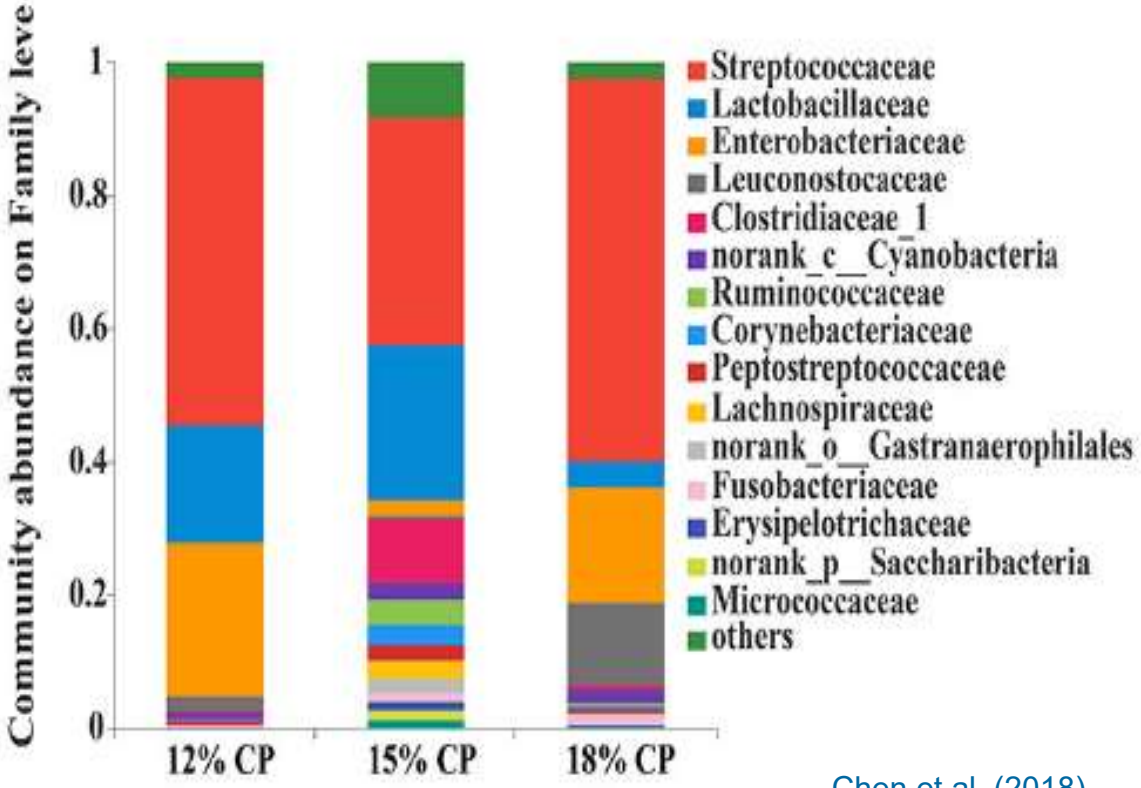
Dietary CP reduction (15% CP) optimizes the microbiota composition in the ileum of growing pigs

Effect of low-protein diets on the distribution of **ileal bacteria** at the family level in growing pigs



Chen et al. (2018)

Pigs: 18 barrows (36.5 kg BW)
Diets: Corn-SBM-wheat bran based
- 12% CP: Deficient in Ile, Val, Phe
- 15% CP: adequate in all AA
- 18% CP: adequate in all AA

Ileum sample: **after 30 d**

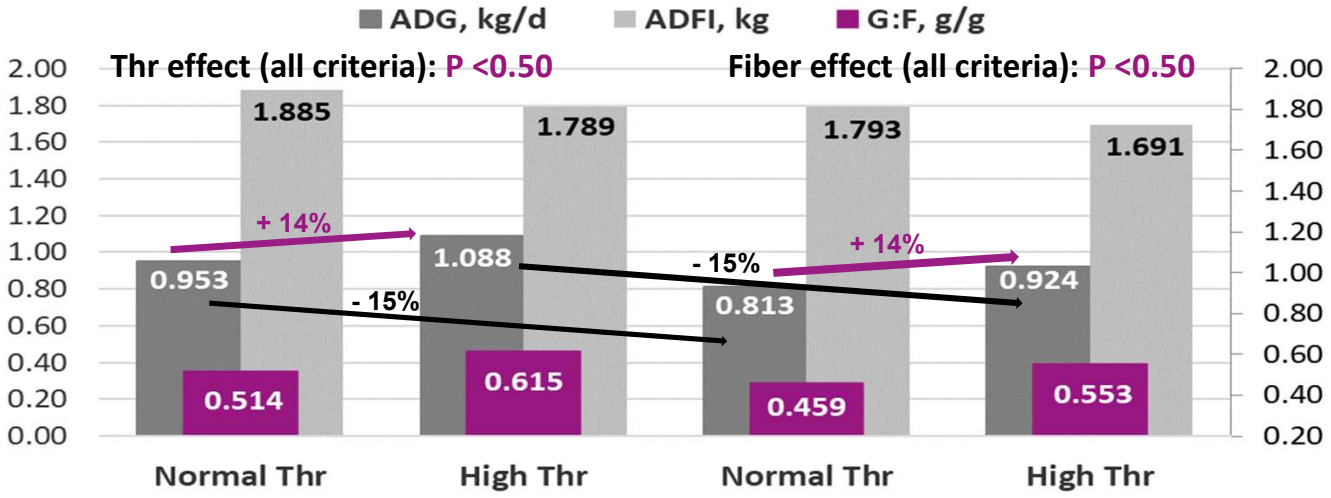
Ileum

- **Streptococcaceae: 53, 35 and 58%** (12% and 15% to 18% CP diets)
- **Enterobacteriaceae** (*E. coli, Salmonella*) was lower in 15% CP diet.
- **Lactobacillaceae: 18, 24 and 4%** (12% and 15% to 18% CP diets)
- Reducing dietary CP increases **Latobacillus:Coliforms**.

EVONIK Leading Beyond Chemistry

Effect of increasing Thr supply in low CP diets above requirement on performance of *Salmonella typhimurium* challenged pigs fed high fiber diets

Animals	128 piglets (22.6 kg BW; 4 pigs/pen; 21-d study)
Diets	2 × 2 factorial (2 Thr (normal or + 20%) x 2 fiber level (Low or High (**10% SBP + 5% wheat bran**); 17.5% CP)



SDF, %	1.80	1.90	3.60	3.70
ISDF, %	11.20	11.80	17.30	16.10

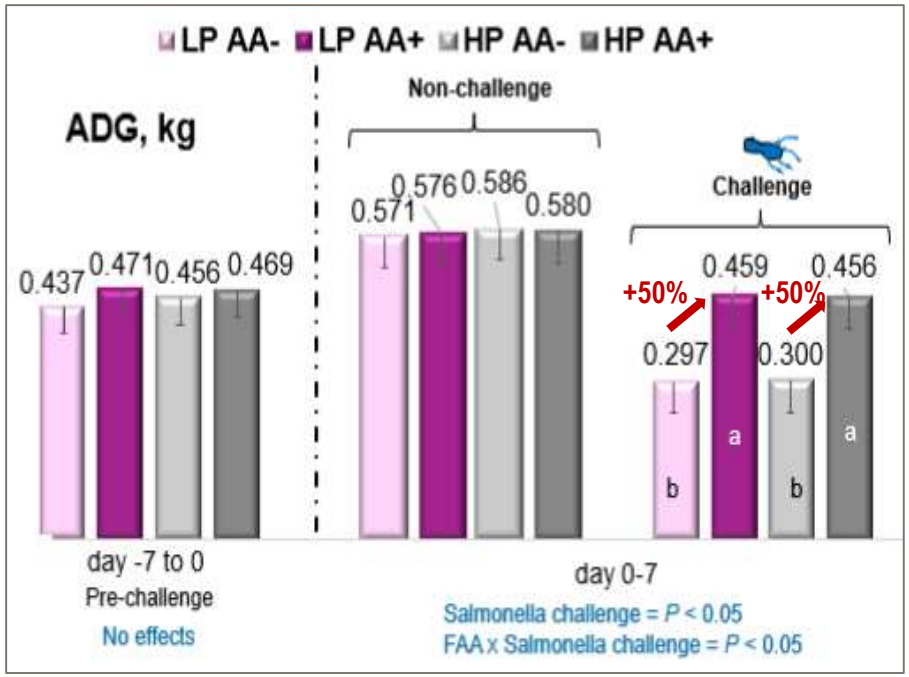
Wellington et al. (2019) J Anim Sci

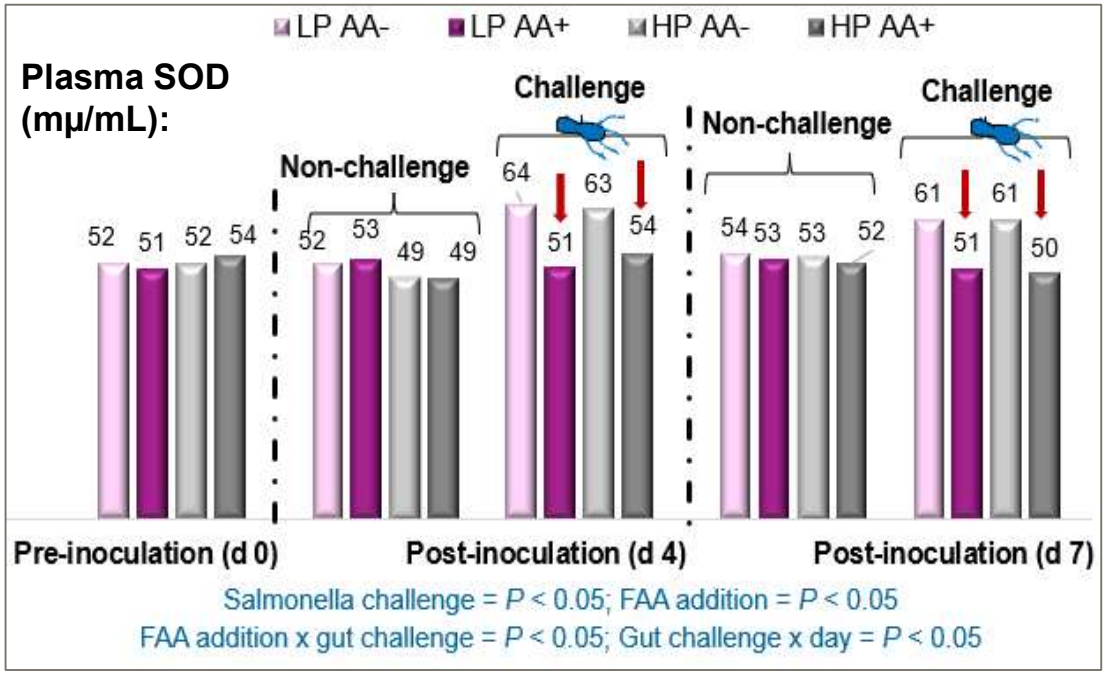
High DF reduced pig performance during an enteric disease challenge, however extra Thr (above requirement) improved pig performance regardless of the DF content.

EVONIK Leading Beyond Chemistry

Increasing FAA supply in both high and low CP diet reduces negative effect of *Salmonella* challenge on ADG and antioxidant capacity in weaned pigs

Animals	64 piglets (13.9 kg BW; 14-d study)
Diets	2 × 2 x 2 factorial; **CP** (**LP** (16%) vs. **HP** (20%)); **AA** (**FAA-** (NRC) vs. **FAA+** (**+20% Thr, Met, Trp**)); **enteric challenge** (**Non-challenge** vs. **Challenge** (orally inoculation; *Salmonella typhimurium* after 7 d))





Rodrigues et al., 2021 (J. Anim Sci)

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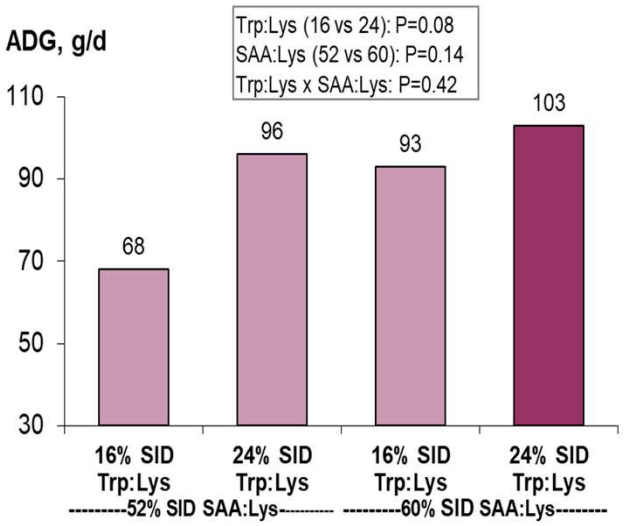
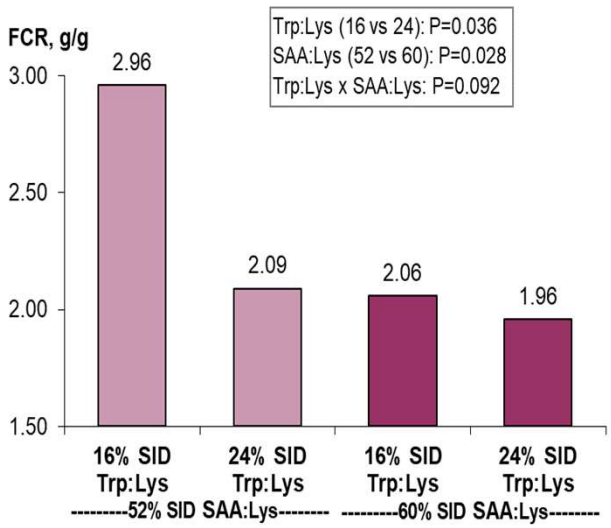
Effect of dietary Trp and SAA addition to moderate CP diets on performance and immune response of weaned pigs challenged with *E. coli* on day 5, 6 and 7 post-weaning

96 male pigs [6.2 ±0.78 kg; weaned at 21 d; 12 replicate pigs (1 pigs/pen)/trt]

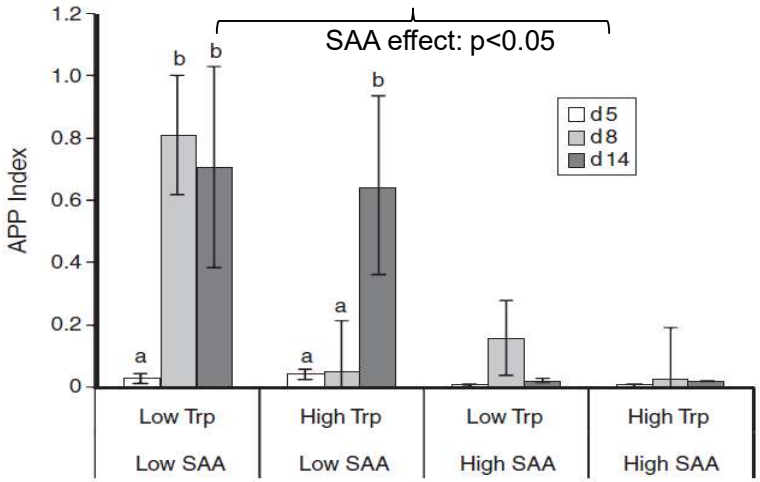
Wheat-barley-full-fat soybean (AGP-free) based diets (Lys was second limiting; SID Lys: 1.25%; 20% CP)

2 x 2 factorial [SID SAA:Lys (52 vs. 60% x SID Trp:Lys (16 vs. 24%)]; 14 d (*E. coli challenge* on d 5, 6 and 7 post- weaning





Acute-phase index (positive APP:negative APP)*



ADG and FCR of *E. coli* challenged pigs were optimized at higher Trp:Lys and SAA:Lys ratios.

*APP Index = (C-RP · PigMAP)/ApoA1

Suppl Trp of reduced inflammatory response in the acute phase, while SAA suppl reduced inflammatory response in the acute- and adaptive-phase.

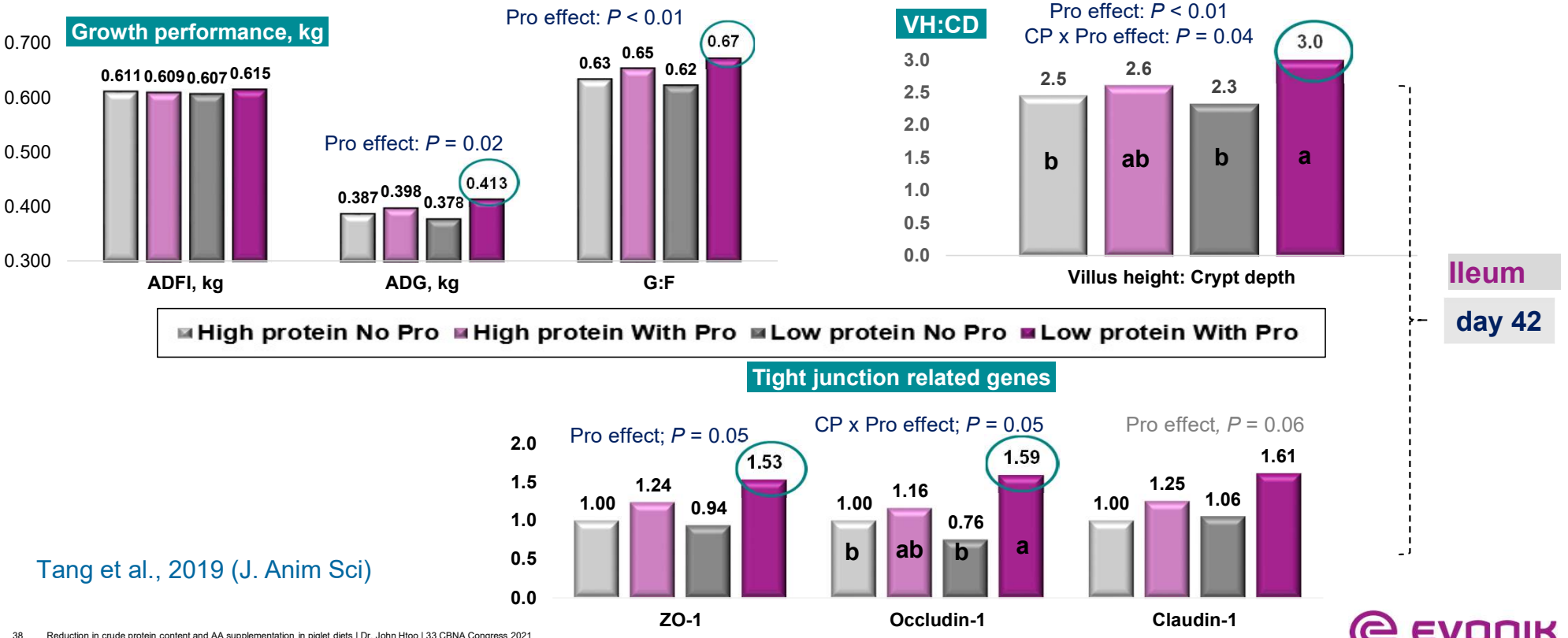
Capozzalo et al. (2017) Animal Prod Sci

EVONIK Leading Beyond Chemistry

Dietary CP reduction combined with addition of *B. subtilis* probiotic (GutCare®) synergistically increase performance and maintain gut barrier function

72 weaned piglets (25 d old; 7.6 ± 0.55 kg BW; 42 d trial; 2 phases)

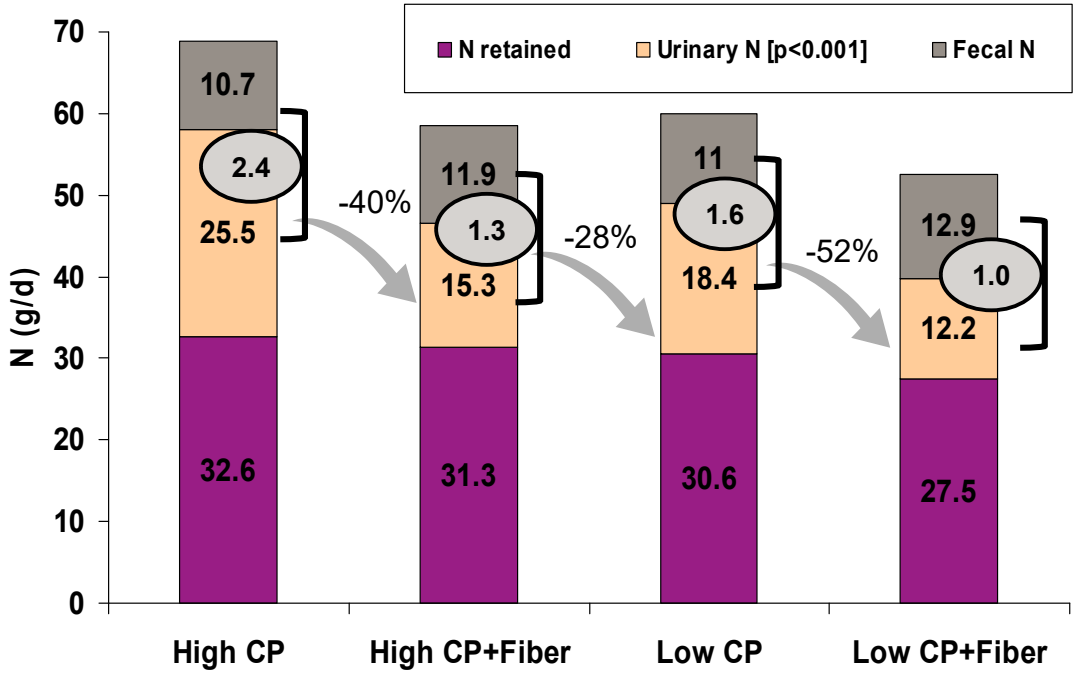
4 diets: 2 × 2 factorial; **CP** (**High**, 20%) vs. **Low**, (17.5%); **Pro** (0 or 500 g/t; ***B. subtilis* DSM32315;** 2 × 10^9 CFU/g.



Tang et al., 2019 (J. Anim Sci)

EVONIK Leading Beyond Chemistry

Reduction of dietary CP reduced urine N excretion and fermentable fiber shifted N excretion from urine to feces in 24 kg pigs



Diets:
High CP = 19% CP
High CP + Fiber = 18% CP + 15% soybean hulls*
Low CP = 16% CP
Low CP + Fiber = 15.6% CP + 15% soybean hulls
Design: N balance

*Soy hulls = Fermentable fiber source

Zervas and Zijlstra, 2002 (J. Anim Sci)

EVONIK Leading Beyond Chemistry

Fermentable protein (fCP) and fermentable fiber (fCHO) level on major bacterial groups, pH, SCFA and microbial metabolites in proximal colon of weaned pigs

32 mixed-sex weaned pigs (8.0± 0.22 kg BW; 4 rep/trt; 2 pigs/pen; 20-d)

2 x 2 factorial; low of high fCP* (14.5 vs 20.0%) x low or high fCHO** (14.5 vs 17.2% TDF)

Pieper et al. (2012); J Nutr

* 20% heat-damage SBM: ** 8% wheat bran + 5% SBP

	low fCP		high fCP		P-value		
	low fCHO	high fCHO	low fCHO	high fCHO	fCHO	fCP	fCHO x fCP
Bacterial counts			***log cfu/g digesta***				
Lactobacilli	8.6[a]	8.1[b]	8.3[ab]	8.6[a]	ns	ns	*
Bacteroides	10.2	10.9	10.6	10.7	*	ns	ns
Cl. leptum	9.8	10.1	9.9	10.2	**	*	ns
Cl. coccoides	10.2	10.8	10.4	10.8	**	0.22	ns
pH	6.1	6.0	6.0	5.8	ns	ns	ns
SCFA (*mmol/kg digesta*)	95.1	98.3	119.5	111.0 2	ns	**	ns
			molar ratio % of total SCFA				
Acetate	57.3	59.9	58.0	62.7	**	ns	ns
Propionate	27.1	25.1	25.7	23.0	*	§	ns
Butyrate	12.2	12.8	12.6	12.1	ns	ns	ns
			µmol/kg digesta				
Ammonia	7.3	3.2	13.8	9.1	**	**	ns
Putrescine	127	104	234	165	**	**	ns
Cadaverine	125	139	279	169	ns	ns	ns
Spermidine	211	225	274	267	ns	**	ns

Dietary fCHO can affect microbiota composition and ameliorate formation of toxic metabolites in the proximal colon of pigs fed diets with high level of fCP.

ns: not significant; § <0.10 * <0.05; ** <0.01

Effect of dietary CP (AA) and protease level on performance of weaned pigs

Effect of dietary CP and protease level on performance of 7-16 kg weaned pigs (d 0-28) Kim et al., 2021 (J Anim Sci Technol)

	CP level			Protease*			P-value		
	19%	17%		0%	0.3%	0.5%	CP	Protease	CP x Protease
BW (d28), kg	15.7	15.7	**Corn: 37 - 41%** **Barley: 5%** SBM = 21 -26% Fish meal: 4%	15.3[a]	15.4[a]	16.5[b]	ns	**	ns
ADG, g	310	313		296[a]	300[a]	340[b]	ns	**	ns
ADFI, g	435	428		420	421	453	ns	§	ns
G:F	0.71	0.73		0.70[a]	0.71[a]	0.75[b]	ns	*	ns

*from a commercial Korean company

ns: not significant; § <0.10 * ≤0.05; ** ≤0.01

Effect of dietary CP and protease level on performance of 6-14 kg weaned pigs Perez-Palencia et al., 2021 (J Anim Sci)

	CP level			Protease**		P-value		
	22%	19% (-15% AA)		0%	0.0125%	CP	Protease	CP x Protease
Phase 1 (d 0-14)#								
ADG, g	154	156	Corn: 44 - 49% SBM = 17% Whey: 24% Soy protein: 2-6% Enzym. SBM = 4%	160	150	ns	§	ns
G:F	0.69	0.67		0.69	0.67	ns	ns	ns
Phase 2 (d 15-28) ¶								
ADG, g	455	396		431	420	**	ns	ns
G:F	0.77	0.69		0.73	0.73	**	ns	ns

**from a commercial Canadian company

ns: not significant; § <0.10 ** ≤0.01

Pigs received a common phase 1 diet. ¶ Diets contained 2,500 FTU/kg phytase).

Content

1. Introduction - development of low protein diet concept
2. Effects of lowering dietary CP level on piglet performance and N excretion
3. Mistakes to be avoided when formulating low protein diets – how low we can go?
4. Advances on low protein diet concept to enhance intestinal health and microbiota
5. Conclusions

Conclusions

- For maintaining optimal growth of nursery pigs, low CP diets should be balanced for adequate level of both EAA and NEAA and net energy.
- How far we can lower CP level depends on its SID Lys level in the diet. Keeping ~ 6.9% SID Lys:CP) is useful to keep minimum NEAA level.
- On average, 1%-unit dietary CP ↓ » ~ 9% ↓ N excretion » ~ 3% ↓ drinking water
- Low CP-AA adequate diets is the first step to maintain gut health and lower incidences of diarrhea.
- Reducing dietary CP may act synergistically with functional AA, probiotics, functional fibers, enzymes.
- A holistic concept of combining “low CP diet with these functional feed additives” should be considered as part of “AGP-free” strategy towards sustainable pig production.

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Thank you

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