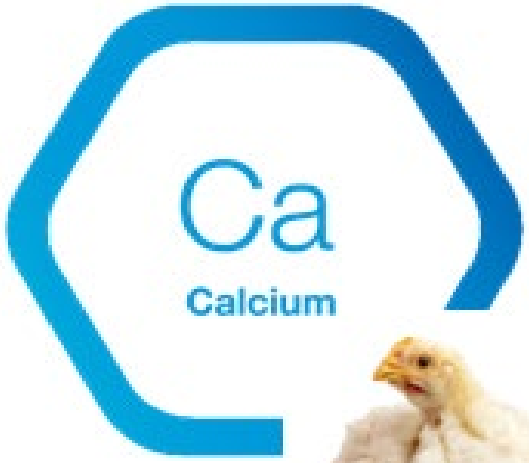

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CALCIUM DIGESTIBILITY IN POULTRY FEED INGREDIENTS AND THE REQUIREMENT OF DIGESTIBLE CALCIUM FOR BROILERS - AN OVERVIEW

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Introduction

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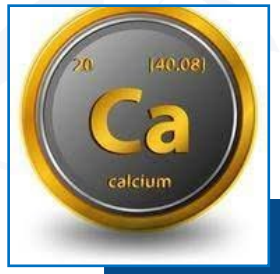
- Calcium (Ca) is the most abundant macro-mineral in the body of animals followed by P.
- Ca is always interrelated to P in their metabolism.
- In skeleton - 2:1 ratio of Ca:P

3 forms	Ca %	P %
1) Hydroxyapatite [$Ca10(PO4)_6(OH)_2$] – in bone (%)	99	80
2) Intracellular fluid (%)	0.9	14
3) Extracellular fluid (%) (bound to protein, bound to anions & ionized)	0.1	1.0



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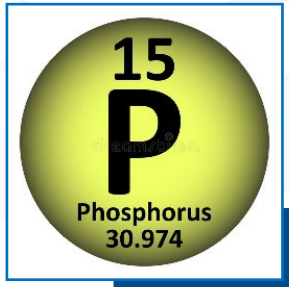


Calcium

- Skeleton (99%)
- Muscle contraction
- Nerve impulses
- Enzyme activation
- Blood clotting

Inadequate supply of Ca & P and improper Ca:P ratio in the poultry diets will cause deficiencies of these minerals and, reduce the growth and bone health

Phosphorous

- Skeleton (80%)
- Energy metabolism
- Protein synthesis
- Growth
- Enzyme activation

Problems of P

- Depletion of non-renewable global inorganic phosphate deposits
- Increasing prices of inorganic phosphate supplements
- Excess P excretion & environmental pollution (Eutrophication)

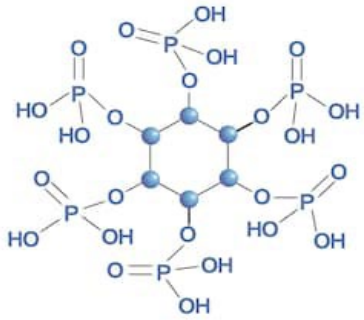
Causes for excess P excretion

- Inability of monogastric animals to fully digest and utilise the P bound in phytic acid
- Additional/excess P in the diet as a safety margin – uncertainty about the true P requirement, P content of ingredients and the availability.
- Confusion regarding the terminology used to describe available P.

  example: available P, non-phytate P,

  retainable P

Terminologies used to describe P availability



Phytic acid

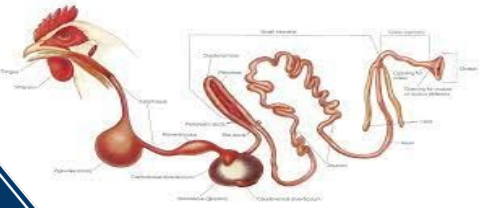
Total P (NRC, 1950)

Available P (NRC, 1984)

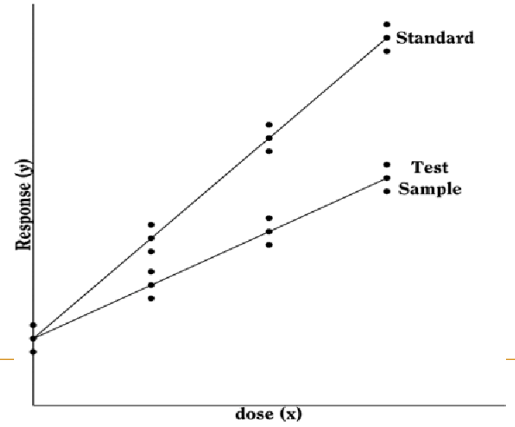
Non-phytate P (NRC, 1994)

Retainable P

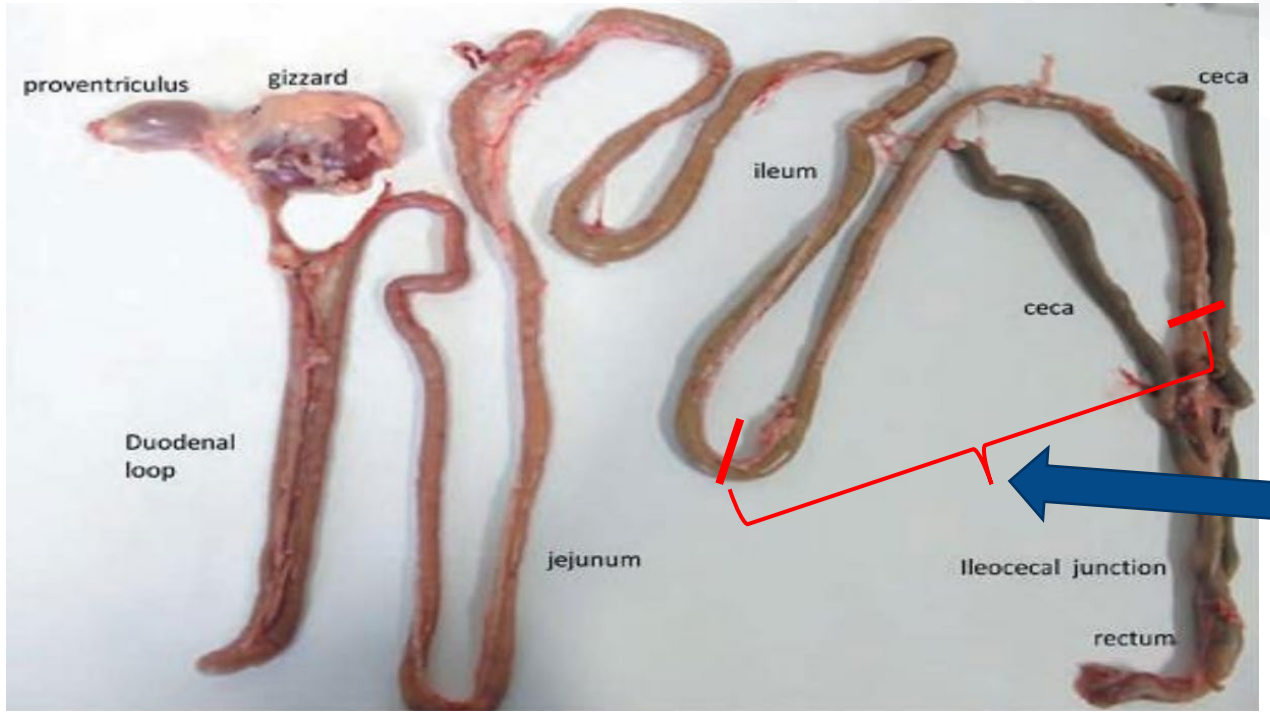
Digestible P



Slope ratio assays



Digesta collection

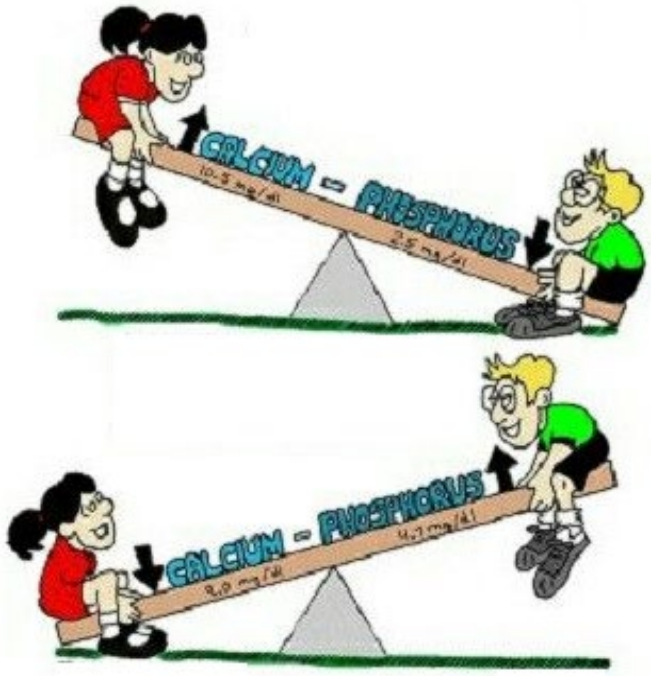


Lower half of ileum

$$\text{Digestibility} = 1 - [(Ti_I/Ti_O) \times (P_O/P_I)]$$

P Source	Ileal P digestibility coefficient	Reference
Meat & bone meal	0.42-0.69	Mutucumarana *et al.* (2015)
Maize	0.43-0.73	Mutucumarana *et al.* (2014; 2015)
Maize DDGS	0.73	Mutucumarana *et al.* (2014)
Wheat	0.46	Mutucumarana *et al.* (2014)
Sorghum	0.33	Mutucumarana *et al.* (2014)
Canola meal	0.47	Mutucumarana *et al.* (2014)
Soybean meal	0.52-0.80	Mutucumarana *et al.* (2014; 2015)
	0.94	Dilger & Adeola (2006)
Dicalcium phosphate	0.79	Van Harn *et al.* (2017)
Monocalcium phosphate	0.67	Shastak *et al.* (2012)

- Ca always interrelated to P in their metabolism. A deficiency or an excess of one will interfere with the proper utilization of the other.
  - ✓ high dietary Ca reduces P digestibility
  - ✓high dietary Ca reduces weight gain
  - ✓high dietary Ca reduces the utilisation of other minerals & nutrients



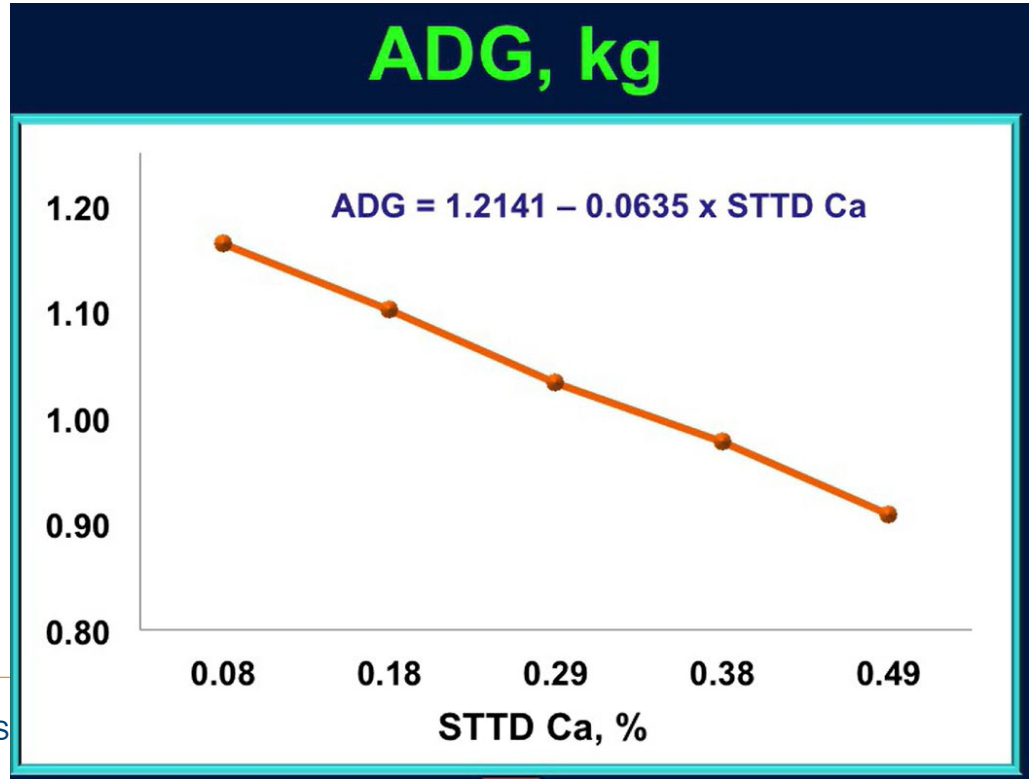
- *Reasons: increases intestinal pH & formation of Ca-P/ Ca-phytate complexes in the digestive tract*

Studies in Pigs (University of Illinois)

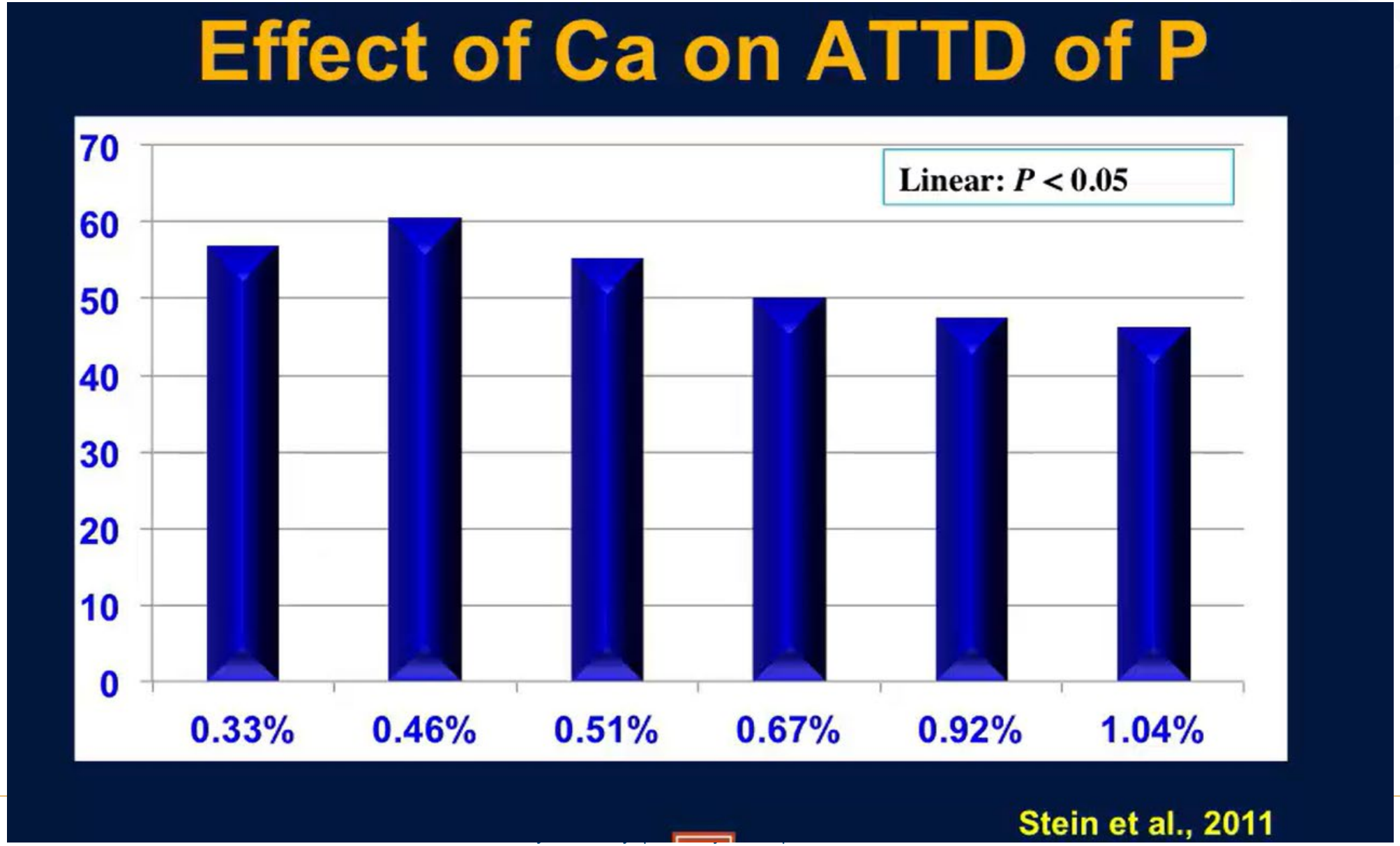
Excess Ca is detrimental to growth

High Ca Low Ca

(González-Vega et al., 2016; Merriman et al., 2017; Wu et al., 2018; Lagos et al., 2019; Vier et al., 2019)



Studies in Pigs (University of Illinois)



Effects of excess calcium on the digestibility of nutrients in poultry

Dietary Ca (g/kg)	Bird class	Effect	Reference
20.0	Broilers	↓ Fe retention	Sell (1965)
16.0	Broilers	↓ retention of fat, Ca and Mg	Atteh & Leeson (1984)
15.3, 21.8, 22.6	Broilers	↑ insoluble form of Ca, Mg, Zn and Fe	Shafey et al. (1991)
12.5	Broilers	↓ Ca Retention	Sebastian et al. (1996)
12.0	Broilers	↓ P, N and fat digestibility	Mutucumarana et al. (2014a)
10.3, 13.3	Broilers	↓ ileal digestibility and retention of P	Abdollahi et al. (2016)
10.0	Broilers	↓ ileal P and protein digestibility	Akter et al. (2018)
16.0	Roosters	↓ digestibility of high-melting triglycerides and hydrogenated fats	Edwards et al. (1960)
45.0	Layers	↓ body, egg and bone Ca retention	Kebreab et al. (2009)

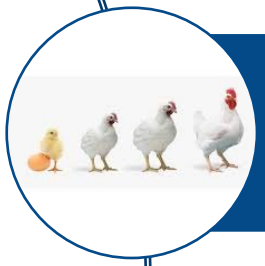
↓ : Decrease ↑ : Increase

Ca digestibility measurement

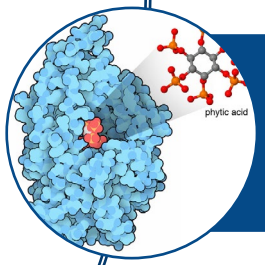
Ca Source	Ileal Ca digestibility coefficient	Reference
Limestone	0.49-0.65	Anwar (2016); Zhang and Adeola (2018)
Oyster shell	0.44	Anwar *et al.* (2017)
Dicalcium phosphate	0.28-0.32	Anwar et al. (2018); David et al. (2019)
	0.61-0.65	Zhang and Adeola (2018)
Monocalcium phosphate	0.33-0.43	Anwar et al. (2018); David et al. (2019)
	0.56-0.77	Angel et al. (2013)
Meat & bone meal	0.41-0.60	Anwar et al. (2015); David et al. (2019)
Fish meal	0.24	Anwar et al. (2018)
Poultry by-product meal	0.29	Anwar et al. (2018)
Canola meal	0.22-0.53	Anwar et al. (2018); David et al. (2020)
Soybean meal	0.33-0.51	David et al. (2020)

Factors affecting Ca digestibility

Basal diet composition



Age of birds



Phytase

Class of bird

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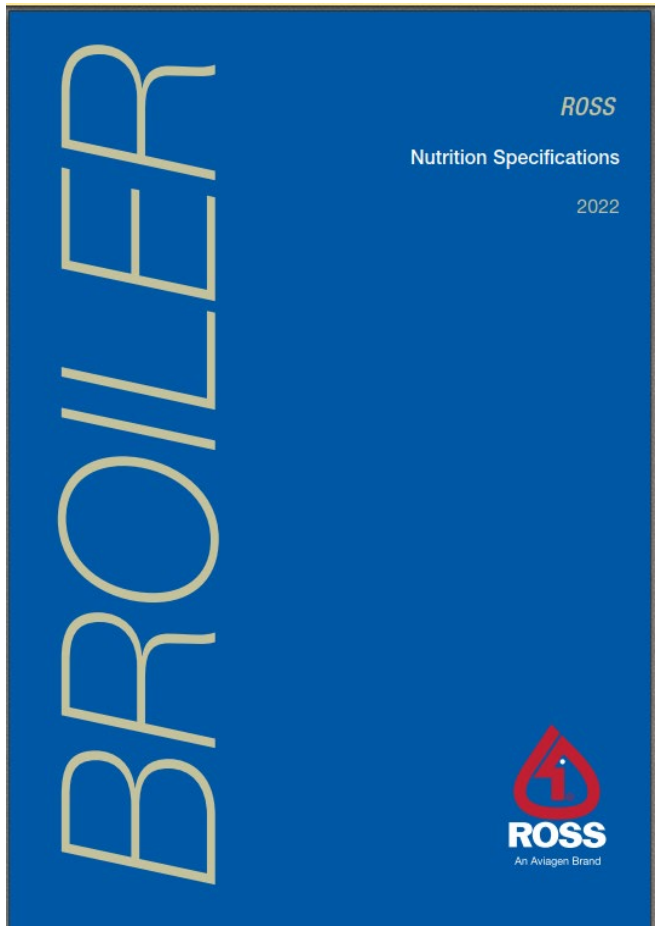
Digestible Ca requirement of broilers

Aviagen's Nutrient Recommendation for Ross Broilers



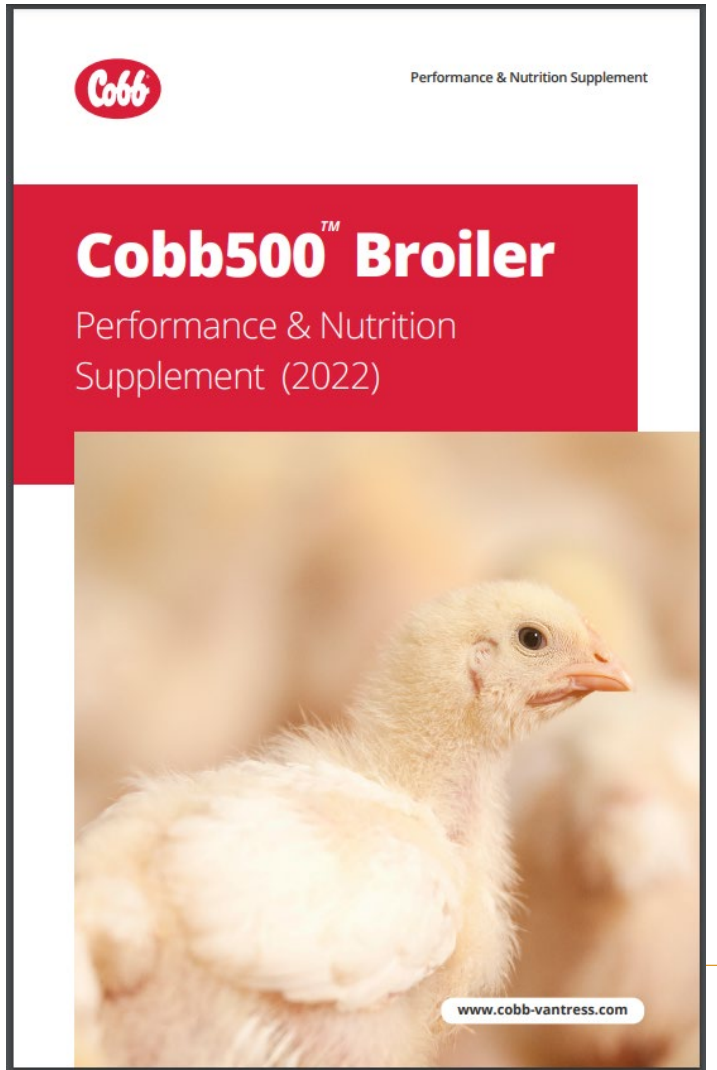
2019

		Starter	Grower	Finisher
Age Fed	days	0 - 10	11 - 24	25 - market
Crude Protein[2]	%	23.0	21.5	19.5
MINERALS				
Calcium	%	0.96	0.87	0.79
Available Phosphorus	%	0.480	0.435	0.395

2022

		Starter	Grower	Finisher
Age Fed	days	0 - 10	11 - 24	25 - market
Energy per kg	kcal	2975	3050	3100
	MJ	12.4	12.8	13.0
Energy per lb	kcal	1349	1383	1406
MINERALS				
Total Calcium	%	0.95	0.75	0.65
Available Phosphorus	%	0.50	0.42	0.36

Cobb500 broiler Nutrient recommendation (2022)



Recommended Nutrient Levels for Medium and Large Broilers

Preferred in Medium and Large Bird Market		Starter	Grower 1	Grower 2	Finisher 1	Finisher 2*
Feeding Amount/Bird	g	455	2100	2100	2100	
	lb	1.00	4.63	4.63	4.63	
Period (Reference)	days	0-12	13-28	29-39	40-49	> 50
Feed Structure		Crumble	Pellet	Pellet	Pellet	Pellet
Crude Protein	%	21-22	19-20	18-19	17-18	17-18
Metabolizable energy (AMEn**)	MJ/kg	12.13	12.34	12.76	12.97	13.18
	Kcal/kg	2900	2950	3050	3100	3150
	Kcal/lb	1315	1338	1383	1406	1429
Minerals						
Calcium	%	0.96	0.80	0.74	0.72	0.68
Available Phosphorus***	%	0.58	0.40	0.37	0.36	0.34

Recommendations – Calcium (Ca) & Phosphorous (P)

Year	Ca	P
NRC (1950)	Total Ca	Total P
NRC (1954)	Total Ca	Inorganic P
NRC (1984)	Total Ca	Available P
NRC (1994)	Total Ca	Non-phytate P
Ross (2019)	Total Ca	Available P
Ross (2022)	Total Ca	Available P
Cobb (2022)	Total Ca	Available P
??	Digestible Ca ?	Digestible P ?

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Benefits of digestible Ca & digestible P use in broiler feed formulations

Minimise oversupply

- Ensure the adequate amount of Ca & P for broilers
- Minimise the oversupply of Ca & P and the excess mineral excretion - **reduce environmental problems**

Low cost

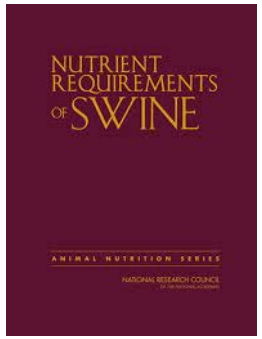
- Reduce the broiler production cost

High performance

- Increase mineral digestibility and growth performance

Requirement of digestible Ca & digestible P – Pigs vs Poultry

- Use of digestible Ca and digestible P has been well established in pigs:
  - ✓Standardised total tract digestible (STTD) P values have been published in NRC (2012)



	Calcium and phosphorus (%)						
Total calcium	0.85	0.80	0.70	0.66	0.59	0.52	0.46
STTD phosphorus	0.45	0.40	0.33	0.31	0.27	0.24	0.21
ATTD phosphorus	0.41	0.36	0.29	0.26	0.23	0.21	0.18
Total phosphorus	0.70	0.65	0.60	0.56	0.52	0.47	0.43

  - ✓Later, STTD Ca: STTD P ratios have also been published in journals (2016-2019)

	STTD Ca: STTD P ratios for different body weight range (kg) of pigs			
	11-25	**25-50**	**50-85**	**100-130**
Growth performance	< 1.40:1	< 1.35:1	< 1.25:1	< 1.10:1
Bone ash	1.70:1	1.80:1	2.00:1	2.30:1
Reference	Lagos et al. (2019b)	González-Vega et al. (2016b)	Lagos et al. (2019a)	Merriman et al. (2017)

Similar Ca requirement studies for poultry was not available before the initiation of our studies at Massey University, New Zealand.

Studies on SID Ca/P requirement – conducted at Massey between 2020-2022

Study 1

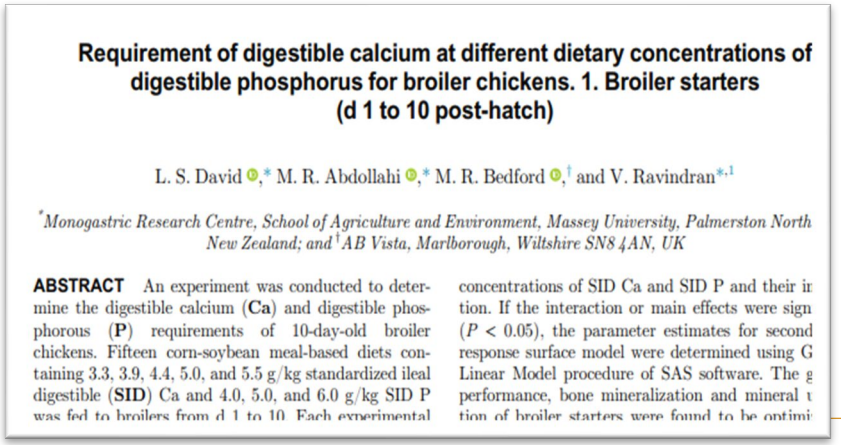
- Broiler starters (day 1-10)
- David *et al*. (2021) *Poultry Science*, 100(11):101439

Study 2

- Broiler growers (day 11-24)
- David *et al*. (2022) *Poultry Science*, 101(11):102135

Study 3

- Broiler finishers (day 25-35)
- David *et al*. (2023) *Poultry Science*, 102(4):102492



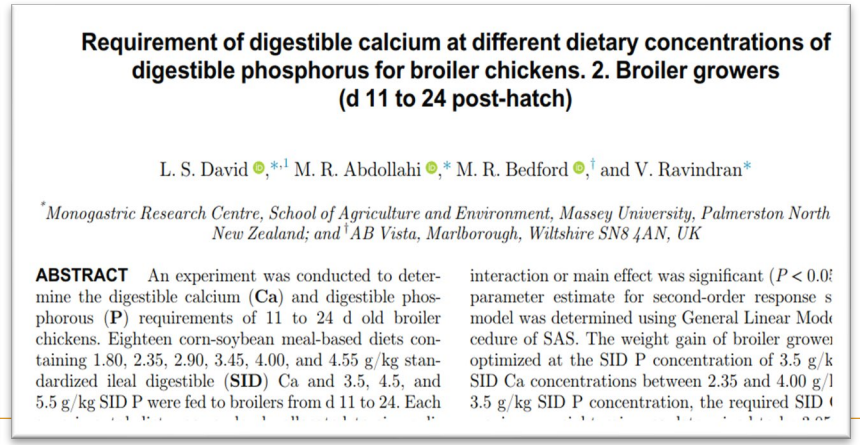
Requirement of digestible calcium at different dietary concentrations of digestible phosphorus for broiler chickens. 1. Broiler starters (d 1 to 10 post-hatch)

L. S. David,*,1 M. R. Abdollahi,* M. R. Bedford,† and V. Ravindran*,1

*Monogastric Research Centre, School of Agriculture and Environment, Massey University, Palmerston North New Zealand; and †AB Vista, Marlborough, Wiltshire SN8 4AN, UK

ABSTRACT An experiment was conducted to determine the digestible calcium (**Ca**) and digestible phosphorous (**P**) requirements of 10-day-old broiler chickens. Fifteen corn-soybean meal-based diets containing 3.3, 3.9, 4.4, 5.0, and 5.5 g/kg standardized ileal digestible (**SID**) Ca and 4.0, 5.0, and 6.0 g/kg SID P was fed to broilers from d 1 to 10. Each experimental

concentrations of SID Ca and SID P and their in tion. If the interaction or main effects were sign ($P < 0.05$), the parameter estimates for second response surface model were determined using G Linear Model procedure of SAS software. The g performance, bone mineralization and mineral t tion of broiler starters were found to be optimi



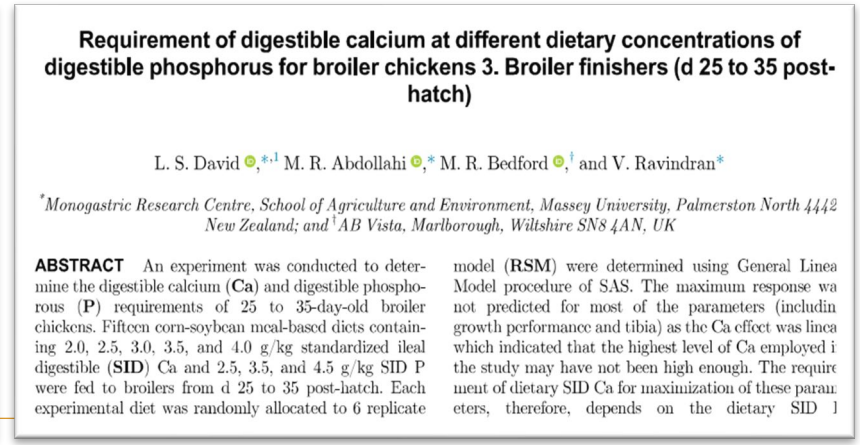
Requirement of digestible calcium at different dietary concentrations of digestible phosphorus for broiler chickens. 2. Broiler growers (d 11 to 24 post-hatch)

L. S. David,*,1 M. R. Abdollahi,* M. R. Bedford,† and V. Ravindran*

*Monogastric Research Centre, School of Agriculture and Environment, Massey University, Palmerston North New Zealand; and †AB Vista, Marlborough, Wiltshire SN8 4AN, UK

ABSTRACT An experiment was conducted to determine the digestible calcium (**Ca**) and digestible phosphorous (**P**) requirements of 11 to 24 d old broiler chickens. Eighteen corn-soybean meal-based diets containing 1.80, 2.35, 2.90, 3.45, 4.00, and 4.55 g/kg standardized ileal digestible (**SID**) Ca and 3.5, 4.5, and 5.5 g/kg SID P were fed to broilers from d 11 to 24. Each

interaction or main effect was significant ($P < 0.0$ parameter estimate for second-order response s model was determined using General Linear Mode cedure of SAS. The weight gain of broiler growe optimized at the SID P concentration of 3.5 g/k SID Ca concentrations between 2.35 and 4.00 g/l 3.5 g/kg SID P concentration, the required SID



Requirement of digestible calcium at different dietary concentrations of digestible phosphorus for broiler chickens 3. Broiler finishers (d 25 to 35 post-hatch)

L. S. David,*,1 M. R. Abdollahi,* M. R. Bedford,† and V. Ravindran*

*Monogastric Research Centre, School of Agriculture and Environment, Massey University, Palmerston North 4442 New Zealand; and †AB Vista, Marlborough, Wiltshire SN8 4AN, UK

ABSTRACT An experiment was conducted to determine the digestible calcium (**Ca**) and digestible phosphorous (**P**) requirements of 25 to 35-day-old broiler chickens. Fifteen corn-soybean meal-based diets containing 2.0, 2.5, 3.0, 3.5, and 4.0 g/kg standardized ileal digestible (**SID**) Ca and 2.5, 3.5, and 4.5 g/kg SID P were fed to broilers from d 25 to 35 post-hatch. Each experimental diet was randomly allocated to 6 replicate

model (**RSM**) were determined using General Linea Model procedure of SAS. The maximum response wa not predicted for most of the parameters (includin growth performance and tibia) as the Ca effect was linea which indicated that the highest level of Ca employed i the study may have not been high enough. The require ment of dietary SID Ca for maximization of these paran eters, therefore, depends on the dietary SID

Standardised ileal digestible (SID) Ca & SID P concentrations used in the studies

	SID P (g/kg)	NPP (g/kg)	SID Ca (g/kg) [Total Ca]					
Broiler starter (d 1-10) [Study 1]	4.0	3.4	3.3 [7.0]	3.9 [8.0]	4.4 [9.0]	5.0 [10.0]	5.5 [11.0]	-
	5.0	4.9						
	6.0	6.4						
Broiler grower (d 11-24) [Study 2]	3.5	2.7	1.80 [3.8]	2.35 [4.8]	2.90 [5.8]	3.45 [6.8]	4.00 [7.8]	4.55 [8.8]
	4.5	4.2						
	5.5	5.7						
Broiler finisher (d 25-35) [Study 3]	2.5	1.5	2.0 [3.7]	2.5 [4.6]	3.0 [5.5]	3.5 [6.4]	4.0 [7.3]	-
	3.5	3.0						
	4.5	4.5						

Ross (2019) – Total Ca

73-115%

44-102%

47-94%

P & Ca (total and SID) content of feed ingredients

Ingredients	Total P (g/kg)[1]	P digestibility (%)	SID P (g/kg)
Maize	2.3	70[2]	1.61
Soybean meal	5.9	75[2]	4.43
Dicalcium phosphate	185	79[3]	146
Monosodium phosphate	225	67[4]	151
	Total Ca (g/kg)	**Ca digestibility (%)**	**SID Ca (g/kg)**
Maize	0.2	50[5]	0.1
Soybean meal	3.5	54[6]	1.89
Dicalcium phosphate	260	36[7]	93.6
Limestone	410	55[7,8]	226

[1] Analysed values.
[2] Mutucumarana et al. (2015)
[3] van Harn et al. (2017)
[4] Shastak et al. (2012)
[5] Assumed value
[6] David et al.(2021)
[7] David et al. (2019)
[8] Anwar et al. (2016)

Statistical analysis

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1. Factorial analysis : SID Ca × SID P

2. Response Surface Model:

$$Y = a + b \times Ca + c \times Ca^2 + d \times P + e \times P^2 + f \times Ca \times P$$

Ca = SID Ca P = SID P

$$\text{SID Ca}_{\text{max/min}} = [(-f \times P) - b)] / (2 \times c)$$

(González-Vega *et al*., 2016)

Summary – Requirement of SID Ca, SID P & their ratio for weight gain & bone ash in broilers

Parameter	SID Ca (g/kg)	SID P (g/kg)	SID Ca: SID P ratio
Broiler Starters (d 1-10):			
Body weight gain	3.32	5.0	0.66
Tibia ash	4.51	5.0	0.87
Broiler Growers (d 11-24):			
Body weight gain	3.05	3.5	0.87
Tibia ash	3.69	3.5	1.05
Broiler Finishers (d 25-35):			
Body weight gain	3.50	3.5	1.00
Tibia ash	3.00-3.50	3.5	0.86-1.00

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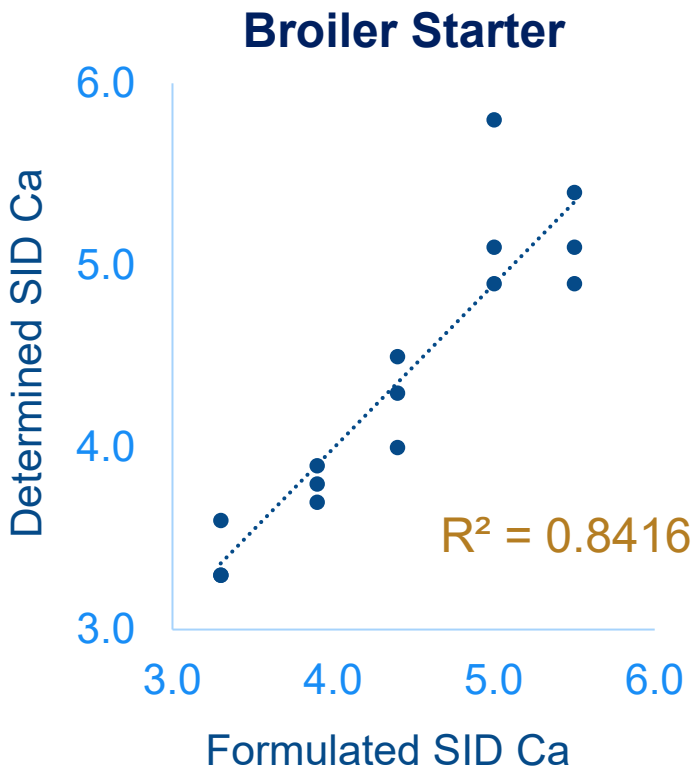
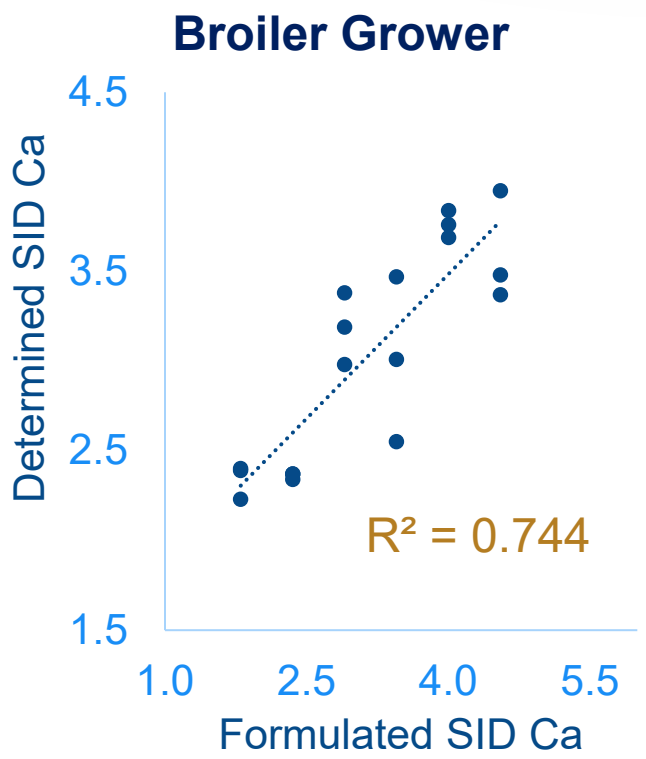
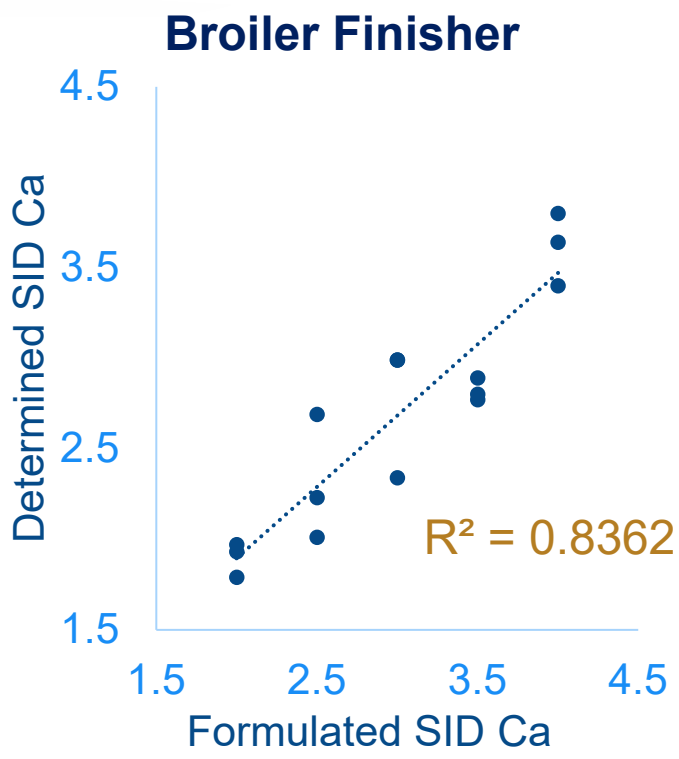
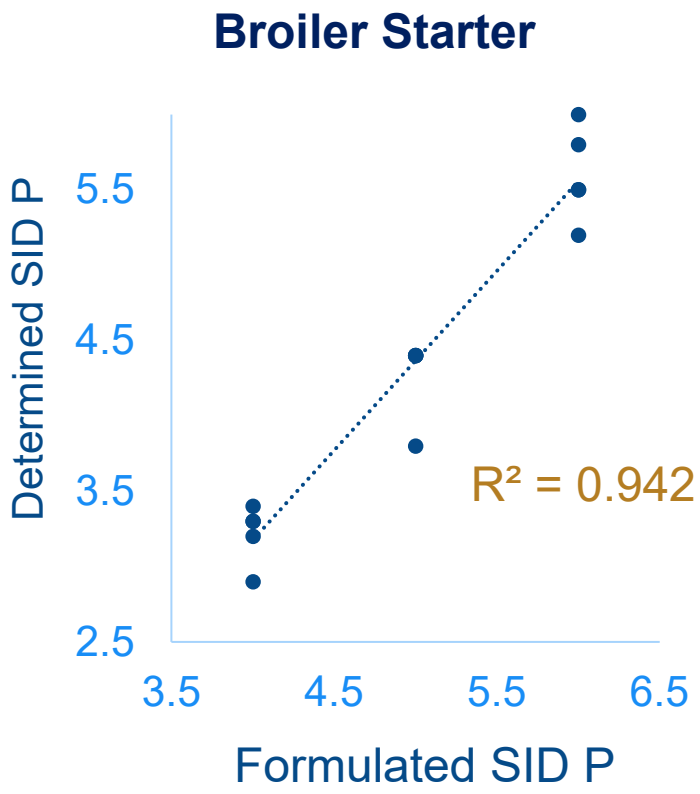
Formulated and determined SID Ca (g/kg) of the experimental diets

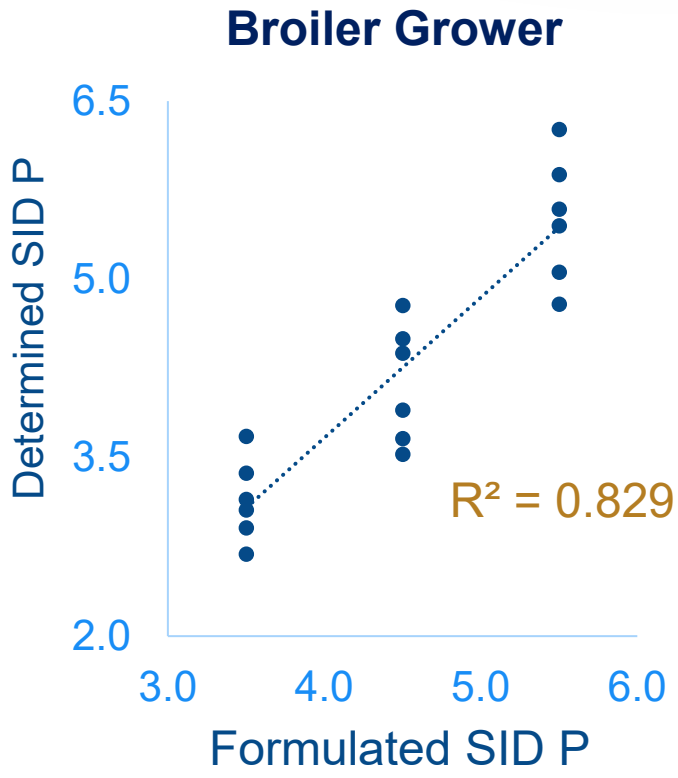


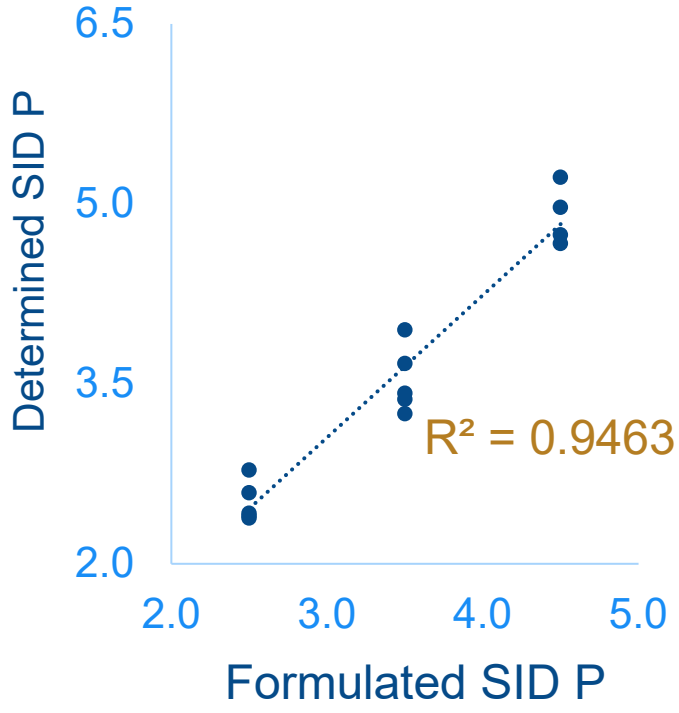




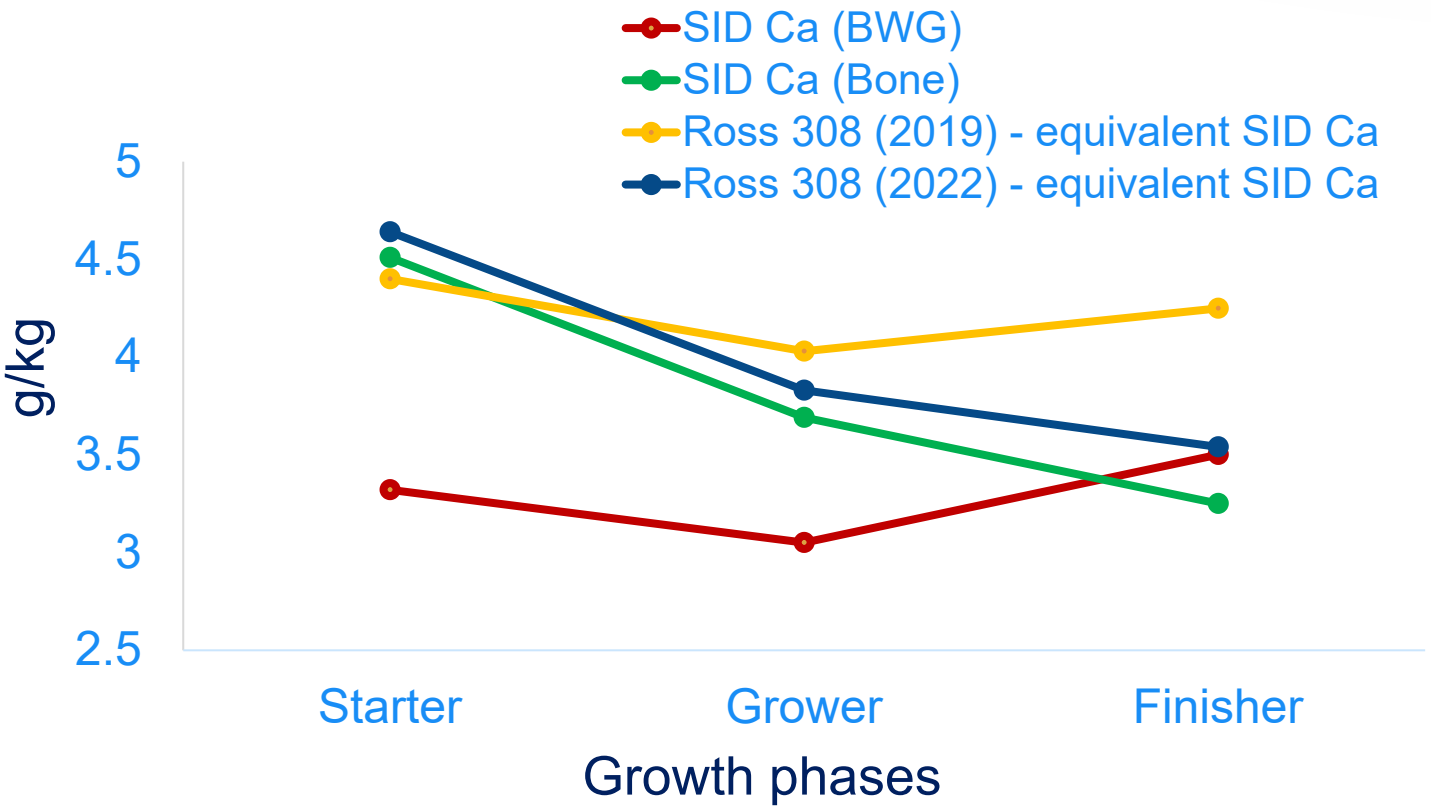
Formulated and determined SID P (g/kg) of the experimental diets

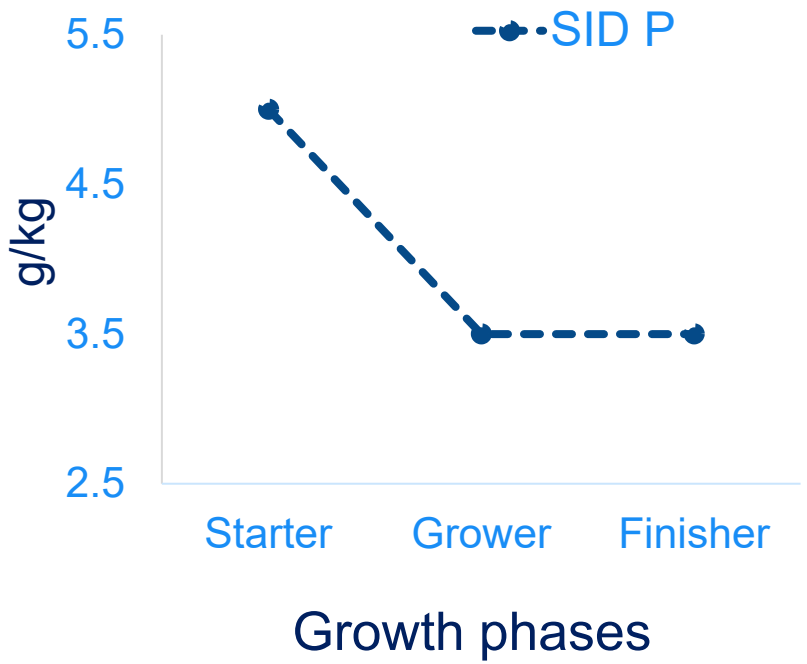






Comparison of SID Ca estimates vs Ross 308 (2019/2022) recommendation for different growth phases





SID Ca (g/kg) requirement of broilers - Comparison

Parameters	Starter		Grower		Finisher	
	Walk et al. (2021) at 4.8 aP	David et al. (2021) at 5.0% SID P [4.87 nPP]	Walk et al. (2022a) at 4.4 aP	David et al. (2022) at 3.5% SID P [2.67 nPP]	Walk et al. (2022b) at 3.9 aP	David et al. (2023) at 3.5% SID P [2.99 nPP]
Body weight gain (g/b)	-	3.32	-	3.05	-	3.50
Tibia ash (g/kg)	5.30	4.51	5.15	3.69	3.70	3.00-3.50

Walk et al. (2021; 2022a,b) – Arbor Acres broilers

David et al. (2021; 2022; 2023) – Ross 308 broilers

Take home messages

- Preliminary data on digestible Ca and digestible P requirement for different growth stages of broilers are now available.
- Predicted requirements for maximum bone ash were higher than those for maximum weight gain in broiler starters & growers, but similar in finishers.
- The general trend suggests that the Ca requirement declined with advancing broiler age.
- SID Ca responses depend on dietary SID P and therefore, the Ca requirement cannot be addressed as a subject distinct from that of P.

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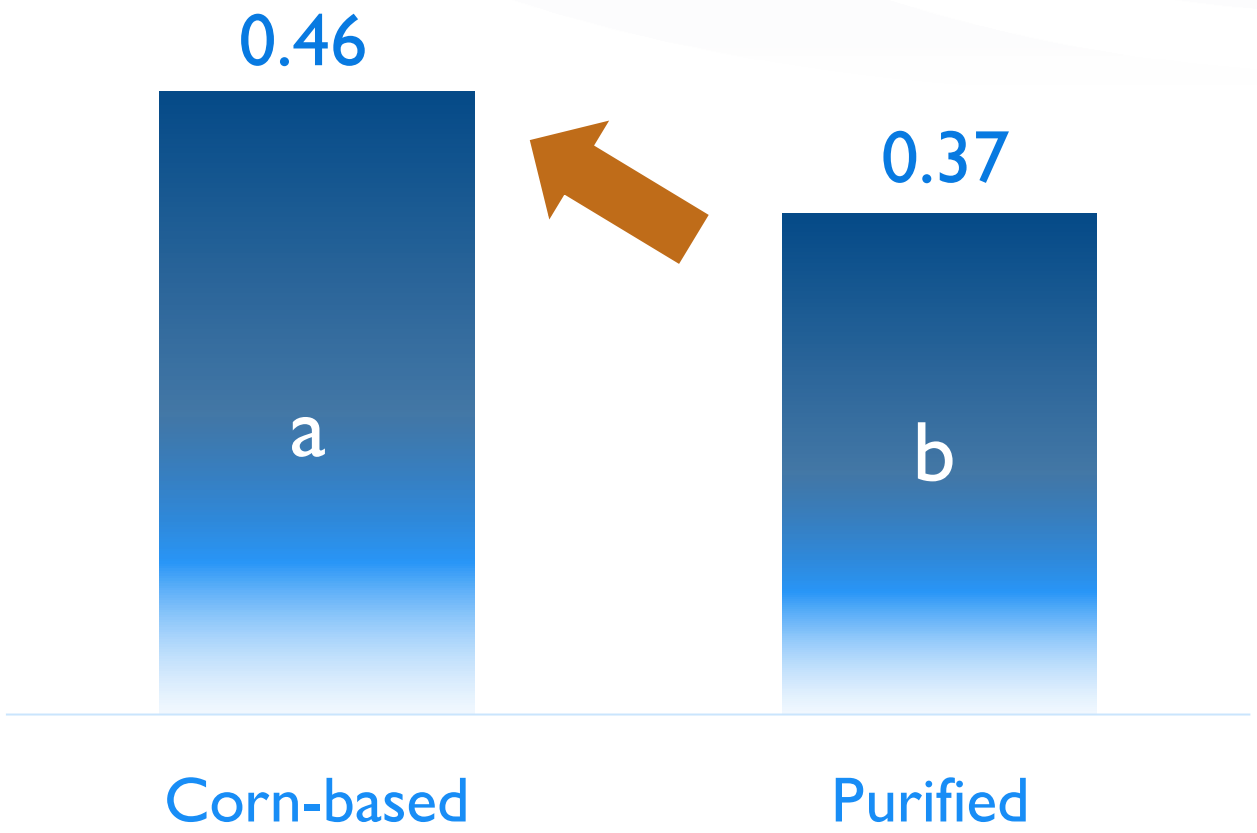
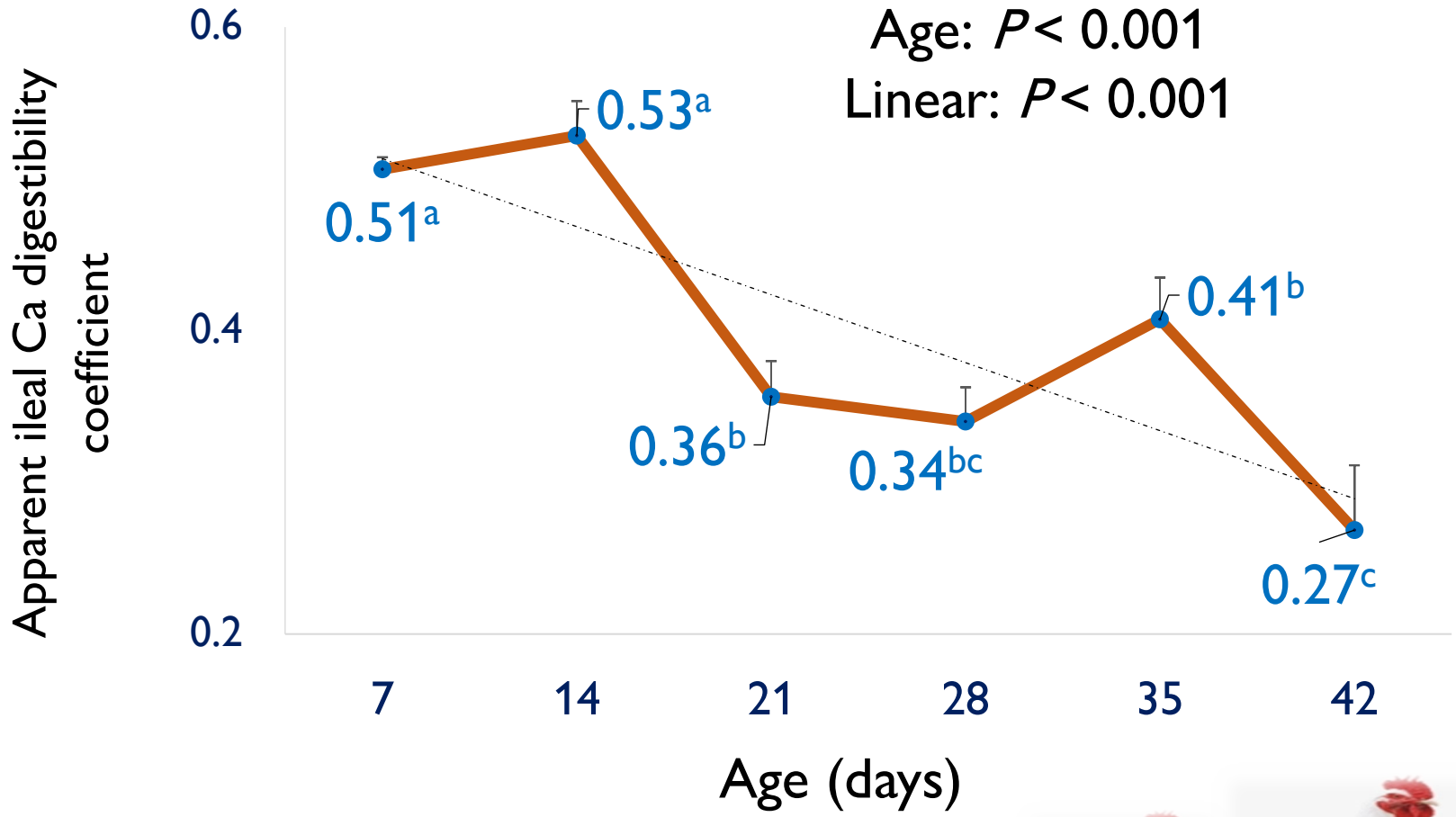
UNIVERSITY OF NEW ZEALAND

Basal diet composition & ileal Ca digestibility

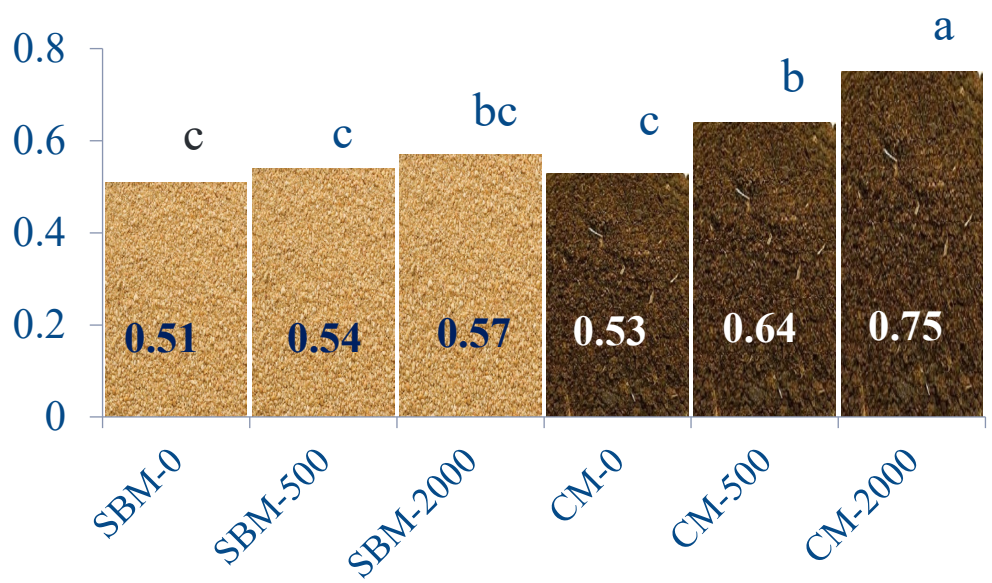


Age & ileal Ca digestibility

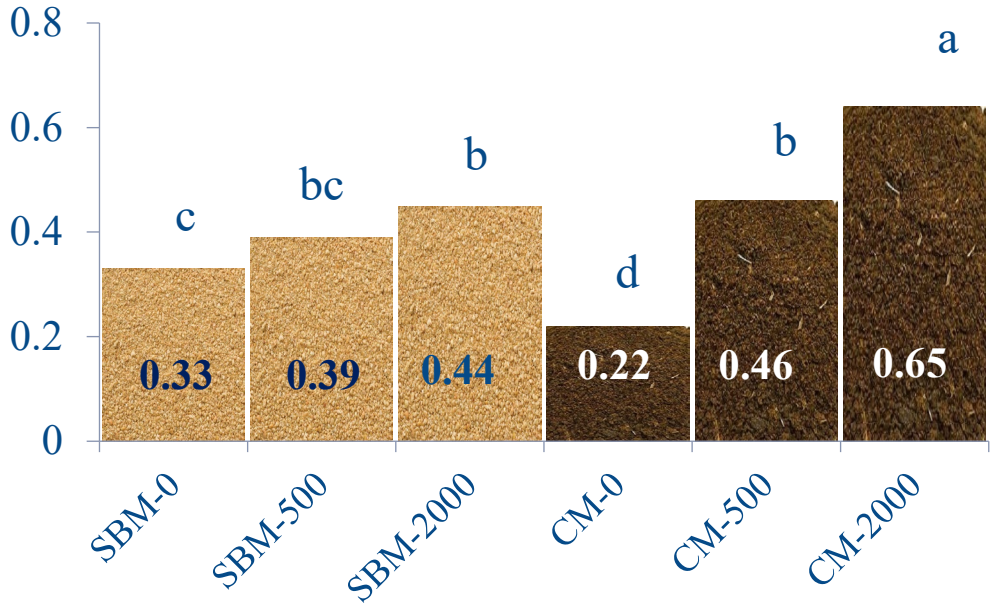


Phytase & ileal Ca digestibility

Starter (d 21)

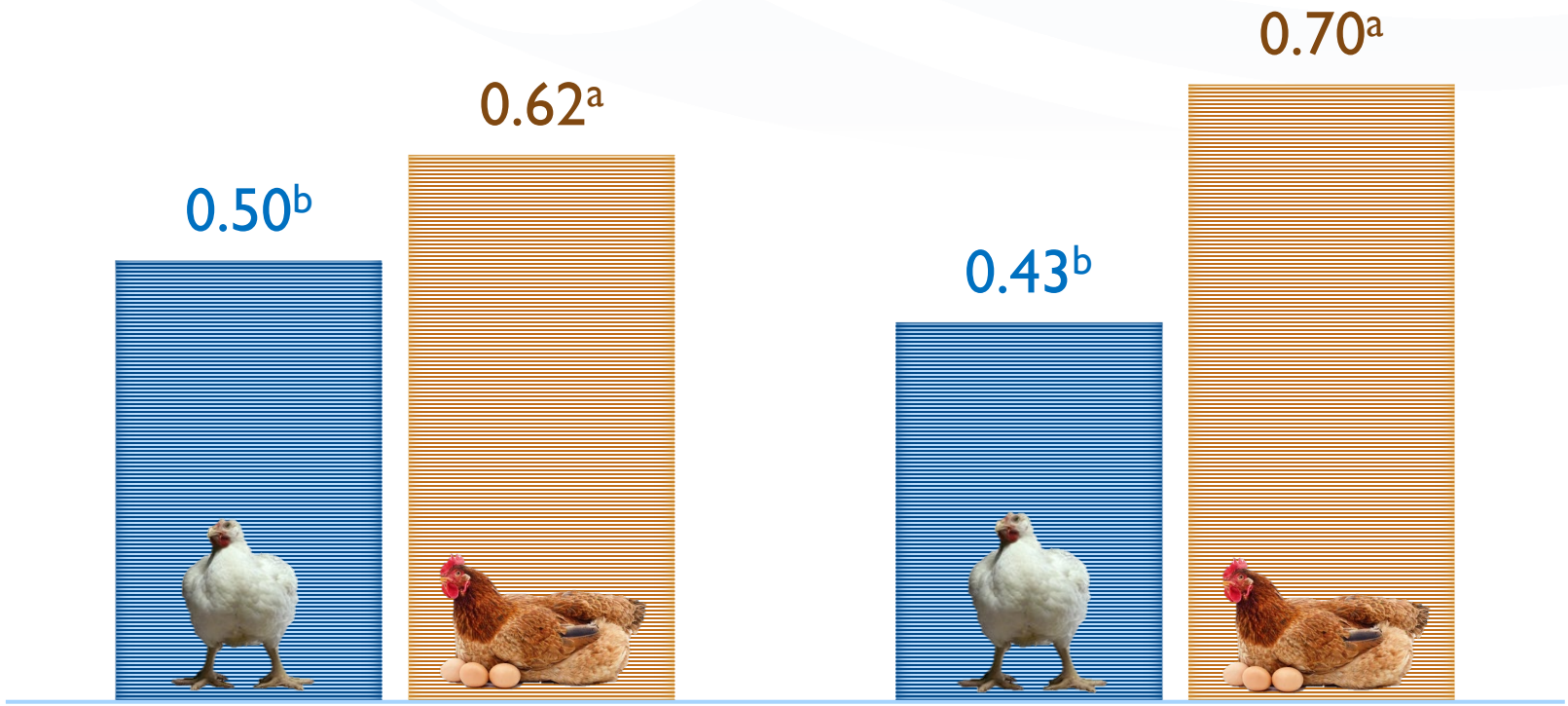


Finisher (d 42)



Soybean meal

Canola meal


0.50b
0.62a
0.43b
0.70a
Limestone A
Limestone B
Broiler
Layer