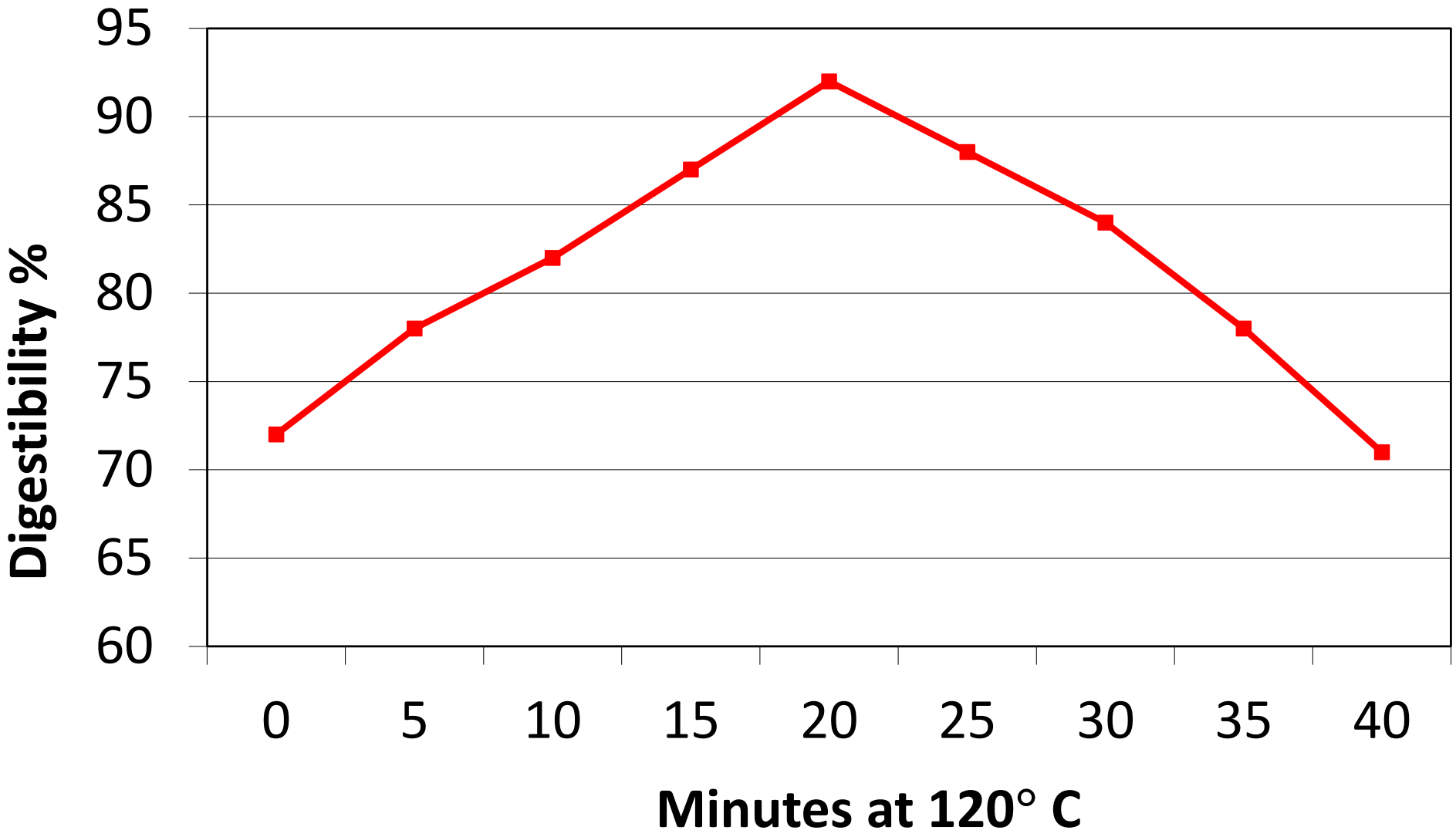
Impact of Thermal Processing on Protein Quality and Monogastric Nutrition

Chad Paulk


CPM

Toasting and protein digestiblity



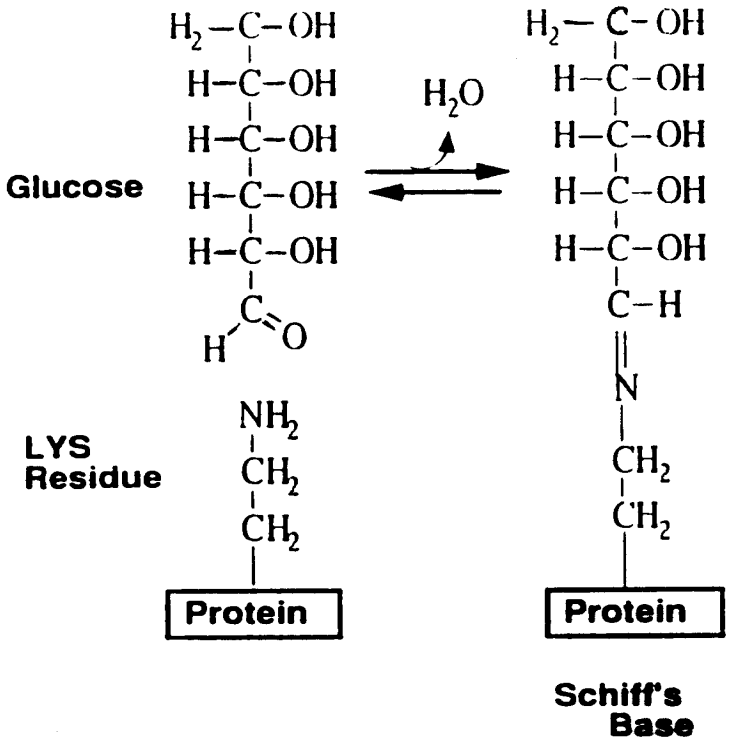
Nitsan and Nir, 1974

Thermal Processing and Protein Quality

- Protein denaturation: transforming well-defined/folded proteins to unfolded state
  - Typically irreversible
  - Usually sudden but only over very specific conditions
  - Accelerated by moisture
- Denaturants
  - Temperature, organic solvents, acid-bases, pH, shear
- Consequences
  - Loss of enzyme activity, toxin destruction, improved digestibility, loss of solubility, textural changes

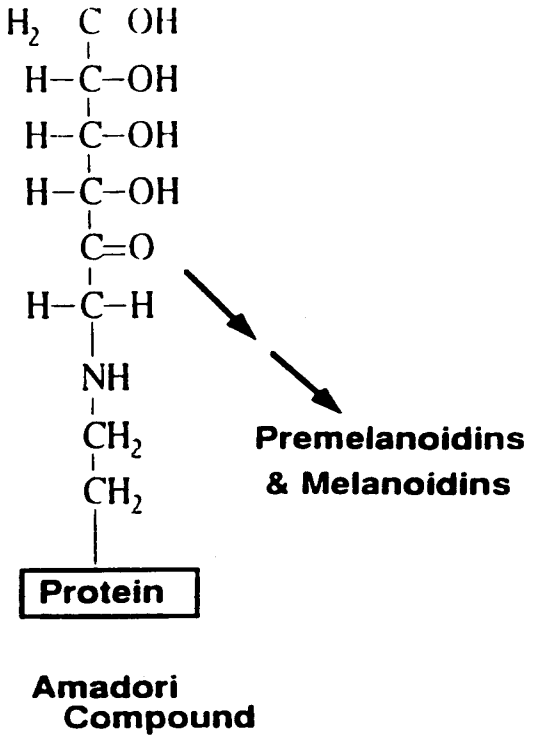
Maillard Reaction

- The carbonyl group of a sugar (glucose) combines with a reactive amine group of an amino acid to form an unstable Schiff's base, glycosylamine.
- When Lys is utilized, reaction derivatives include 1-deoxy-D-fructosyl and 1-D-deoxy-lactulosyl
  - Reversible reaction with deanimation by intestinal microflora
  - Laboratory assays detect Lys
  - Not available by absorption by monogastrics



Maillard Reaction

- The Amadori compound is converted into enediols (premelaldins and melanoidins), which are converted to deoxy-hexodiuloses (color, odor, flavor)
  - Lys residue is denatured, reduced detection by analytical assays and monogastric animal absorption



Multi-factorial response

- Oven-dried DDGS had reduced Lys digestibility at a drying temperature of 100C
- Oven-dried SBM minimal effect at a drying temperature of 125C for 30 min
- When does heat damage occur?
  - Ingredient
  - Temperature
  - Moisture/water activity
  - Pressure
  - pH

QA: How do we measure?

TABLE 2. Effect of autoclaving soyflakes on chick performance, protein solubility, urease index, protein dispersibility index, and trypsin inhibitor (Chick Assay 1)[1]

Item	Weight gain[2]	Gain:feed ratio[3]	Protein solubility[4]	Urease index	Protein dispersibility index[4]	Trypsin inhibitor[5]
	(g)	(g:g)	(%)	(units of pH change)	(%)	(units/g)
Autoclaving time, min						
0	178[c]	0.578[bc]	97	2.40	76	44.2
6	180[bc]	0.557[c]	93	2.20	63	31.0
12	189[b]	0.599[b]	93	2.10	63	26.8
18	204[a]	0.671[a]	94	1.80	47	12.3
24	207[a]	0.685[a]	81	0.20	30	3.4
30	205[a]	0.678[a]	81	0.30	32	4.5
36	210[a]	0.682[a]	78	0.10	24	2.6
Soybean meal	210[a]	0.693[a]				
Pooled SEM	3	0.010	1.0		2.0	2.08

[a–c]Means in a column with no common superscript are significantly different ($P \leq 0.05$).

[1]Values for weight gain and gain:feed ratio are means of four pens of five chicks from 8 to 17 d of age, and values of protein solubility, urease index, protein dispersibility index, and trypsin inhibitor are means of duplicate analyses on the soyflakes.

[2]Quadratic increase as a function of increased autoclaving time ($P < 0.07$).

[3]Linear increase as a function of increased autoclaving time ($P < 0.001$).

[4]Linear decrease as a function of increased autoclaving time ($P < 0.001$; $r^2 = 0.94$).

[5]Quadratic decrease as a function of increased autoclaving time ($P < 0.001$).

Batal et al., 2000

QA: How do we measure?

TABLE 4. *Effect of autoclaving of soybean meal on chick performance (1 to 21 days) and on protein solubility, urease activity, and orange G-binding capacity, Experiment 3*

Treatment (min)	Weight gain (g/chick)	Feed:gain ratio	Protein solubility (%)	Urease activity (pH units of change)	Orange G bound (mg/g of meal)
0	423[ab]	2.26[b]	82.3	.00	76.4
5	452[a]	2.12[b]	72.6	.00	74.8
10	444[a]	2.24[b]	66.9	.00	71.7
20	405[b]	2.36[b]	60.5	.00	70.9
40	254[c]	2.60[a]	46.1	.00	70.0

[a–c]Means within each column with no common superscripts are significantly different (P<.05).

Araba and Dale, 1990

QA: How do we measure?

Table 1. Chemical composition of soybean meal after heat treatment

	Soybean meal			
Item[1]	Not heated	Autoclaved at 125°C for 15 min	Autoclaved at 125°C for 30 min	Oven dried at 125°C for 30 min
DM, %	88.1	87.6	86.2	88.8
Ash, %	5.91	5.87	5.85	5.97
AEE, %	1.44	1.21	1.35	1.31
CP, %	48.5	49.2	48.3	49.1
Furosine, %	0.015	0.023	0.026	0.016
Lys:CP ratio,[2] %	6.29	5.75	5.57	6.25

Gonzalez-Vega et al., 2011

Soybean meal

Item, %	Quality Target
PDI, %	15-30
KOH Solubility, %	78-84
Lys:CP	> 6%
Trypsin Inhibitor, TIU/g	3600-7000
Urease, Δ pH	0.00-0.1

Reactive Lysine

Table 5. Assessment of various methods for determining lysine (lys) concentration (with digestibility coefficients in parenthesis) in cold-pressed, expeller-extracted and solvent-extracted canola meals (from van Barneveld *et al.* 1999*a*)

ID, ileal digestible. Statistics show results of analysis of digestibility coefficients only. Values within a row followed by the same letter are not significantly different (at $P = 0.05$). s.e.m., standard error of the mean; ***, $P < 0.001$

Method	Canola meal lysine concentration (g/kg, air-dry)			Statistics	
	Cold-pressed	Expeller	Solvent	Diet	s.e.m.
Total lys	17.41	17.25	18.70	–	–
Reactive lys	13.00	10.88	11.38	–	–
Apparent ID lys	14.66 (0.84)a	13.20 (0.77)b	14.74 (0.79)b	***	0.012
True ID lys	16.02 (0.92)a	14.49 (0.84)b	16.08 (0.86)b	***	0.012
App. ID reactive lys	11.15 (0.86)a	8.53 (0.78)b	9.23 (0.81)c	***	0.007
True ID reactive lys	12.35 (0.95)a	9.79 (0.90)b	10.35 (0.91)b	***	0.007

Van Barneveld et al., 1999

Pearson coefficient correlation of SBM (n =22)

	CP	NDFom	Oligos.	PDI	KOH sol	TIA	Reactive Lys
CSID LYS	0.370	-0.354	0.302	0.385	0.619**	0.416	0.486*

Frikha et al., 2012

Individual SBM Analysis

Item, %	CSBM	42SBM	49SBM	52SBM
Dry matter	89.53	93.74	92.62	93.74
Crude protein	46.86	41.82	49.19	51.79
Crude fat	1.58	1.94	1.61	1.84
Crude fiber	3.85	5.91	3.60	3.41
ADF	6.68	7.75	6.83	6.93
NDF	12.03	14.24	7.83	8.24
Ash	6.89	6.37	6.93	6.82
Avail. Lys	2.80	2.43	2.89	3.08
Lys: CP	6.34	6.22	6.28	6.20
Avail. Lys: total Lys	94.3	93.5	93.5	96.0
Avail. Lys: CP	5.98	5.81	5.88	5.95
KOH solubility	86.27	74.30	85.72	76.95
Trypsin inhibitor, TIU/g	5,840	1,566	4,435	6,781
Total AA	45.30	40.56	47.85	50.64
Indispensable AA				
Arg	3.25	2.79	3.42	3.67
His	1.20	1.10	1.28	1.33
Ile	2.23	2.00	2.35	2.48
Leu	3.55	3.19	3.75	3.98
Lys	2.97	2.60	3.09	3.21
Met	0.65	0.59	0.70	0.73
Phe	2.36	2.10	2.49	2.64
Thr	1.78	1.65	1.90	1.97
Trp	0.64	0.64	0.72	0.74
Val	2.31	2.09	2.45	2.56

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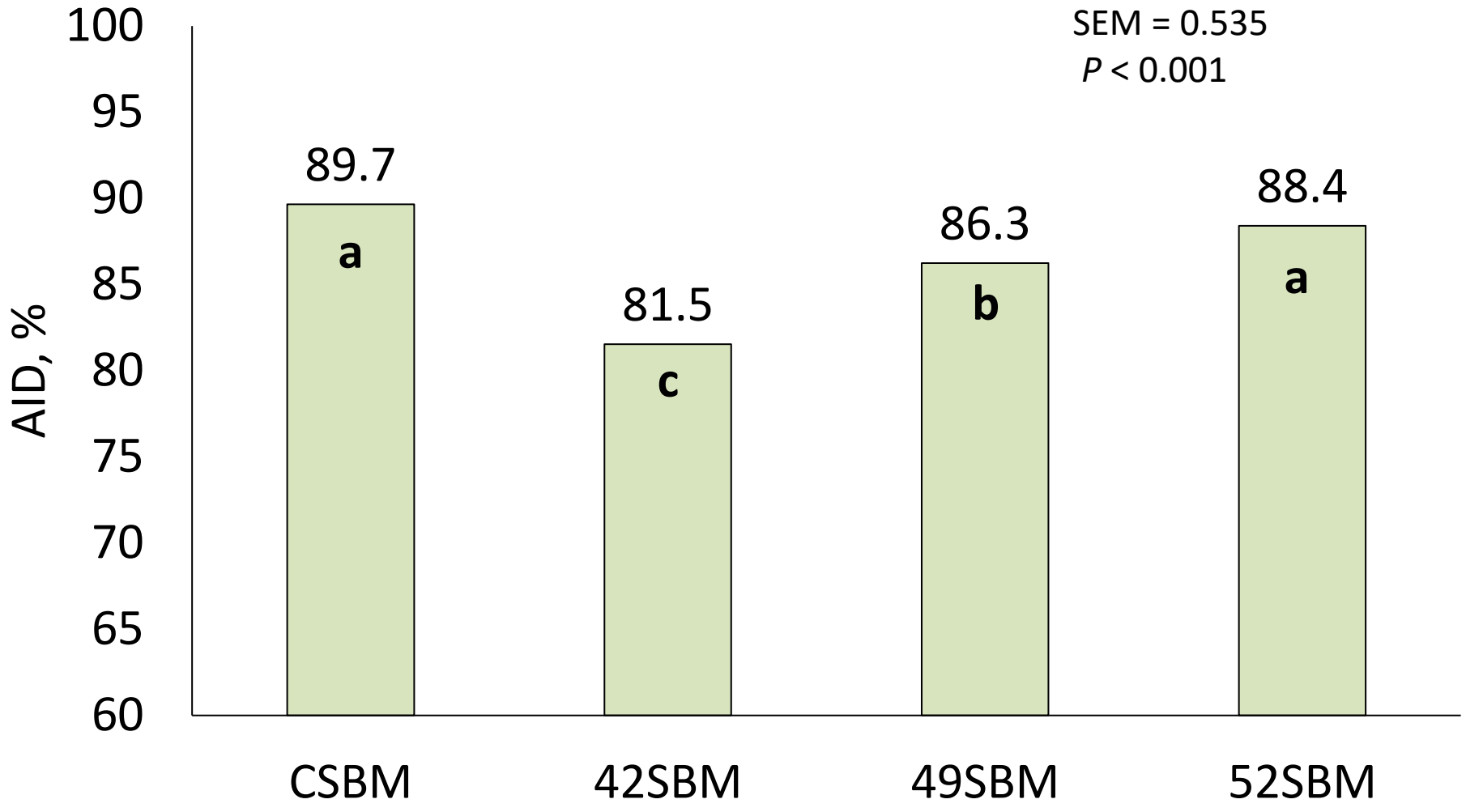
Broiler AID Lysine, %



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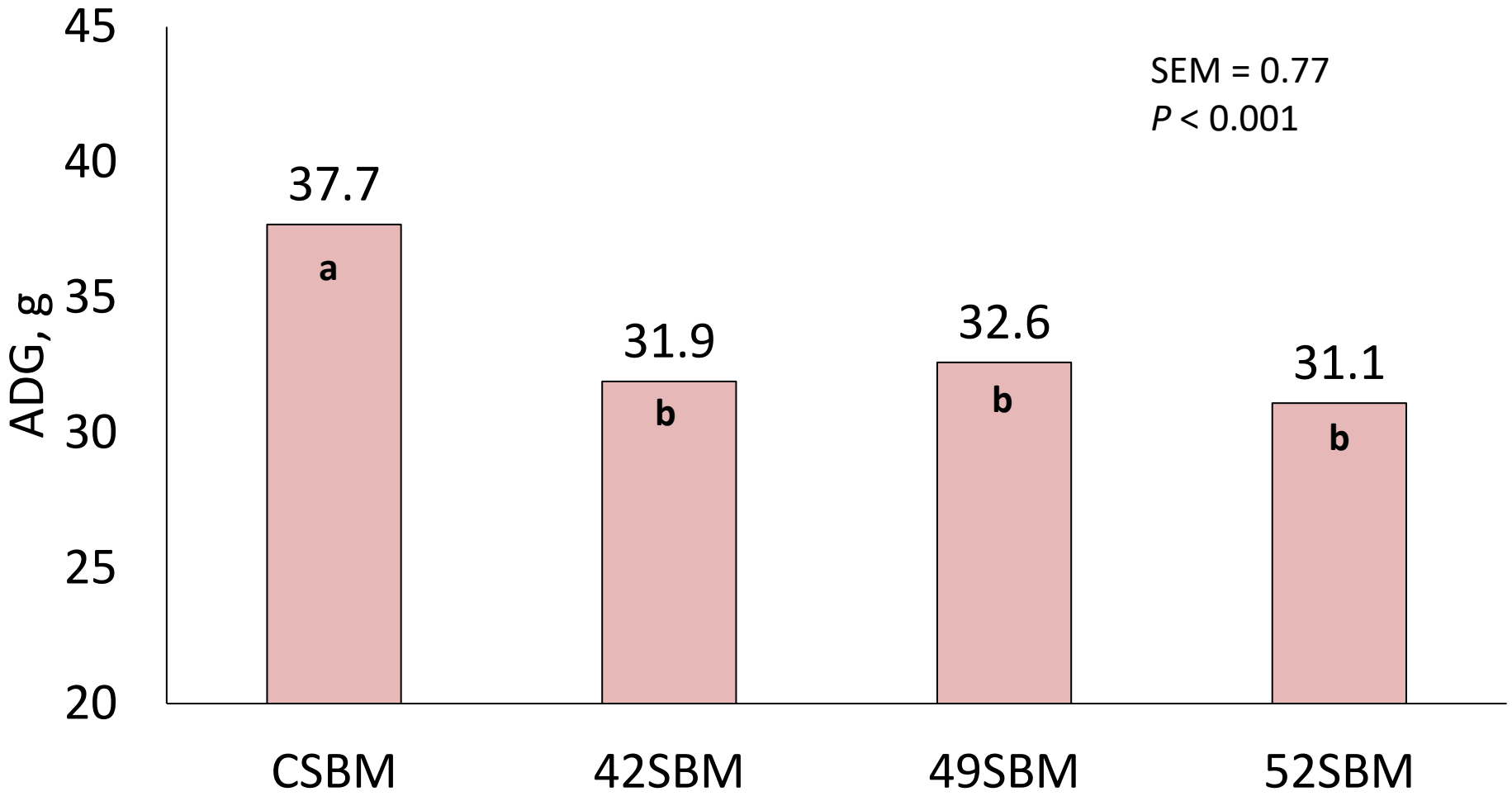
Broiler Average Daily Gain



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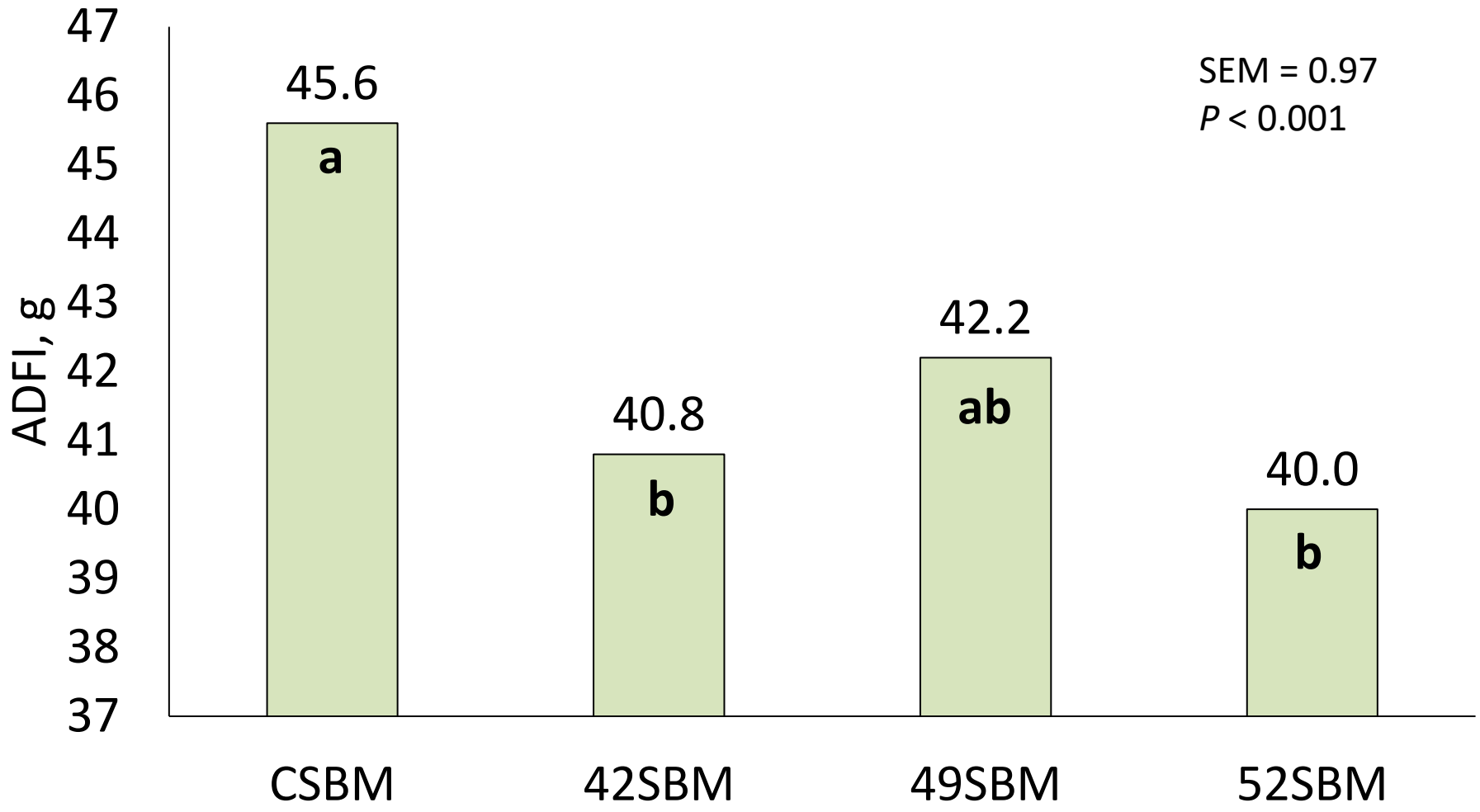
Broiler Average Daily Feed Intake



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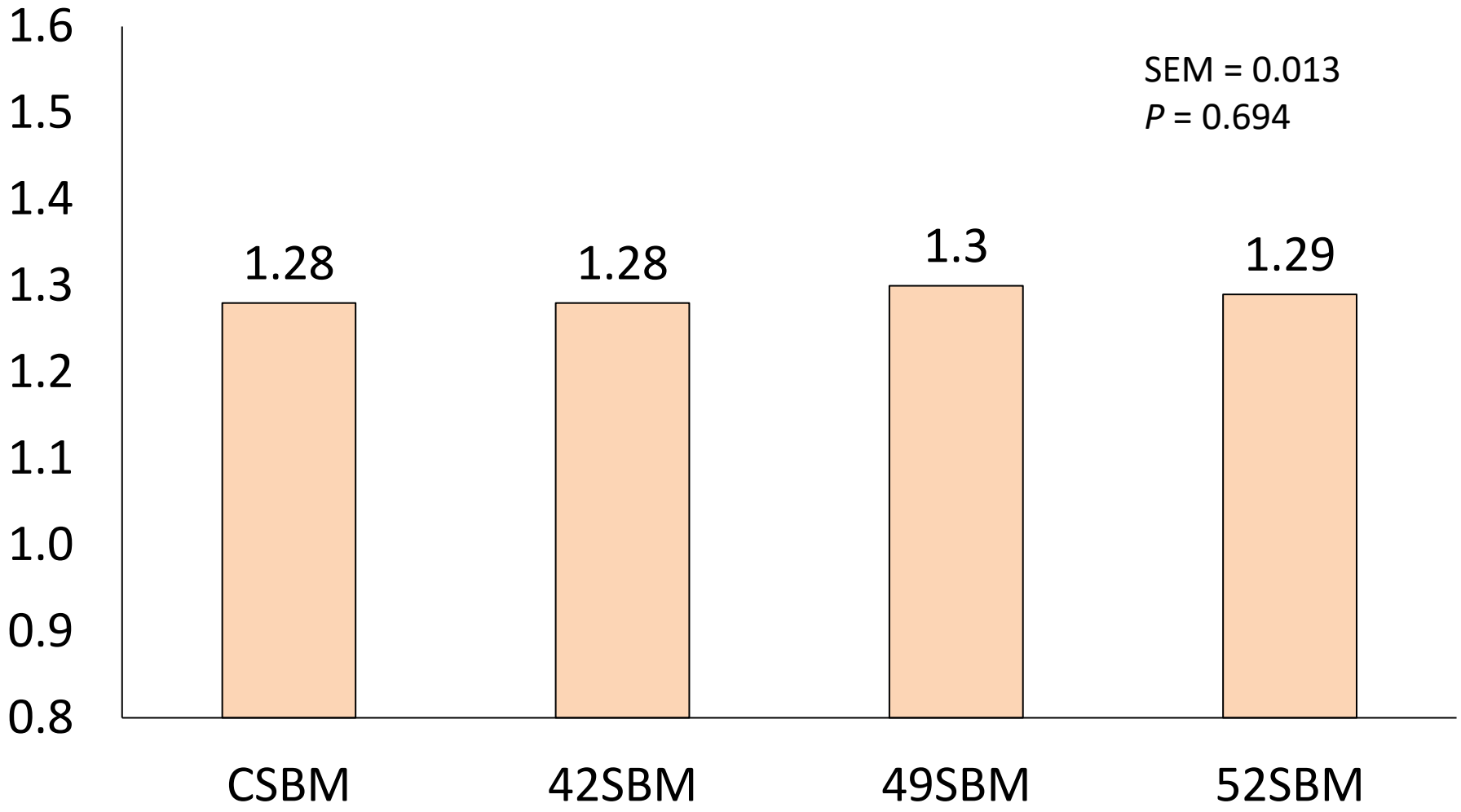
Broiler Feed Conversion Ratio



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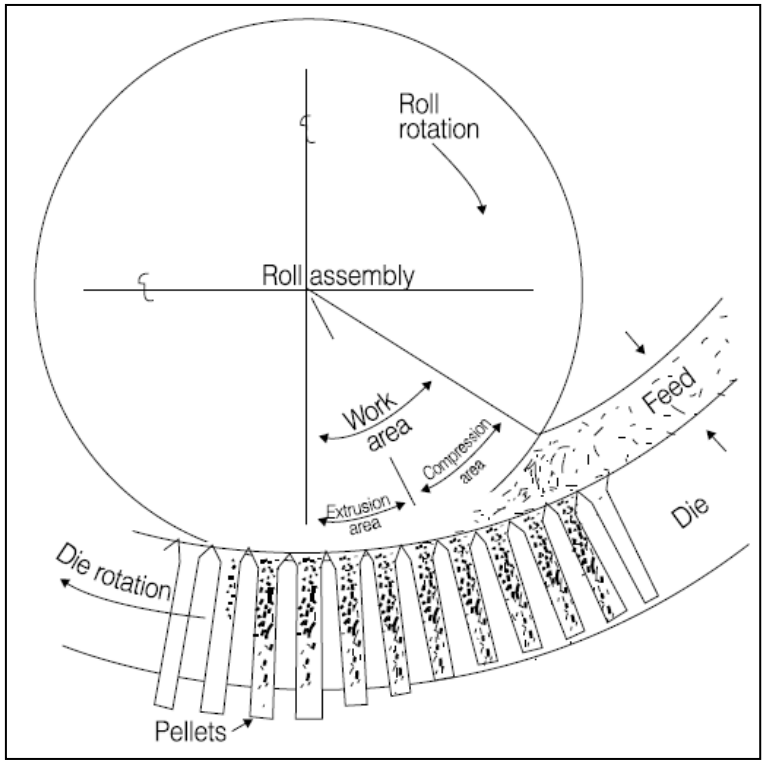
How do explain the differences?

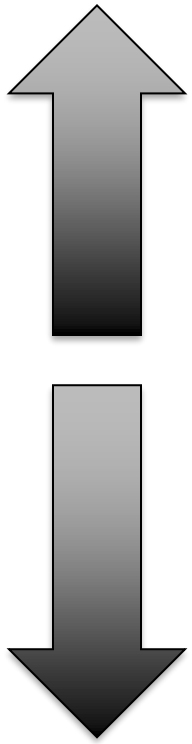
- Is it “protein quality?”
- What else could we measure to be indicative of “protein quality?”
- Is there something else we are missing?
  - Oligosaccharides
  - Antigens

Thermal Processing: Pelleting



Pelleting

Purpose

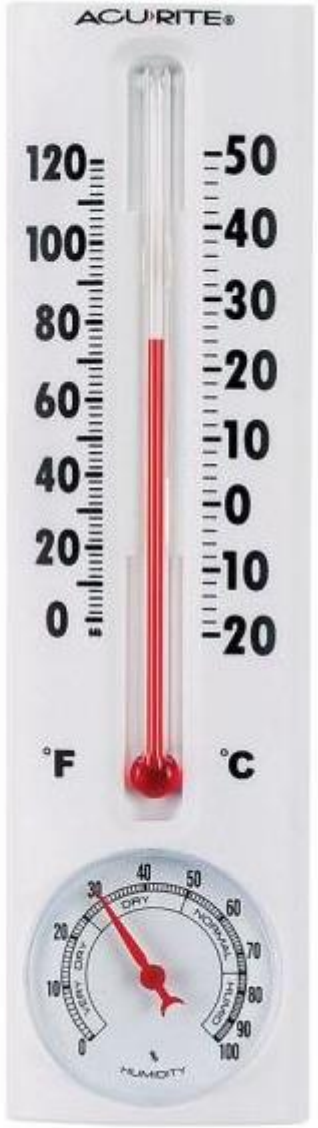


- Palatability
- Animal performance
- Feed handling

- Feed wastage
- Selective feeding
- Ingredient segregation
- Pathogenic organisms

- Conditioning Temperature
- Steam Pressure
- Retention time
- Moisture
- Die thickness

Behnke, 1994


ACU-RITE
120
100
80
60
40
20
0
-50
-40
-30
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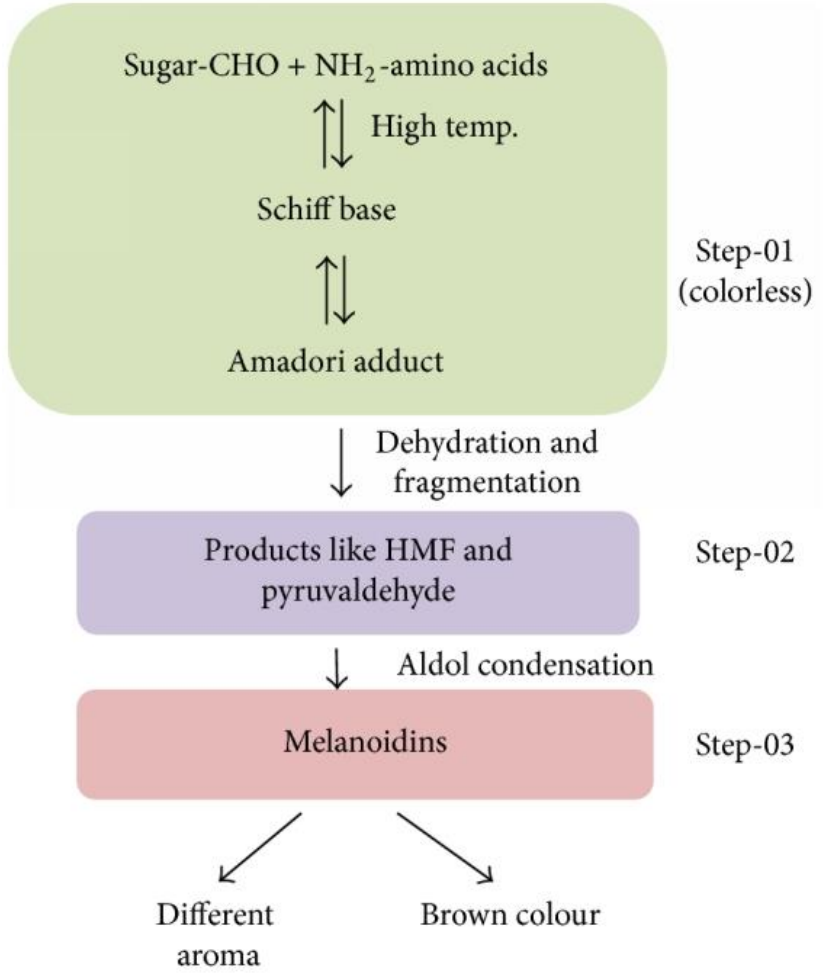
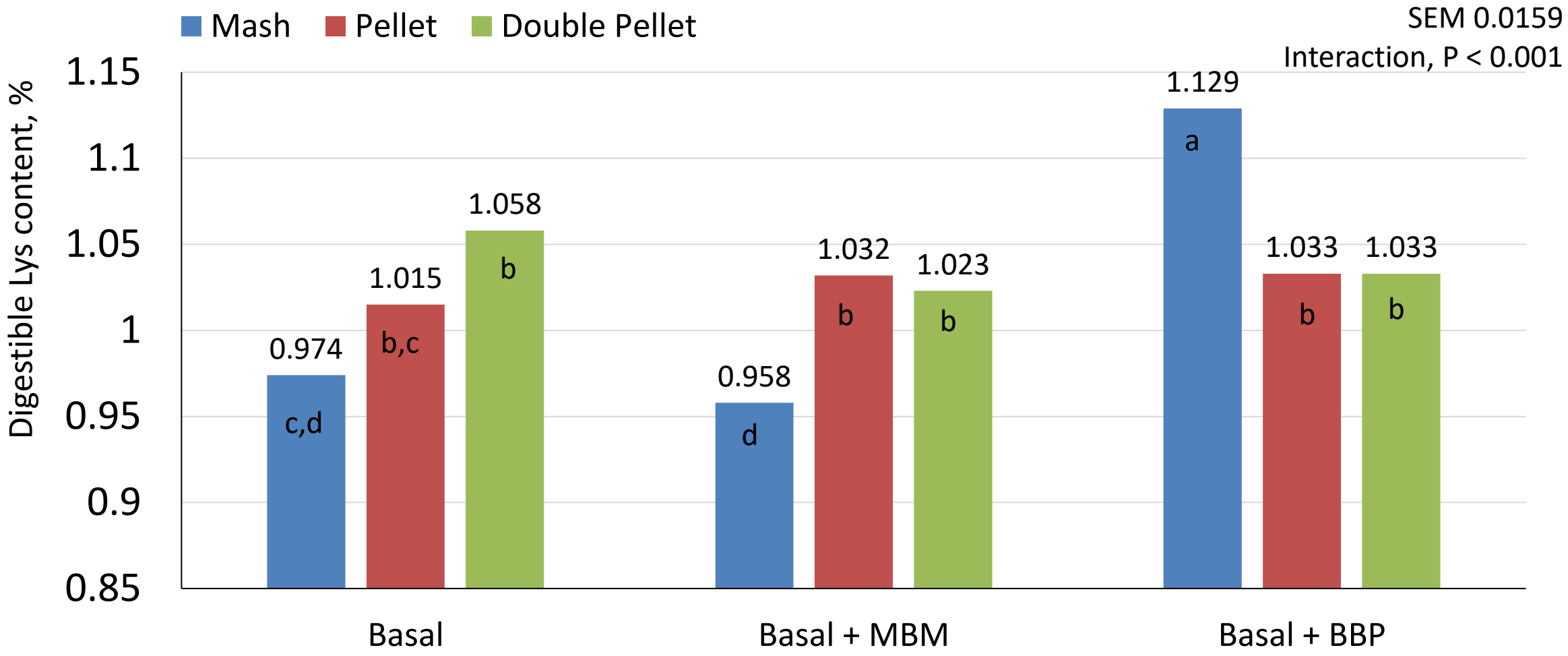

Sugar-CHO + NH_2-amino acids
High temp.
Schiff base
Amadori adduct
Step-01
(colorless)
Dehydration and
fragmentation
Products like HMF and
pyruvaldehyde
Step-02
Aldol condensation
Melanoidins
Step-03
Different
aroma
Brown colour

Broilers

- Treatments were 3 × 3 factorial
  - Diet formulation
    - Corn, soybean meal, and 5% DDGS
    - Basal + 5% meat and bone meal (MBM)
    - Basal + 7.5% bakery byproduct (BBP)
  - 3 diet forms
    - Mash
    - Pellet
    - Double pellet
  - Conditioning temperature 90°C, 10 second retention time
  - Diet = 4.7 x 44 mm

Bergeron et al. 2018

Digestible Lys Concentration, %



Bergeron et al. 2018

Table 5. Descriptive Feed Analysis Data and Mean Data for the Digestible Lysine Concentration for Comparison.

Treatment		Total lysine[4]	In vitro available lysine[4]	Digestible lysine concentration[5]	Trypsin inhibitor complex activity (TIU/g)[6]
Basal	Unprocessed mash[1]	1.19	1.16	0.97	2750
	Single pelleted[2]	1.24	1.16	1.01	2360
	Double pelleted[3]	1.19	1.16	1.06	2250
Basal + MBM	Unprocessed mash[1]	1.26	1.21	0.96	2260
	Single pelleted[2]	1.25	1.20	1.03	2080
	Double pelleted[3]	1.26	1.22	1.02	2110
Basal + BBP	Unprocessed mash[1]	1.25	1.22	1.13	2290
	Single pelleted[2]	1.21	1.18	1.03	2170
	Double pelleted[3]	1.24	1.21	1.03	2110

[1]Feed that was not thermally processed.

[2]Feed that was conditioned at 90°C and extruded through a 4.7 × 44 mm pellet die.

[3]Feed that was conditioned at 90°C and extruded through a 4.7 × 44 mm pellet die, ground then conditioned again at 82°C and extruded again through a 4.7 × 44 mm pellet die.

[4]Determination of total protein lysine and in vitro available lysine: AOAC 975.44.

[5]Digestible Lysine Concentration, Adedokun et al. [35].

[6]Trypsin Inhibitor Complex Activity AOCS Official Method Ba 12–75.

Bergeron et al. 2018

Key Conclusions

- Pelleting and double pelleting improved FCR compared to unprocessed mash
- DAAC Lys increased with pelleting in the basal and MBM diets but decreased in the Basal + BBP diets.

Swine

- Treatments were arranged in a 2 × 2 × 2 factorial design with
  - 2 crystalline amino acid inclusions (low vs high)
  - 2 reducing sugar levels (RS; low vs high)
  - 2 diet forms (mash vs pellet)

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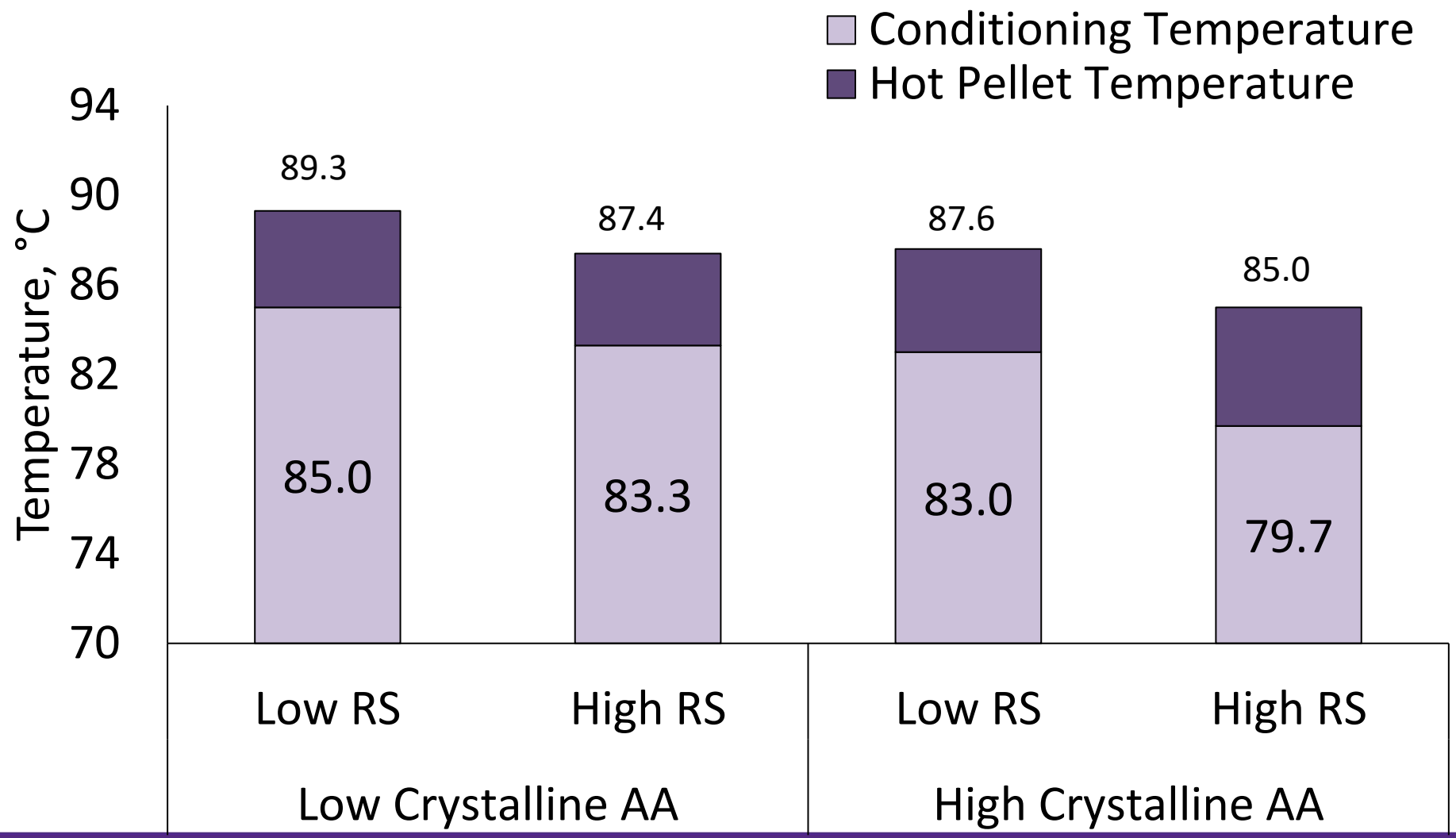
Table 1. Diet composition, Exp. 1 (as-fed basis)[1,2]

Crystalline AA Reducing sugars	Low Low	Low High	High Low	High High
Ingredient, %				
Corn	75.00	44.11	79.68	52.98
Soybean meal	21.00	15.70	16.19	6.85
Dried distiller's grain with solubles	---	20.00	---	20.00
Bakery meal[3]	---	15.00	---	15.00
Soybean oil	1.23	2.70	0.90	2.10
Calcium carbonate	0.70	0.83	0.70	0.85
Monocalcium P, 21%	1.00	0.60	1.10	0.70
Sodium chloride	0.50	0.50	0.50	0.50
L-Lysine-HCl	0.18	0.23	0.33	0.50
DL-Methionine	----	---	0.04	---
L-Threonine	0.09	0.04	0.16	0.16
L-Tryptophan	0.01	0.01	0.04	0.06
L-Valine	---	---	0.07	---
L-Isoleucine	---	---	0.01	0.01
Trace mineral premix[4]	0.30	0.30	0.30	0.3
TOTAL	100	100	100	100

Pelleting Temperature



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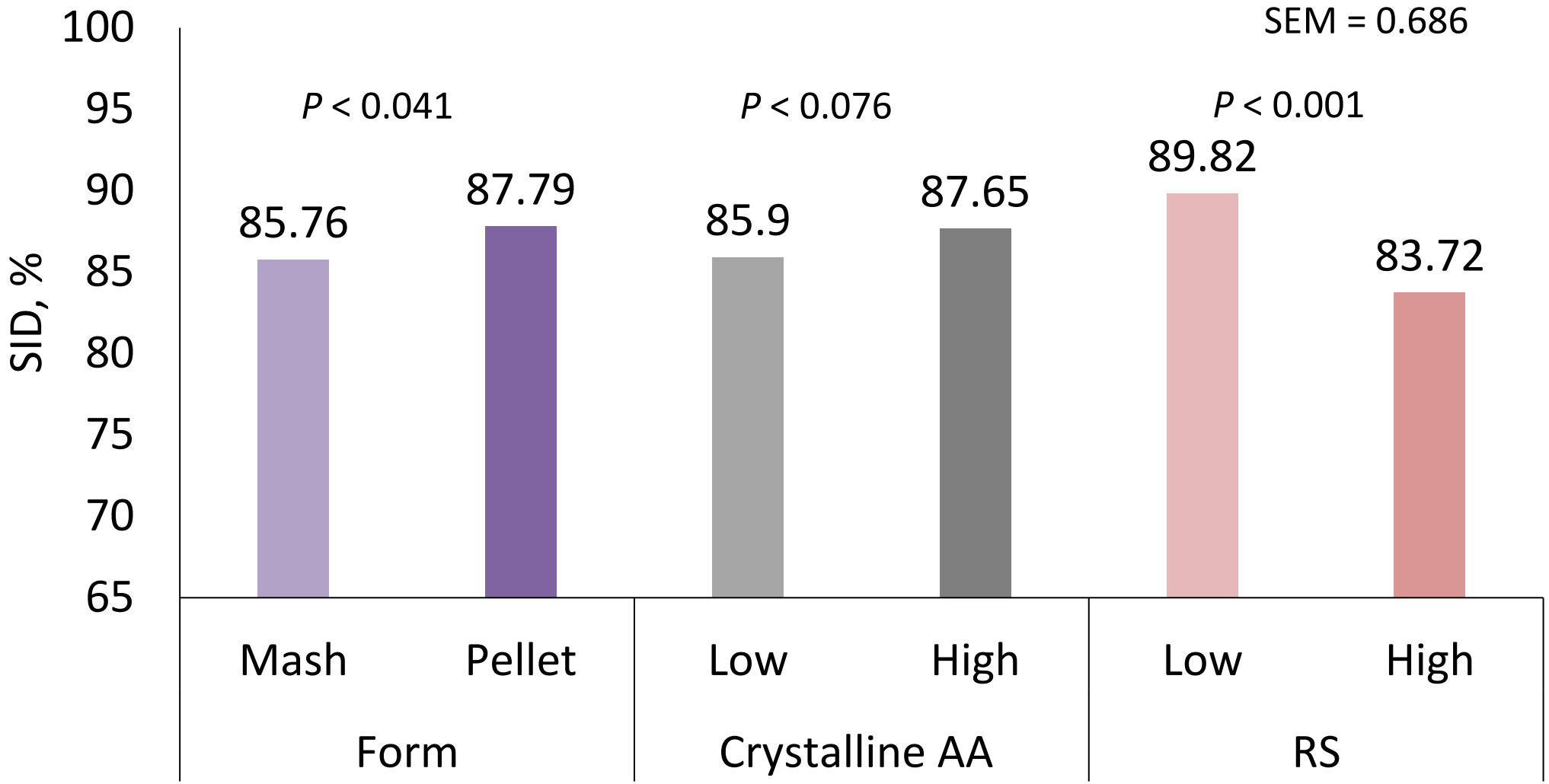
SID Lysine, %



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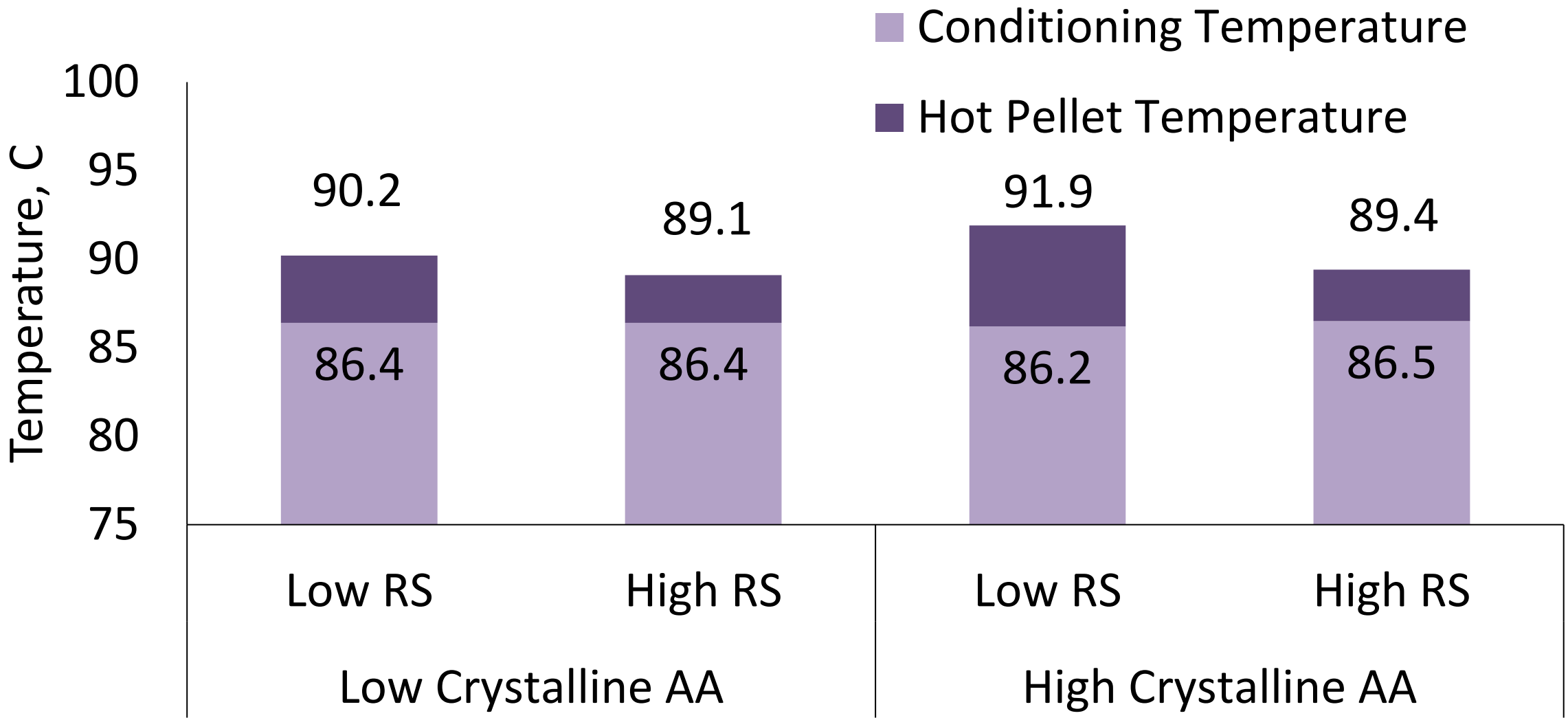

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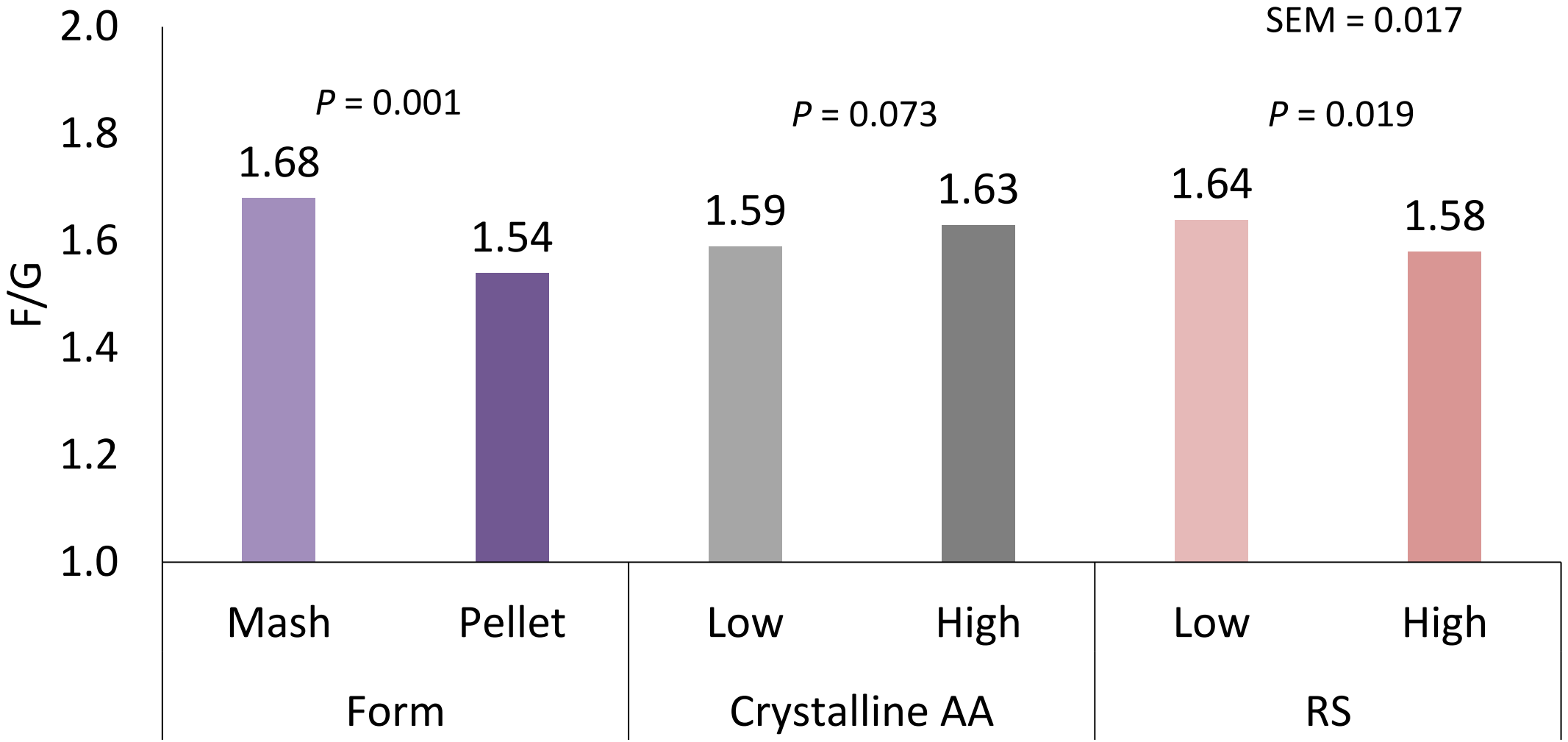
Feed Efficiency



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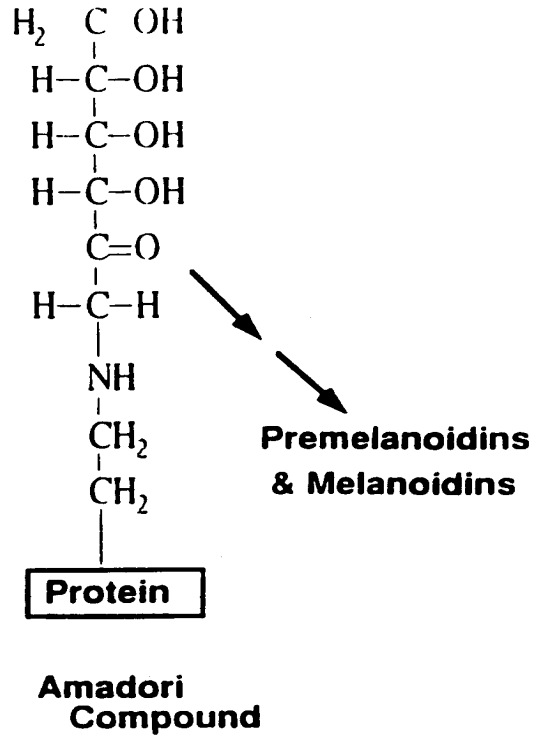
Conclusions

- There was no evidence of interactions between diet types, indicating that increasing amounts of crystalline AA and RS did not increase the Maillard reaction to a point of reducing AA digestibility when pelleting diets using the reported conditions.
  - Pelleting diets resulted in improved AA digestibility
  - Crystalline AA concentration did not influence AA digestibility of indispensable AA except for the SID of tryptophan which was increased in diets with increased concentrations of crystalline AA.
  - Pigs fed diets with high RS, formulated with 20% DDGS and 15% bakery, resulted in decreased AA digestibility compared to the corn soybean meal-based diet.

How do we measure?



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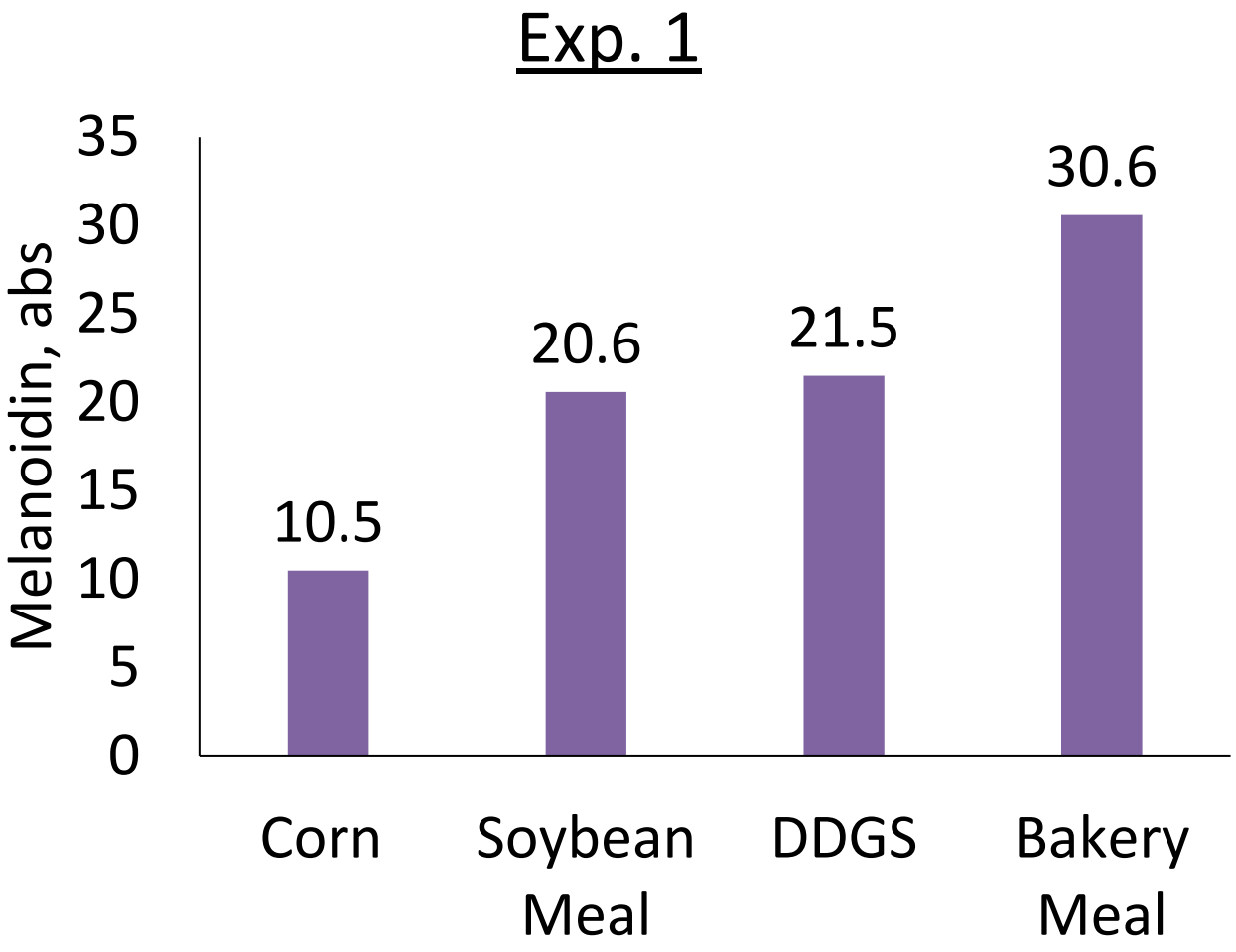
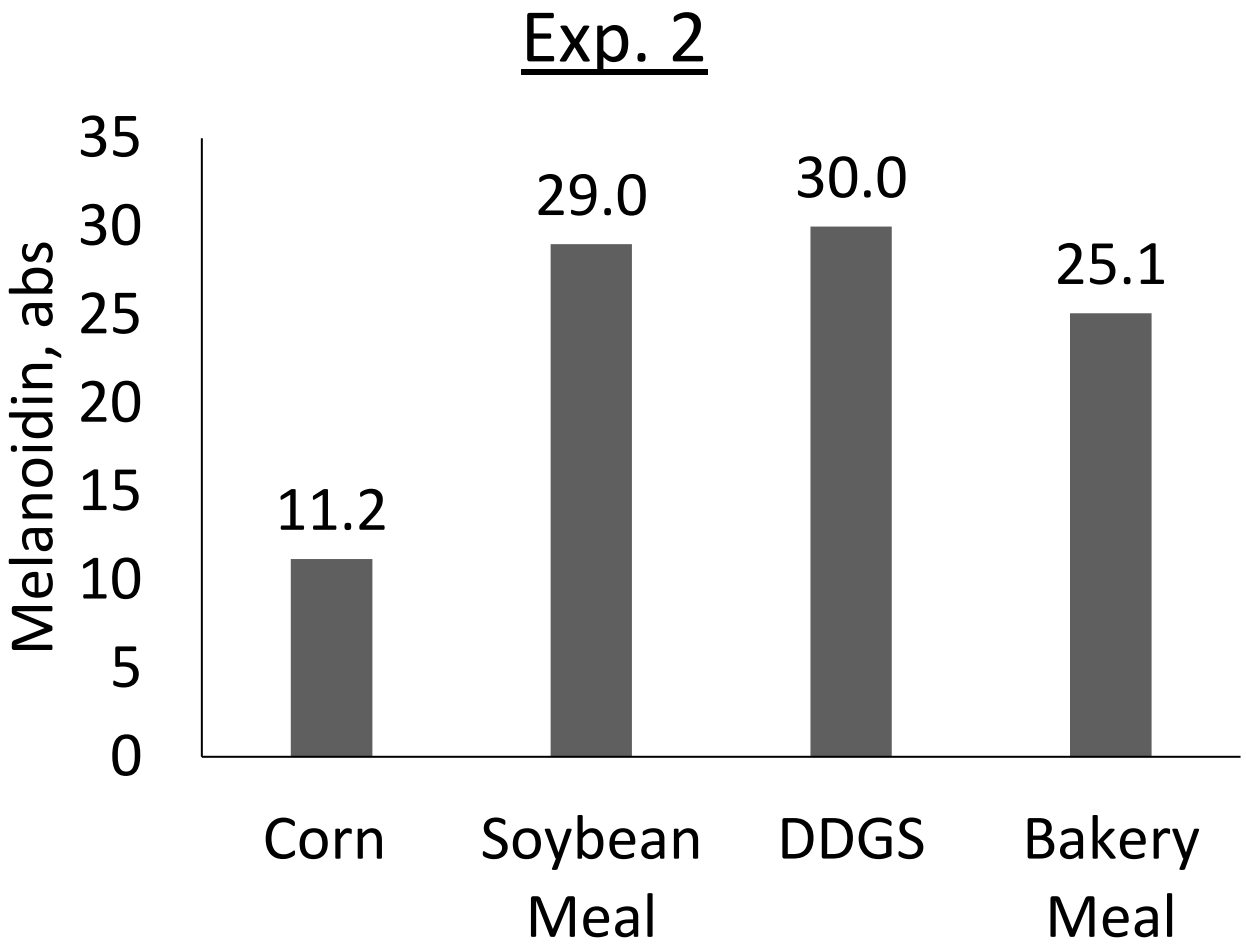
[a–c]Means within each column with no common superscripts are significantly different (P<.05).

Ingredient Melanoidin





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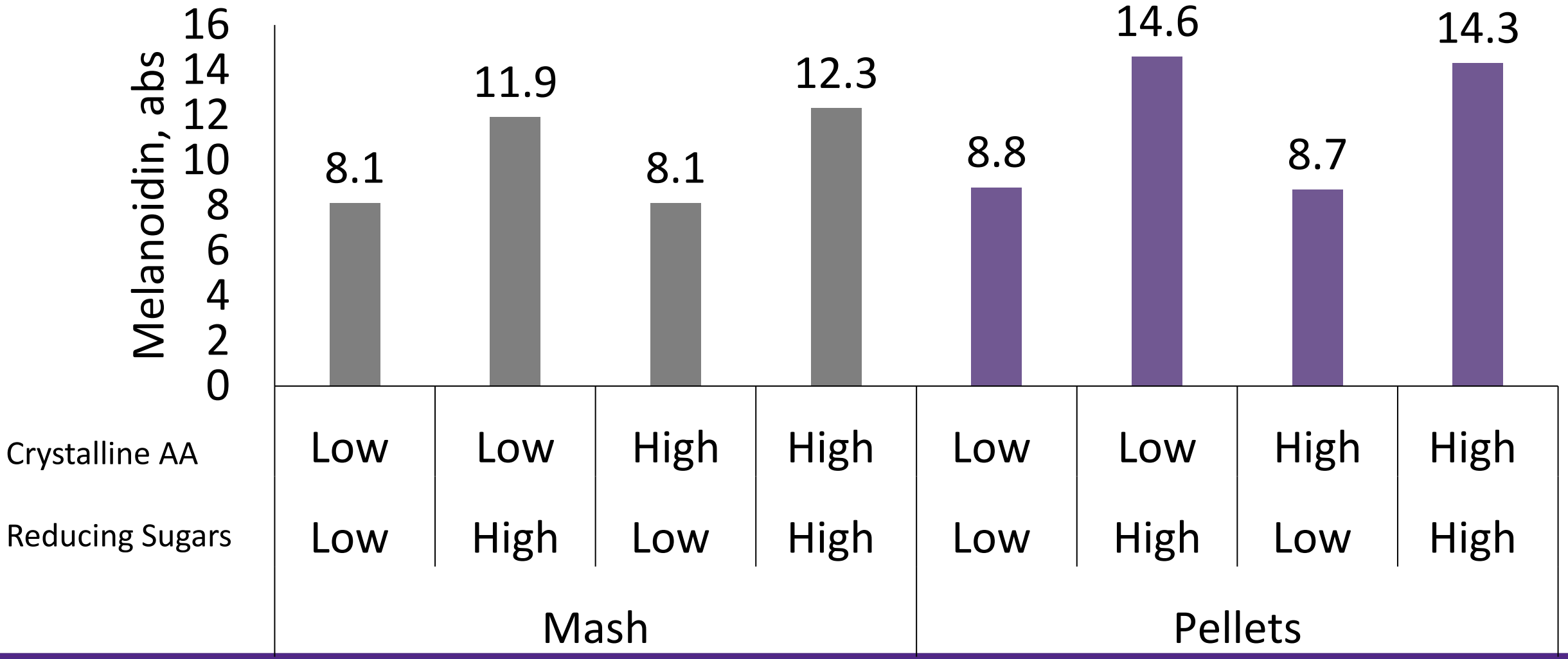
Diet Melanoidin



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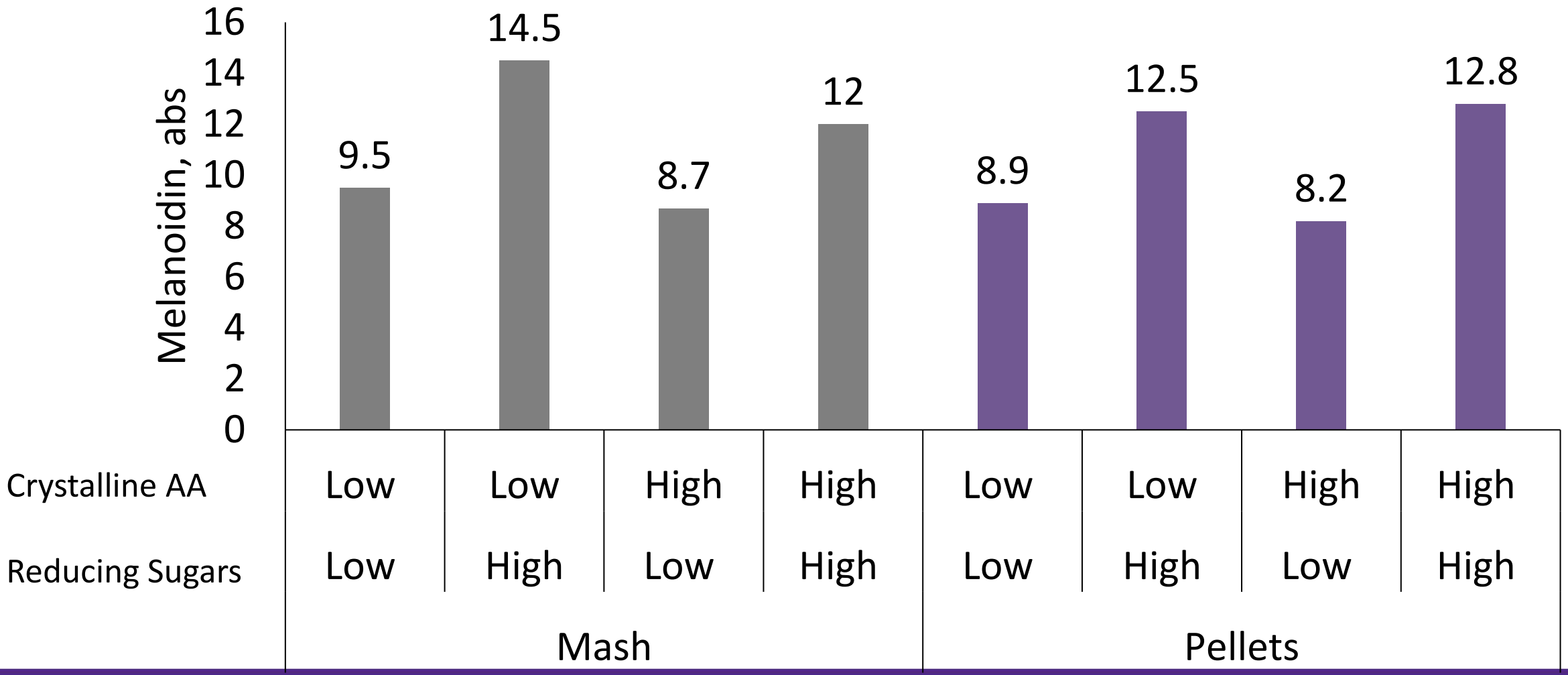
Diet Melanoidin



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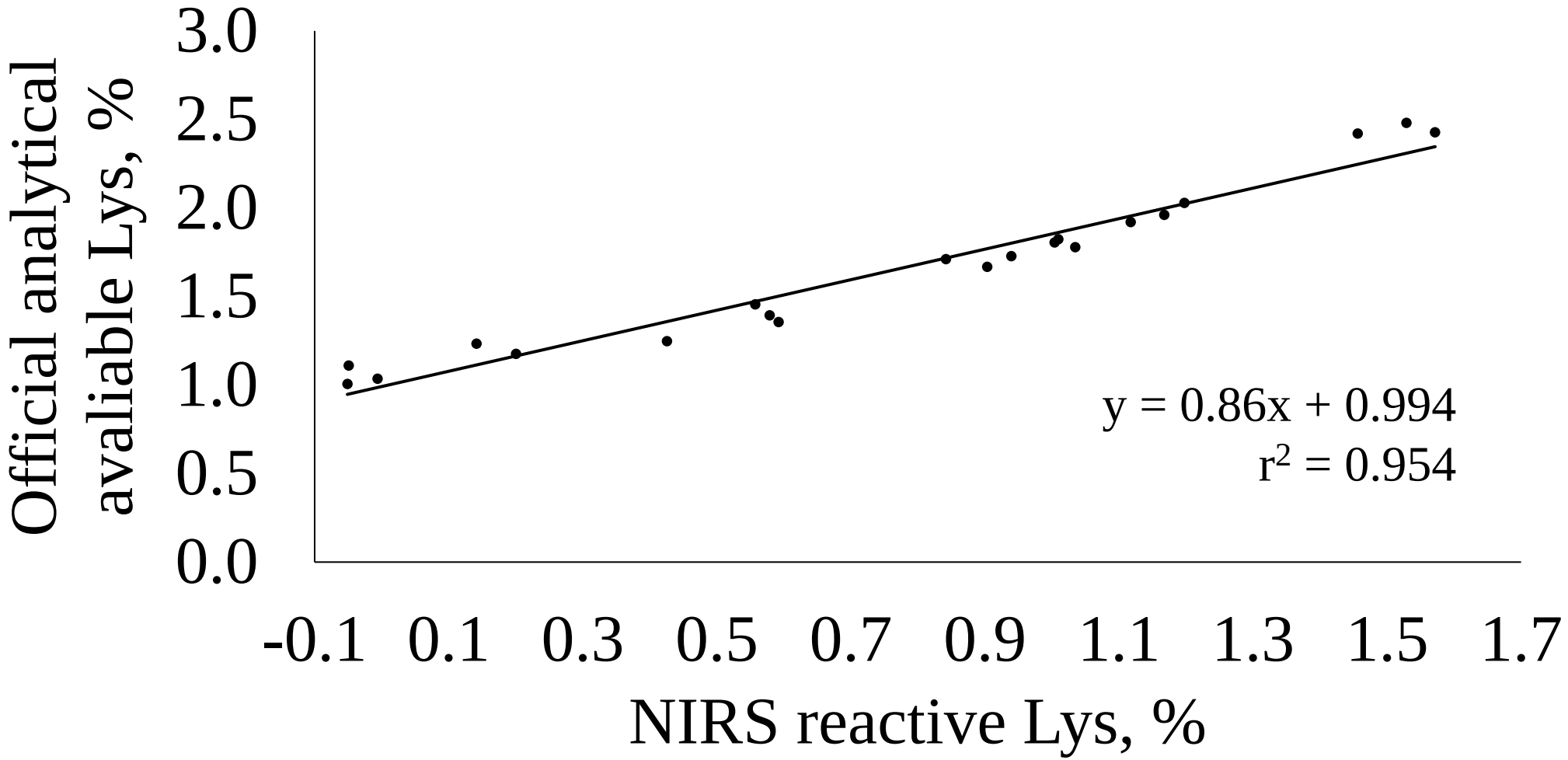
NIR vs available Lys



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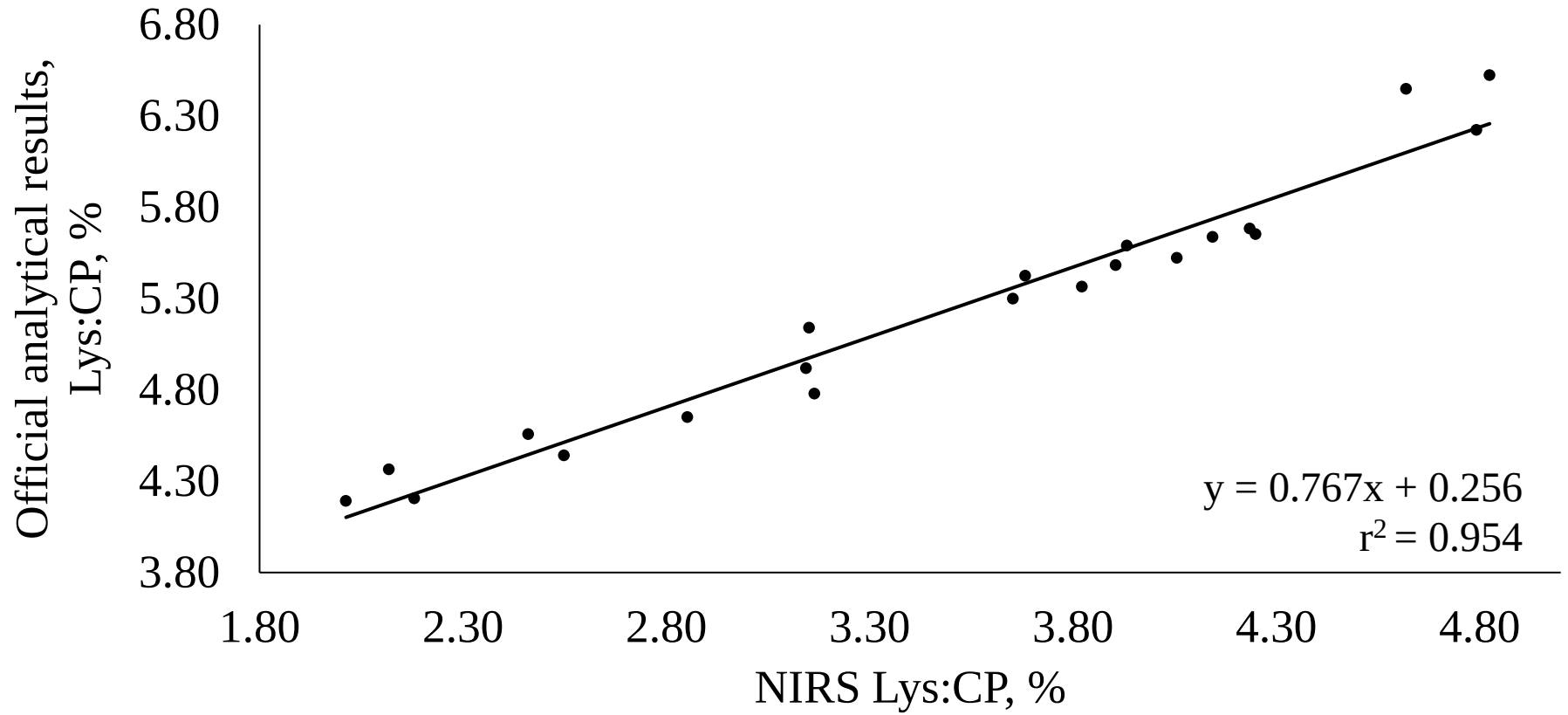
Lys:CP NIR vs Analytical



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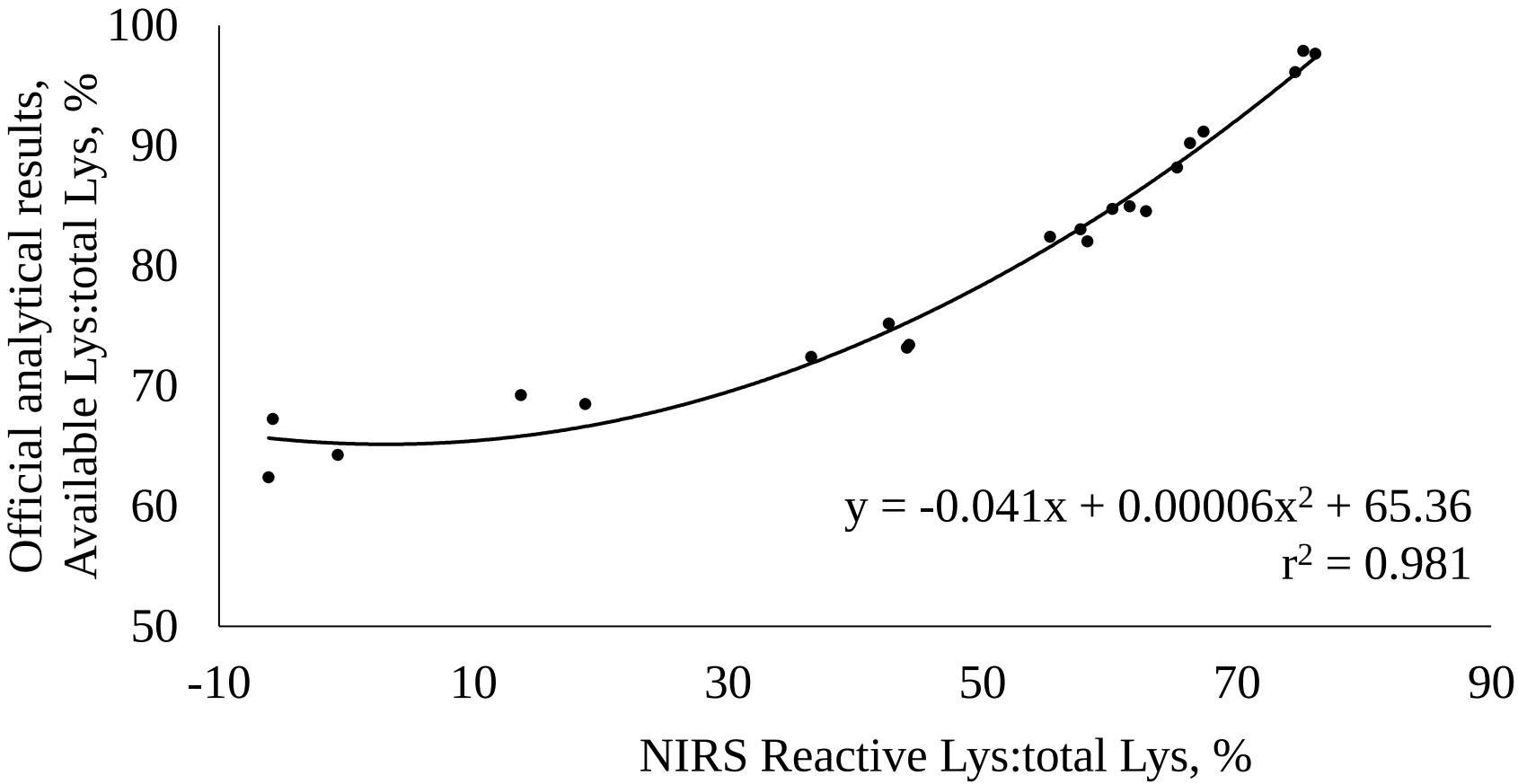
Available Lys:total Lys



Dunmire et al. 2019

Questions?

https://www.grains.k-state.edu/research/AnimalFeedandPetFood/feed_science_research_extension/index.html