Reduced Oil DDGS – It's Not the Fat, It's the Fiber

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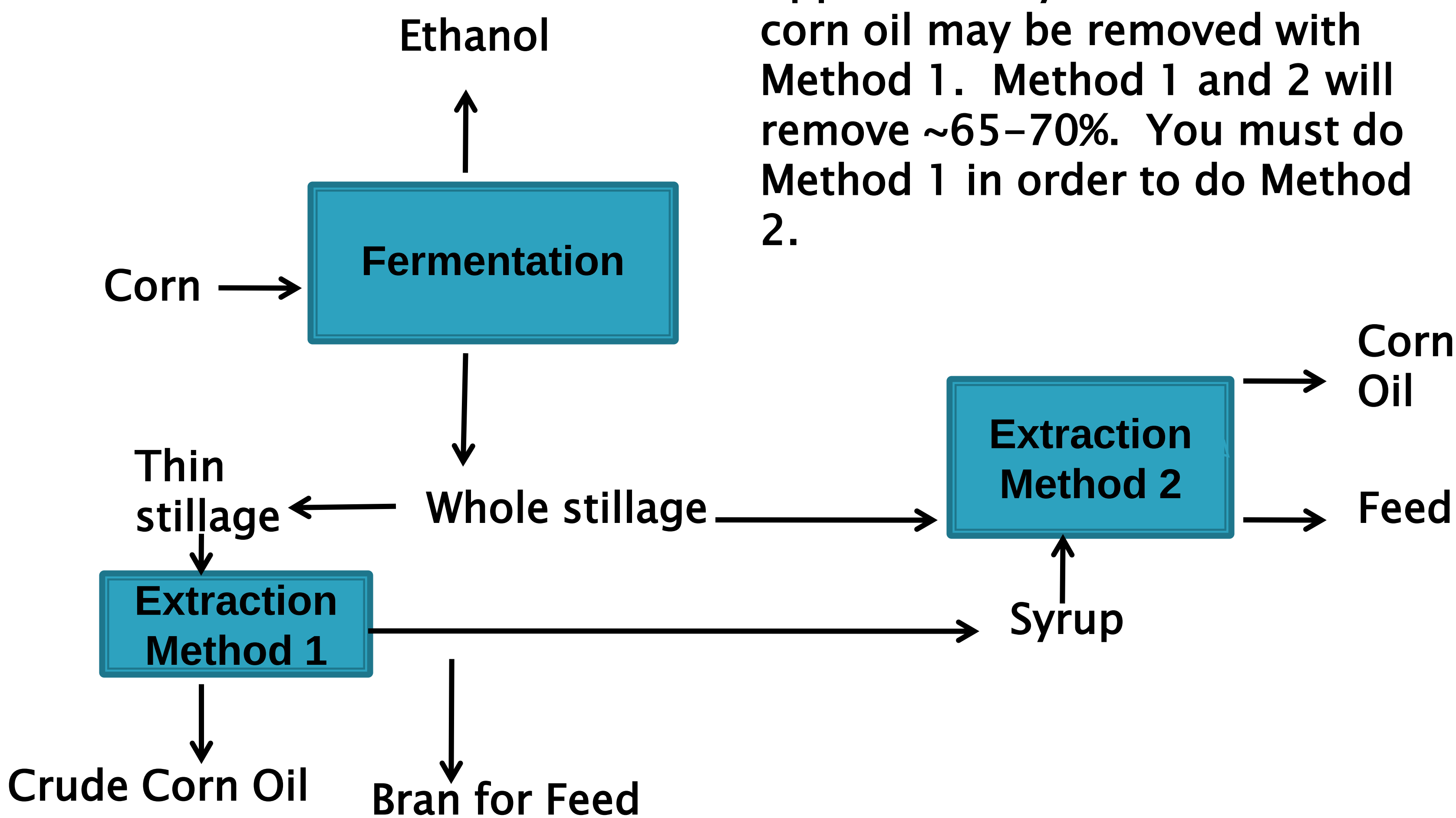
Why DDGS oil extraction?

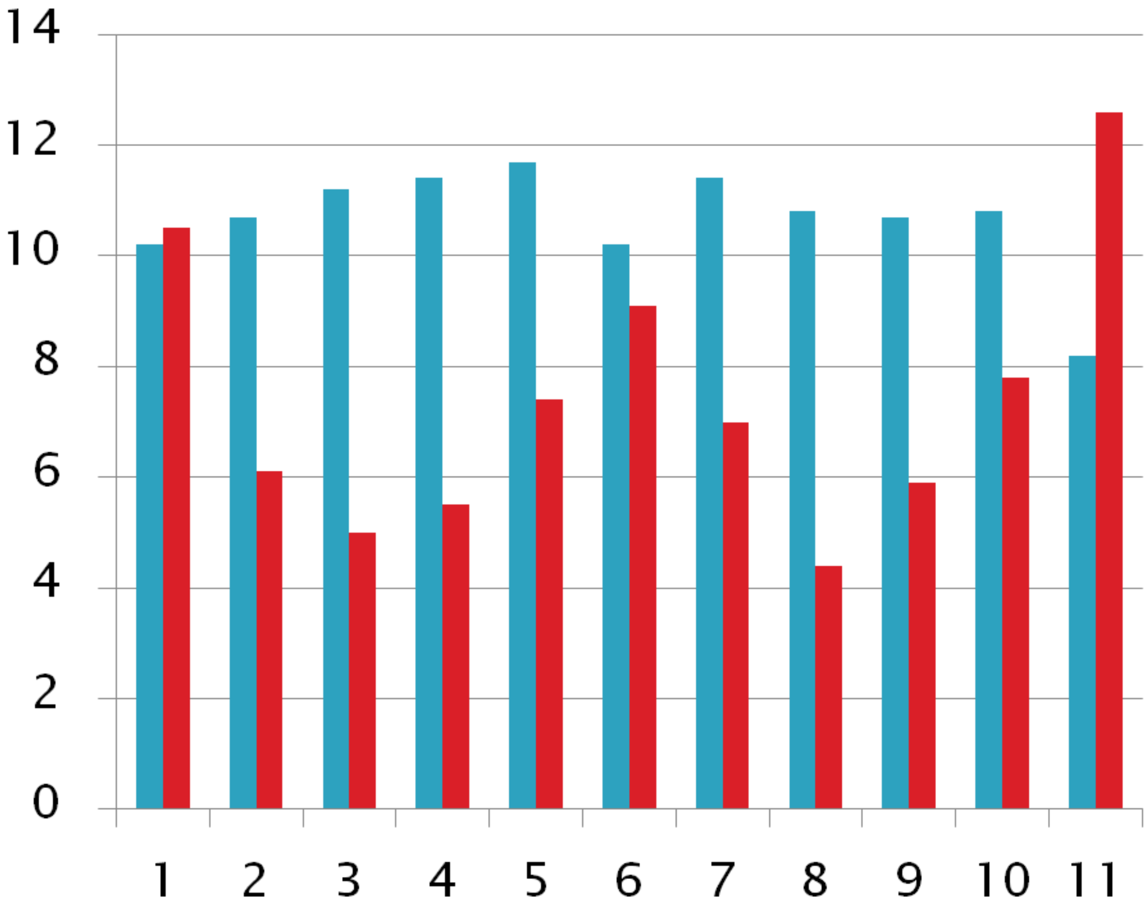
- Oil extraction in the ethanol industry:
  - 50% of plants are currently extracting oil
  - 75% will be extracting oil by the end or 2012
- Economic returns from oil extraction are high
  - Price of crude corn oil is $0.45/lb
- Capital costs are low relative to returns
  - 100 million gallon plant
  - $3 million total investment
    - 2 centifuges, building, electrical, tubing, etc.
  - Extract 20 million lbs oil/year ($0.45/lb)
  - Revenue = $9 million/yr.
    - Investment recovery is 3 to 4 months in most plants
- Crude fat content ranges from 5 to 13%
  - Most reduced oil DDGS is 8 to 9% crude fat

“Back-end” oil extraction process

Approximately 30% of available corn oil may be removed with Method 1. Method 1 and 2 will remove ~65-70%. You must do Method 1 in order to do Method 2.

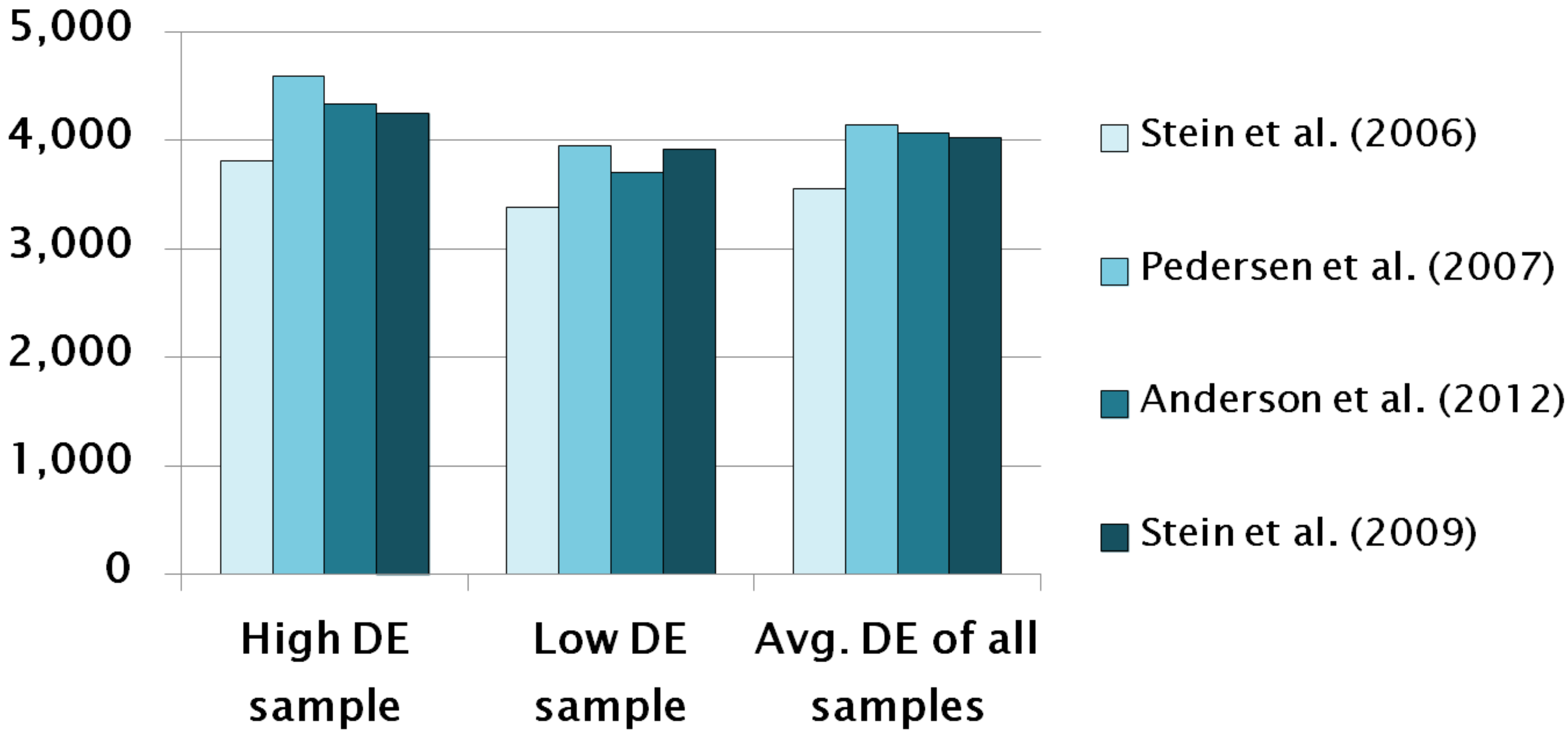


Crude fat content of DDGS has always varied among and within sources

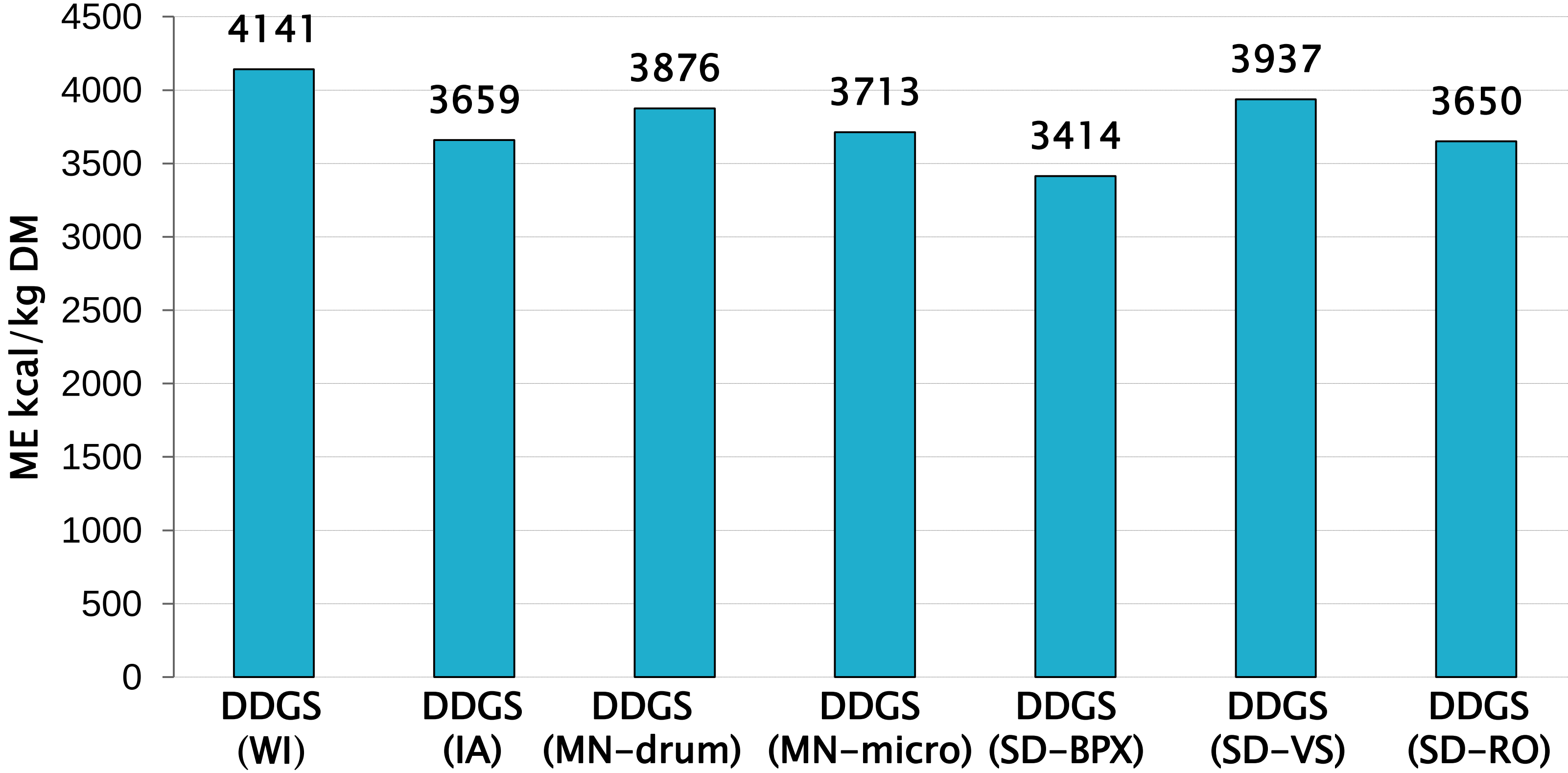


Spiehs et al. (2002)

DE content (kcal/kg DM) has also varied among "typical" DDGS sources (summary of 4 studies)



ME content (DM basis) of corn DDGS from 7 different process technologies

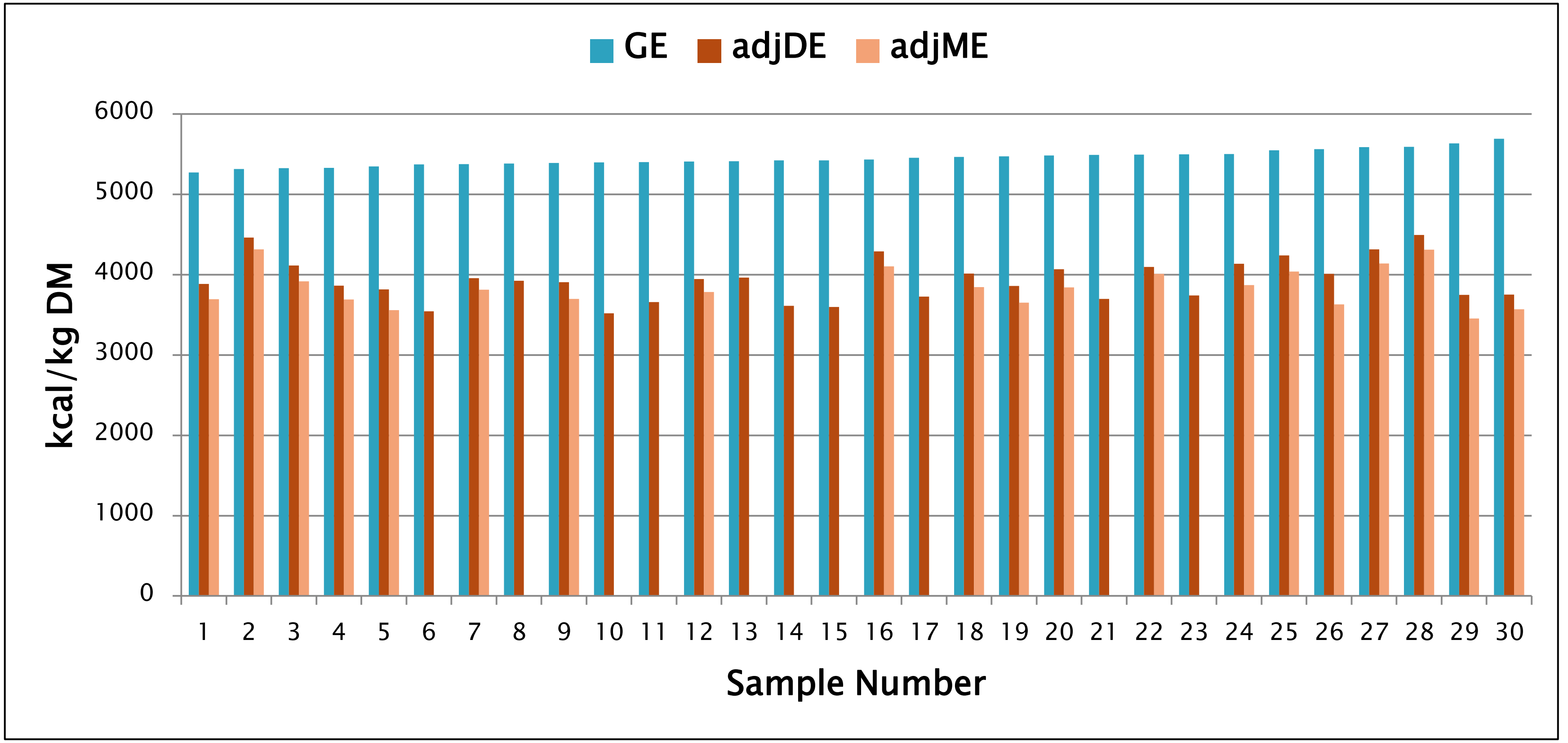


Anderson et al. (2012)

CV's of DE and ME values of DDGS sources vary among experiments

Source: Anderson et al. (2012), Pedersen et al. (2007), Stein et al. (2006), Stein et al. (2009)

GE does not vary as much as DE and ME among DDGS sources



Note: DE and ME of DDGS within experiment were 'adjusted' relative to the DE and ME content of the corn basal diet

Source: Stein et al. (2006) [10], Pedersen et al. (2007) [10], Stein et al. (2009) [4], Anderson et al. (2012) [6]

ATTD of energy in DDGS is much less than corn[1]

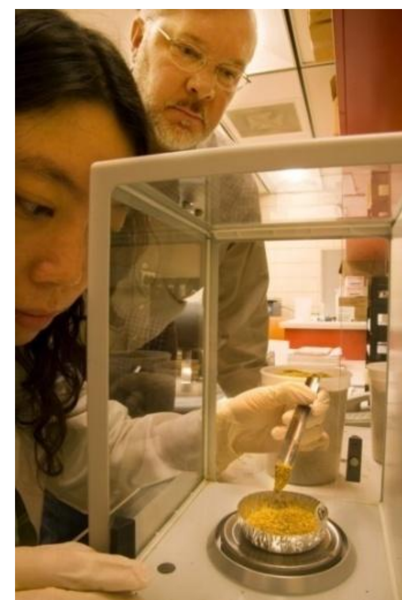
	Corn	DDGS Average	DDGS SD	DDGS Lowest Value	DDGS Highest Value
GE, kcal/kg DM	4,496	5,434	108	5,272	5,592
ATTD[2] of energy, %	**90.4**	**76.8**	2.73	73.9	82.8
DE, kcal/kg DM	4,088	4,140	205	3,947	4,593
ME, kcal/kg DM	3,989	3,897	210	3,674	4,336

[1] Data from 10 DDGS sources (Pedersen et al., 2007) (adapted from Stein and Shurson, 2009)

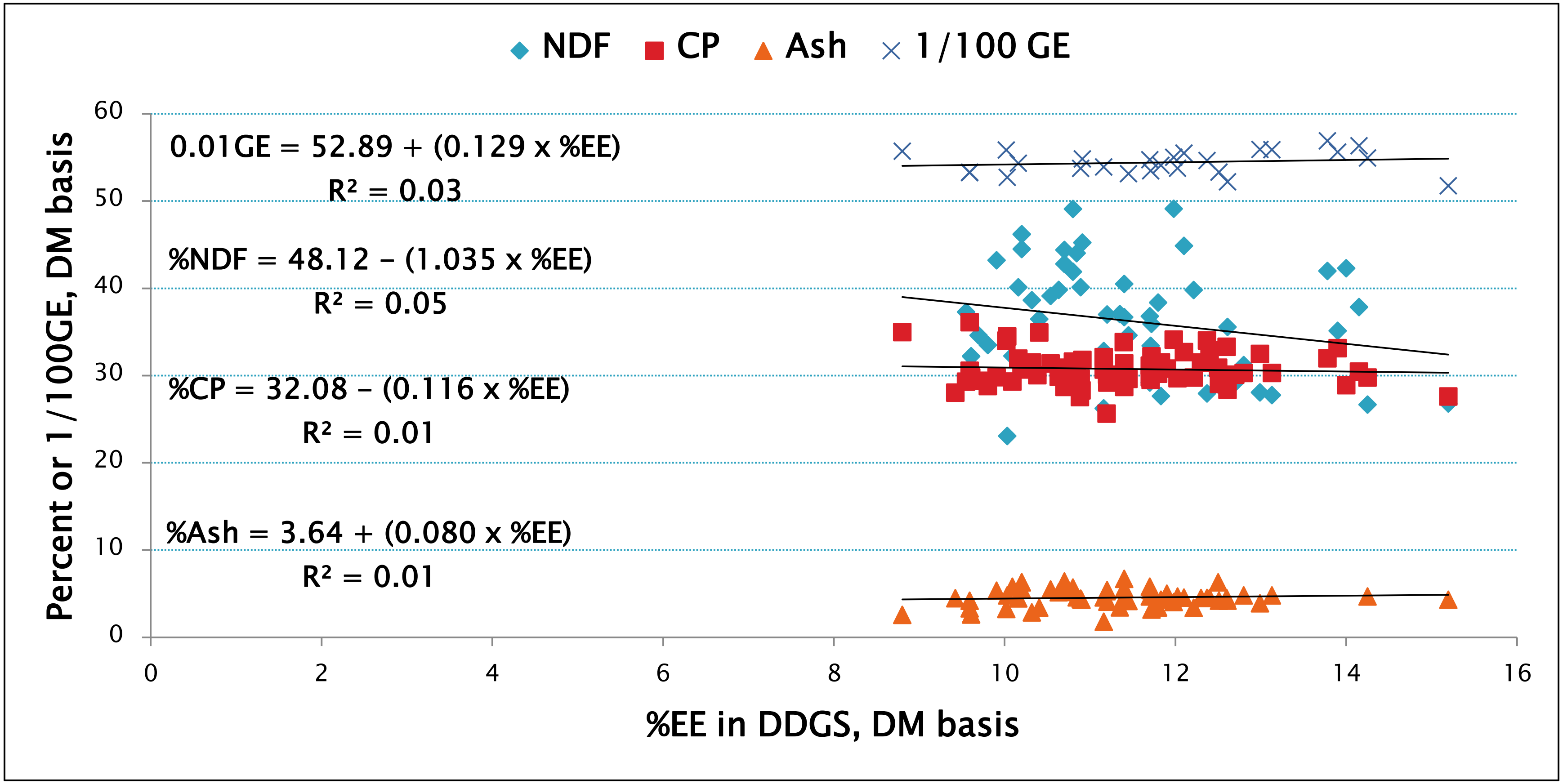
[2] ATTD = apparent total tract digestibility

Why does DE and ME content of DDGS vary so much?

- Different processes used in DDGS production
- Variable fat levels among sources
- Variable carbohydrate composition and digestibility
- Particle size varies from 200 to >1200 microns
- Experimental and analytical methods used



What is the relationship between GE, NDF, CP, and ash with EE in DDGS?



Summary of published DDGS composition data from the scientific literature

What Carbohydrates Should We Measure and What Do They Represent?

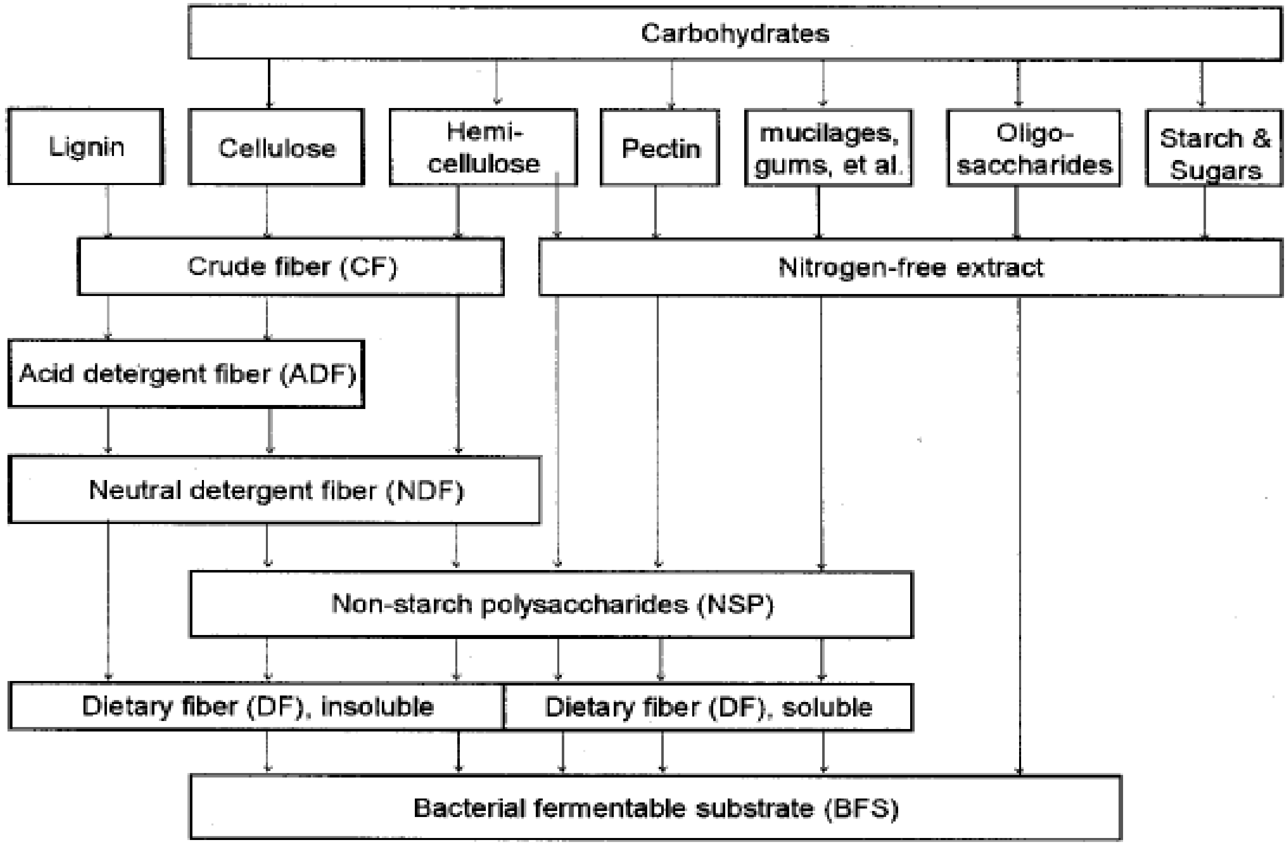


Figure 1.2. Classification of the carbohydrates (adapted from Bakker et al. (1998))

Concentration of carbohydrates and ATTD of dietary fiber in corn DDGS

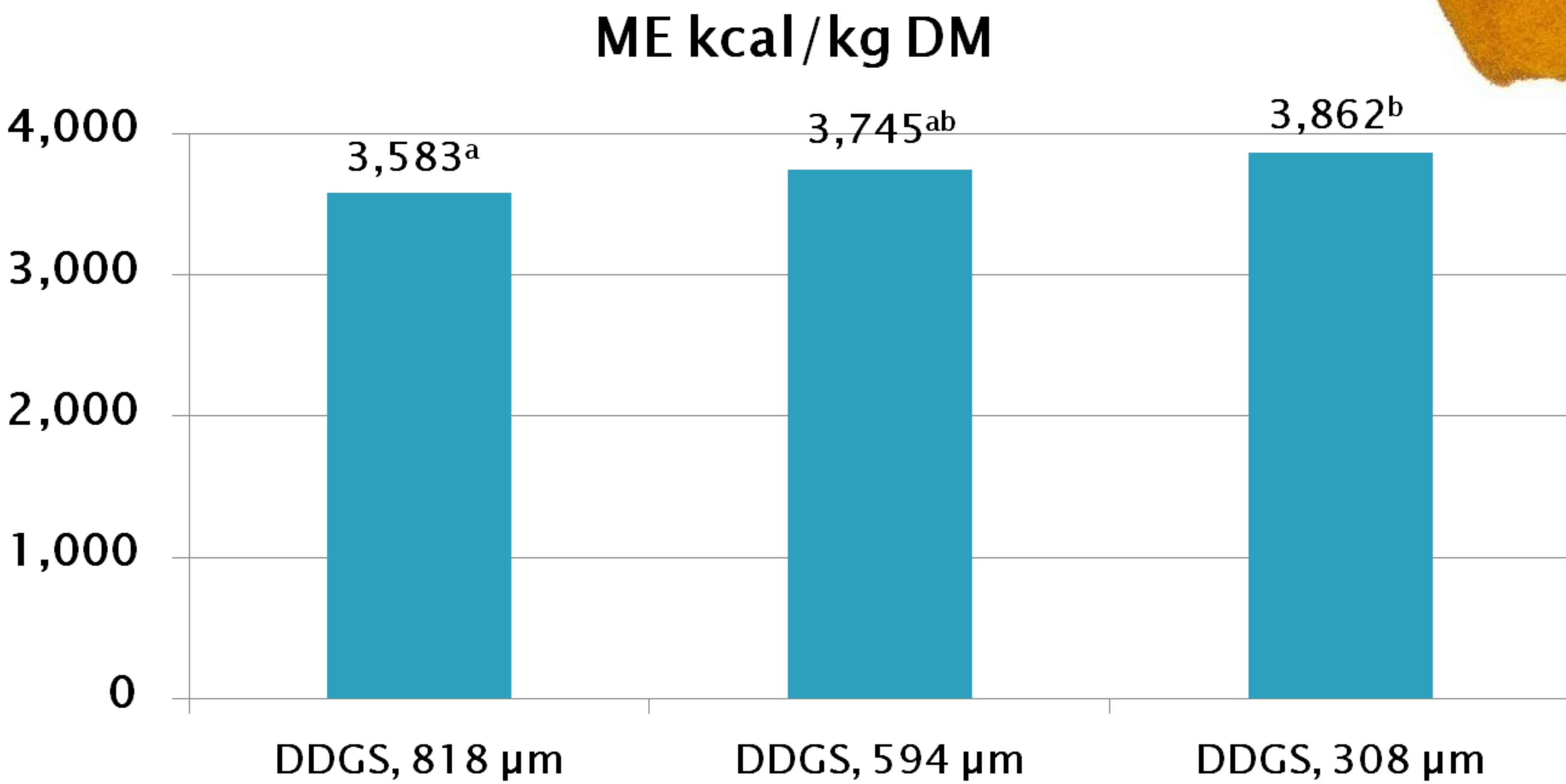
Carbohydrate fraction	Average	Range	SD
Total starch, %	7.3	3.8 – 11.4	1.4
Soluble starch, %	2.6	0.5 – 5.0	1.2
Insoluble starch, %	4.7	2.0 – 7.6	1.5
ADF, %	9.9	7.2 – 17.3	1.2
NDF, %	25.3	20.1 – 32.9	4.8
Insoluble total dietary fiber, %	35.3	26.4 – 38.8	4.0
Soluble dietary fiber, %	6.0	2.4 – 8.5	2.1
Total dietary fiber, %	42.1	31.2 – 46.3	4.9
ATTD, total dietary fiber, %	43.7	23.4 – 55.0	10.2

Stein and Shurson (2009)

Why does DE and ME content of DDGS vary so much?

- Variability in procedures and labs

ME (kcal/kg DM) of DDGS of varying particle sizes (Liu et al., 2011)

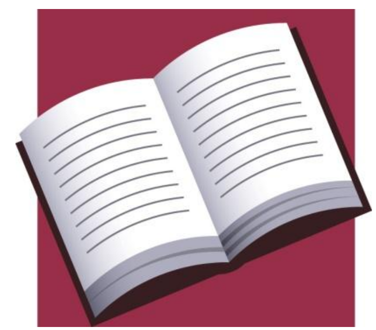


Each 25 µm reduction in DDGS particles size increases ME by 13.46 kcal/kg DM

Effect of DDGS particle size ($P = 0.04$)

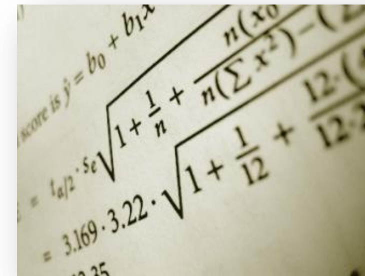
How should we estimate DE or ME content of DDGS?

- *In vivo* balance studies
  - Most accurate
  - Impractical
    - Time consuming
    - Expensive
    - Applicable only to samples evaluated



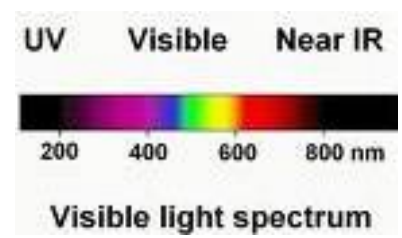
- "Book values"
  - Which ones?
  - Don't account for variation among sources
  - Robustness of data sets and sampling
  - Compositional changes after values are published

How Should We Estimate DE or ME Content of DDGS?



- Prediction equations
  - Which one?
  - Applicable to any sample?
  - Accuracy has not been validated (current NPB project)
  - Best equations may require data that are not routinely measured
    - E.g. GE, TDF

- NIR
  - Great idea but…
    - Need > 200 samples for good calibrations
    - Cost
    - Time



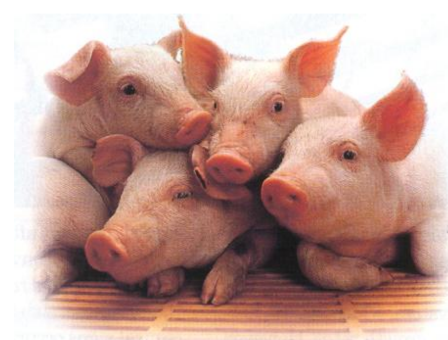
Examples of ME prediction equations for corn co-products/DDGS in swine diets

ME kcal/kg DM = (0.949 × kcal **GE**/kg DM) – (32.238 × % **TDF**) – (40.175 × % **ash**)

Anderson et al. (2012) $r^2 = 0.95$ SE = 306

ME kcal/kg DM = − 4,212 + (1.911 × **GE**, kcal/kg) − (108.35 × % **ADF**) − (266.38 × % **ash**)

Pedersen et al. (2007) $r^2 = 0.94$ SE = not provided



Challenges of using ME equations

- Accuracy has not been validated
- Are they representative of nutrient variability among sources?
- Some analytes required by equations (e.g. GE, TDF) are not:
  - routinely measured
  - expensive
- Analytical variability among labs and procedures affects accuracy (e.g. NDF).
- Adjustments for fat and fiber in some equations seem counterintuitive.
- Methods used to determine DE and ME values vary
- Methods used to develop regression equations
- Effect of particle size?

Published ME estimates (DM basis) for "typical" DDGS vs. oil extracted DDGS

	Dahlen et al. (2011)	Jacela et al. (2011)	Anderson et al. (2012)
Crude fat, % DDGS	10.02	--	11.15
Crude fat, % OE-DDGS	8.80[1]	4.56[2]	3.15[2]
ME, kcal/kg DDGS	2,964	--	3,790
ME, kcal/kg OE-DDGS	2,959	2,858[3]	3,650
ME, kcal/1% oil[4]	4	ND	18

[1] Obtained from DDG (no solubles added)
[2] Obtained from a solvent extraction process
[3] DE was determined and used to calculate ME = DE – 0.68 x CP (Noblet and Perez, 1993).
[4] Assumes a linear relationship between DDGS crude fat content and ME value.

Determination of DE and ME content of reduced oil DDGS in swine–Experiment 1

- 11 DDGS sources were evaluated (+basal)
- Range in nutrient profile (DM basis)
  - Crude fat – 8.6 to 13.2%
  - NDF – 28.8 to 44.0%
  - Starch – 0.8 to 3.9%
  - Crude protein – 27.7 to 32.9%
  - Ash – 4.3 to 5.3%

- **Particle size ranged from 622 to 1078 μm**
- 30% DDGS source was added to a corn basal diet (97.2% corn)
- **Fed to 84 kg gilts with an ADFI of 2.4 kg**
- 12 replications per DDGS source
- 9-d adaptation period and 4-d total collection period

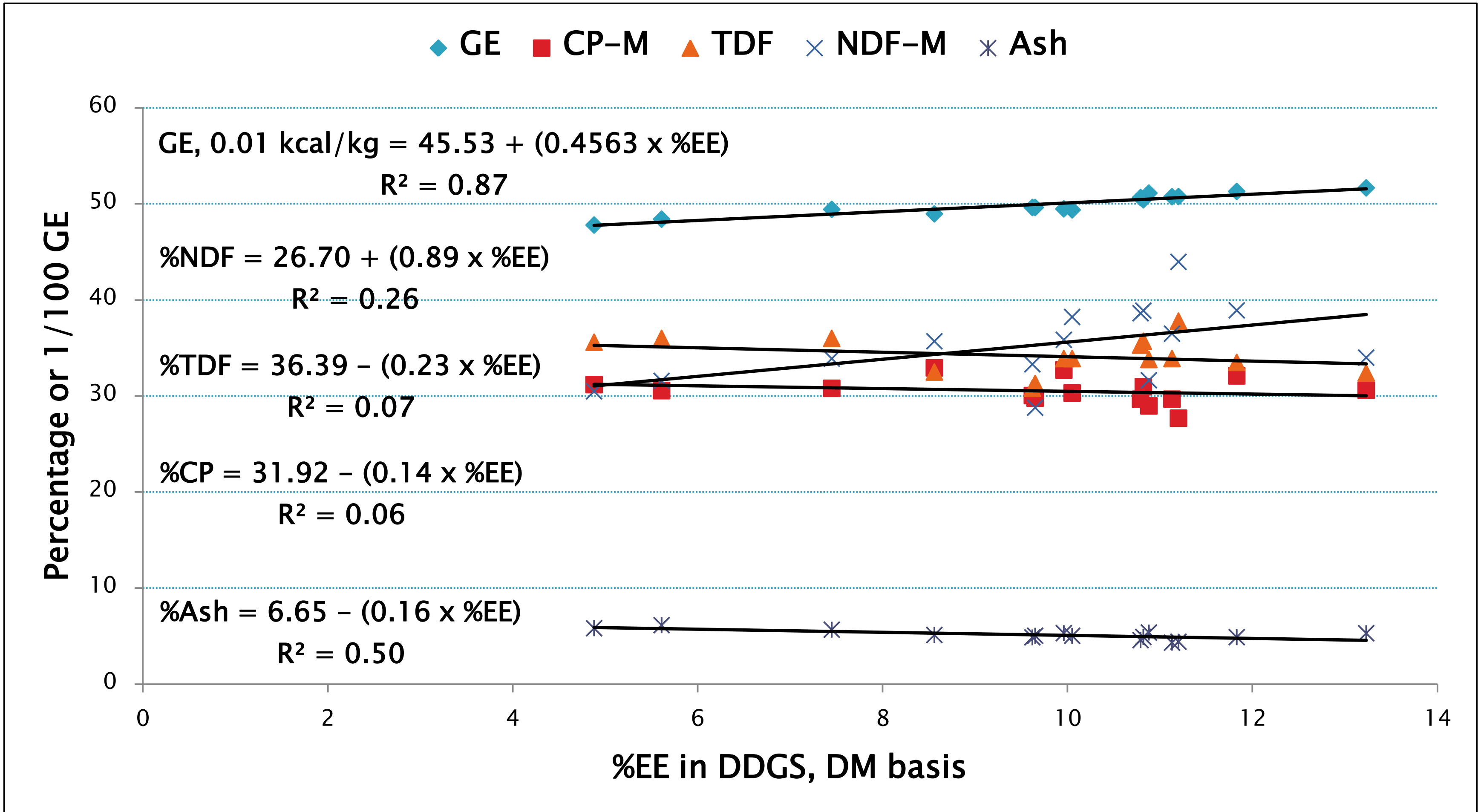
Determination of DE and ME content of reduced oil DDGS in swine–Experiment 2

- 4 DDGS sources were evaluated (+basal)
- Range in nutrient profile (DM basis)
  - **Crude fat – 4.9 to 10.9%**
  - **NDF – 30.5 to 33.9%**
  - **Starch – 2.5 to 3.3%**
  - **Crude protein – 29.0 to 31.2%**
  - **Ash – 5.4 to 6.1%**
- **Particle size ranged from 294 to 379 µm**
- 30% DDGS source was added to a corn basal diet (97.2%)
- **Fed to 106 kg gilts with an ADFI of 2.7 kg**
- 15 replications per DDGS source
- 8-d adaptation period and 3-d total collection period

General Calculations & Statistics

- DE and ME of each RO-DDGS source was calculated by:
  - DE or ME contributed by the basal diet was subtracted from the DE or ME of the test diet
  - Result was divided by the inclusion rate (30%) of each RO-DDGS in the diet (difference method)
- DE and ME of the basal diet was used as a covariate to determine the DE and ME values, respectively, among all groups of pigs
- Stepwise regression was used to determine the effect of RO-DDGS composition on apparent DE and ME
  - Variables with P-values ≤ 0.15 were retained in the model

Relationship of RO-DDGS composition to EE content in Experiment 1 and 2



ME ranking of DDGS sources and nutrient content (DM basis) – Experiment 1

DDGS Source	ME, kcal/kg	Crude fat, %	NDF, %	Crude protein, %	Starch, %	Ash, %
8	3,603	13.2	34.0	30.6	1.3	5.3
11	3,553	11.8	38.9	32.1	1.1	4.9
9	3,550	9.7	28.8	29.8	2.8	5.0
6	3,513	9.6	33.0	30.1	3.4	4.9
7	3,423	10.1	38.2	30.3	2.2	5.0
2	3,400	11.1	36.5	29.7	3.9	4.3
4	3,362	8.6	35.7	32.9	0.8	5.1
3	3,360	10.8	38.6	29.7	1.6	4.6
10	3,327	10.0	35.9	32.7	1.0	5.3
1	3,302	11.2	44.0	27.7	1.8	4.4
5	3,277	11.1	39.7	31.6	0.9	5.0

Green = highest value
Red = lowest value

We can't use crude fat to estimate ME content!! (Experiment 1)

DDGS Source	DDGS Source 11	DDGS Source 9	DDGS Source 8	DDGS Source 5
ME, kcal/kg	3,553	3,550	3,603	3,277
Crude fat, %	11.8	9.7	13.2	11.1
Starch, %	1.1	2.8	1.3	0.9
NDF, %	38.9	28.8	34.0	39.7
Crude protein, %	32.1	29.8	30.6	31.6
Ash, %	4.9	5.0	5.3	5.0

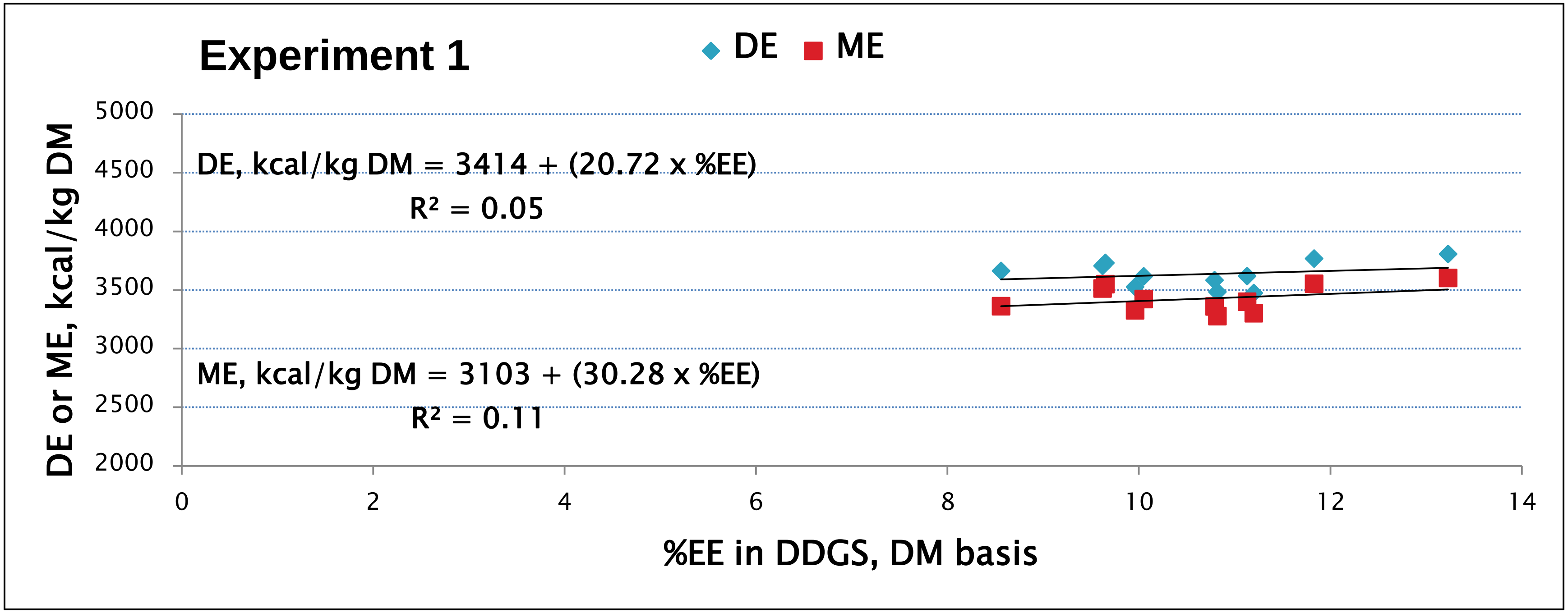
In this experiment, a reduction in crude fat **DID NOT** increase NDF and TDF.

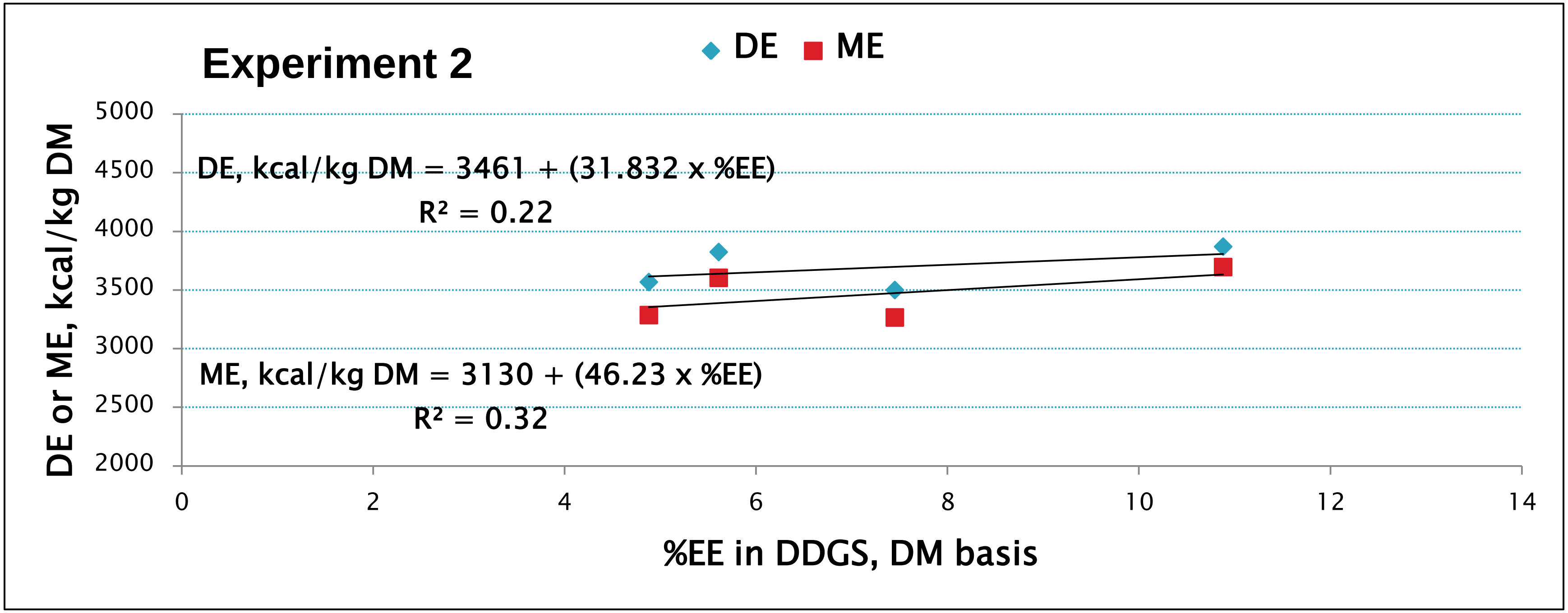
Comparing DDGS Source 11 vs. 9:

2.1 percentage unit decrease in fat reduced ME by **3** kcal/kg

Comparing DDGS Source 8 vs. 5:

2.1 percentage unit decrease in fat reduced ME by **326** kcal/kg


Experiment 1
DE
ME
DE, kcal/kg DM = 3414 + (20.72 x %EE)
R² = 0.05
ME, kcal/kg DM = 3103 + (30.28 x %EE)
R² = 0.11
DE or ME, kcal/kg DM
%EE in DDGS, DM basis
5000
4500
4000
3500
3000
2500
2000
0
2
4
6
8
10
12
14


Experiment 2
DE
ME
DE, kcal/kg DM = 3461 + (31.832 x %EE)
R² = 0.22
ME, kcal/kg DM = 3130 + (46.23 x %EE)
R² = 0.32
DE or ME, kcal/kg DM
%EE in DDGS, DM basis
5000
4500
4000
3500
3000
2500
2000
0
2
4
6
8
10
12
14

Nutritional components evaluated in multiple regression analysis (DM basis)

- Bulk density
- Particle size
- GE
- CP
- Starch
- TDF
- NDF, ADF, Hemicellulose
- EE
- Ash, Phosphorus, Sulfur

ME prediction equations – Univ. Missouri Analysis Experiment 1

(1) ME kcal/kg DM = 4,548 – (49.7 x % TDF) + (52.1 x % EE)

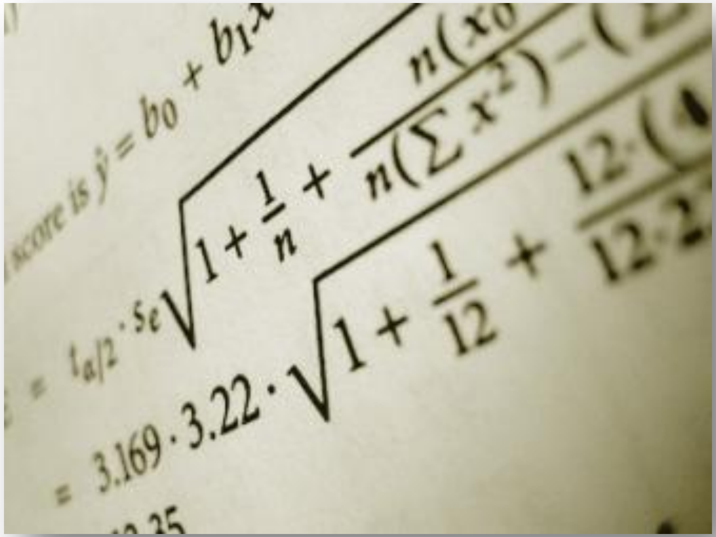
SE = 49 R^2 = 0.85

(2) ME kcal/kg DM = 3,711 – (21.9 x % NDF) + (48.7 x % EE)

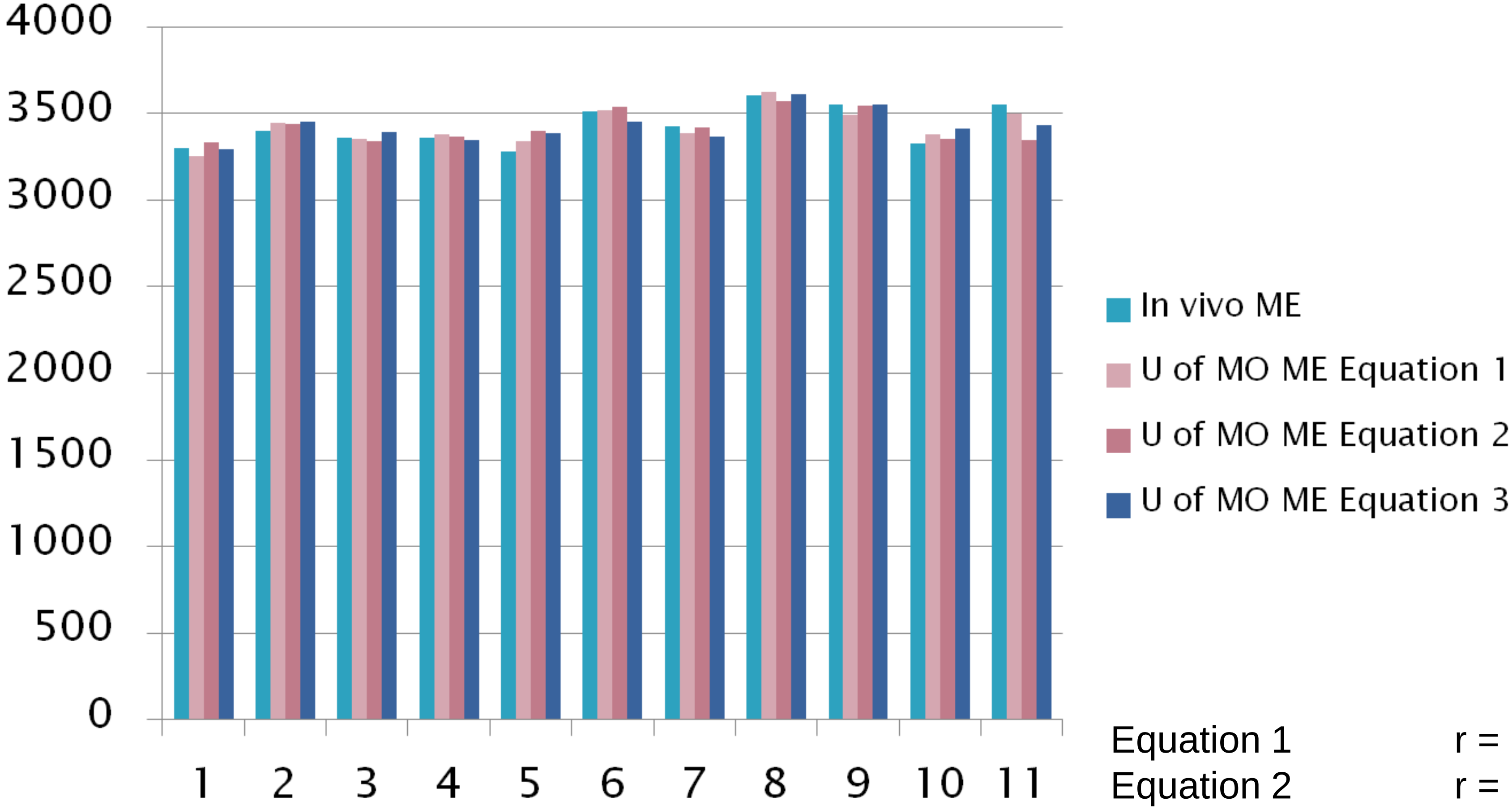
SE = 75 R^2 = 0.65

(3) ME kcal/kg DM = 4,132 – (57.0 x % ADF)

SE = 76 R^2 = 0.59



Comparison of RO-DDGS ME prediction using University of Missouri lab results and derived equations



Equation 1	r = 0.92
Equation 2	r = 0.77
Equation 3	r = 0.80

ME prediction equations – USDA-ARS Analysis Experiment 1

(1) ME kcal/kg DM = 1,352 + (0.757 x GE kcal/kg) – (51.4 x % TDF)

SE = 50 R^2 = 0.84

(2) ME kcal/kg DM = 4,440 – (68.3 x % ADF)

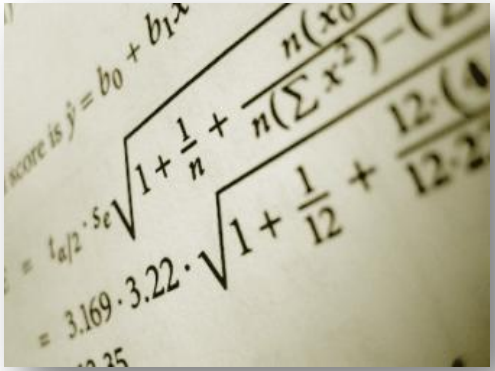
SE = 58 R^2 = 0.76

(3) ME kcal/kg DM = 283 + (0.866 x GE kcal/kg) – (38.1 x % NDF)

SE = 70 R^2 = 0.69

(4) ME kcal/kg DM = 4,051 – (32.9 x % NDF) + (48.1 x % EE)

SE = 75 R^2 = 0.64



ME prediction equations – University of Missouri Analysis Experiment 2

No parameters were significant at $P \leq 0.15$.

ME prediction equations – USDA-ARS Analysis Experiment 2

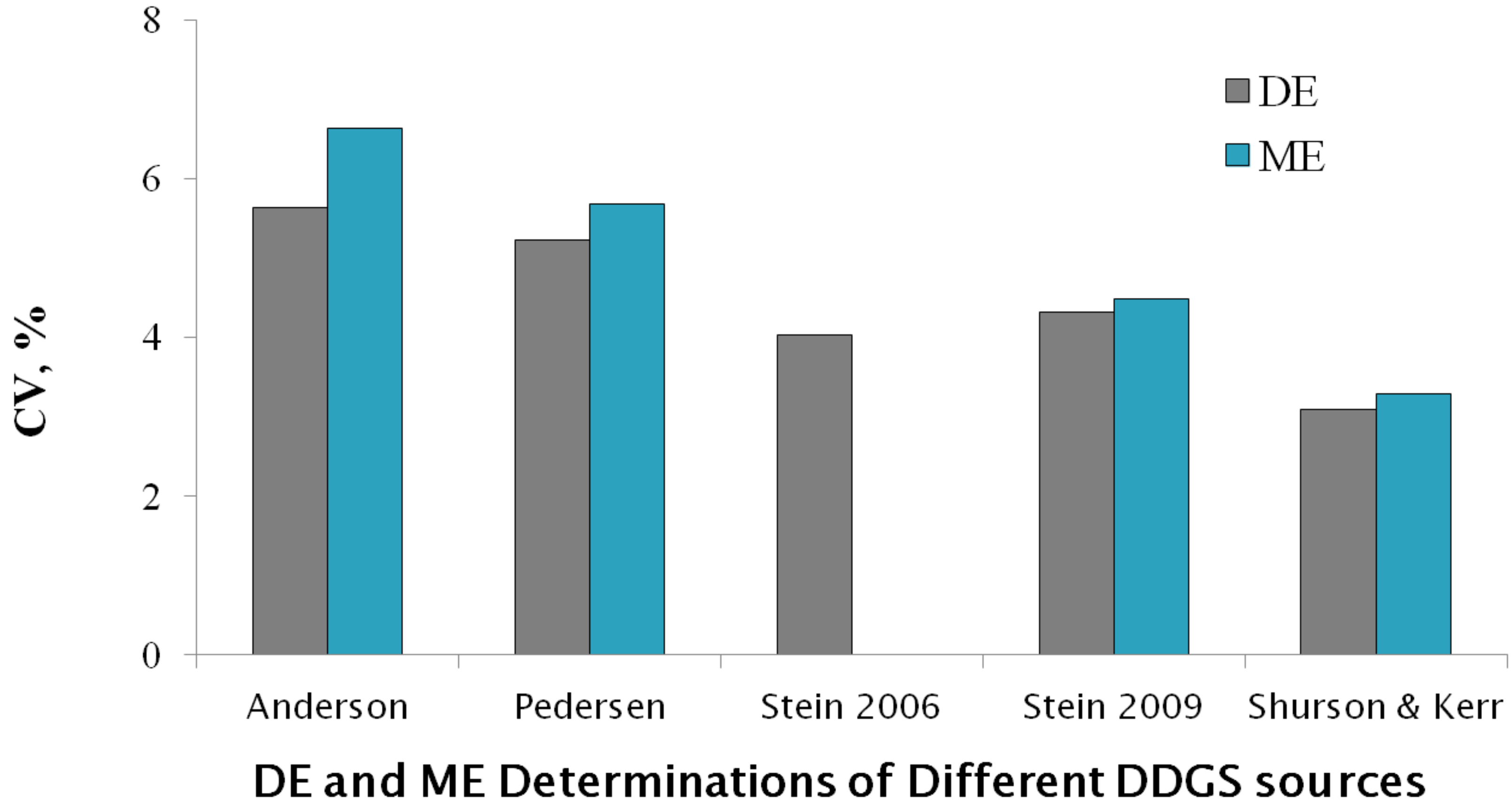
(1) ME kcal/kg DM = 15,573 – (307.9 x % Hemicellulose) - (1.32 x % GE)

SE = 1.3 $R^2 = 0.99$

(2) ME kcal/kg DM = 6,500 – (166.8 x % Hemicellulose)

SE = 117 $R^2 = 0.81$

CV's of DE and ME values of DDGS among sources within experiments



Anderson et al. (2012), Pedersen et al. (2007), Stein et al. (2006), Stein et al. (2009), Shurson and Kerr (Unpublished)

DDGS ME Prediction Equations from Pedersen et al. (2007)

(1) ME kcal/kg DM = −10,866 − (108.12 × % **ash**) + (37.55 × % **CP**) − (8.04 × % **starch**) − (71.78 × % **EE**) − (164.99 × % **ADF**) + (15.91 × % **NDF**) + (3.007 × **GE**, kcal/kg) $r^2 = 0.99$

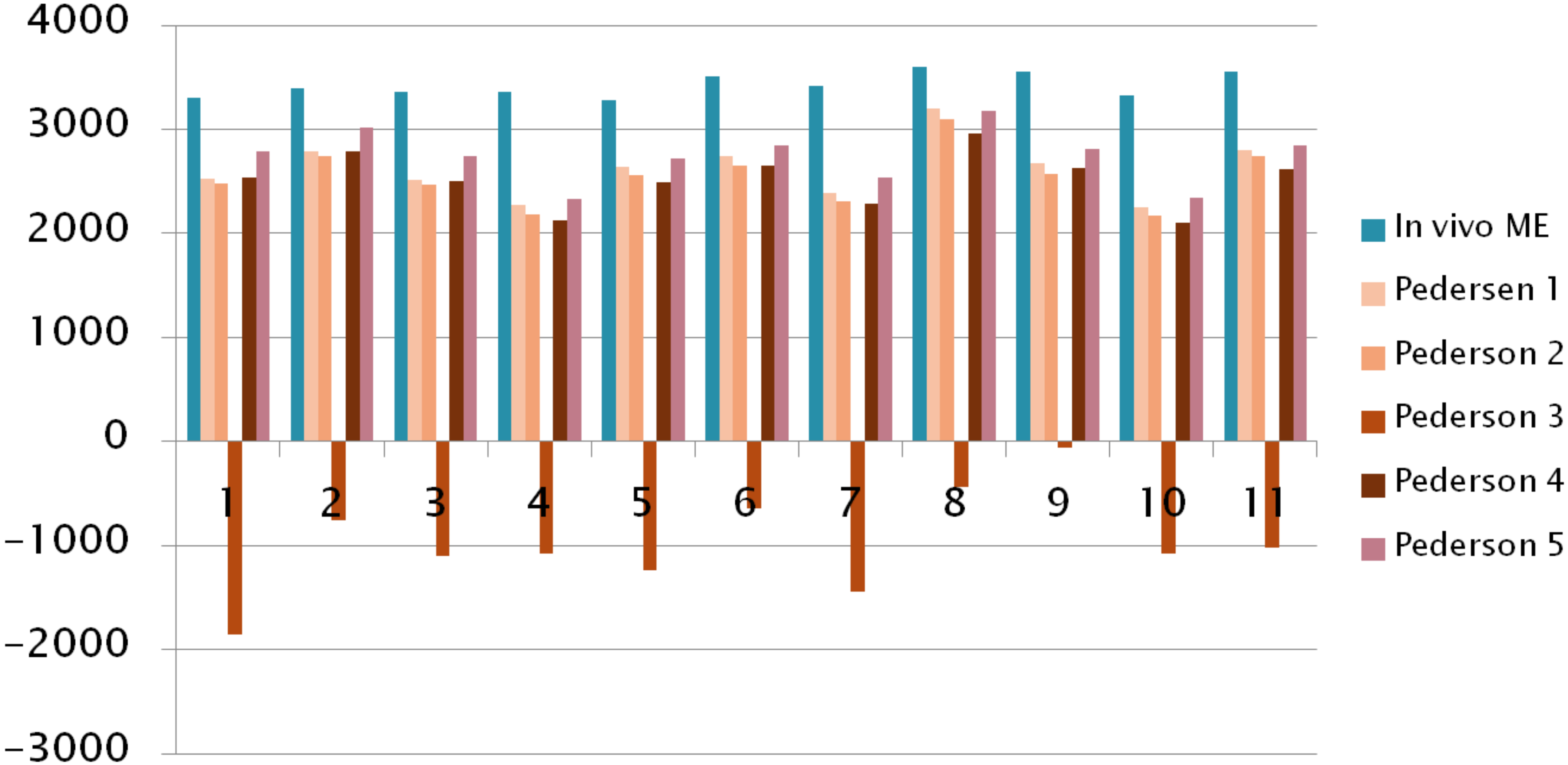
(2) ME kcal/kg DM = −11,128 − (124.99 × % **ash**) + (35.76 × % **CP**) − (63.40 × % **EE**) − (150.92 × % **ADF**) + (14.85 × % **NDF**) + (3.023 × **GE**, kcal/kg) $r^2 = 0.99$

(3) ME kcal/kg DM = −10,267 − (175.78 × % **ash**) + (23.09 × % **CP**) − (71.22 × % **EE**) − (137.93 × % **ADF**) + (3.036 × **GE**, kcal/kg) $r^2 = 0.99$

(4) ME kcal/kg DM = −7,803 − (223.19 × % **ash**) − (61.30 × % **EE**) − (121.94 × % **ADF**) + (2.702 × **GE**, kcal/kg) $r^2 = 0.97$

(5) ME kcal/kg DM = −4,212 − (266.38 × % **ash**) − (108.35 × % **ADF**) + (1.911 × **GE**, kcal/kg) $r^2 = 0.94$

In vivo RO-DDGS ME vs. Pedersen et al. (2007) prediction equation estimates



Pedersen equations significantly underestimate ME in our data set
Equation 5 resulted in the closest ME predictions

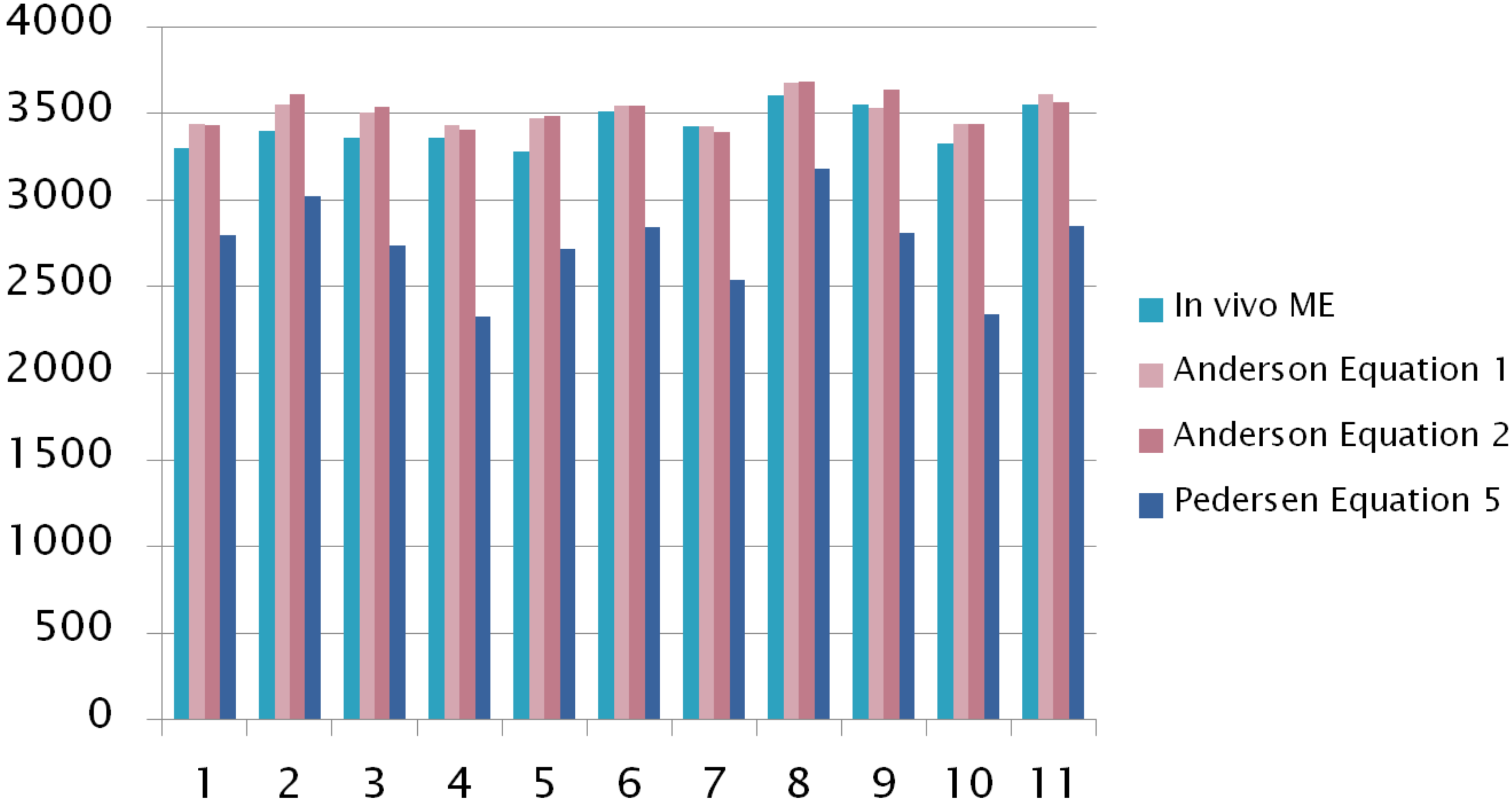
DDGS ME Prediction Equations from Anderson et al. (2012)

- Dehulled, degermed corn
- Dried solubles
- Oil
- Starch
- Germ meal (2)
- DDGS (7)
- Gluten meal
- HP-DDG (3)
- Bran (2)
- Gluten feed

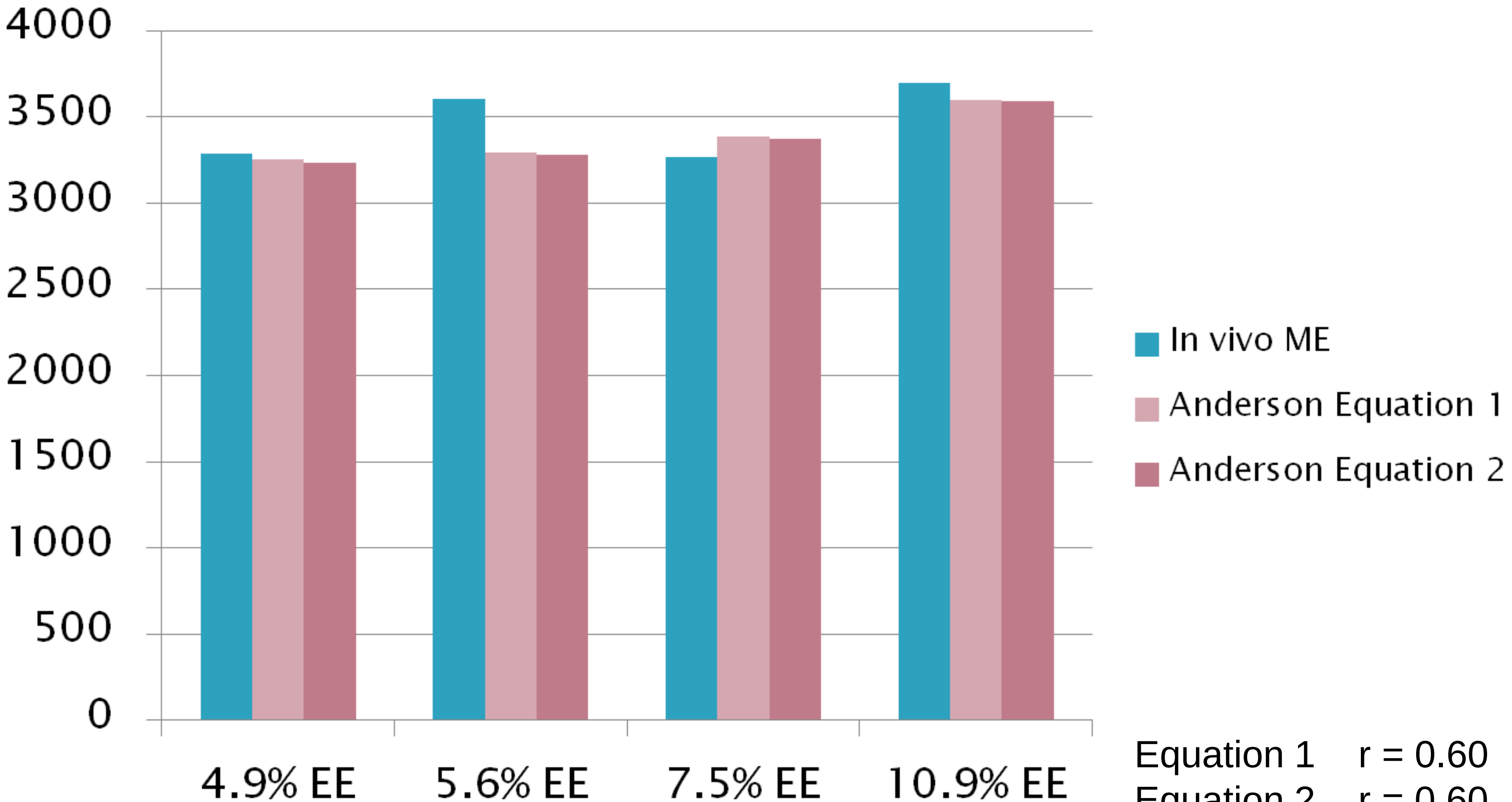
(1) ME kcal/kg DM = (0.90 × **GE**, kcal/kg) − (29.95 × % **TDF**)
$r^2 = 0.72$

(2) ME kcal/kg DM = (0.94 × **GE**, kcal/kg) − (23.45 × % **NDF**) − (70.23 × % **Ash**)
$r^2 = 0.68$

Anderson equations and University of Missouri analysis reasonably predict ME content of RO-DDGS (Experiment 1)

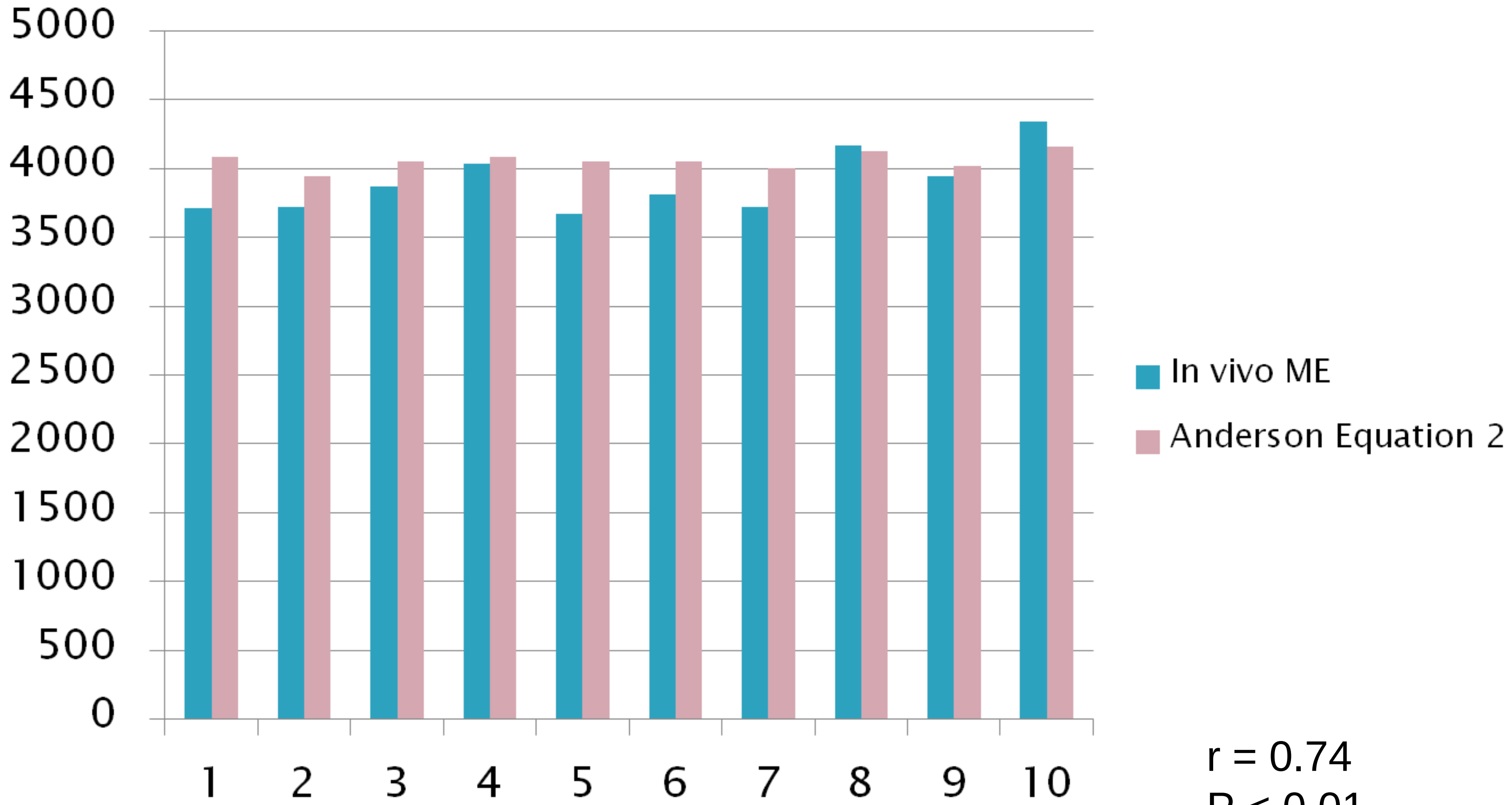


Use of Anderson equations and University of Missouri analysis to predict RO-DDGS ME content (Experiment 2)



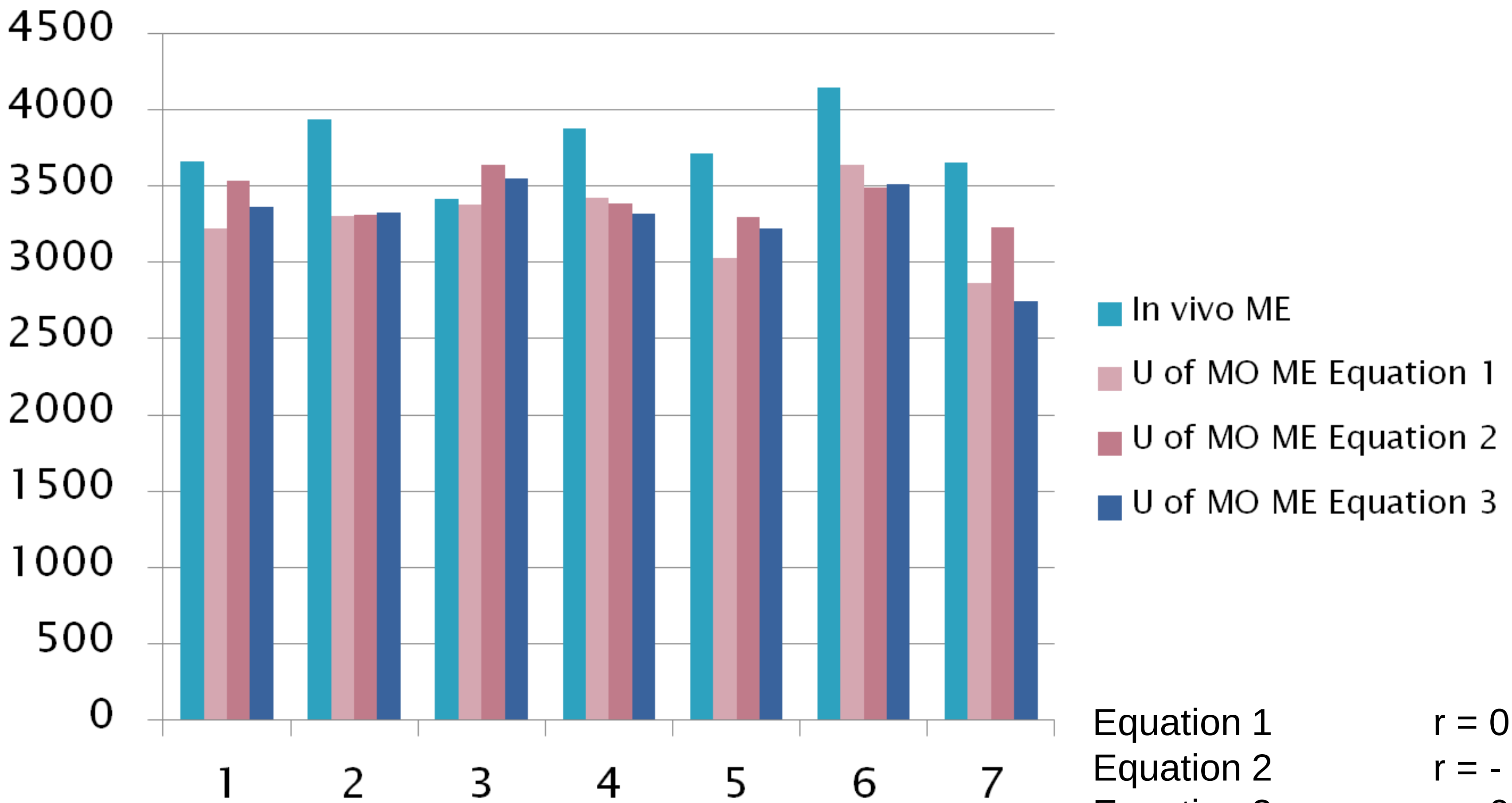
Equation 1 r = 0.60
Equation 2 r = 0.60

Anderson equations reasonably predict Pedersen et al. (2007) DDGS ME content



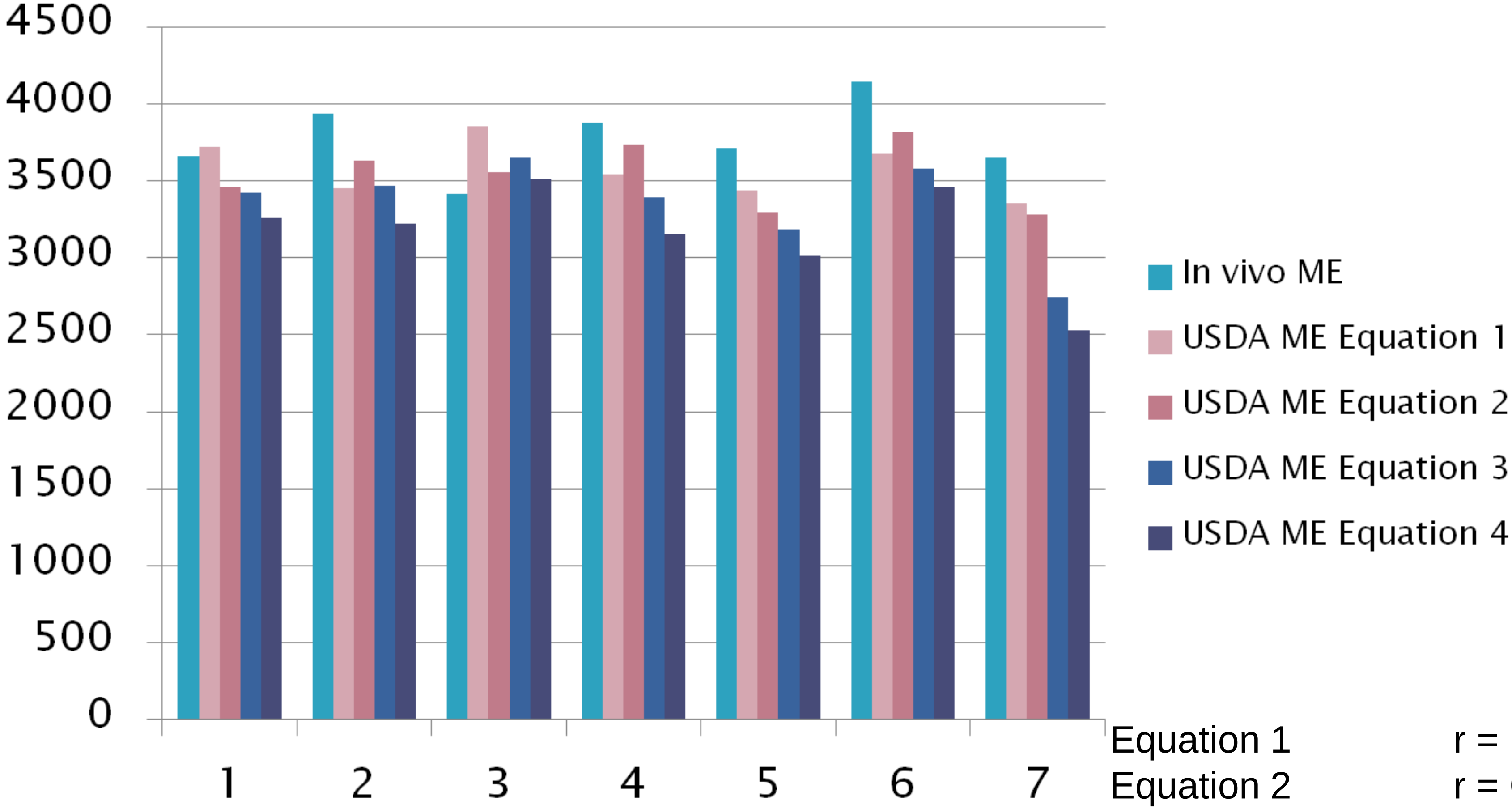
r = 0.74
P < 0.01

Shurson/Kerr equations (U of MO analysis-Exp. 1) underestimate ME in Anderson DDGS (including RO-DDGS)



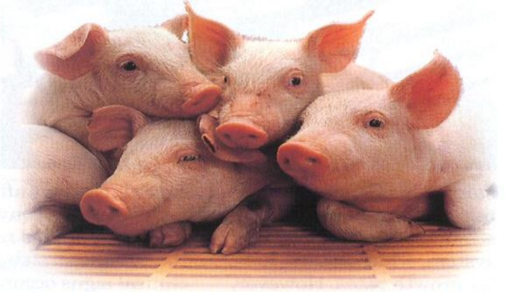
Equation 1 r = 0.52
Equation 2 r = - 0.27
Equation 3 r = 0.16

Shurson/Kerr equations (USDA analysis–Exp. 1) underestimates ME in Anderson DDGS (including RO-DDGS)



Equation 1 r = - 0.27
Equation 2 r = 0.64
Equation 3 r = 0.18
Equation 4 r = 0.15

Conclusions



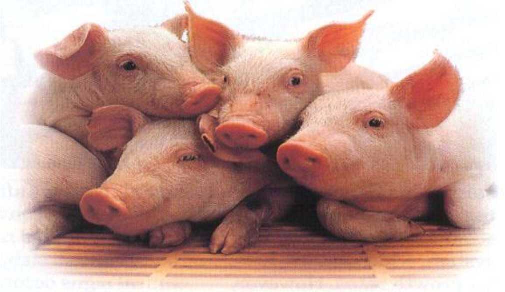
- A percentage unit reduction in crude fat **DOES NOT** accurately estimate the change in DE and ME in RO-DDGS

- Prediction equations with the highest R^2 and lowest SE should be used to estimate DE and ME
  - GE and TDF content are the most predictive (Anderson et al., 2012)
    - Expensive and more difficult to obtain from commercial labs

- How do we deal with significant lab-to-lab and analytical variation in chemical analysis?

- Accurate assessment of fiber content continues to be a challenge in RO-DDGS

Conclusions

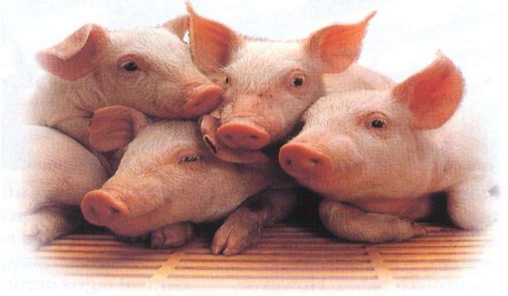


- **Reasonable predictions (within RO-DDGS) can be obtained using:**
  - **(1) ME kcal/kg DM = 4,548 – (49.7 x % TDF) + (52.1 x % EE) U of MO analysis**
    SE = 49 R^2 = 0.85
    (2) ME kcal/kg DM = 3,711 – (21.9 x % NDF) + (48.7 x % EE) U of MO analysis
    SE = 75 R^2 = 0.65

- Variation in ME content in RO-DDGS is no greater than previously reported for "typical" DDGS

- Pedersen et al. (2007) equations underestimated ME content in RO-DDGS used in this study

Conclusions



- Anderson et al. (2012) equations provide reasonable estimates of ME in RO-DDGS used in this study
  - ME kcal/kg DM = (0.90 × **GE**, kcal/kg) − (29.95 × % **TDF**)
  - ME kcal/kg DM = (0.94 × **GE**, kcal/kg) − (23.45 × % **NDF**) − (70.23 × % **Ash**)

- Shurson/Kerr equations did not accurately estimate ME content in DDGS and low-oil DDGS from Anderson et al. (2012)
  - Robustness of the data set is critical for accurate ME estimates

Acknowledgements

- Funding provided by:
  - MN Corn Research and Promotion Council
  - USDA-ARS

- 11 DDGS sources provided by CHS

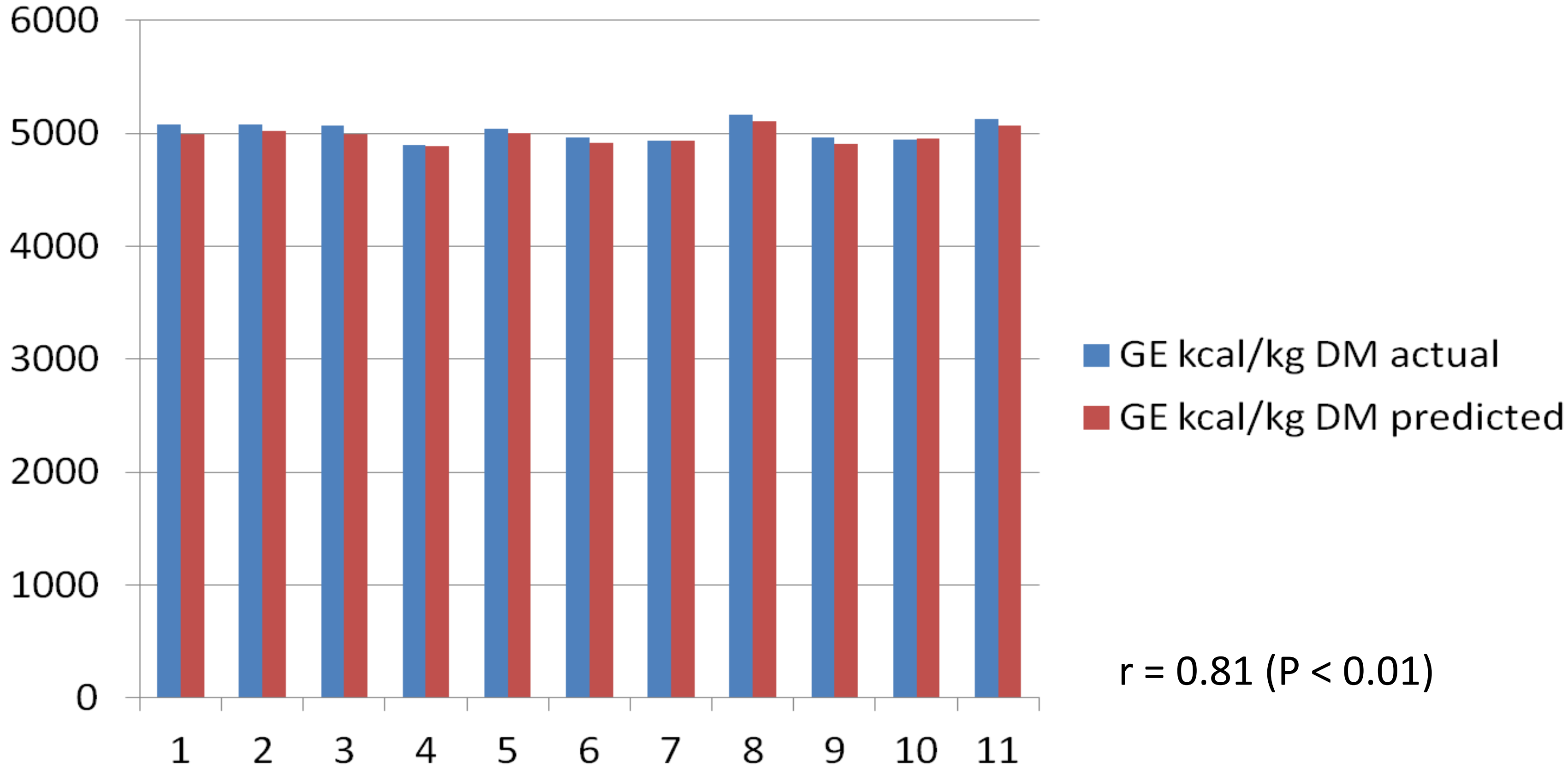
Options for estimating GE in DDGS

- Commercial labs
  - Not many have this capability
  - Time to get results
- Purchase a bomb calorimeter and obtain results internally?
  - Initial cost is ~$35,000
- Develop NIR calibrations
  - None currently exist
  - Cost?
  - Large (~250) number of samples are needed
- Use accurate prediction equations

Which GE prediction equation should we use?

$$GE = 4{,}195 + (21.26 \times \text{crude protein}) + (48.27 \times \text{crude fat})$$

Anderson et al. (2012)

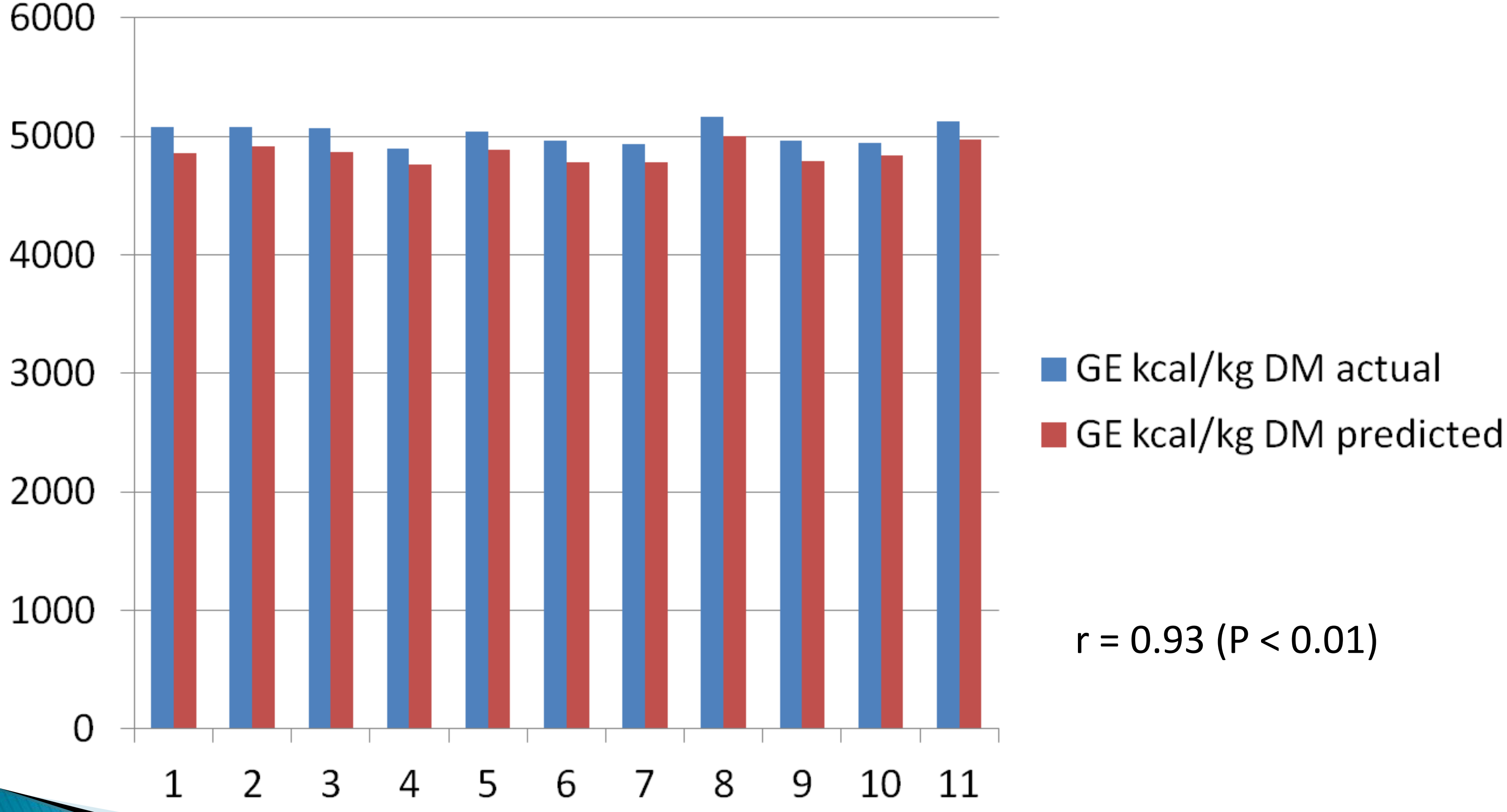


r = 0.81 (P < 0.01)

Shurson/Kerr samples

$$GE = 4{,}143 + (56 \times \%\ EE) + (15 \times \%\ CP) - (44 \times \%\ Ash)$$

Ewan (1989)

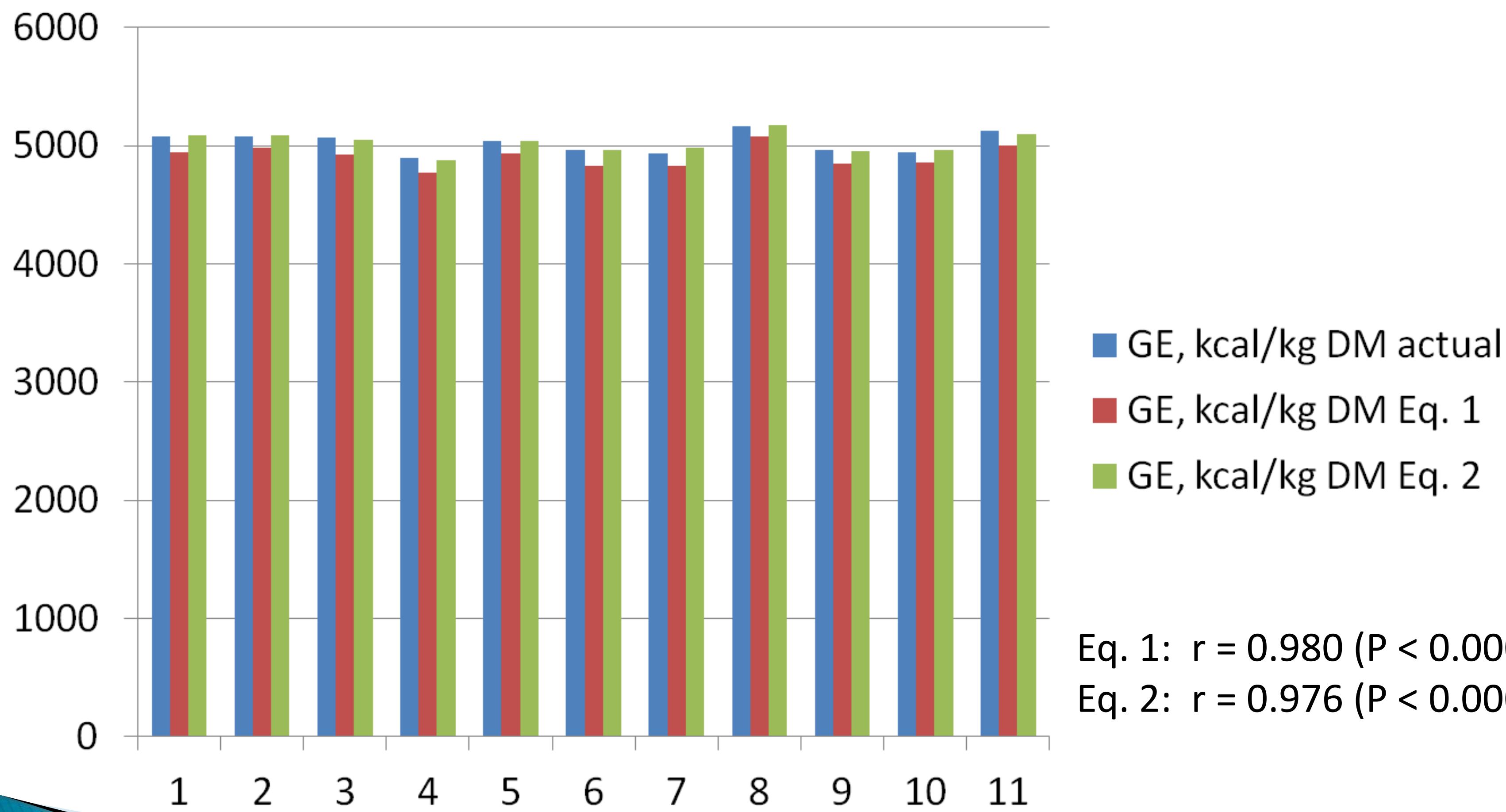


r = 0.93 (P < 0.01)

Shurson/Kerr samples

Equation 1. GE = 4,597 + (64.45 × % EE) – (52.65 × % Ash)
Equation 2. GE = 4,529 + (54.21 × % EE)**

Shurson/Kerr (2012)



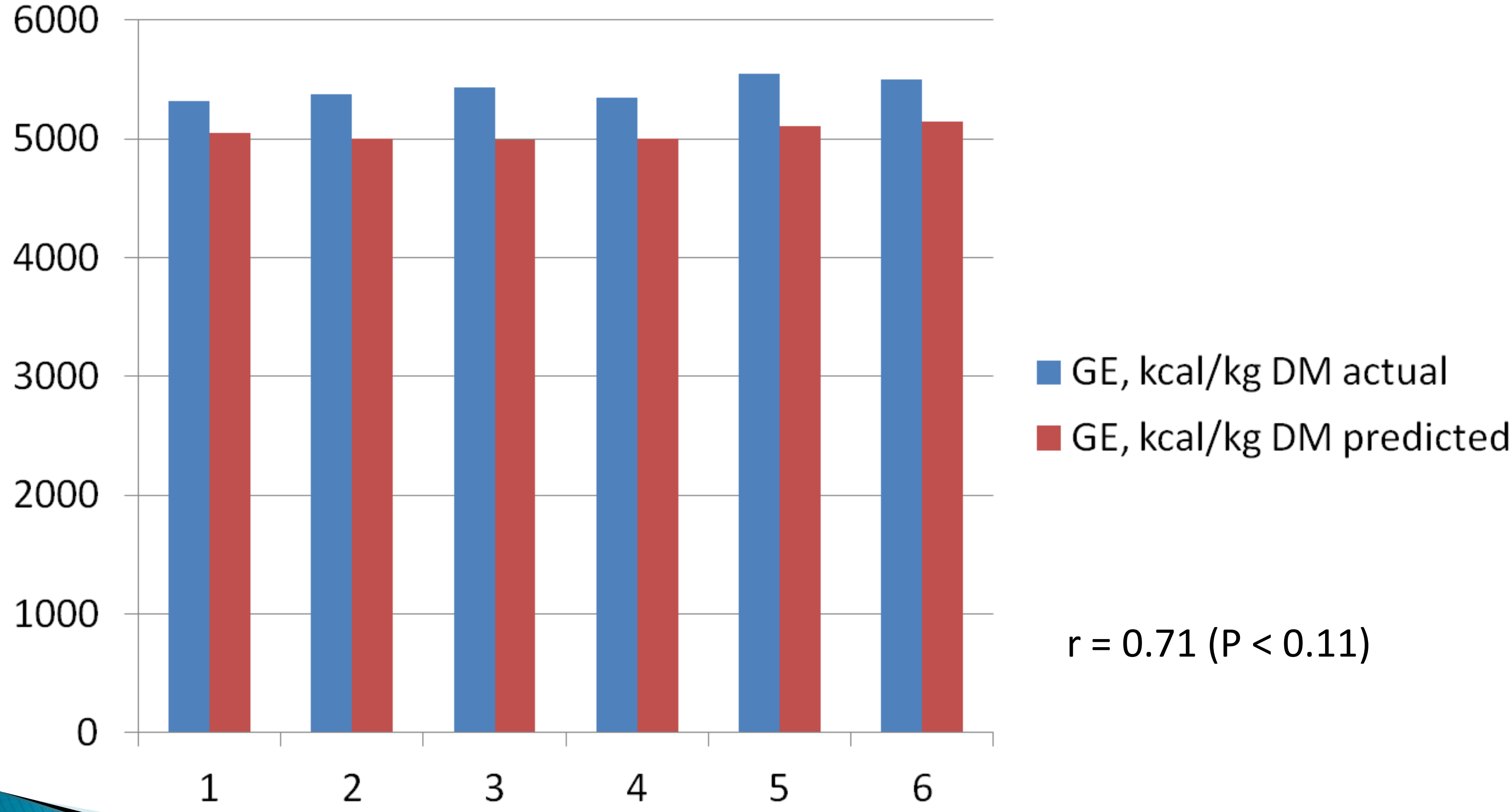
Eq. 1: $r = 0.980$ ($P < 0.0001$)

Eq. 2: $r = 0.976$ ($P < 0.0001$)

Shurson/Kerr samples

$GE = 4{,}143 + (56 \times \%\,EE) + (15 \times \%\,CP) - (44 \times \%\,Ash)$

Ewan (1989)

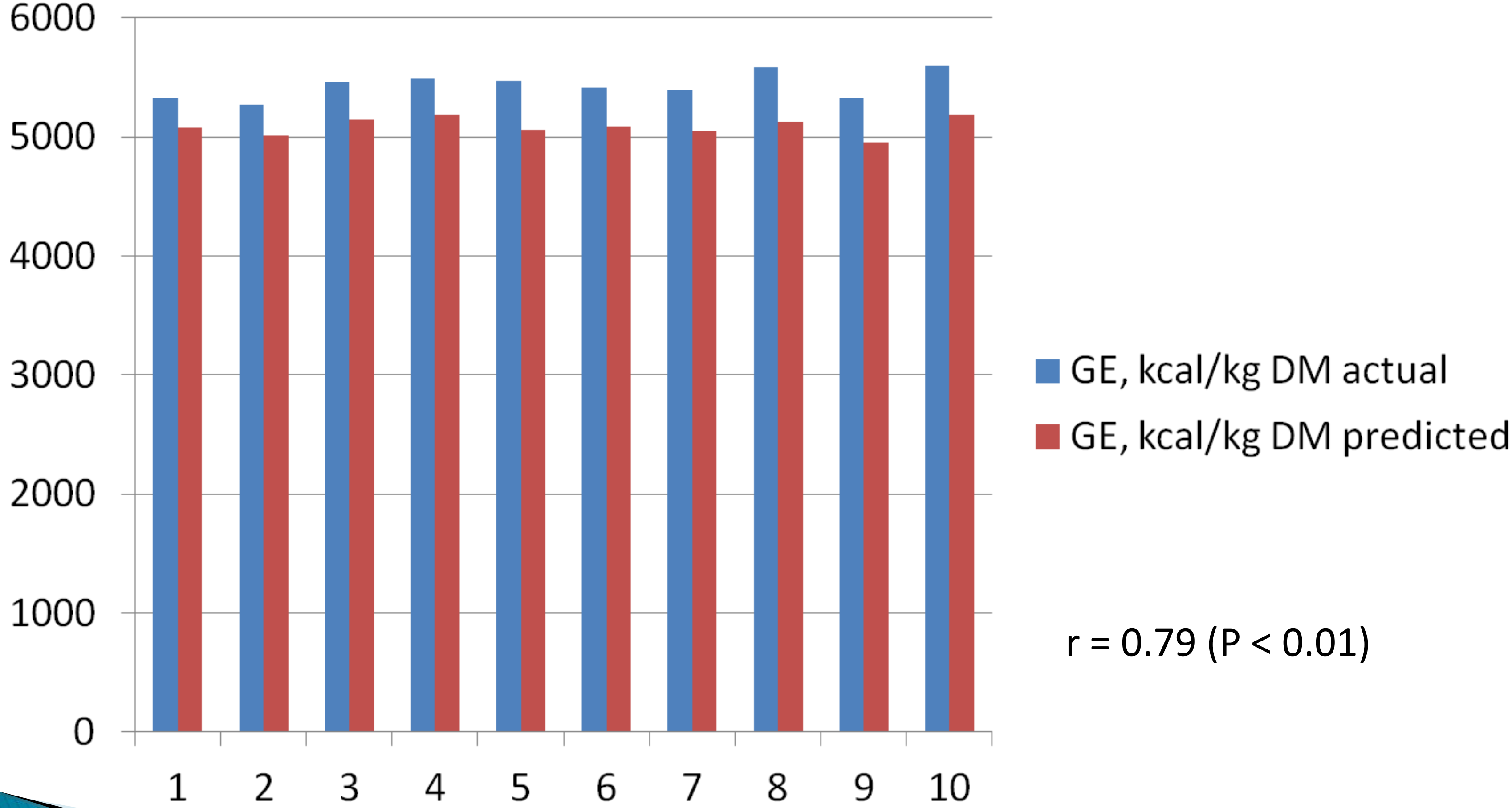


$r = 0.71$ ($P < 0.11$)

Anderson (2012) samples

GE = 4,143 + (56 × % EE) + (15 × % CP) – (44 × % Ash)

Ewan (1989)



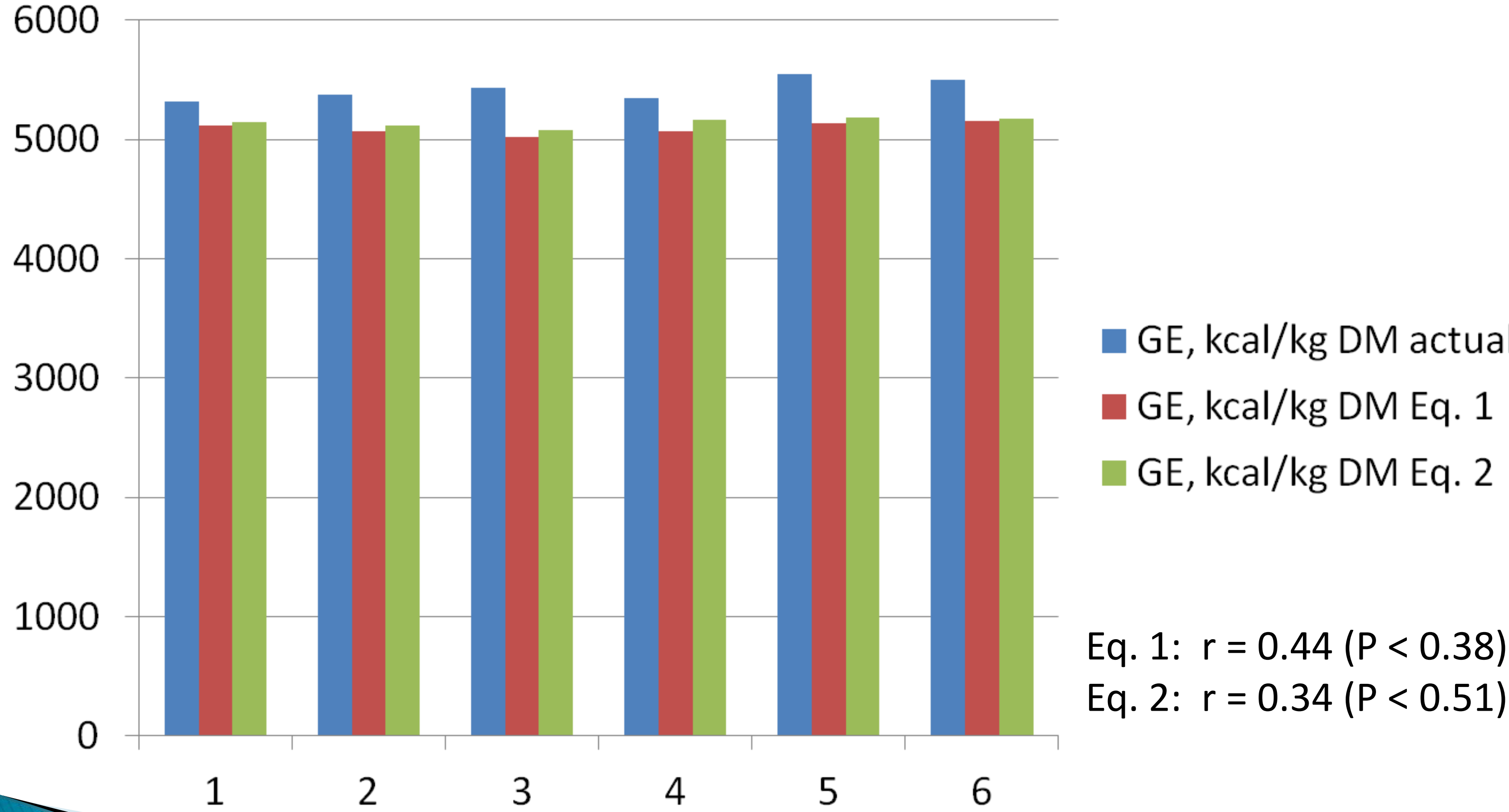
$r = 0.79$ ($P < 0.01$)

Pedersen et al. (2007) samples

Equation 1. $GE = 4,597 + (64.45 \times \% EE) - (52.65 \times \% Ash)$

Equation 2. $GE = 4,529 + (54.21 \times \% EE)$

Shurson/Kerr (2012)



Eq. 1: $r = 0.44$ ($P < 0.38$)

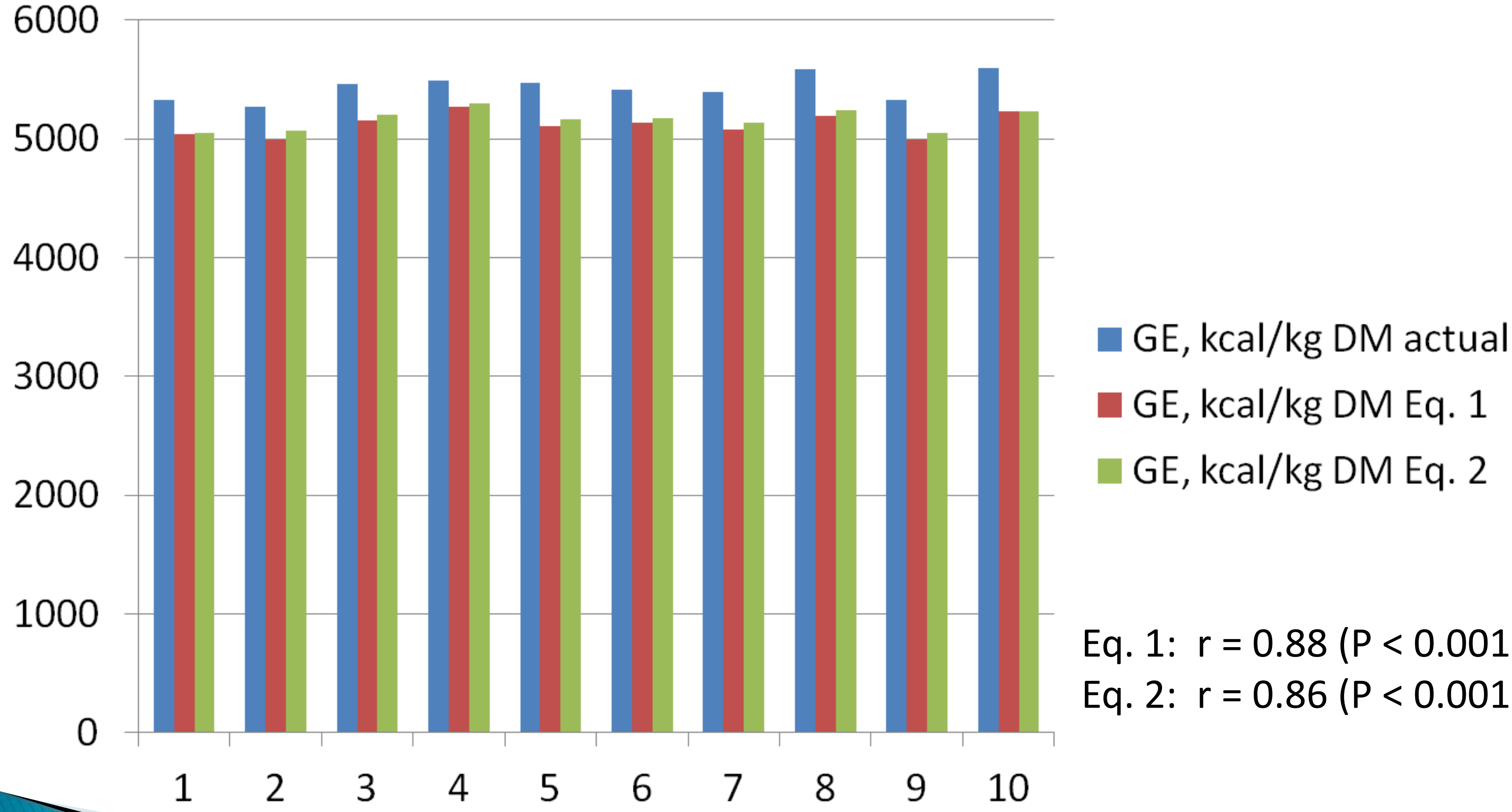
Eq. 2: $r = 0.34$ ($P < 0.51$)

Anderson (2012) samples

Equation 1. GE = 4,597 + (64.45 × % EE) – (52.65 × % Ash)

Equation 2. GE = 4,529 + (54.21 × % EE)

Shurson/Kerr (2012)



Eq. 1: $r = 0.88$ ($P < 0.001$)

Eq. 2: $r = 0.86$ ($P < 0.001$)

Pedersen (2007) samples

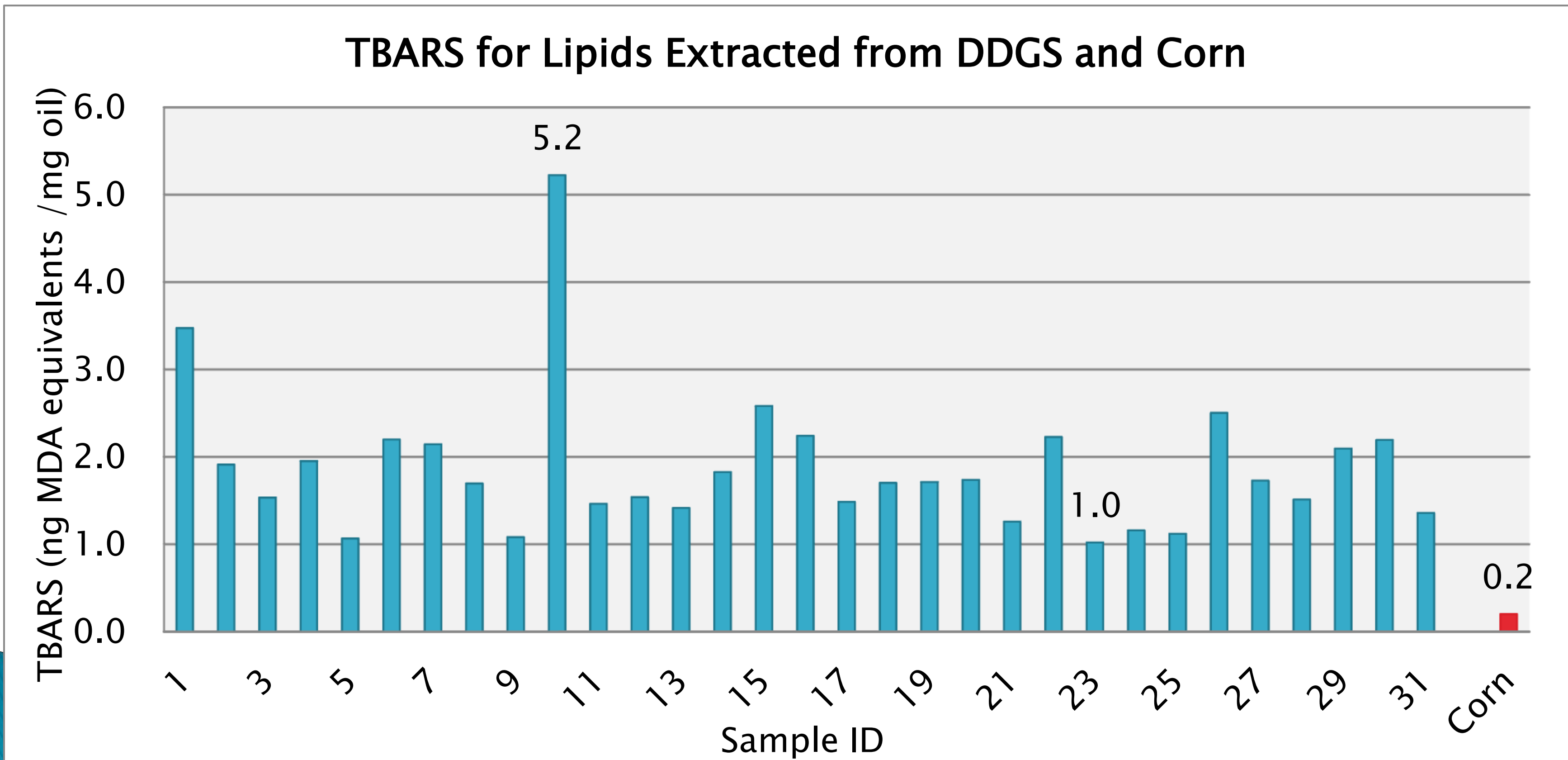
Conclusions

- Anderson et al. (2012) and Shurson/Kerr GE prediction equations provide the most accurate estimates of GE in reduced oil DDGS samples.
  - Choosing equations with the highest correlations does not necessarily result in the best GE estimates.

- Ewan (1989) and Shurson/Kerr equations do not accurately predict GE from a diverse group of corn co-products (e.g. Anderson et al., 2012)

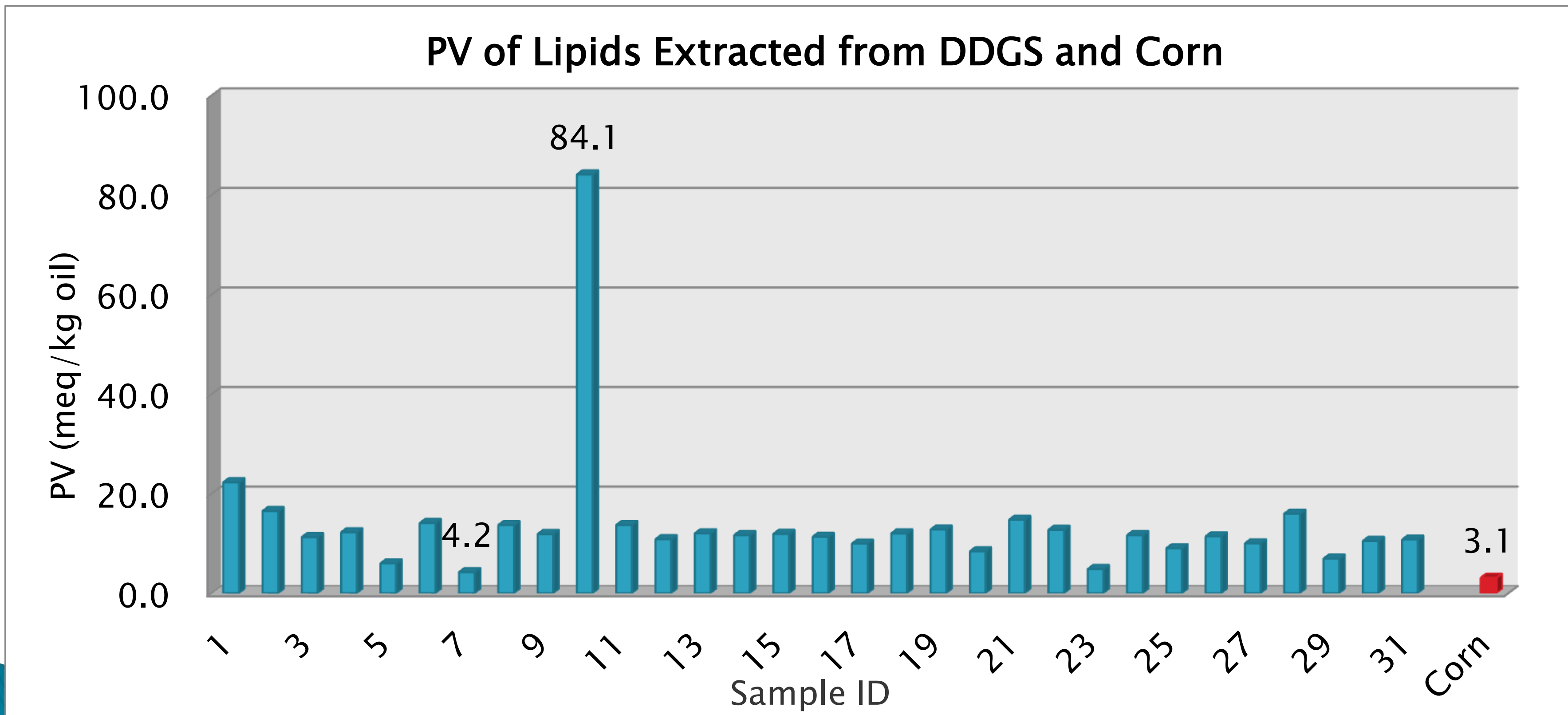
Lipid oxidation among DDGS sources measured by TBARS

- TBARS values for 31 DDGS samples ranged from 1.0 to 5.2 ng MDA equivalents/mg oil.
  - The highest TBARS value among DDGS samples was 25 times greater than that of the reference corn sample (0.2 ng MDA equivalents/mg oil).

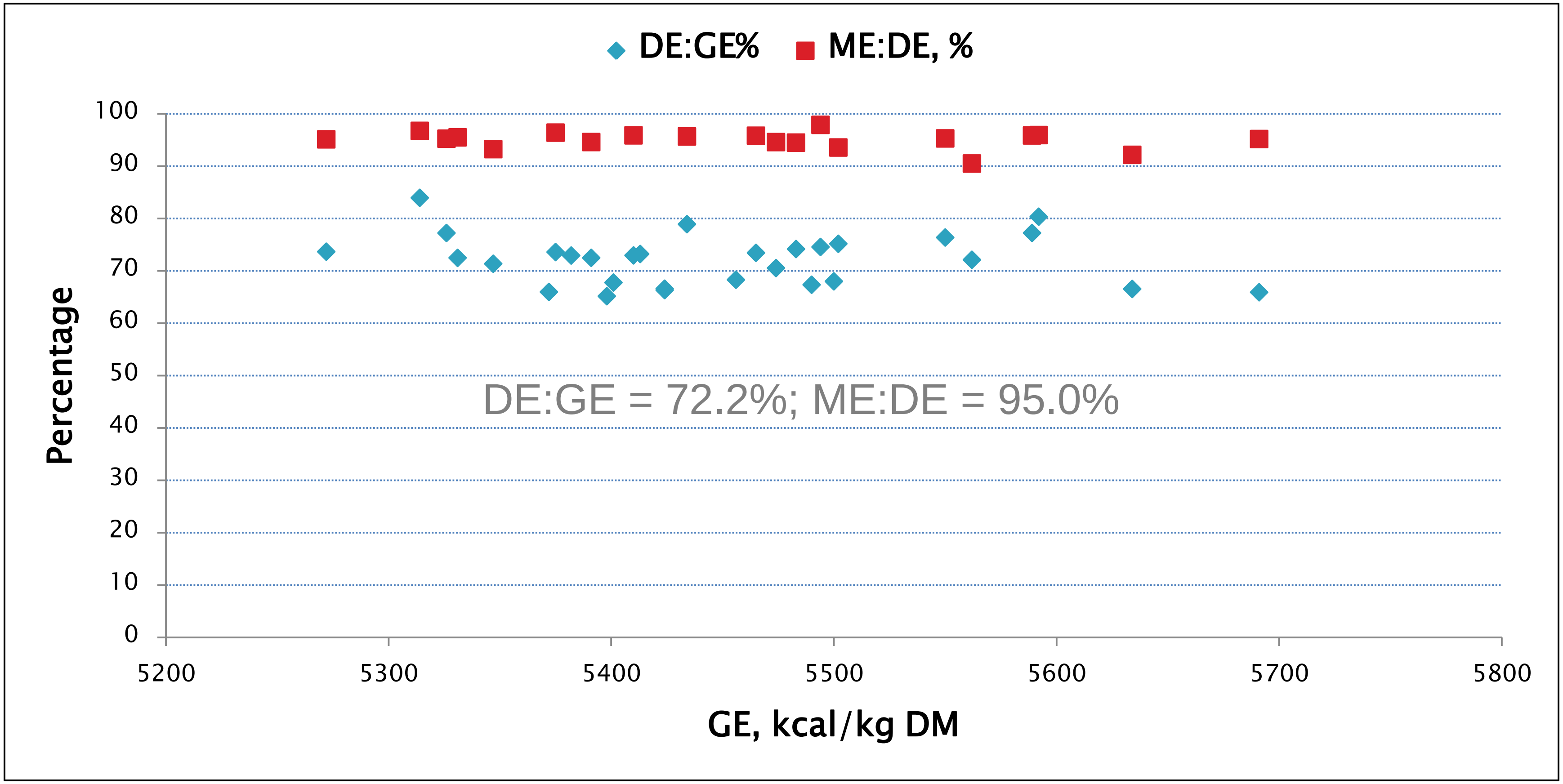


Lipid oxidation among DDGS sources measured by peroxide value

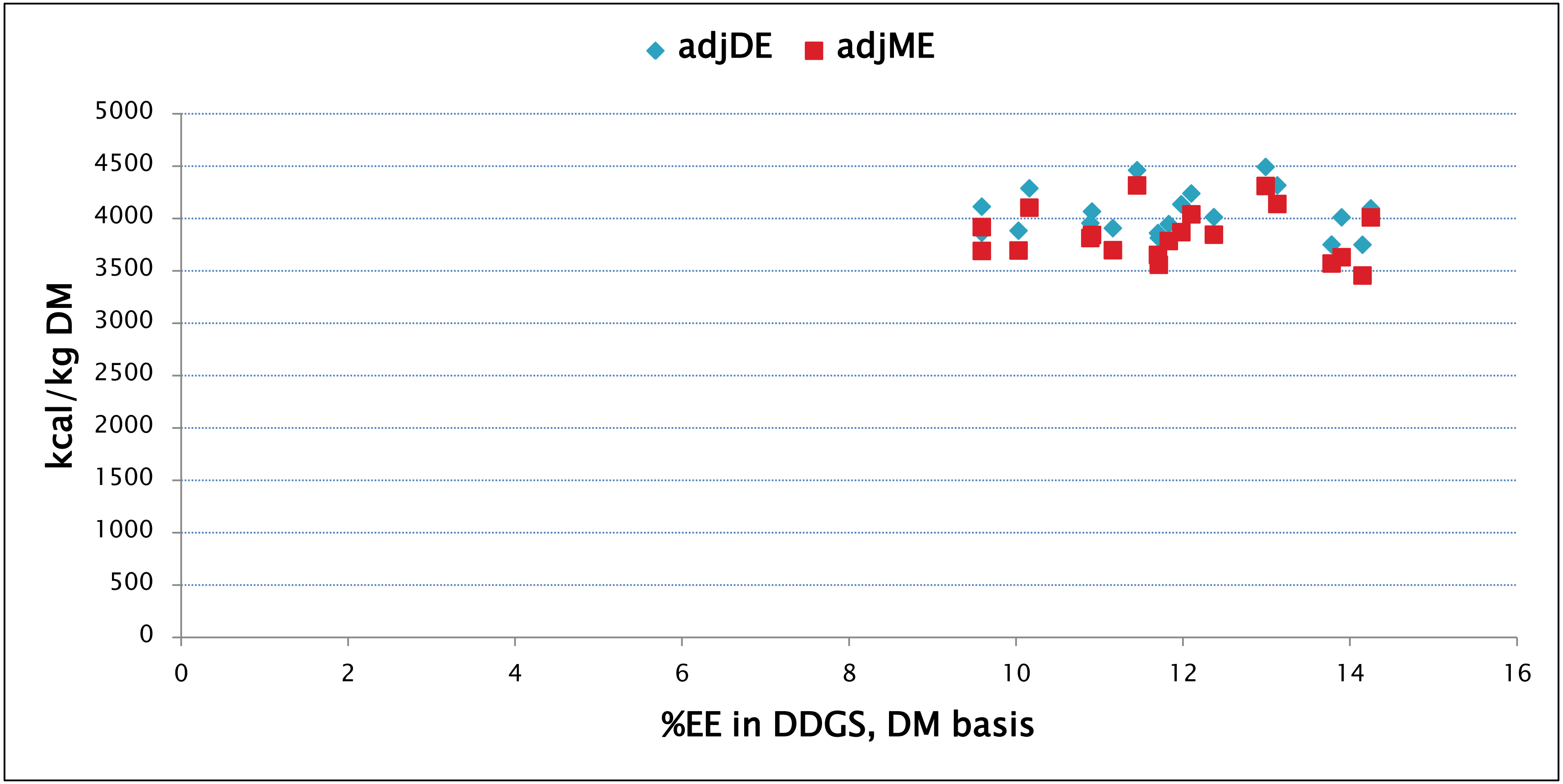
- PV of 31 DDGS samples ranged from 4.2 to 84.1 meq/kg oil.
  - The highest PV among DDGS samples was 27 times greater than that of the reference corn sample (3.1 meq/kg oil).



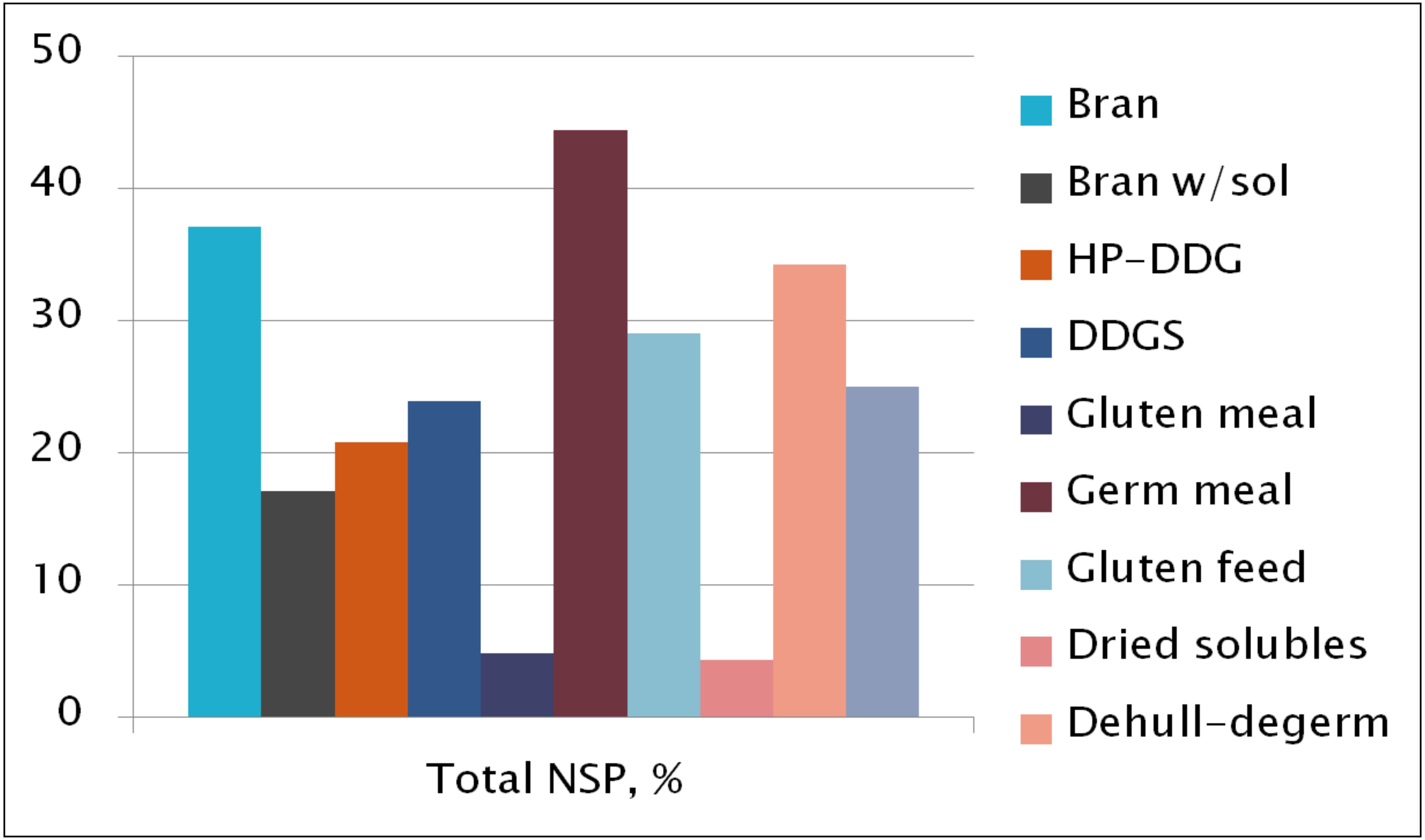
DE:GE and ME:GE of DDGS



DE and ME of DDGS

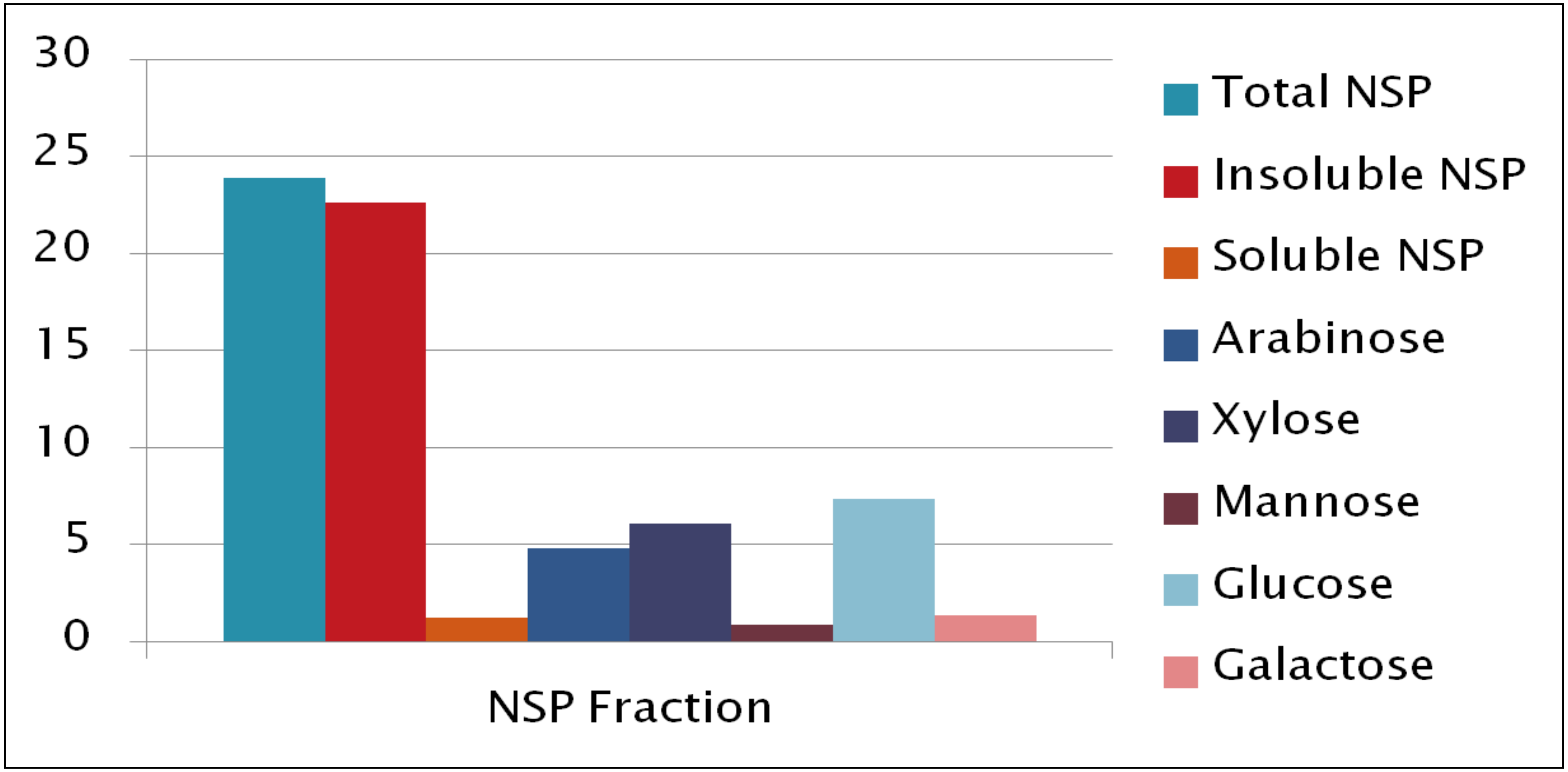


Total NSP of corn co-products (as-is basis, %)



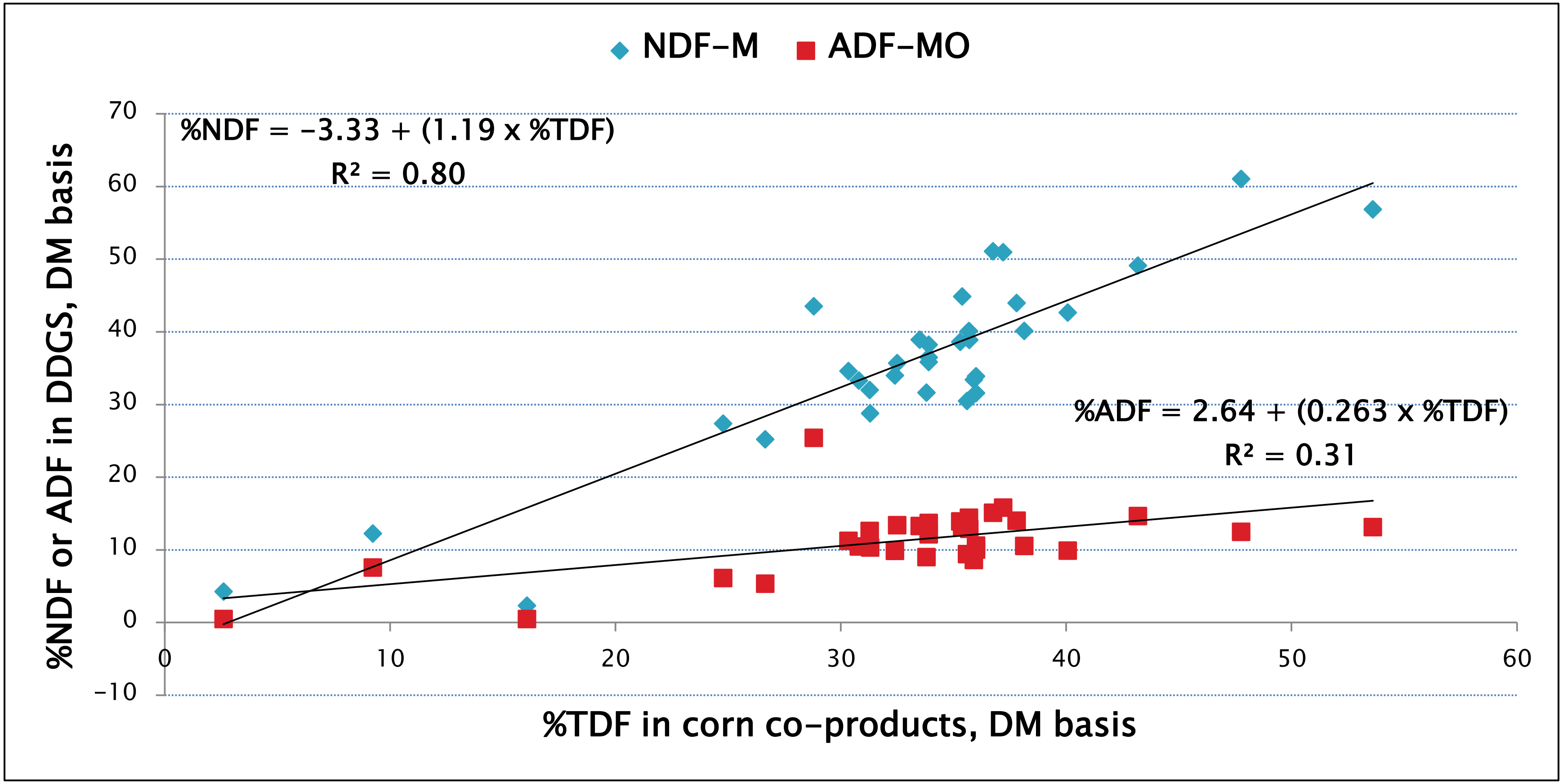
Patience and Kerr, 2010 (unpublished)

NSP composition of DDGS (as-is basis, %)

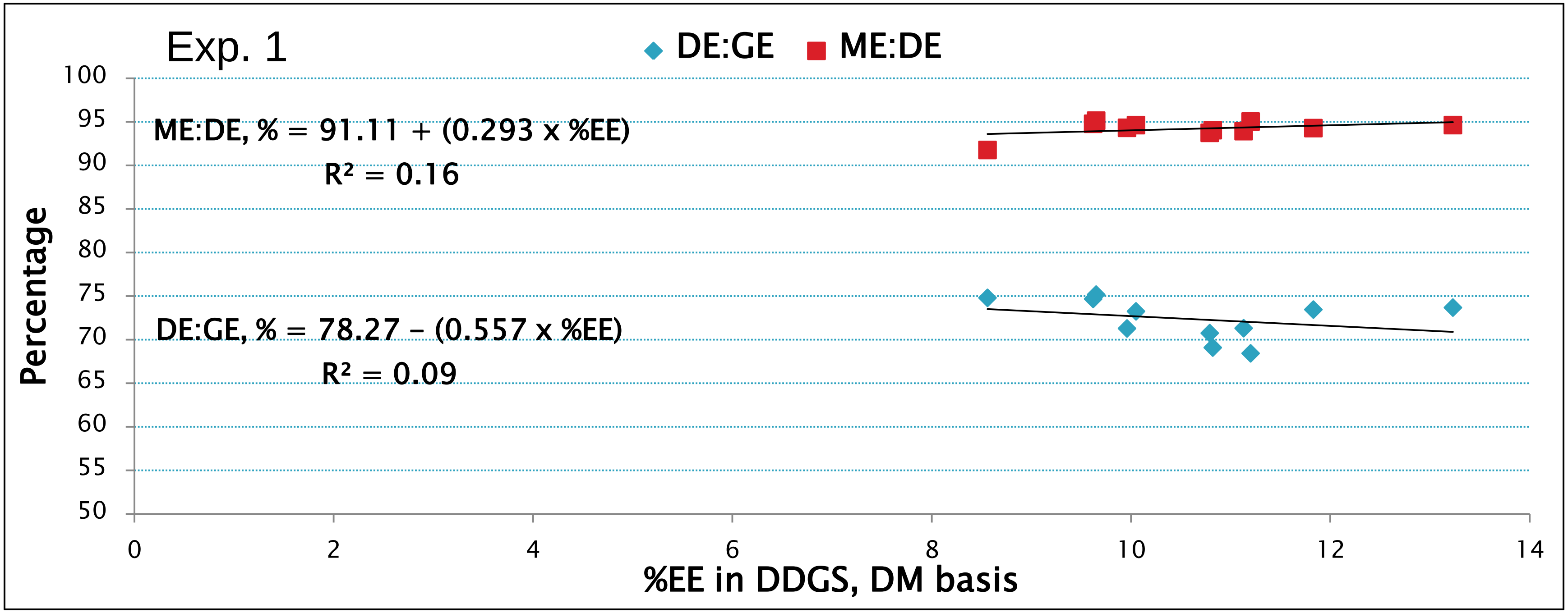


Rhamnose, ribose, and fucose analysis resulted in high lab error and data are not presented. Patience and Kerr, 2010 (unpublished)

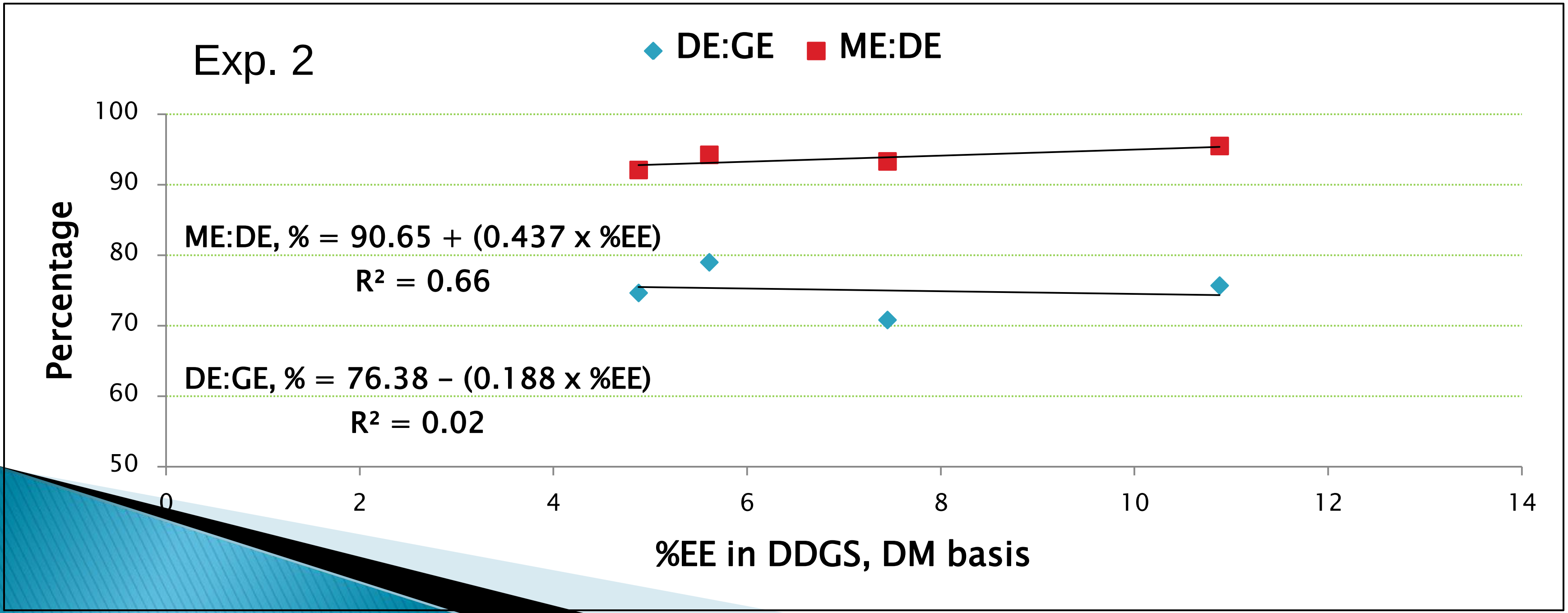
NDF and ADF relative to TDF



Anderson et al., 2012; Shurson & Kerr, 2012 unpublished

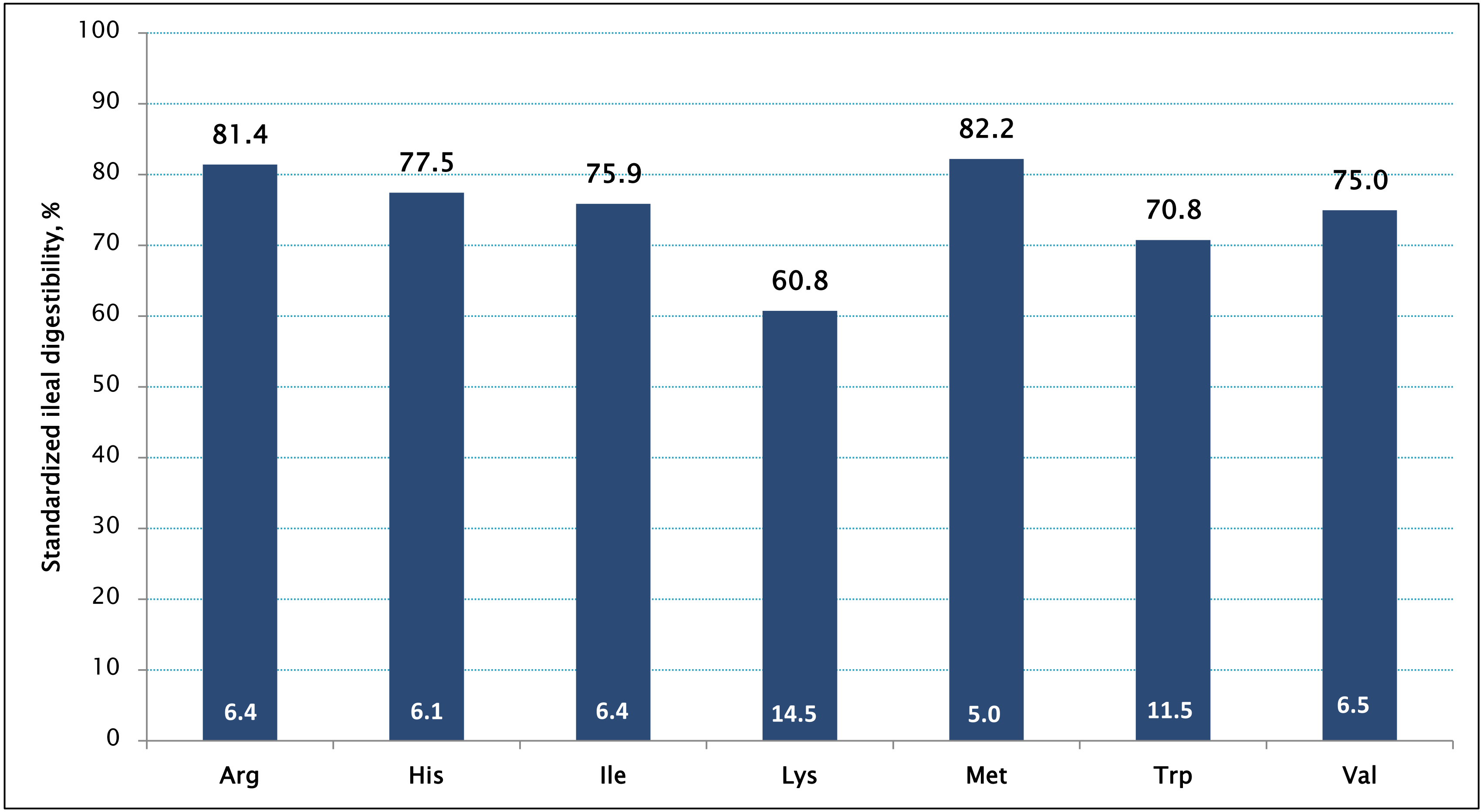


Exp. 1
DE:GE
ME:DE
100
95
90
85
80
75
70
65
60
55
50
Percentage
ME:DE, % = 91.11 + (0.293 x %EE)
R² = 0.16
DE:GE, % = 78.27 – (0.557 x %EE)
R² = 0.09
0
2
4
6
8
10
12
14
%EE in DDGS, DM basis



Exp. 2
DE:GE
ME:DE
100
90
80
70
60
50
Percentage
ME:DE, % = 90.65 + (0.437 x %EE)
R² = 0.66
DE:GE, % = 76.38 – (0.188 x %EE)
R² = 0.02
0
2
4
6
8
10
12
14
%EE in DDGS, DM basis

Standardized Ileal AA Digestibility



J. Anim. Sci. 84:853-860, 2006 (10); J. Anim. Sci. 84:1722-1728, 2006 (5); J. Anim. Sci. 86:2180-2189 (12); Asian-Aust. J. Anim. Sci. 22:1016-1025, 2009 (4); J. Anim. Sci. 87:2574-2580, 2009 (8); J. Anim. Sci. 88:3304-3312, 2010 (1); J. Anim. Sci. 89:1817-1829, 2011 (1)