Feeding sugar, starch, and fermentable carbohydrates for high producing dairy cows

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Goals for formulating diets for carbohydrates

- Provide low-fill, highly fermentable diets
- Maintain adequate ruminal pH
- Consistent fermentation over time

Carbohydrate Intake

starches, sugars

NDFiber

Fermentable carbohydrates

Highly Ruminally Available

Effective NDF

Digestible NDF

Physical NDF

Microbial Digestion

Stimulates Chewing

Saliva secretion:

80 gal/d 7 lb Na bicarb, 3 lb phosphate buffers

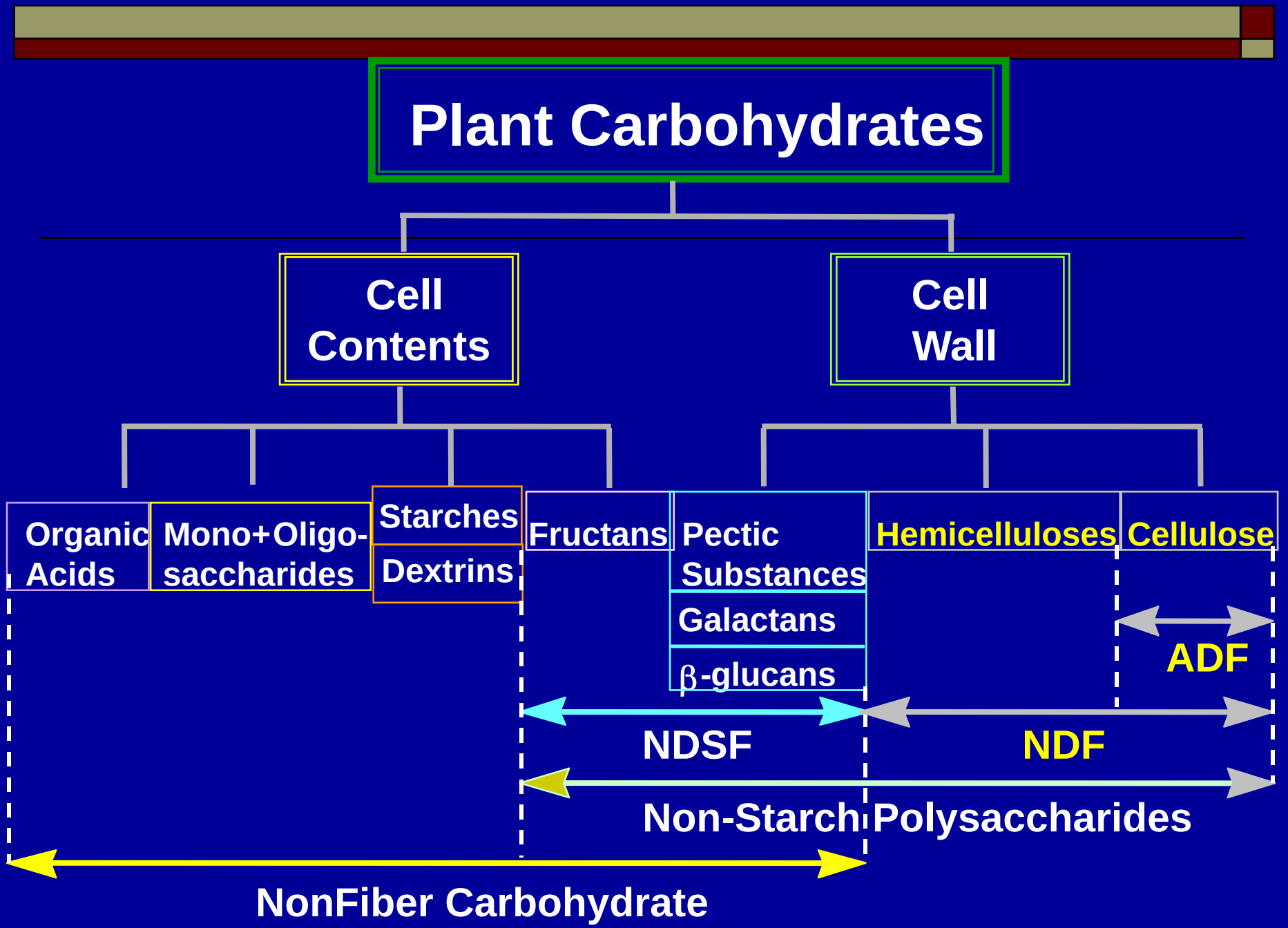
Acid Production from VFAs

Buffering agents:

NH3, forage, protein

What are nonstructural carbohydrates?

- Soluble component found in the plant's cell contents
  - Consist of
    - Sugars
    - Starch and Pectin
    - Fructans
  - Fermentation acids from ensiled forages
  - Bacteria love this stuff!!


Plant Carbohydrates
Cell Contents
Cell Wall
Organic Acids
Mono+Oligo-saccharides
Starches
Dextrins
Fructans
Pectic Substances
Galactans
β-glucans
Hemicelluloses
Cellulose
ADF
NDSF
NDF
Non-Starch Polysaccharides
NonFiber Carbohydrate

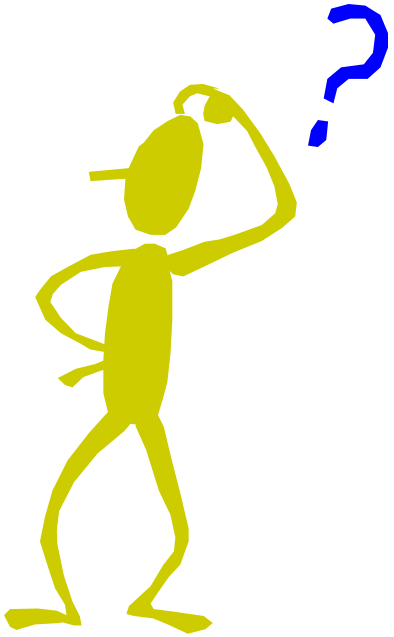
Hall, 2000

Major carbohydrates (CHO) and their fermentation end-products

	CHO	End-products
Alfalfa hay	Pectin; Starch	Acetate; Propionate/**Lactate**
Corn silage	Starch	Propionate/**Lactate**
Grass hay	Fructan, Sugar	Propionate/**Lactate**
Barley	Starch; b-glucans	Propionate/**Lactate**; Acetate
Corn	Starch	Propionate/**Lactate**
Wheat	Starch; b-glucans	Propionate/**Lactate**; Acetate
Beet pulp	Pectin; Sugar	Acetate; Propionate/**Lactate**
Citrus pulp	Pectin; Sugar	Acetate; Propionate/**Lactate**
Soyhulls	Pectin	Acetate

Starch in Dairy Rations

- How much starch is in feedstuffs?
- How available is the starch to digestion?
- How much can we feed?



Alternative Starch Sources

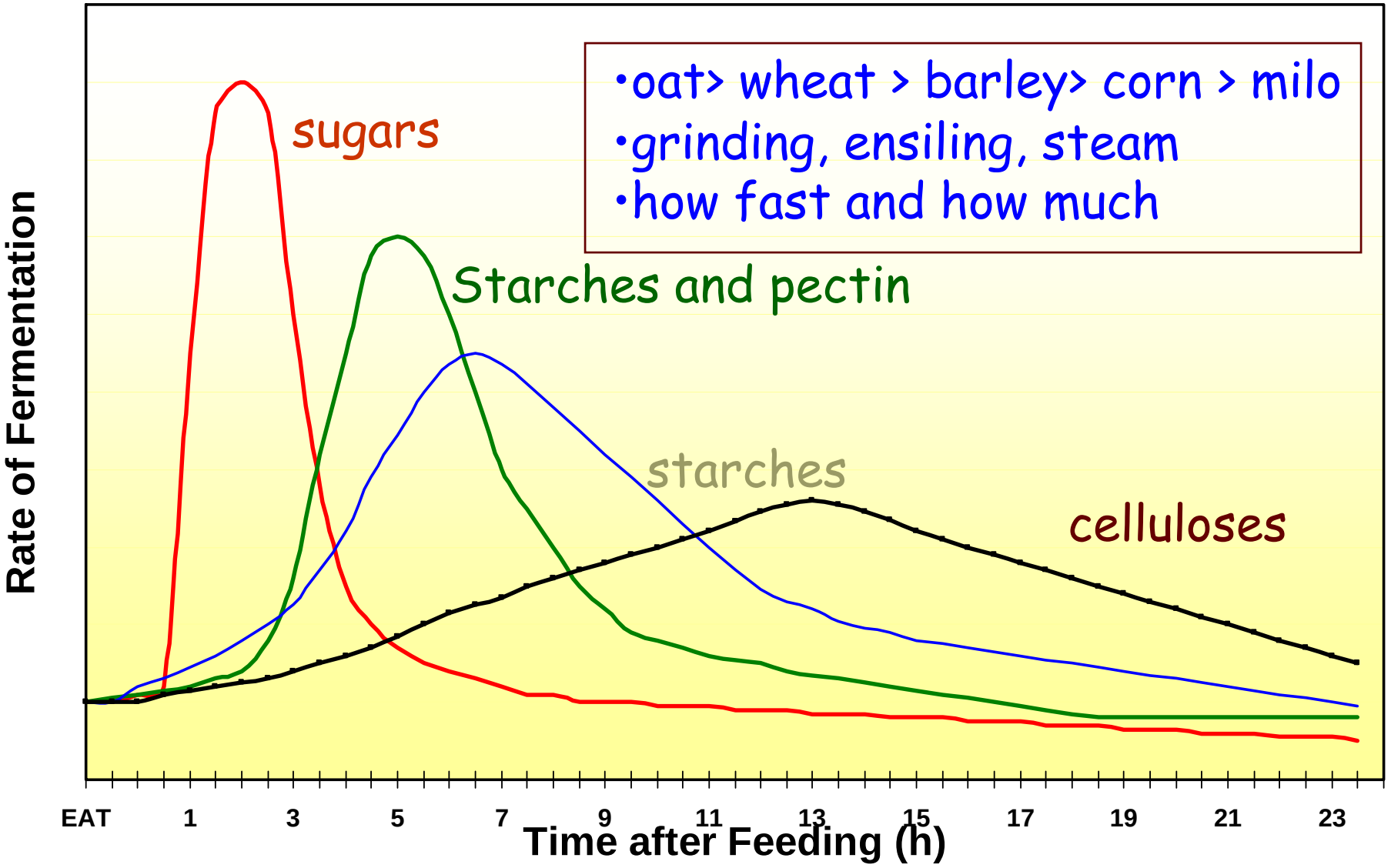
	Starch	Sugar	Sol Fiber
	----------%		----------
Wheat	64	2	3
Corn	70	14	0
Barley	58	2	3
Bakery waste	45	8	2
Corn gluten	20	2	3
Hominy	49	4	2
Wheat midds	22	5	6
Cookie meal	48	10	2
Molasses	0	61	0
Beet pulp	1	8-20	21
Citrus pulp	2	24	34
Corn distillers	3	4	8

Dietary starch content (DM%) of high producing herds surveyed in the US

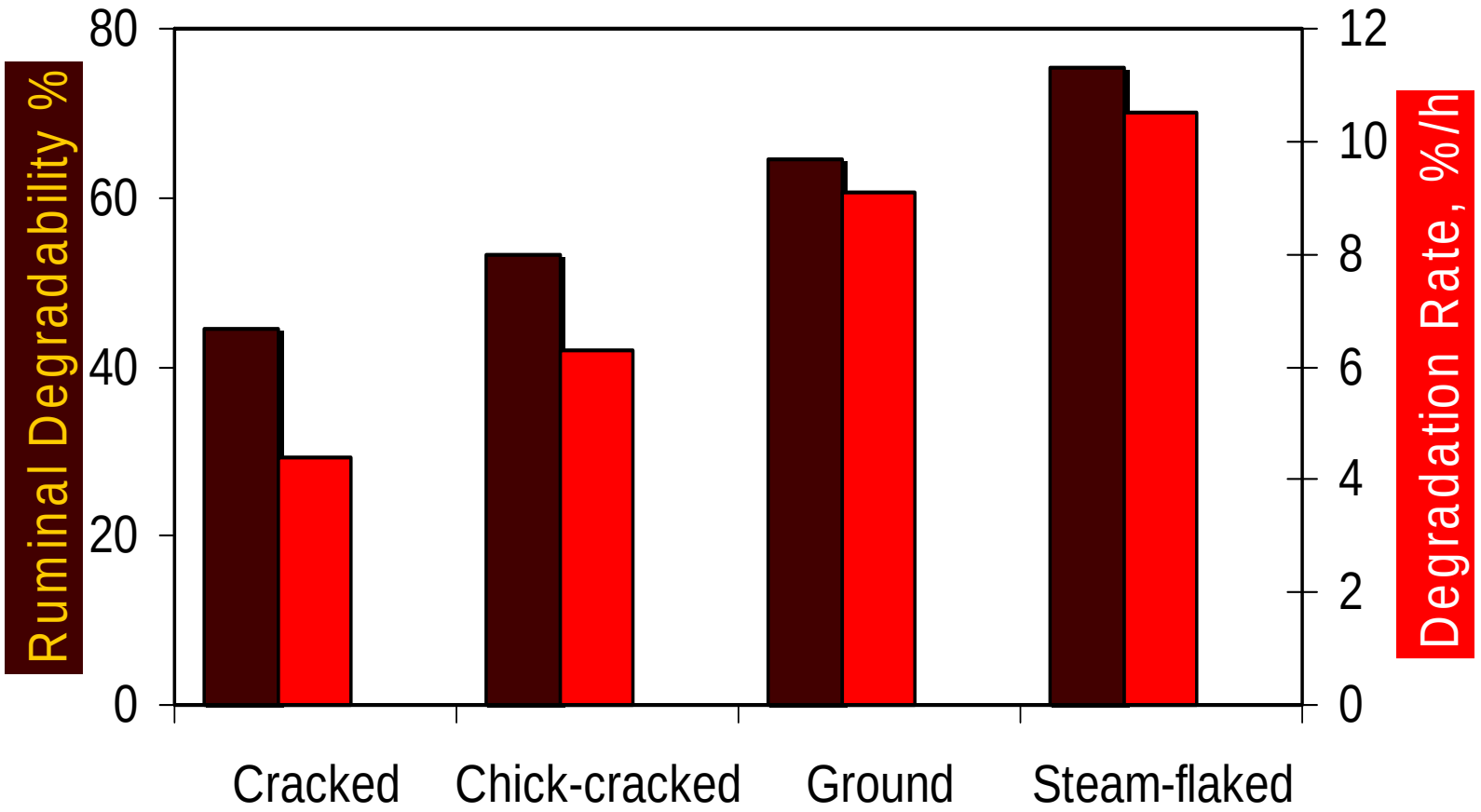
Reference	Region	RHA	Herds	Starch, % Minimum	Starch, % Maximum
Hall and Van Horn, 2001	US	-	-	15	27
Johnson et al, 2002	WA	28,000	7	17	25
Shaver and Kaiser, 2004	WI	29,000	6	25	30
Chase, 2006	East, Midwest	29,000	25	21	30

Dann and Grant, 2009

Ruminal Feed Carbohydrate Fermentation Profile



In situ starch degradability of corn



Lykos and Varga, 1995

Ingredient composition of low, medium, and high starch diets fed to lactating Holstein cows

	Diet		
Ingredient (%, DM basis)	Low	Medium	High
Corn silage	30.2	30.2	30.4
Grass silage	18.5	18.5	18.6
Alfalfa hay	5.0	5.0	5.0
Corn meal	3.4	10.1	16.9
Soybean meal, 48%	7.1	8.0	8.4
Beet pulp	6.7	3.4	-
Wheat midds	13.4	10.1	6.8
Distillers grain with solubles	9.7	8.7	7.8
Molasses	1.3	1.3	1.3
Urea	0.25	0.34	0.42

Dann and Grant, 2009

Analyzed chemical composition of diets containing low, medium, and high levels of starch.

	Diet		
Item	Low	Medium	High
DM, %	48.2	48.7	48.2
CP, %	17.4	17.6	17.2
Soluble protein, % CP	39.7	40.9	43.0
ADF, %	22.2	20.8	20.0
NDF, %	38.0	36.5	34.2
NFC, %	33.9	35.2	38.5
Nonstructural carbohydrates, %	22.6	24.9	28.2
Starch, %	17.7	21.0	24.6
Sugar, %	4.8	3.9	3.6
Ether extract, %	4.6	4.6	4.3
NEL, Mcal/kg	1.61	1.62	1.65
In vitro starch digestibility, 6 h	82.5	77.3	73.6

Dann and Grant, 2009

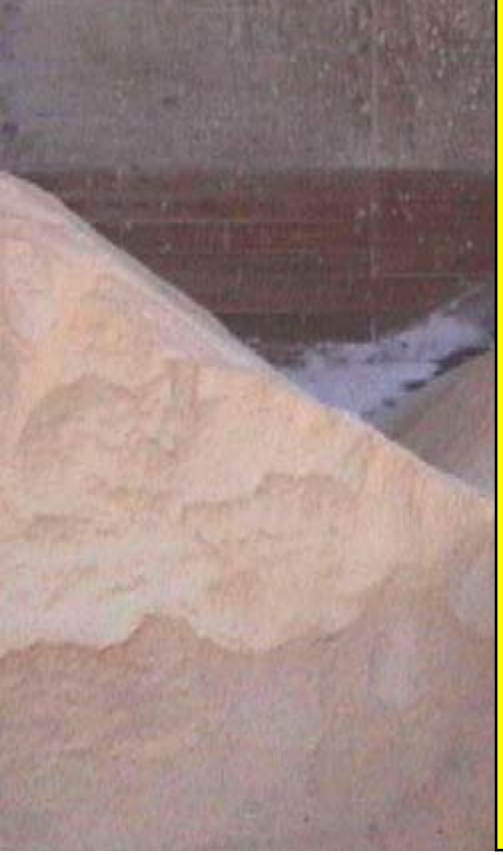
Lactational performance of low, medium, and high starch diets fed to lactating Holstein cows

	Diet		
Item	18% starch	21% starch	25% starch
DMI, lb/d	58	59	58
Milk, lb/d	94	96	97
Fat, %	3.57	3.57	3.48
Protein, %	3.09	3.18	3.14
3.5%FCM/DMI, lb/lb	1.64	1.62	1.68
Fermentable NDF, %	12.2	11.5	10.8
Fermentable starch, %	12.5	16	19.5
Fermentable soluble fiber, %	7.7	6.8	5.9
Fermentable sugar, %	3.5	3.2	2.9

Dann and Grant, 2009

NFC Levels for Various Ration Types to Maximize Microbial Growth

% NFC in TMR		When diet ingredients are:
33-36%	-	barley, wheat midds, HM corn, finely ground corn
37-39%	-	high quality hay crop forages; corn silage rations include non forage fiber sources (NFFS)
40-42%	-	high in average/good quality hay crop silage; corn silage (coarsely processed) rations when ration contains NFFS



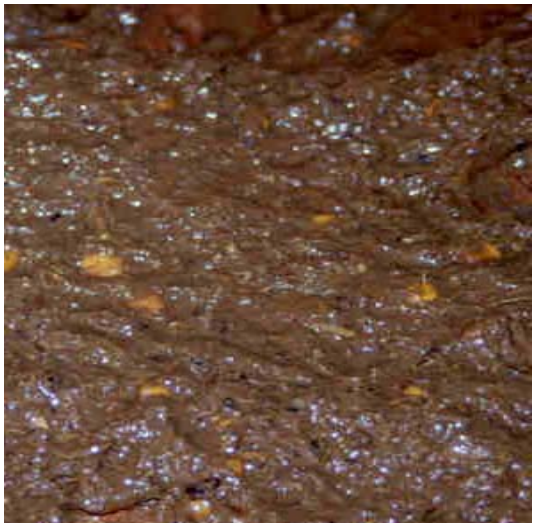
When Is Fine Too Fine and Coarse Too Coarse When Processing Grain?

Signs Too Coarse:

High intake

Poor performance

See seed or starch

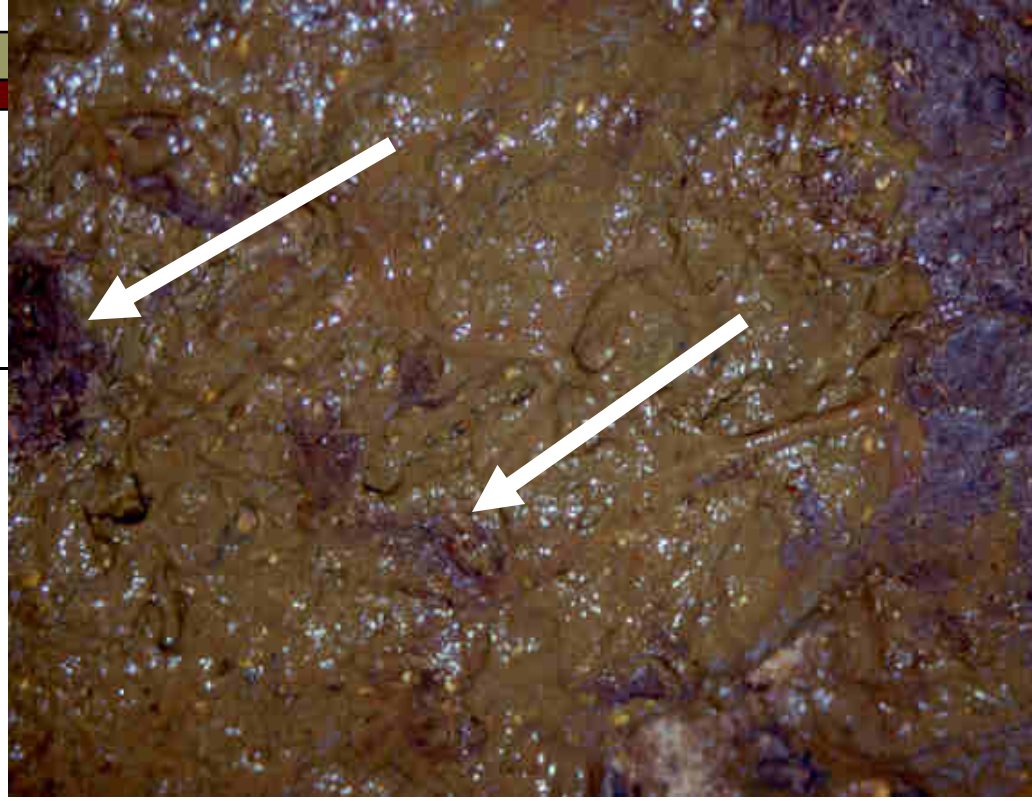


Signs Too Fine:

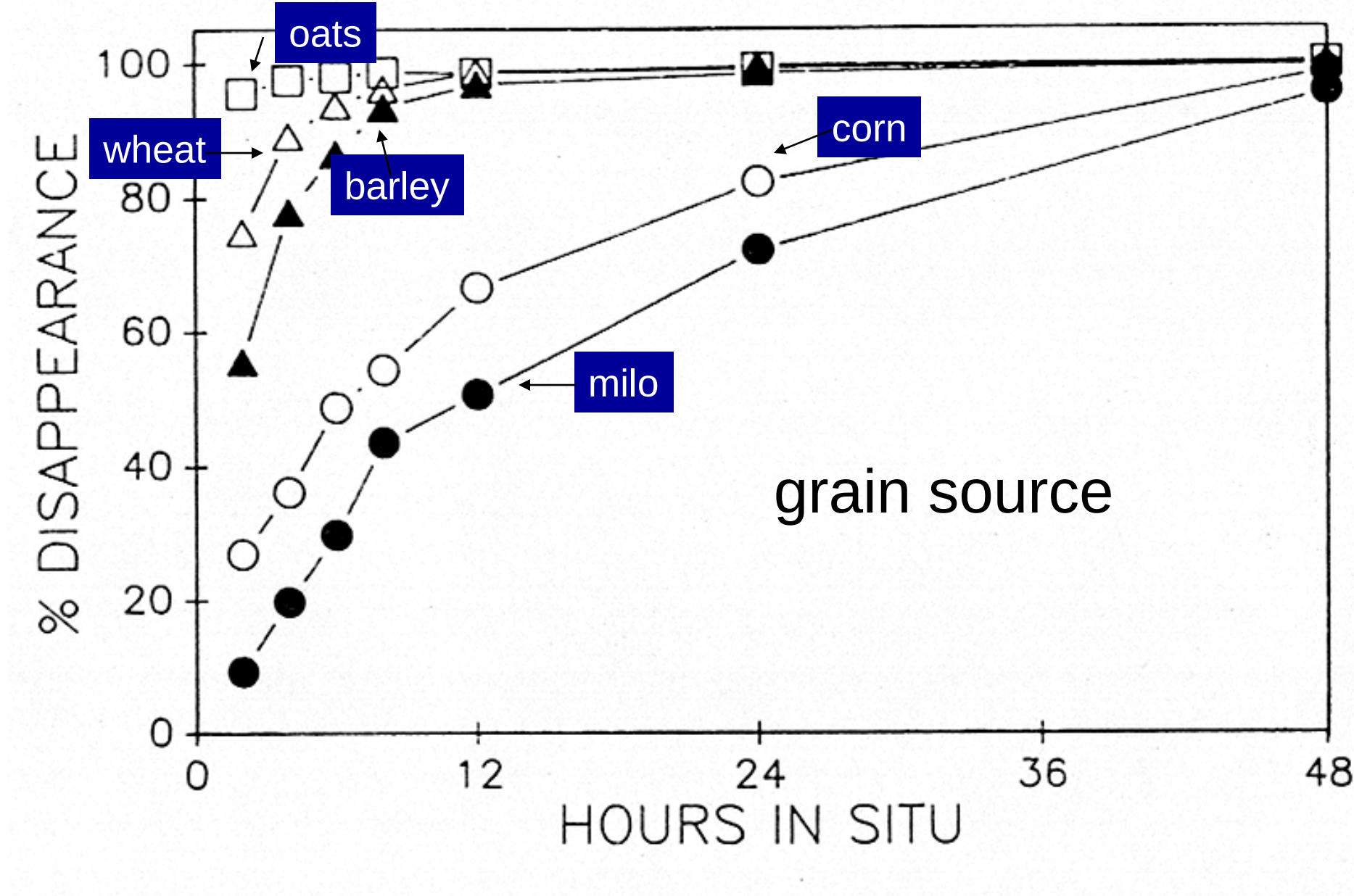
Acidosis

Sorting of grain

Depressed DM intake



If a great deal of fermentable material, usually mostly carbohydrate, reaches the hindgut, then diarrhea may occur due to an extensive hindgut fermentation and we may see mucins in the manure


oats
wheat
barley
corn
milo
grain source
% DISAPPEARANCE
100
80
60
40
20
0
0
12
24
36
48
HOURS IN SITU

Dry ground corn retained on #4 or 8 sieves may not digest well.

Finer grinds may be better utilized but amount fed, fiber feeding & feeding management must be good

Particle Size Guidelines

Screen size	#4	#8	#16	#30	Pan
H.M. Corn (>30%)	75	25	0	0	0
H.M. Corn (25-30)	25	50	25	0	0
H.M. Corn (<25%)	0	0	30	50	20
Dry corn	0	0	30	50	20

Hutjens recommendations

Particle size and feed source

Feed	Grind mm	Mean Size μm	<50 μm	In situ starch disapp. %
Barley	0.8	288	41.3	98.3[a]
	3.0	540	30.3	94.6[ab]
	6.0	1,267	17.9	90.9[b]
Corn	0.8	342	10.4	67.8[a]
	3.0	540	9.0	61.0[a]
	6.0	966	10.5	44.0[b]

kp = 0.06

Cerneau and Michalet-Doreau, 1991

[a,b,c] $P < 0.05$

Penn State Dairy Farm trial

2005	Fat, %	Protein, %	2006	Fat, %	Protein, %
Oct	3.62	3.06	Oct*	3.64	**3.12**
Nov	3.64	3.10	Nov	3.85	3.13
Dec	3.60	3.10	Dec	3.78	3.14
Average	3.62	3.08		3.72	3.13

switched to fine ground corn the middle of Oct

DMI, lb/d	Corn	Cow #	Feed cost	IOFC	DMI-Efficiency
62	Coarse	60	$4.05	$10.79	1.5
65	Fine	60	$4.26	$12.44	1.63

Cows averaged 95 lb milk/d; milk price $15.50/cwt; benchmark for IOFC:>$8

Effect of corn processing on milk production

Lykos, Varga and Casper, 1997	cracked	HMC ground	
DMI, lb/d	57	57	
Milk, lb/d	94	100	Latin square
Fat, %	3.5	3.4	
NDFiber dig, %	58	57	

Dann and Varga, 1999	cracked	steam-flaked (360 g/l)	
DMI, lb/d	46	45	
Milk, lb/d	95	99	9 week lactation study
Fat, %	3.5	3.3	
NDFiber dig, %	43	35	

Rumen fermentable carbohydrates, lb/d

	Low	High
Sugar + VFA	2.0	2.9
Starch + pectins + B-glucans	9.5	8.6
Available fiber	2.2	3.7
Rumen fermentable CHO, lb (%):	**13.6 (41)**	**15.2 (45)**

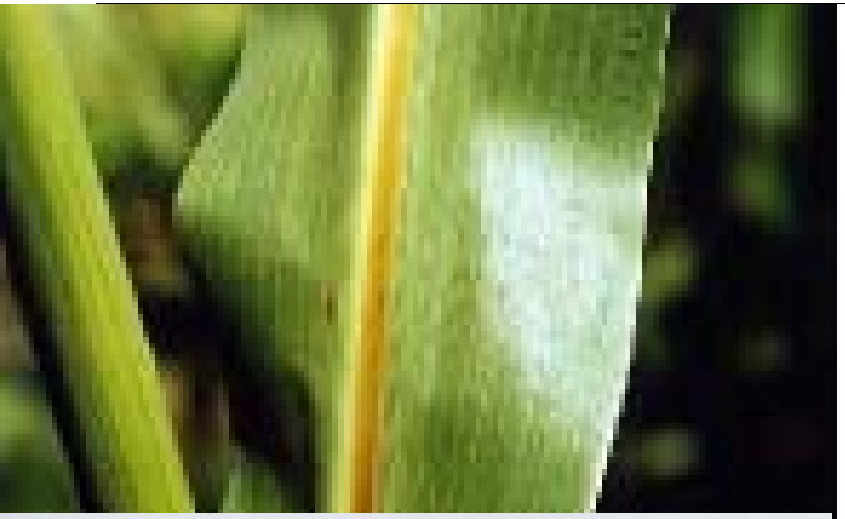
(~25 - 30% starch)

Lykos and Varga, 1997

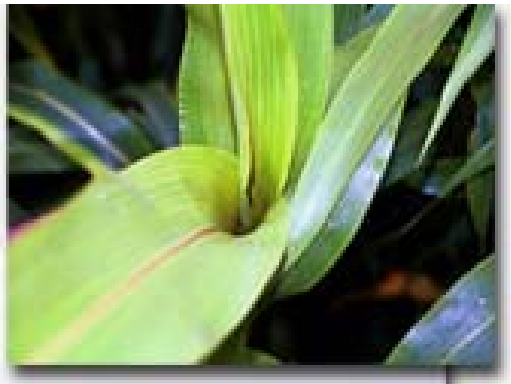
Warning signs of carbohydrate imbalance (excessive NFC)

- More corn in manure
- Loose manure
- Low milk production peak
- No milk persistency
- Increased incidence of ketosis, displaced abomasum, and reproductive problems
- ↓ DMI
- ↓ milk fat %
- Feet problems (laminitis)

Carbohydrates in balance for a healthy cow



Fermentable carbohydrates: Importance of corn silage



BMR vs. conventional corn silage studies

Multiparous cows fed the BMR CS during the transition period continued to produce ~ 2 kg more milk during wks 6 – 15 ($P < 0.09$)

Santos, Moreira, Wu, and Satter, J Dairy Sci, Vol. 84, Suppl. 1:1438, and USDA Forage Research Center Newsletter

At calving	BMR C S	Isogenic control	P <
Cumulative 3.5% FCM, kg			
0 – 50 dim	1779	1753	0.75
50 – 150 dim	3410	3198	0.02
150 – 300 dim	3927	3796	0.50

R. A Longuski, MSU thesis, 2003

Prepartum corn silage feeding study

Corn silage analyses

- Planted in 2005; trial went from 7-06 to 2-07

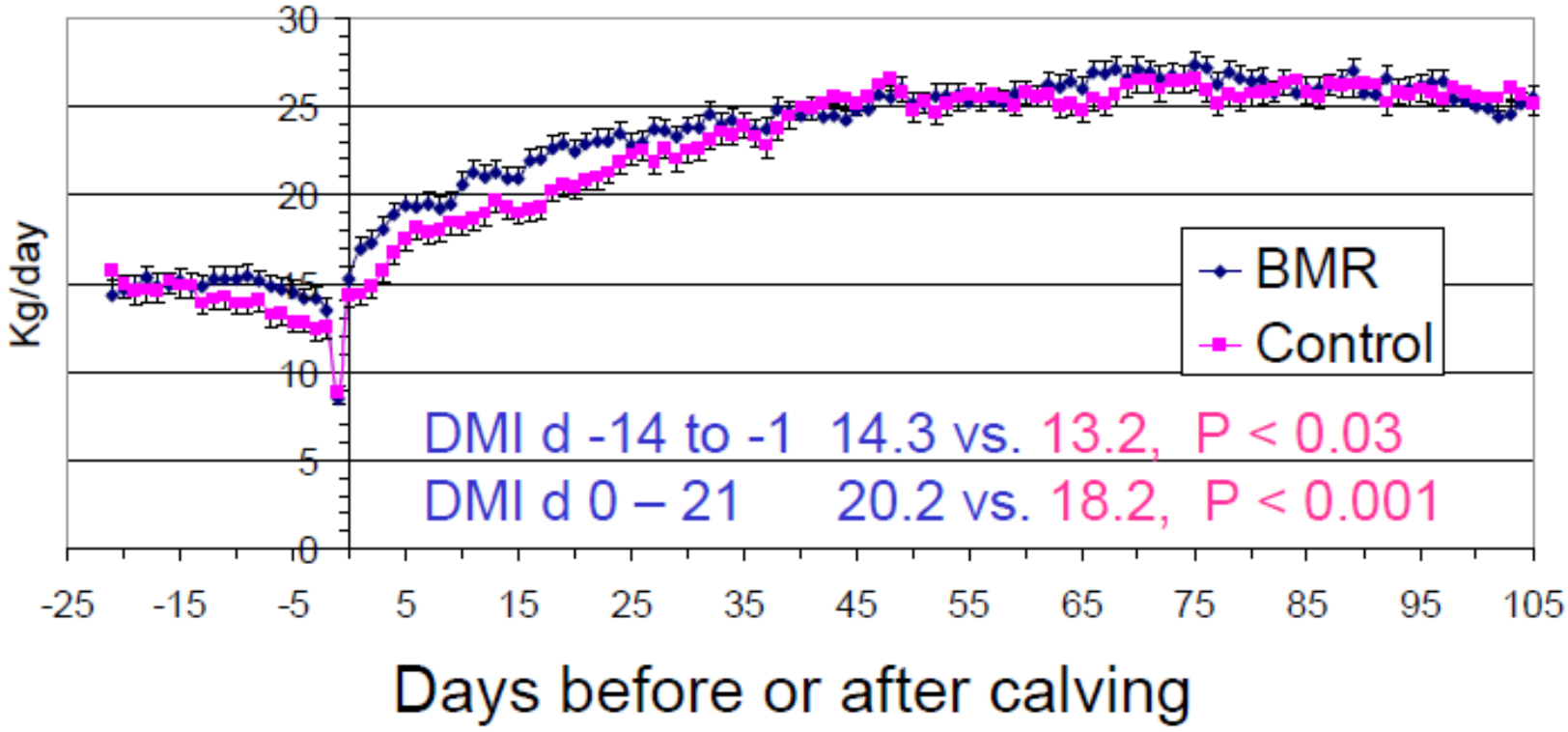
% of DM	Conventional		BMR
DM	31.2		29.8
Crude protein	8.5		9.1
ADF	26.1		25.8
NDF	44.1		45.5
Lignin	3.2		2.3
Starch	28.5		21.3
In vitro starch digestibility	68.1		69.1
Soluble fiber	2.9		6.2
Ash	3.7		4.1
Total VFA	10.1		10.4
pH	3.72		3.74
NDFd, 30 h	56.8	(17 points)	73.8

Prefresh - Diet Designs

% of TMR, DM	Dry Close Conventional	Dry Close BMR
Corn silage	46.4	47.8
Alfalfa haylage	7.2	6.9
Wheat straw	18.1	18.1
Corn meal	.8	3.6
Citrus pulp	7.2	7.2
Wheat midds	4.4	4.7
Corn gluten feed	1.4	1.8
SBM-48	5.6	2.9
Corn gluten meal	.5	.5
Blood meal	1.45	1.45
Feather meal	.5	.5

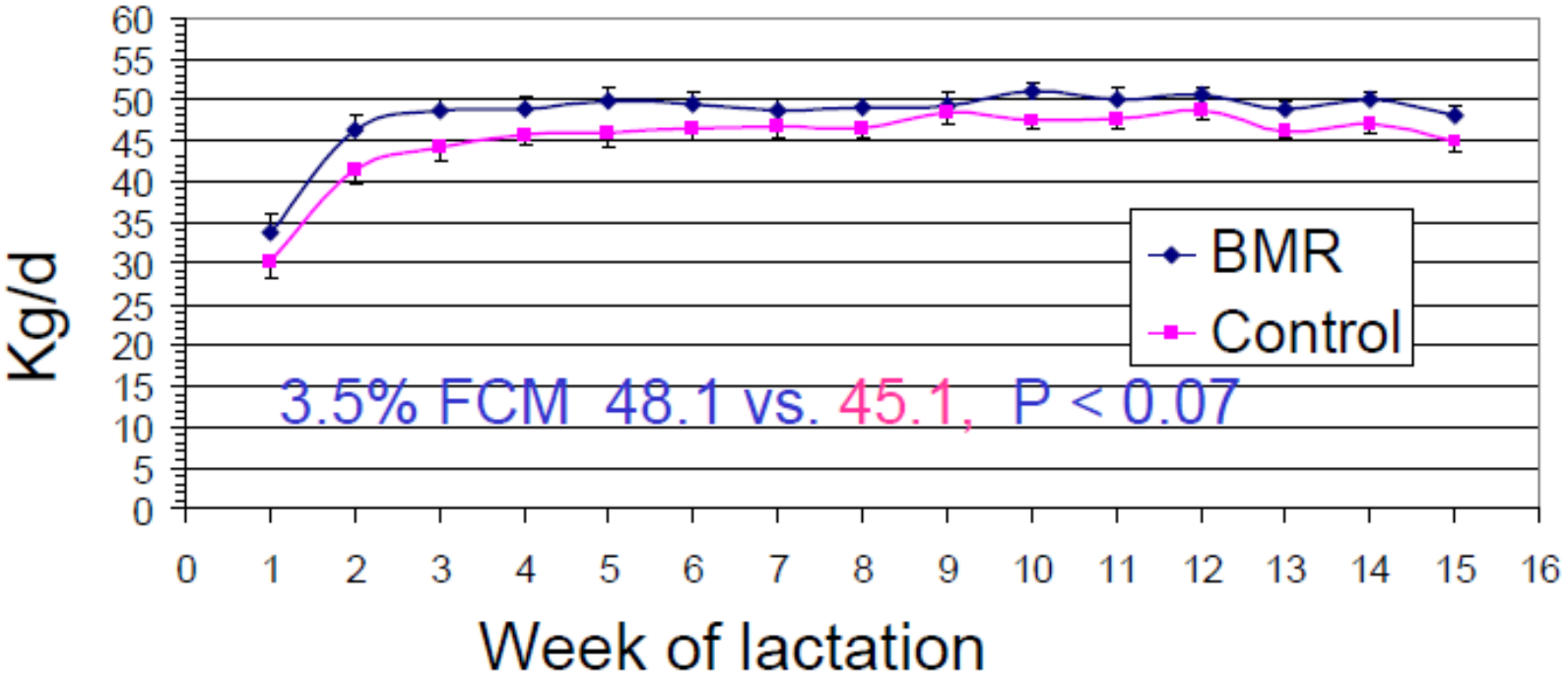
Stone et al, 2008

DMI of cows fed BMR or Conventional corn silage during the transition period



Stone et al, 2008

3.5% FCM of cows fed BMR or Control corn silage during the transition period



Fat, %	3.85	3.90	0.66
Fat, kg	1.63	1.76	0.068
True protein, %	3.06	3.01	0.72
True protein, kg	1.30	1.34	0.45

Stone et al, 2008

Penn State study comparing BMR vs. conventional corn silages at two inclusion levels

Nutrient Composition of Diets (% of ration DM)

	CONV35	CONV50	BMR35	BMR50
Crude Protein, %	16.3	16.1	16.1	16.1
Soluble Protein, % CP	28.4	28.4	29.7	29.7
RDP, % CP	53.4	53.4	54.6	54.5
ADF, %	21.8	20.8	21.6	20.5
NDF, %	34.0	33.5	33.6	32.9
Starch, %	24.3	27.6	25.2	28.4
NFC, %	40.6	42.7	41.2	43.3
Fat, %	4.8	4.7	4.8	4.8
Forage NDF, % DM	27.9	26.8	27.7	26.6

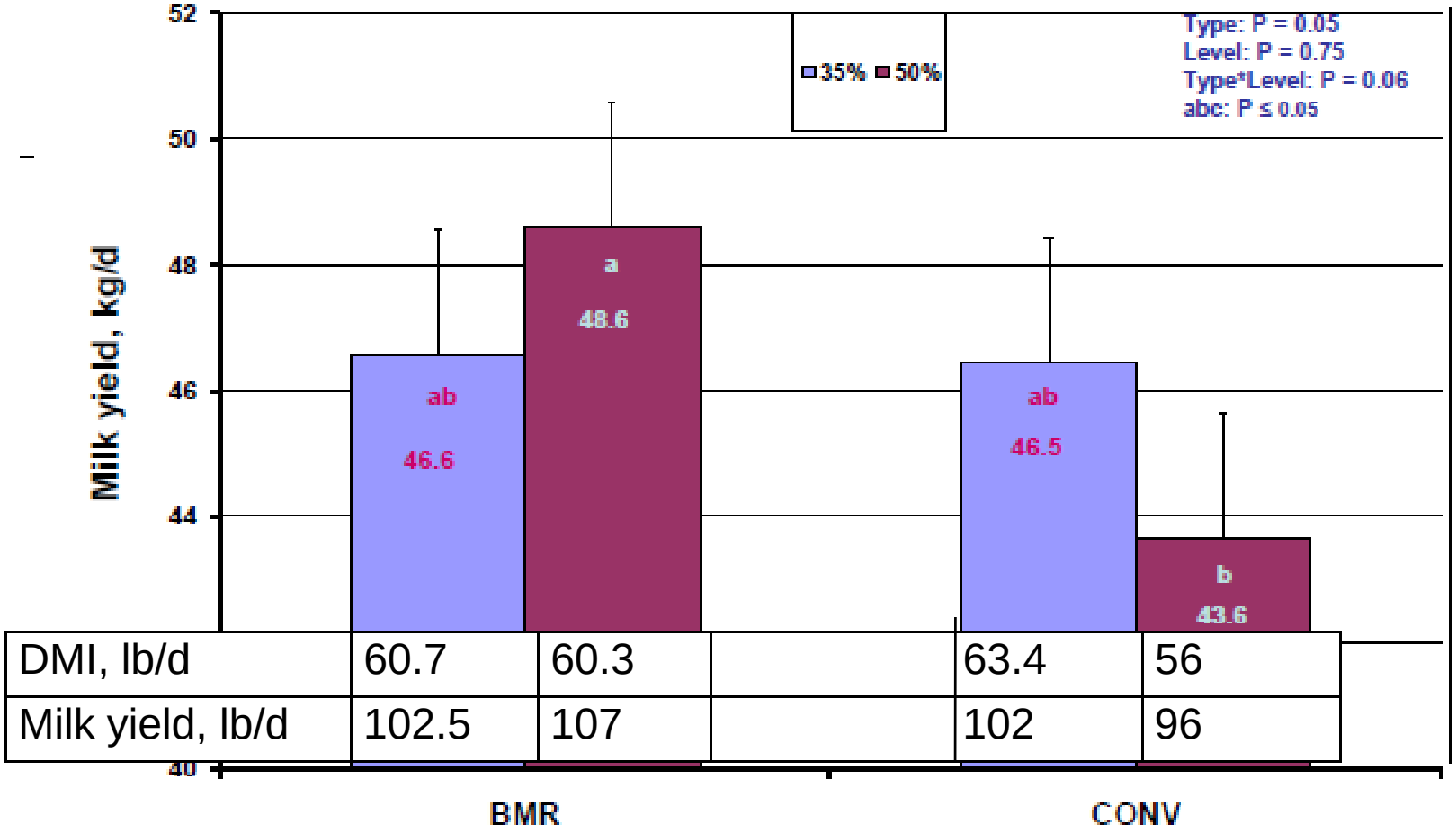
Edwards and Varga, 2008

Ingredient Composition of Diets (% of ration DM)

	CONV35	CONV50	BMR35	BMR50
Corn silage	35	50	35	50
Alfalfa haylage	14.8	0	14.8	0
Fine ground corn	8.2	4.9	10.1	6.8
Straw/grass hay	8.1	8	8.1	7.9
Roasted SB	7.6	7.6	7.6	7.7
Canola	7.0	10.6	5.5	8.4
Cookie byproduct	6.8	6.8	6.8	6.8
Sugar blend	4.3	4.3	4.3	4.3
Turbomeal	4.6	3.7	4.2	3.9
Vit & min	1.9	2.0	1.9	1.9
urea	0	0.25	0	0.25

Edwards and Varga, 2008

Interaction of corn silage type and level on milk yield



DMI, lb/d	60.7	60.3		63.4	56
Milk yield, lb/d	102.5	107		102	96

3.6 fat%
2.9% protein

Edwards and Varga, 2008

Effect of corn silage type on nutrient digestibility

	Treatment						
	35% BMR	35% CONV	50% BMR	50% CONV	SEM	Type	P-Value Level
	% Digestibility						
DM	55.64[a]	58.22[a]	65.20[b]	64.73[b]	1.81	0.58	<0.01
CP	51.28[a]	52.43[a]	60.04[b]	62.96[b]	2.32	0.42	<0.01
NDF	32.97[a]	34.17[a]	45.77[b]	40.13[ab]	2.67	0.45	<0.01

Edwards and Varga, 2008

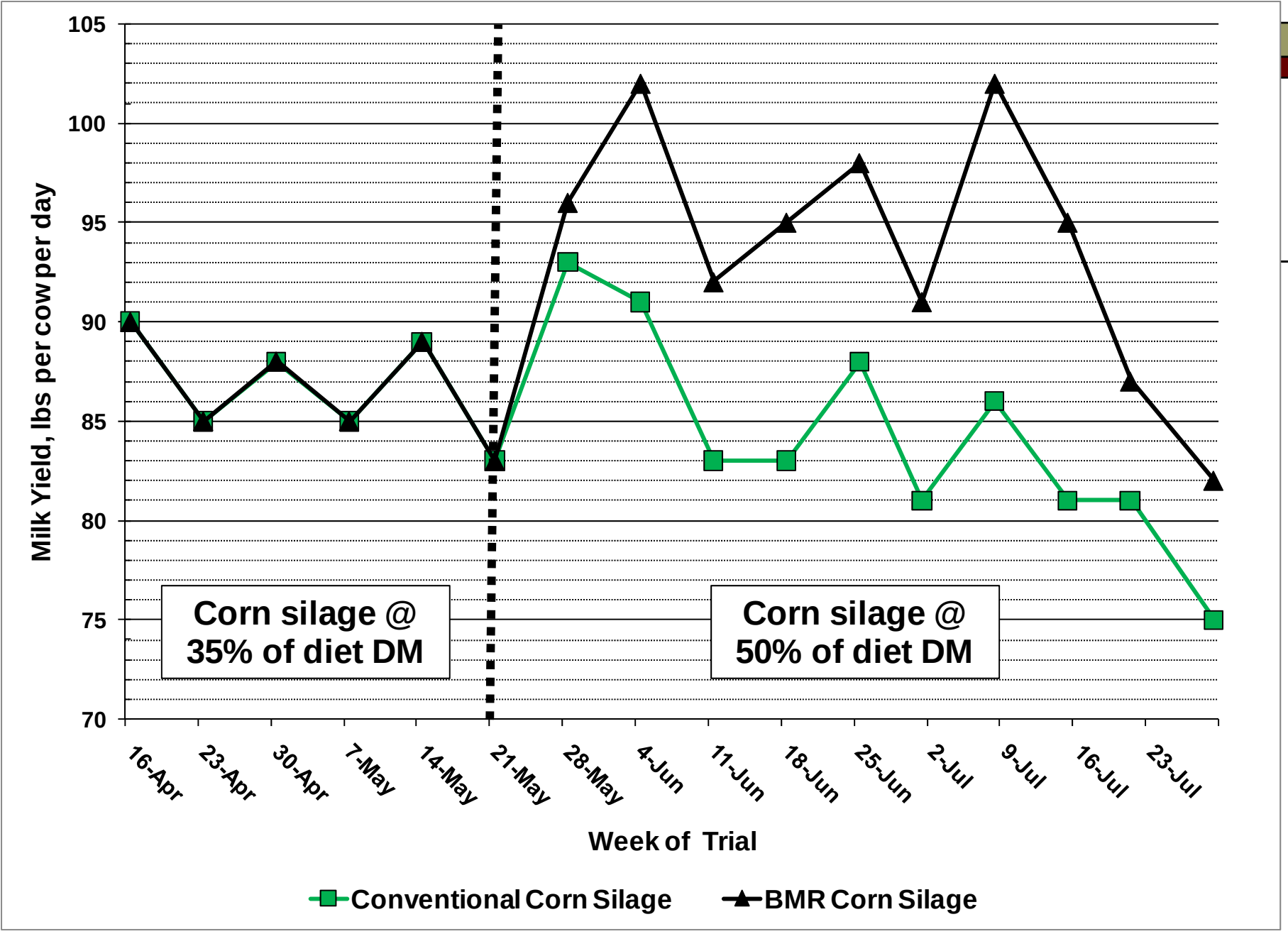
Penn State Study free stall companion study

Actual DM pounds

58% Forage Ration (CS at 35% of DM)	
BMR/Conv CS-39.5%DM	20.0
GRA HAY/STRAW	4.8
BAG 1 HLG-33.3%DM	8.7
GROUND CORN-PSU	6.0
COOKIE MEAL	4.0
SUGAR	2.5
SOYBEANS COOKED	4.5
CANOLA MEAL	3.3
TURBO MEAL	2.5
MIN-VIT MIX	1.9
LIMESTONE GD 38%CA	0.07
	58.5

58% Forage Ration (CS at 50% of DM)	
BMR/Conv CS-39.5%DM	29.3
GRA HAY/STRAW	4.6
GROUND CORN-PSU	4.0
COOKIE MEAL	4.0
SUGAR	2.5
SOYBEANS COOKED	4.5
CANOLA MEAL	4.9
TURBO MEAL	2.3
MIN-VIT MIX	1.9
UREA 45% N	0.15
LIMESTONE GD 38%CA	0.23
	58.5

Ishler, Varga and Edwards, 2008



Ishler, Varga and Edwards, 2008

Conventional vs. BMR corn silage
60 cows per group

	Milk lbs/d	Fat %	Prot %	DMI lbs/d	DMI Eff
BMR 35%	**93**	**3.7**	**2.9**	**61**	**1.7**
CONV 35%	**91**	3.7	2.8	61	1.5
BMR 50%	**94**	**3.7**	**3.0**	**61**	**1.6**
CONV 50%	**85**	3.6	3.0	58	1.5

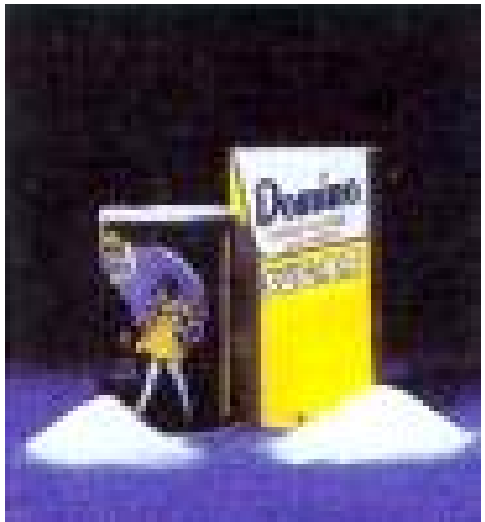
Ishler, Varga and Edwards, 2008

IOFC – 50% Corn Silage Rations

- BMR
  - Avg. milk income/cow = $20.62
  - Avg. feed cost/cow = $4.59
  - IOFC/cow = $16.03
- Conventional
  - Avg. milk income/cow = $18.65
  - Avg. feed cost/cow = $4.24
  - IOFC/cow = $14.41

Note: averaged for June and July

SUGAR FOR COWS



Sugar in diets for dairy cows

- Responses have been variable!
  - How sugar is fermented by rumen bacteria depends on diet
  - The types of sugars used
  - Fermentable carbohydrates
  - Rumen degradable protein
  - Fiber type and concentration

Sugar sources

Ingredient	*% Sugar*
Cane molasses	40-50
Liquid Supplements	~30
Bakery/Cookie Waste	5.5 – 16.6
Chocolate BP	29.6 – 34.1
Citrus Pulp	15 - 30
Beet Pulp	12 -13
Condensed Whey	16.5

Sugar contribution from feedstuffs

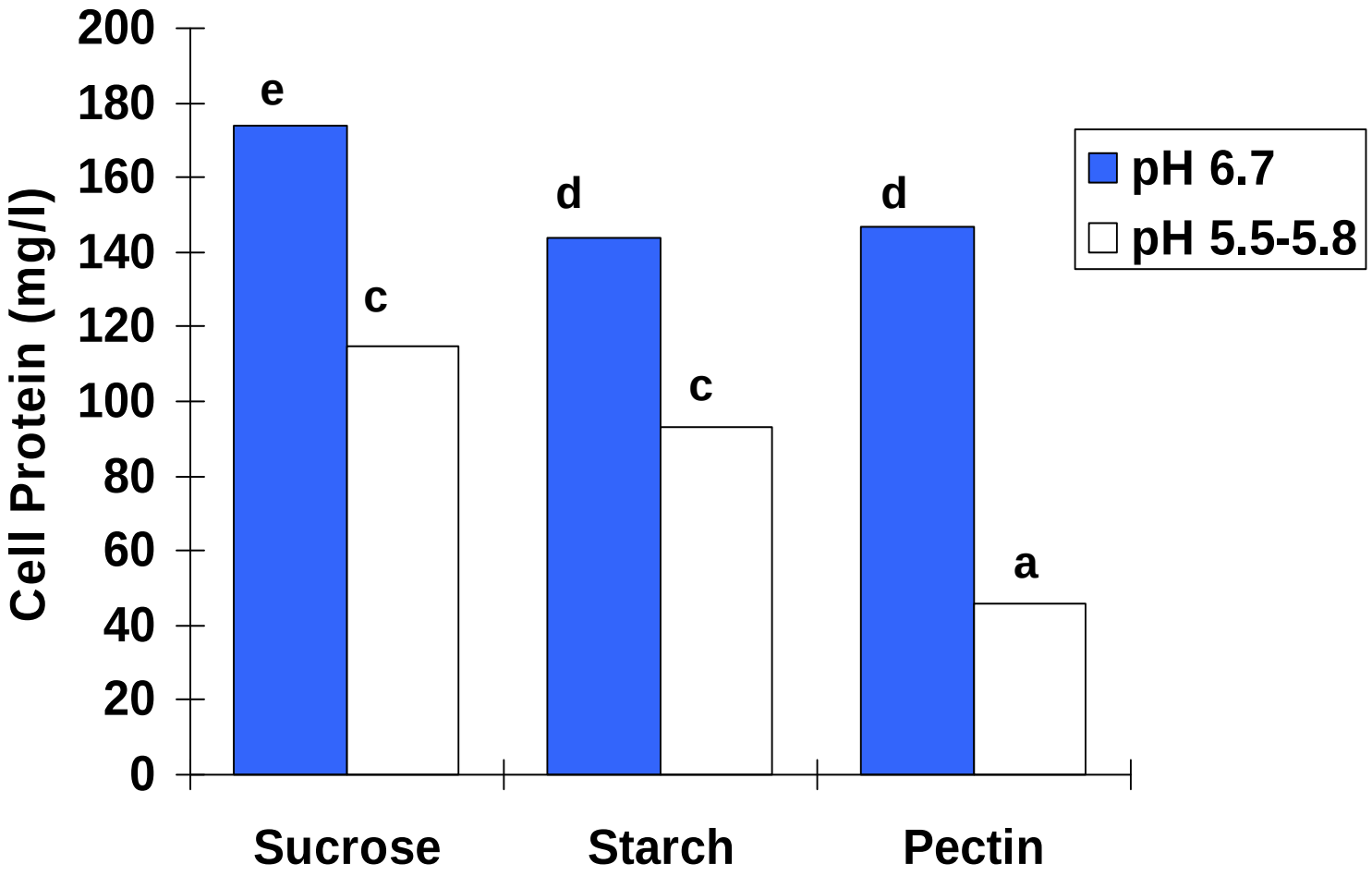
	Sugar % Range		Sugar % Range
Corn Grain	0.8 – 4.0	Alfalfa Hay	2.8 – 11.1
Soybean meal	10.4 – 11.8	Haylage	2.2 – 5.1
Corn Silage	0.7 – 8.4	Whole Cottonseed	1.5 – 2.2

Least squares means of organic acid production (mM).

Sucrose mg	Total Organic Acids 24 hour	Acetate 24 hour	Propionate 24 hour	Butyrate 24 hour	Lactate 4 hour
65	25.8	15.9	7.4	2.4	0.12
130	39.6	22.7	12.8	4.0	1.75
195	53.8	29.9	17.6	6.0	4.82

Hall, 2002

Microbial Cell Protein Produced From Fermentations by Mixed Rumen Microbes at Different pH In Vitro



Different letters differ, $P < .05$.

Stroebel and Russell, 1986

Starch vs. sugar effects on microbial metabolism

- Bacteria provided diets containing high proportions of RFC can accumulate appreciable amounts of polysaccharides
- High starch diets induce a more prolonged period of bacterial polysaccharide accumulation than diets containing soluble sugars
- Gradual release of polysaccharide may explain why the conversion of NPN to MCP is more efficient with starch than sugar

McAllan and Smith, 1974

Changes in milk yield and composition with changes in sucrose and starch supplementation.

	Added Sugar				
Variable	0.0%	2.5%	5.0%	7.5%	Linear
DMI, kg/d	24.5	25.6	26.0	26.0	0.01
FCM, kg/d	40.5	42.2	43.9	43.2	0.11
Fat, %	3.81	3.82	4.07	4.16	0.01
Protein, %	3.24	3.22	3.27	3.30	0.23

Broderick et al., 2007

Effect of replacing corn with sucrose on pH and VFA concentrations

	Added Sugar				
Variable	**0%**	**2.5%**	**5.0%**	**7.5%**	**P<**
pH	**6.05**	**5.93**	**5.91**	**5.97**	
	----------mol/100ml----------				
Acetate	**56.5**	**56.8**	**55.4**	**54.7**	
Propionate	**26.6**	**25.6**	**25.2**	**25.5**	
Butyrate	**14.3**	**14.9**	**15.8**	**16.6**	**0.08**
NDF digestibility, %	**61.3**	**58.8**	**59.4**	**66.1**	**0.15**
Starch, digestibility %	**82.9**	**83.7**	**82.6**	**85.3**	**0.06**

Varga et al, 2001

Why is there a lack of response to sugar at times?

- Wasting of energy by rumen bacteria- when supply of fermentable carbohydrates exceeds the needs for bacterial growth
- Fermentation of sugar generates more ATP than was needed by the bacteria for growth and maintenance
- Likely to occur on diets which already contain highly fermentable starch sources
- Or if rumen degradable protein supply is not adequate for the amount of fermentable carbohydrate
- If rumen ammonia N is high, adding sugar may not lower the ammonia N concentration because fermentation becomes uncoupled due to lack of amino acid N and an increase in fermentation rate

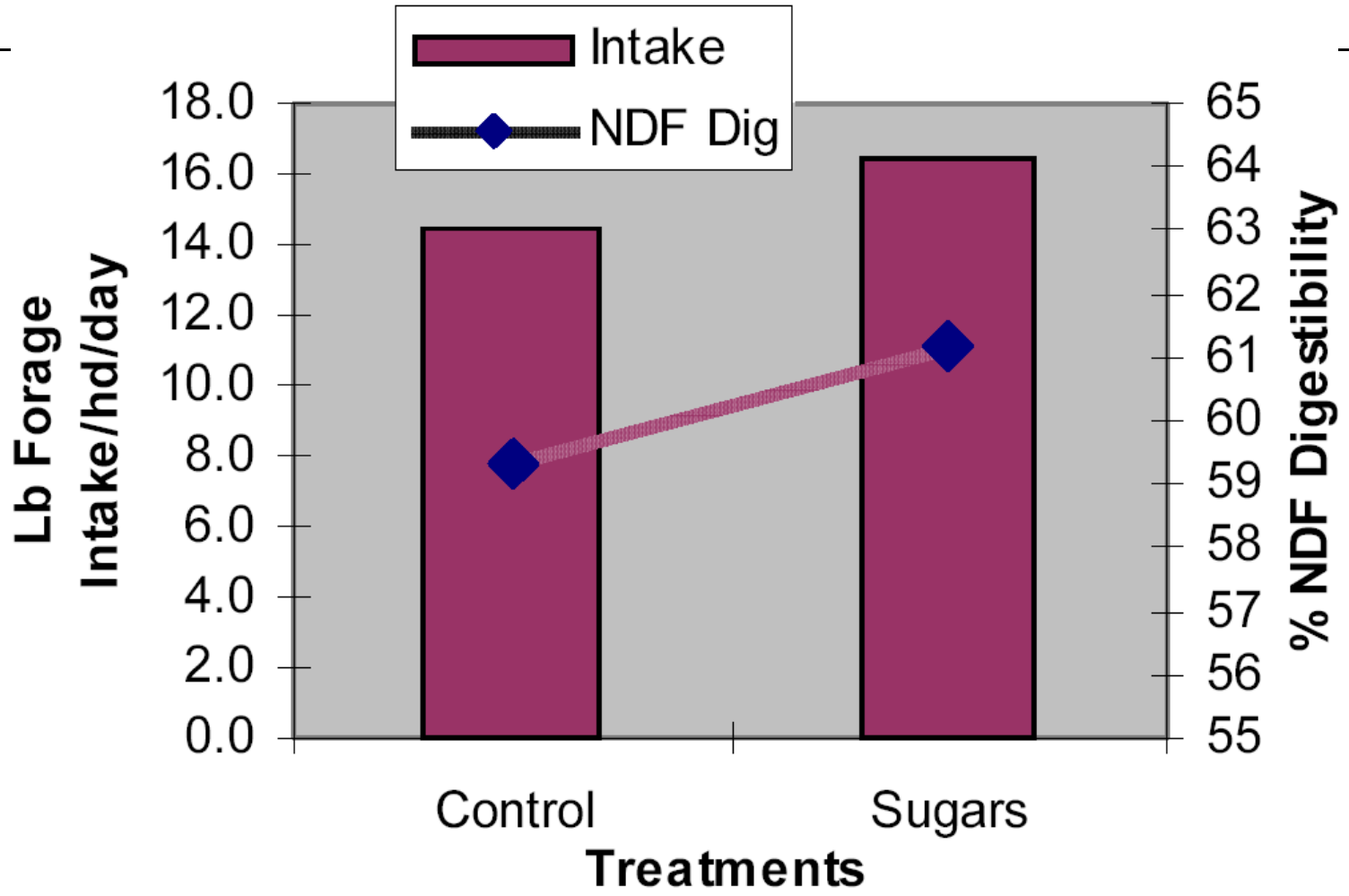
Effect of sugar

- When amino acid availability is low, S. bovis will use ammonia N as a N source
- When they use ammonia N as a N source the shift to lactate fermentation occurs at a slower growth rate
- To prevent a shift to lactate production, sugars need to be added to dairy diets in moderate amounts and in combination with protein sources such as soybean meal and canola meal

When to consider sugar feeding to cows

- Relatively mature hay, silage and haylage
- Silage and haylage that went through extended fermentation – likely to have happened if it was put up either too wet or too dry.
- High soluble protein in hay and haylage
- Low feed intake

Effect of Sugar on Forage Value



JAS ,1999

Sugar in diets for dairy cows

- Molasses based liquid supplements and sugar are readily digestible sources of energy for dairy cattle
  - May increase DMI and milk yield
  - May enhance fiber digestibility
  - Can altering ruminal microbial populations
  - When fed at less than 7% of ration DM can be used with similar efficiency as corn for milk production

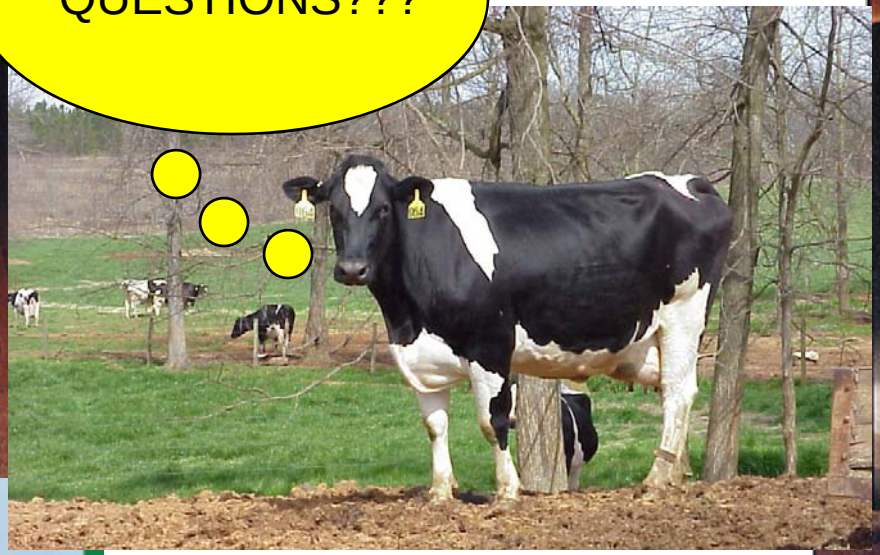
Tentative Carbohydrate guidelines for the early lactation cow

Nutrient	Lbs	% DM	Min, % DM	Max, % DM
DM	54			
Total NDF	16.2	30	30	34
Fermentable NDF	5.67	10.5	10.5	12
Sugar	2.7	5	4	8
Starch	13.5	25	21	27
Fermentable starch	11.3	21	15	22
Soluble fiber	3.2	6	4	8
Ferm. soluble fiber	2.7	5	3	7
NFC (no silage acids)	19.2	36	29	43

Sniffen and Hoover, 2004 with GAV swag

got milk?

QUESTIONS???



THANK YOU!