

Oklahoma State University

Cattle Grain Processing Symposium



November 15 - 17, 2006
Tulsa, Oklahoma

MP-177



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Prologue to the Cattle Grain Processing Symposium:

The Organizing Committee:

Chris Richards, Fred Owens, Clint Krehbiel, Gerald Horn, and Dave Lalman; Department of Animal Science.

The concept of this symposium as originally proposed by Fred Owens was to host a 30 year follow-up to the High Moisture Grain Symposium hosted in July 1976 by Oklahoma State University in Stillwater, OK. As the committee developed the program, the focus became broadened to encompass a wider range of grain processing to appeal to a larger audience.

Timeliness of the conference became evident as the industry was facing increased fuel cost affecting processing methods. As we reach publication of the proceedings, the industry is faced with historically unprecedented high grain and fuel prices due to competitive use of grains for bio-fuel, industrial and export needs. This is following several years of record production, but a wet spring over much of the Corn Belt threatening the current year's crop. This is pushing the need to optimize use of grains and to evaluate the effective use of byproducts from the bio-fuels industry for finished beef production. Additionally, demand for middle choice quality grade or higher beef remains strong while the industry is recording several years of decline in production of beef for that market.

Papers in this symposium represent the expertise of speakers selected and invited from the US and Canada by the organizing committee. Each proceeding paper represents research and opinions as represented by the speaker. It is not the intent of this proceeding to provide an extensive review of all grain processing, but rather create a platform for free and open discussion on related topics currently of interest to the industry.

John Matsushima and Jim Sprague agreed to provide historical perspectives, while Ken Eng and Mike Galyean provided summary highlight comments. Fred Owens graciously served as the primary reviewer for the proceedings and

provided an additional paper reviewing dry matter determination methodology.

A large thank you goes out to the sponsors listed below and on the back of the proceedings. The conference was held November 15th to 17th, 2006 at the Marriott Southern Hills in Tulsa, OK. About 181 people attended the conference including scientist and industry personnel from the US, Canada, Mexico, and Australia. These written papers were gradually prepared and collected after the fact from all speakers, edited, questions and answers transcribed and this proceeding published through Oklahoma State University. The organizing committee is indebted to the speakers who made time in their schedules and participated with very minimal compensation to present and write their findings and ideas for this symposium.

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Wednesday November 15

6:30 p.m. Welcome.....Chris Richards

Processing Background

6:40 p.m. Processing history.....John Matsushima

6:55 p.m. Processing application.....Jim Sprague

Grain Composition Basics

7:10 p.m. Nutrient composition of grains & processed grains.....Larry Berger

7:25 p.m. Starch type, structure & effect on digestion.....Tim McAllister

7:55 p.m. **Speaker panel/discussion**

8:10 p.m. **Reception**

Thursday November 16.....Moderator: David Lalman

Grain Processing Basics & Quality Control

8:00 a.m. Moisture addition & particle size reduction.....Leland McKinney

8:25 a.m. Steam flaking: consultant perspective.....Steve Armbruster

8:50 a.m. High moisture quality control & fecal starch.....Bob Lake/
John Thornton/Britt Hicks

9:20 a.m. Processing focused hybrids.....Steve Soderlund

Processing Comparisons

9:45 a.m. Advantages of feeding whole shelled corn.....Steve Loerch

10:10 a.m. **Break**

10:25 a.m. Flaked grain variables.....Chris Reinhardt/Jim Drouillard

10:50 a.m. High moisture grain: harvest & processing.....Terry Mader/Steve Rust

11:15 a.m. Reconstitution.....Mike Brown/Paul Defoor

11:35 a.m. **Speaker panel/discussion**

12:00 p.m. **Lunch**

Fermentation and Analysis.....Moderator: Gerald Horn

1:00 p.m. Fermentation aids.....Bill Rutherford

1:25 p.m. Protein, starch, soluble sugar, fiber and ethanol fractions, pH, acids.....
Dave Taysom

1:50 p.m. Processing adj. factors & dairy intake discounts.....Noah Litherland

2:10 p.m. Ruminal & postruminal starch.....Fred Owens

2:40 p.m. Absorption, energetics, utilization.....Kyle McLeod

3:05 p.m. **Break**

Processing Effects on Management

3:20 p.m. Processing costs/returns.....Tom Peters

3:45 p.m. Type & amount of protein supplementation.....Mike Brown

4:10 p.m. Type, form and level of forage.....Robbi Pritchard

4:35 p.m. Adaptation diets.....Clint Krehbiel

5:00 p.m. **Speaker panel/discussion**

Friday, November 17.....Moderator: Clint Krehbiel

Associative Effects and Management

8:00 a.m. Combinations of processed grains.....Rick Stock

8:25 a.m. Inclusion of co-products: university research.....Galen Erickson

8:50 a.m. Inclusion of co-products: industry prospective.....Rob Cooper

9:15 a.m. Inclusion of co-products: why the interaction?Andy Cole

9:40 a.m. Formulation of ruminant byproduct diets for fermentable NDF and non structural carbohydrates.....Mike Thonney

10:05 a.m. **Break**

Intake and Performance Limitations

10:20 a.m. Factors limiting feed/energy intake.....Jock Buchanan-Smith

10:45 a.m. Digestive disturbances: acidosis, laminitis, bloat.....Karen Beauchemin

11:10 a.m. **Speaker panel/discussion**

Conference Summary

11:30 a.m. Practical considerations.....Ken Eng

11:45 a.m. Research needs.....Mike Galyean

12:00 p.m. **Conclusion**

HISTORY OF FEED PROCESSING

John K. Matsushima
Colorado State University
Fort Collins, CO
matsushi@lamar.colostate.edu



INTRODUCTION

Since cattle have the ability to masticate and regurgitate the feed(s) which they consume we would assume that it was not necessary to process (mechanically or by other means) the feed for them. In the early days, conditions were different when cattle survived by grazing on pasture or were fed harvested forages and fed a minimum quantity of grain.

As time changed to increase the performance of animals it became necessary to increase the energy level in the diet by feeding a larger quantity of concentrates. Various grains became available. The cereal grains were found to possess varying characteristics such as shape, size, texture, etc. The

digestibility and palatability of these grains in their natural condition were found to be different to some degree. Through technology the development and introduction of processed cereal grains (as well as roughages) brought about the increase in animal performance and efficiency of meat and milk production.

CHRONOLOGY (HISTORICAL EVENTS RELATED TO FEED PROCESSING)

Although there have been numerous events that have transpired through the years in connection with feeding cattle, especially with high concentrate feeds, a few of these events are listed to tie in with history of feed processing. These events are listed in chronological order:

Chronology: Historical events related to feed processing

-
- 1800 Heavy grain feeding to beef cattle started in Ohio.
 - 1840 Corn sheller and hammer mill were invented.
 - 1852 Land-grant colleges endowed under Morrill Act.
 - 1885 Commercial feed manufacturing industry began in Chicago.
 - 1898 First publication of "Feeds and Feeding" by W.A. Henry.
 - 1908 American Society of Animal Science adopted (formerly American Society of Animal Nutrition and American Society of Animal Production).
 - 1920 Hybrid seed corn was produced and sold on limited basis.
 - 1939 The rumen fistula was introduced for digestion studies (by Michigan State University researchers, C.F. Huffman and associates).
 - 1942 Commercial cattle feeding began to emerge.
 - 1962 Flaked corn introduced to large feedlots.
 - 1963 The Net Energy system was designed by Lofgreen and Garrett for the beef cattle industry.
-

WHY PROCESS FEEDS?

There are several cereal grains that are available for livestock feeding. The production and harvesting rates as well as the prices of these grains usually varies with the geographical and climatic conditions. Livestock feeds (cereal grains) in harvested condition differ in many characteristics and therefore may be justifiable for processing prior to cattle feeding. These characteristic differences are noted in Table 1. The nutrient content of the grain may also be a contributing factor.

Table 1. Why process feeds?

Livestock feeds (grains) in harvested condition differ in:	
1. Size	
2. Texture	
3. Shape	
4. Maturity	
5. Moisture (length of storage)	
6. Palatability ???	

GRAIN PROCESSING METHODS

Prior to the introduction of hybrid corn around 1920, flint and dent corn were fed to fattening cattle.

This type of corn was hard and flinty. Hence, the practice of soaking the kernels emerged. An interesting trial in Kansas compared the performance of steers fed dry whole corn or whole soaked corn. Pigs followed the steers in each pen and the performance of pigs was also compared. The results provided the following thumb rule: “Ten pigs per ten steers.”

There was another interesting observation in scanning through the early history of feed processing. Although Indian corn was not commonly used for livestock feed this type of corn became a useful tool for “rate of passage” study. Again, the Kansas researchers fed two pens of steers – one pen was fed “white” colored whole corn and the second pen was fed “red” colored whole corn. The “test”

was to determine the “time” it took the kernels to pass through the digestive tract by counting the undigested kernels in the droppings every hour after feeding. White kernels were found to be easier to count and more consistent in the results.

There are probably more than a dozen different methods of processing grains for cattle, particularly feedlot cattle. Many of these processing methods were investigated between 1950 and 1975. During this period, there were more than 200 research trials that were published.

Among the various methods of processing grains it appears appropriate to classify them into two categories – Dry or Wet process. The processing methods with the beginning date of each method are shown in Table 2.

Table 2. Grain processing methods

Dry Process		Wet Process	
Method	Year Started ¹	Method	Year Started ¹
Grinding	1840	Soaking ²	????
Crimping	1930	Cooking, boiling ²	????
Pelleting	1957	Steam rolling (barley)	1930
Extruding	1966	Steam flaking (corn)	1950
Popping	1966	High moisture-ensile	1958
Micronizing	1970	Pressure cooker-roll	1966
Roasting	1975	Reconstitute ³ (milo)	1968
		Exploding (milo)	1972

¹ Approximate dates.

² These methods did not alter physical characteristics. Used for hard, dry grains.

³ Add hot water (160 °F), 20-30% moisture, cure 21 days in air tight silo, and roll.

THE BEGINNING OF COMMERCIAL CATTLE FEEDING

When commercial cattle feeding began to emerge in the mid to late 1940s, the race for the title of “King of the cattle feedlot industry” started. The three contenders were:

1. Warren H. Monfort, Greeley, Colorado
2. Louis Dinklage, Wisner, Nebraska
3. Earle Brookover, Garden City, Kansas

The three feeders met periodically, usually in West Point or Omaha, Neb., to discuss various means of improving their feeding operation. They invited John Matsushima from the University of Nebraska quite frequently. All three operators kept accurate records and agreed that the *feed cost* was the most expensive part of their business –

approximately 75 to 80 percent. What can be done to reduce this feed cost?

At one meeting in Omaha on a cold winter day when the temperature was several degrees below zero the three feeders and Matsushima were having breakfast. Instead of having the regular menu of bacon and eggs the four orders were either oat meal or corn flakes with “hot milk.” A bright idea flashed Matsushima’s brain -- “Why not feed corn flakes to the cattle in the feedlot?” The idea might have been good but the big question was “how will the corn be processed and who will do it?”

At another meeting in Omaha, in the late 1950s, it was decided to approach a large feed manufacturing plant, John Nixon & Co. to design an equipment to make corn flakes for a feedlot operation. Russ Kendall,

the mill operator and salesman for Nixon & Co. offered to assist.

Before the plans went too far along Matsushima was lured away from Nebraska to Colorado by Warren Monfort. Louis Dinklage's offer of a new

Cadillac to Matsushima to remain at Nebraska went for naught and the corn flake idea went to Colorado in 1961. The results from the first two feeding trials at Colorado convinced Warren and Kenny (son of Warren) to switch from ground corn to flake corn. In 1964, they installed 16 new flaking machines.

Table 3. Early corn flaking process, Colorado State University, 1962

-
1. No. 2 grade, 12% moisture corn used.
 2. Gravity flow of whole corn into 15 in. x 34 in. x 6 ft. steam chamber.
 3. Five steam jets located in chamber.
 4. Duration of steam treatment – 11 to 12 minutes.
 5. Temperature in steam chamber – approx. 200°F.
 6. Two corrugated steel rollers at bottom of steam chamber.*
 7. Setting of two rollers – produce 1/32 inch thick flaked corn.
 8. Moisture content of flaked corn leaving rollers – 20%.
 9. Denver Roll; Roskamp Mfg. and Ross Machine & Mill Supply.*
-

* 1962-1964.

PROTOTYPE DEVELOPMENT OF FLAKING MACHINE

In order to prepare “corn flakes,” starting with whole dry corn, it was necessary to have two pieces of equipment – one to add moisture to the dry grain and the other to flatten the kernels. To add moisture to the grain, steam is much faster than using ordinary cold water. To flatten the kernel that has been moistened, appropriate roller machine is necessary to make flakes of proper thickness. The production rate is very important and therefore the design of the moisture adding compartment must coincide with the capacity to which the roller equipment can handle.

In order to prepare the desired “corn flakes” for cattle feeding it took nearly two years to develop prototype flaking equipment. The assistance of three roller machine companies was involved. The most difficult portion of developing the prototype was the moisture addition (steam chamber) – the location and number of steam jets and the shape plus the dimensions (width, depth and length). Brief description and results in the prototype development of the steamed corn flakes are noted in Table 3.

EARLY FEEDING TRIAL (COLORADO)

While the prototype flaking equipment was undergoing several changes at Colorado State University a cooperative feeding trial was conducted with a small commercial feedlot. The results from this test are shown in Table 4.

As the commercial feedlot test was being completed another similar feeding trial was started at the Colorado State University research center. The results from the feeding trial are shown in Table 5.

DENSITY CHARACTERISTICS OF FLAKED GRAINS

Concurrently with the feeding trials various laboratory tests were conducted. One of the tests included the density (weight per volume) comparisons between flaked corn and cracked corn (Table 6). The milo comparisons are data from Oklahoma.

Theurer et al (1999) indicated “...decreasing flake density from 437 to 283g/l (34 to 22 lb/bu) of steam processed corn or sorghum increased the proportion of starch digested in the rumen and digestive tract, resulting in less dietary starch digested in the small intestine. Decreasing flake density increased N digestibility when fed sorghum grain but not when they were fed corn.”

Table 4. Flaked corn vs. cracked corn; 1962. First cooperative field trial. Colorado*

Treatment	Dry, Cracked Corn	Steam Flaked Corn
No. cattle	49	52
Initial weight, lbs	784.60	805.60
Final weight, lbs	1102.90	1140.80
Total gain, lbs	318.30	335.20
Avg. daily gain, lbs	2.51	2.64
Feed intake/day/head	20.28	19.77
Grain/lb of gain	8.08	7.50
Grain intake as percent of body wt, %	2.15	2.04
Roughage (dry basis) intake as percent of body wt, %	0.60	0.57
Dressing percent	64	63.74

*CSU in cooperation with Red Bird Feed & Grain Co., Eaton and Henry Schneider and Henry Ruff (commercial feeders), Ault, Colorado.

Table 5. Flaked corn vs. cracked corn vs. cooked-cracked corn*

Treatment	Regular Cracked Corn ¹	Cooked, Cracked Corn ²	Cooked, Flaked Grain ³
Initial weight, lbs	517	515	516
Final weight, lbs	920	896	904
Avg. daily gain, lbs	2.63	2.49	2.54
Avg. daily ration, lbs	21.20	21.80	19.60
Feed required/cwt gain (air dry), lbs	803	877	772
Dressing percent	61.70	62.90	62.90
Carcass grade ⁴	17.30	17.70	16.90

* 1963. Colorado.

¹ 70% corn and 30% barley mix.

² 70% corn and 30% barley mix; cooked 12 minutes at 200°F.

³ 70% corn and 30% barley mix; cooked 12 minutes at 200°F and rolled.

⁴ Ch+ = 18; Cho = 17.

Table 6. Change in weight per volume by processing

Corn ^a		Milo ^b	
	Wt/bu, lbs ^c		Wt/bu, lbs ^c
Whole dry corn	56.5	Whole dry milo	59.1
Regular cracked corn	50.6	Coarsely ground	49.7
Steam flaked	24.2	Steam flaked	23.3

^a Colorado State University.

^b Oklahoma State University.

^c Air dry basis.

Swingle et al (1999) reported that “Steam flaking of sorghum grain improves feeding value by 12-15 % principally by improving digestibility of starch in the rumen and total tract. Optimal flake density for steam flake sorghum appears to be 360 g/l (28 lb /bu).”

Daily feed intake, daily gain, feed efficiency and carcass grades between the two comparisons

were quite similar. (Hence, small feedlot operations can use flaked corn that was processed several days before feeding). Zinn and Barrajas (1997) reported “Retrogradation or loss of starch solubility was not enhanced by air drying corn after steam flaking. The characteristics of digestion and hence the feeding value of steam flaked corn are not altered by air drying before feeding.”

Table 7. Findings from early trials*

1. Flaked corn was lower in density vs. cracked corn:
27 lbs/bu (flaked) vs 38 lbs/bu (cracked) at 13% moisture. (Approximately 30% lighter.)
2. When fed in feedlot rations, flaked corn ration resulted in lower feed intake but daily gains were similar to cattle fed cracked corn.
 - (a) Hence, feed efficiency was increased 8 – 10%.
 - (b) No difference in carcass grade.
3. Results were comparable when flaked corn was fed *immediately* after processing or *air dried* to around 15% moisture and then fed.

*1962-1964. Colorado.

Table 8. Early questions on feed processing¹

1. Which grain processing method improves "feed efficiency" in feedlot cattle?
2. What factors account for this increase in feed efficiency?
 - a. Increase in density of processed grain?
 - b. Change in surface area for easier access to rumen microorganisms?
 - c. Change in starch (gelatinization)? (birefringence)?
 - d. Increase in moisture absorption?
 - e. Change in rate of passage through digestive tract?
 - f. Shift in proportion of volatile fatty acids?
 - g. All of the above?

¹ Timeframe: 1960 – 1980.

Table 9. Water uptake of corn particles due to processing*

Method of Process	Soaking Time Minutes	Water Uptake, grams/ 100 grams
Dry roll (cracked)	1	43
Flaked	1	90
Dry roll (cracked)	10	49
Flaked	10	75
Dry roll (cracked)	30	60
Flaked	30	153

* 1966. Colorado.

EARLY QUESTIONS ON FEED PROCESSING

In the early stages when the flaking process of grain, particularly corn, was getting under way (Table 7), there were many unanswered questions. These questions are listed in Table 8.

EFFECT OF PROCESSING ON MOISTURE ABSORPTION

Undoubtedly there are many factors that will determine the extent of moisture absorption in the *processed* grain. Table 9 shows the rapid rate of water absorption by flaked corn as compared to cracked corn.

Moisture absorption in whole dry corn in the steam chamber can be increased at a faster rate by the application of a tempering agent.

EFFECT OF THICKNESS OF FLAKES

The flaking process introduced a number of questions when the method emerged. One of these was: "How 'thick' should the flakes be?" Results from the first feeding trial at Colorado (1967) indicated that "thin flakes" appeared to be superior to "thick" flakes. (Table 10). Average daily gain was 4.3% greater by the steers fed the thin flake and feed efficiency was 7.8% superior as compared to the steers fed the thick flake.

Table 10. Thickness of flaked corn*

Treatment	Thin 1/32 in	Thick 1/12 in	Fine Ground 1/4 in
Initial weight, lbs	485	483	490
Final weight, lbs	946	923	922
Avg. daily gain, lbs	2.82	2.70	2.65
Avg. daily corn consumption, lbs ¹	(12.41)	(12.66)	(12.83)
Avg. daily feed consumption ¹			
Feed consumed/ lb gain ¹	6.14	6.66	6.88
Dressing percent, %	64.21	63.71	63.25
Carcass grade: % Choice	93	92	92
% Good	7	8	8

* 1967. Colorado Expt. Station.

¹ Air dry basis.

Osman et al (1970) indicated "...degree of increase in starch digestion in barley and sorghum grain appears to be linearly related to thickness of flakes, thinner the flakes, the better the grain is utilized."

Zinn (1993) found that "steam processing in addition to rolling will further increase the net energy for maintenance value of barley by 2.8 to 7.0%, depending on the thinness of the flake. The comparative feeding values of dry-rolled, steam rolled course, and steam-rolled thin barley are 90, 92, and 96% of the value of steam-flaked corn."

Brown et al (2000) suggested that the optimum rate and efficiency of gain in feedlot steers occurred when corn was steam flaked to a bulk density between .36 and .26 kg/l (28 to 20 lb/bu). They also found that by increasing the degree of processing the enzymatic starch availability increased but the protein and ash content of the product decreased.

FLAKING AND STARCH GELATINIZATION

A. Methods of measuring starch gelatinization:

Since starch is the major component of cereal grains its contribution to the effectiveness of feed processing is quite obvious. The application of steam to the whole grain should be the initial step in the starch gelatinization process. Further gelatinization should occur as the moisturized grain passes through the rollers.

Three methods were used at Colorado during the initial period when the flaking process emerged. The three methods used are shown in Table 11. The enzymatic hydrolysis, using beta amylase, was determined to be the most reliable method. During the mid 1960s the starch gelatinization data was compared to the feedlot trial data where the thickness of flake trial were being conducted. The early data comparisons showed that 50% starch gelatinization was optimal.

Table 11. Methods of starch gelatinization analysis (Colorado)

1. Early methods of gelatinization analysis
 - a. Optical birefringence.
 - b. Congo orange staining
 - c. Enzymatic hydrolysis (beta amylase)
(Early data showed this method to be most consistent.)
2. Early data showed 50% gelatinization to be optimal.

B. Greatest gelatinization: at steaming vs. at rolling

The degree of *total* starch gelatinization in the flaking process should be more important than comparing the degree of gelatinization during the steaming period or during the rolling period.

Variations in the results will probably occur due to such conditions as: duration of steaming, type of roller, setting of the rollers, etc. The Kansas data (1966) indicates that the greatest gelatinization occurs during the *rolling* process (Table 12).

Table 12. Starch gelatinization of corn and milo¹

	% moisture	% gelatinization
Corn grain	17.1	----
Corn after steaming	22.0	16
Corn after flaking	20.5	48
Flaked corn after airlift	20.6	40
Milo grain	13.6	----
Milo after steaming	17.8	12
Milo after flaking	14.2	40-70 ²
Flaked milo after airlift	14.6	47-69 ²

¹ Phil Phar, Kansas (1966).² % gelatinization variation, may be due to thickness of flakes.**Table 13.** Effect of processing on starch granules and digestibility*

	Method of Processing			
	Cracked	Flaked	Flake-Cracked	Cook-Cracked
Starch granules:				
Per cent ¹	99	50-75	50-60	98
Digestibility:				
Dry matter, %	70.1	77.5	77.1	72.4
Protein, %	59.6	66.8	65.6	62.5
Acid detergent fiber, %	33.3	40.9	38.7	40.2

*1966. Colorado. (Johnson).

¹ Birefringence (starch granules examined with polarizing microscope).

EFFECT OF PROCESSING ON STARCH GRANULES

Processing of feeds changes the physical characteristics of cereal grains, certain processing methods alter the starch granules. Johnson (1966) determined the differences in corn starch granules due to processing by the “birefringence” method. The starch granules were examined with a polarizing microscope. The results are shown in Table 13.

Steam flaked corn showed considerable difference in starch granules as compared to dry cracked corn. Digestibility of protein and dry matter were slightly higher in steam flaked corn than in cracked corn. (Table 13).

Microscopic determination of loss of birefringence is the most rapid, sensitive, reproducible method for the determination of gelatinization (Seib, 1971). Other methods such as bulk measurement, water absorbing capacity, diastatic enzyme conversion and artificial rumen digestion by measuring VFA production have been used to measure starch alteration due to feed processing (McLaren, 1968).

SITE AND EXTENT OF STARCH DIGESTION

Even prior to the entrance of the processed grain into the digestive tract of the feedlot steer such feed as steam flaked corn or other steam flaked grains, the grain starch has already been prepared for microbial and enzymatic digestion through gelatinization. The extent or degree of gelatinization in the feed processing could then potentially affect the site and extent of starch digestion through the digestive tract.

Diet and intake can affect ruminal fermentation and subsequent supply of starch to the small intestine (Richards et al. 2003). Stock et al. 1987) found that at high diet intakes, 400 to 2,300 g of starch can flow to the small intestine of beef steers. Owens et al. 1986) indicated small intestinal starch digestibility ranging from 47 to 88%. Starch digestion in the small intestine is theoretically more energetically efficient than ruminal fermentation (Harmon and McLeod, 2001).

Table 14. Starch digestion in the small intestine (SI)*

Source	Diet	Digestibility entering SI, %
McCullough	88% whole corn	88.3
Laudert	80% cracked corn	59.1
Remillard	60% cracked corn	68.1
DeLay	90% flaked corn	69.5
McCullough	88% flaked corn	86.2
McLaren	80% extruded corn, 10% gelat.	15.0
	80% extruded corn, 40% gelat.	9.8
	80% extruded corn, 90% gelat.	6.1

*Colorado State University: Animal Science graduate students.

Starch digestion studies in the small intestine at Colorado indicated that the method of processing corn may vary from 6.1 to 86.2% with a high of 88.3% for whole corn. When the corn was processed through an extruder the digestibility of the starch was very low. The comparisons are shown in Table 14.

FECAL STARCH AS A MEASURE OF FEED PROCESSING EFFECT

Starch in steam flaked corn is digested to a greater extent in the rumen and entire digestive tract than

starch in whole shelled corn (Galyean et al., 1976). Although it would be rather rare to feed a combination of flaked corn and whole shelled corn in an ordinary feedlot ration the New Mexico researchers (Lee et al., 1982) found no difference in the percentage of fecal starch when flaked corn and whole shelled corn were fed in equal proportions. However, when flaked corn and whole shelled corn were fed separately, as expected, the percentage of fecal starch from the steers fed flaked corn was 39 to 59% lower than the steers fed the whole corn ration (Table 15).

Table 15. Fecal starch and pH changes during feeding period of steam flaked corn and whole corn*

Diet ^f	Days on Feed							
	56 days		84 days		112 days		140 days	
	pH	%starch ^e	pH	%starch ^e	pH	%starch ^e	pH	%starch ^e
100W:0SFC	6.30 ^a	14.0 ^a	6.19 ^{ab}	11.4 ^b	6.49	21.2 ^a	6.06 ^a	21.7 ^a
75W:25SFC	6.35 ^a	13.9 ^a	6.33 ^a	14.8 ^a	6.40	14.9 ^b	6.04 ^a	8.7 ^b
50W:50SFC	6.58 ^b	12.2 ^b	6.43 ^a	13.9 ^a	6.33	13.8 ^b	6.09 ^a	8.9 ^b
25W:75SFC	6.74 ^b	10.1 ^c	6.74 ^c	7.1 ^c	6.39	9.4 ^c	6.36 ^b	5.6 ^c
0W:100SFC	6.81 ^b	5.7 ^d	6.42 ^a	4.5 ^d	6.36	3.6 ^d	6.20 ^b	3.3 ^d

*New Mexico (1982:Lee, Galyean and Lofgreen).

^{a,b,c,d} Means in the same column with different superscripts differ ($P < 0.05$).

^e dry matter basis.

^f W = whole corn; SFC = steam flaked corn.

Table 16. Fecal starch and pH of whole corn and cracked corn at 140 days feeding period*

	Whole	Cracked	Fine Ground	Whole-Crack Mixture**	Whole-Fine Mixture**
Experiment 1					
Fecal starch, %	16.8	17.0	20.4	16.3	20.3
Fecal pH	5.73	5.78	5.69	5.82	5.67
Experiment 2					
Fecal starch, %	23.7	23.6	20.5	23.5	21.6
Fecal pH			(data not given)		

*Nebraska (Turgeon, Brink and Britton).

**50-50 mixture.

Results from Nebraska (Turgeon et al., 1983) found 16.8% and 23.8% fecal starch in two separate trials (Table 16). These figures compare closely to the 21.7% fecal starch found by the New Mexico researchers.

EFFECT OF FEED PROCESSING ON VOLATILE FATTY ACIDS (VFA)

The concentration and proportion of various volatile fatty acids can be obtained

from the rumen by a stomach tube or from fistulated animals. The results obtained from either method were found to be quite comparable (Table 17, 1966).

Whole corn has a higher percentage (42%) of butyric acid but a lower percentage (33%) of propionic acid as compared to ground corn (Sharp et al., 1982) (see Table 18).

Table 17. Volatile fatty acids (VFA) in rumen fluids¹

Sampling Method	Flaked Corn		Cracked Corn	
	Stomach Tube	Fistula	Stomach Tube	Fistula
	Molar percentage of total VFA			
Acetic	57.3	58.2	55.5	61.7
Propionic	26.4	27.0	29.6	25.1
Butyric	12.9	11.3	11.0	10.1
Valeric	3.5	3.5	3.9	3.1
A/P ratio	2.2	2.2	1.9	2.5

¹ 1966. Johnson (Colorado).

Table 18. Rumen volatile fatty acid concentrations in whole vs. ground corn (moles/100mol)*

	Whole Corn	Ground Corn	SE
Acetic	45.5	39.3	4.5
Propionic	31.2 ^a	46.9 ^b	4.6
Butyric	16.24 ^a	9.38 ^b	1.5
Isobutyric	1.00	0.71	0.15
3-methyl butyric	0.80 ^a	0.48 ^b	0.08
Valeric	2.60 ^a	1.83 ^b	0.21
Caproic	1.10 ^a	0.69 ^b	0.13

* Oklahoma (1982. Sharp, Johnson and Owens).

^{a,b} = Means with different superscripts differ ($P < 0.05$).

EFFECT OF PROCESSING ON DIGESTIBILITY OF GRAINS

If processing changes the density, particle size, surface area, starch characteristic of the grain as it enters the rumen its "condition" should be made

favorable for the microflora and thereby increase the digestibility.

A comparison of steam flaked corn with cracked corn in a Colorado trial (Johnson, 1966) showed an increase in dry matter, protein and ether extract digestibility as compared to cracked corn (Table 19).

Table 19. Digestibility of flaked and cracked corn, %*

	Flaked	Cracked
Dry Matter	74.8	70.1
Protein	64.5	59.6
Ether Extract	85.1	78.2
Acid Detergent Fiber	33.6	33.3

*1966. Colorado (Johnson).

The general pattern as indicated by numerous trials shows that cattle fed steam flaked corn or steam flaked sorghum have higher digestibility of grain and correspondingly superior feed efficiency as compared to cattle fed dry cracked grain.

EFFECT OF OTHER METHODS OF FEED PROCESSING

During the span of approximately 40 years (1930 to 1970) there were nearly twelve different methods of feed processing that were explored. Besides the steam flaking process another method was investigated and has continued to be adapted to the feedlot industry.

A. High moisture grain processing

As the cattle feeding industry started to mushroom in the mid-western section of the United States in the mid 1950s the small cattle feeders began to utilize their home-grown feeds. The harvested corn was usually too high in moisture (30%) and therefore difficult to store in the corn cribs without artificial

drying. Ensiling such corn would preserve the corn without deterioration. Purdue University (1958) reported the first successful feeding trial using high-moisture ear corn. The cattle on high moisture ear corn gained 9% more with 5% better feed efficiency as compared to the cattle fed regular dry ear corn.

Later, high-moisture shelled corn was ground and stored in glass-lined silos or in concrete silos. Commercial feedlots in the mid-west and other cattle feeding areas began to utilize this method of processed grain supply. Some feedlots using corn silage as their only roughage source did not use high-moisture corn in the feeding program because of reduced dry matter intake and daily gain.

Data from Oklahoma (1988) showed that the cattle fed high-moisture corn gained more than the cattle fed steam-flaked corn with comparable feed efficiency. (Table 20).

Table 20. Feedlot performance of cattle fed processed grains¹

Corn	Dry Rolled	Steam Flaked	Whole Shelled	High Moisture
Daily gain, lbs	2.75	2.75	2.75	2.84
Feed intake, lbs ²	17.07	15.70	17.02	16.50
Feed efficiency, lbs ²	6.21	5.71	6.19	5.81
Improvement:				
Total ration		+8.1%	+0.3%	+6.5%
Grain only		+10.9%	+0.4%	+8.1%
Grain in diet, %	74	74	78	80

¹ 1988. Wagner (Oklahoma).

² Dry matter basis.

Table 21. Feedlot performance of cattle fed processed grains¹

Milo	Dry Rolled	Steam Flaked	High Moisture Processed	Popped, Exploded or Micronized
Daily gain, lbs	2.56	2.76	2.76	2.76
Feed intake, lbs ²	16.79	16.06	15.7	16.07
Feed efficiency, lbs ²	6.56	5.82	5.68	5.82
Improvement:				
Total ration		+11.2%	+13.4%	+11.2%
Grain only		+15.1%	+17.2%	+15.2%
Grain in diet, %	74	74	78	74

¹ 1988. Wagner (Oklahoma).

² Dry matter basis.

B. Popped, exploded or micronized

Oklahoma researchers (1988) found the cattle fed popped, exploded or micronized milo made similar gains with equal feed efficiency as the cattle fed steam-flaked milo. (See table 21).

GRAIN PREFERENCE BY CATTLE (CALVES)

Prior to the use of “modern” processed grains (such as steam flaked) a rather unique experiment was conducted by Arkansas researchers in 1959 (Table 22). Three different cereal grains (corn, milo and oats)

were fed whole, coarse grind, fine grind, pellet, and ground pellets on free choice basis to determine the preference by calves. The calves preferred the whole oats of the 15 different choices while the calves offered the ground oat pellets ranked last.

It would be interesting to see a comparison of corn, sorghum, barley and oats with the “modern” feed processing methods -- whole (control) vs. steam-flake vs. high moisture vs. coarse grind in a finishing ration.

Table 22. Grain preference by cattle (calves)*

	Whole	Coarse Grind	Fine Grind	Pellet	Ground Pellets
	lbs	lbs	lbs	lbs	lbs
Corn	139	145	140	93	37
Milo	171	131	61	144	55
Oats	186	176	98	88	27

*1959. Arkansas (15@315 lb calves, 105 days). Lespedeza hay.

STEAM-FLAKED CORN VS. STEAM-FLAKED MILO

The choice of using steam-flaked corn or steam-flaked milo in a cattle finishing ration would undoubtedly depend upon the availability and cost of the unprocessed grain.

Slight differences may occur in the fuel cost of processing the two grains since the steam application time to the milo grain is longer. The performance (daily gain and feed efficiency) of cattle and carcass quality are very similar (Table 23).

SUMMARY

The choice of feed processing by different methods for the beef cattle feedlot industry appears to be *steam-flaking*. The favorable results from the chemical laboratory to the live animal experimental feeding trials in the literature survey of more than 200 published reports reveal this choice. This choice is substantiated by the wide use of the method in the current cattle feeding industry.

There are a number of reasons why steam-flaking is the choice for processing corn and milo. A few of these reasons are noted in Table 24.

Table 23. Steam flaked corn vs. steam flaked milo*

	Steam Flaked Corn	Steam Flaked Milo
Avg. daily gain, kg	1.79	1.79
Daily feed, kg	9.77	9.68
Gain/feed	0.183	0.184
Dressing %	63.0	63.8
% choice grade	83	83

*1992. Kansas State (Brandt et al.).

Table 24. Summary: Why steam-flaking is the choice for feed processing

Flaking appears to be the choice for processing corn and milo for feedlot rations in finishing cattle (flaking vs. cracked)

1. 8 to 12% superior feed efficiency (feed/gain).
 2. 10 to 30% decrease in density (weight per bushel) on dm. basis.
 3. 8 to 10% faster rate of passage through alimentary tract.
 4. 3 to 6% increase in dry matter digestibility.
 5. 35 to 50% increase in water uptake.
 6. Optimum starch gelatinization is approximately 50%.
 7. Slight alteration in proportion of volatile fatty acids.
 8. Decrease in energy loss as methane gas.
 9. No difference in carcass quality.
 10. Flaked corn and flaked milo are nearly equal in feedlot rations.
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GRAIN PROCESSING – EQUIPMENT AND APPLICATION

James I. Sprague

Livestock Nutritionist and writer for Feed-Lot Magazine

Newton, KS 67114

njs0128@yahoo.com



INTRODUCTION

Many research workers and livestock nutritionists have contributed to our understanding and application of feed processing for livestock. The machinery equipment industry has developed and modified grain-milling equipment to enhance feed production and feed handling. This gradual evolution has led to quite sophisticated systems for the processing of grain for beef and dairy cattle. Only a few of the highlights of the application and the changes in grain processing will be mentioned in this paper. It is impossible to credit all of the scientists and industry people that have contributed to our knowledge about grain processing. One recent review of the effect of processing applications on nutrient utilization by cattle is provided by an article in *Feedstuffs* (Owens, 2006).

Reasons for grain processing changes at cattle feedlots

Cattle feeders are continuously upgrading their feed processing systems. Reasons for such changes in grain processing are attempts to: (1) increase speed of feeding, (2) improve material handling for efficiency and labor costs, (3) reduce purchased energy costs, (4) improve grain utilization, (5) reduce shrinkage from wind loss, and (5) attract customers with modern equipment (Sprague 2006).

Processing equipment used

Grain processing equipment commonly used includes: (1) hammer mills and large capacity portable tub grinders, (2) roller mills whose rolls turn at the same speed for crimping and cracking/cutting dry grain, (3) roller mills with a differential drive so that one roll turns faster than the other to both cut and grind the grain, and (4) large diameter roller mills for steam flaking or crushing moist grain.

A total integrated application system.

Processing of grain for cattle typically is only one-step or segment of totally integrated application feeding system. Specific steps inherent in the total feed handling system are: (1) selection of grain type

and variety that will be impacted by the roughage program, (2) the grain receiving system, (3) the grain storage systems, (4) the pre-processing system (often used for moisture control), (5) the processing system and equipment required (each with unique opportunities and challenges), (6) the system for handling and storing processed grain, and finally (7) the feeding program that also differs depending on the target animal's diet (e.g., low roughage, high roughage and all concentrate.) In some cases, grain feeding is separated from grain processing to reduce investment by livestock producers that use smaller amounts of grain. For example, many feed mills will flake grain and deliver the dried processed grain to multiple dairies.

Various parts of a feeding system for cattle should be integrated with trade-offs to achieve the desired level and economics of livestock production. For example the process that leads to the most efficient grain utilization may not be the least costly when one considers the total system. Cost factors at each step will impact other decisions along the chain in order to maximize each step's contribution. The economic law of diminishing returns also applies at each step.

All of the steps of the grain processing system offer unique opportunities to either assist in handling of grain or to improve feed conversion. One example is the development of rapid harvesting, efficient material handling and processing of high moisture (HM) grain with massive combines and trucks or wagons, front-end loaders, tub grinders, and roller mills. Equipment for steam flaking to improve feed conversion also can be massive, expensive, and quite labor-intensive.

The grain source affects application of grain processing. The grain type (varieties or hybrids within each type) will impact the selection of a grain processing system. Corn may be processed in numerous ways including being fed whole (without processing). However, milo, barley and wheat must be processed to make full utilization of their energy and nutrients.

Characteristics of corn varieties ideal for ensiling as high moisture (HM) corn or for steam flaking may not be the same characteristics preferred for feeding as whole or dry rolled corn. For example, waxy corn, either processed or fed whole, proved useful for improving cattle performance at South Dakota State University (Pritchard and Bruns 2003). However, during steam flaking, waxy hybrids can form gelatinous sheets; adhering to and accumulating on the flaking rolls, these thickening sheets can abruptly halt the rolls of a steam flaker (Owens, personal communication). Corona, Owens, and Zinn (2006) concluded that “differences in corn vitreousness have an appreciable impact on the feeding of dry processed corn for feeding cattle. This effect is minimized by steam flaking.” Galen Erickson and his co-workers at University of Nebraska’s 2006 Beef Cattle Day compared soft with hard endosperm types of corn hybrids being fed as dry rolled or ensiled HM corn. They indicated that “Producers feeding corn as dry rolled corn (DRC) may want to consider selecting hybrids with larger softer kernels. If a more intense processing method is used such as high moisture ensiled, hybrid selection may not be as important.” (Luebbe et al 2006) Animal scientists at other research station, practicing animal nutritionist consultants, and cattle producers also have recognized this fact. Indeed, many commercial feedlots with steam flakers reject loads of corn grain with low density (under 57 pounds per bushel) to avoid floury hybrids and maintain flake quality and consistency.

Quality of grain

Quality of the grain also can impact the preferred processing method. For example, light test weight sorghum grain may be better utilized as finely ground ensiled high moisture or as reconstituted HM grain rather than as steam flaked grain due to wide variation in berry size within a batch of grain that complicates efficient flaking of the mixture.

The storage of in-bound grain. Ensiled HM grain stored in bunkers silos will be ground or rolled before it is stored. But when stored in oxygen limiting structures, HM grain often is stored whole (without processing) and rolled when is removed from the storage structure. Speed of processing can be important. For rolling or grinding grain for storage in bunker silos, grinding must be very rapid

to keep up with the rapid speed of grain harvest. This requires very large capacity hammer mill grinders or multiple roller mills to ensile an entire year’s grain within just a week or two.

One advantage of bunker over tower silos is the reduced energy cost of storage; grain does not need to be elevated into bunker silos. Removal of the HM grain at feed-out time is simple and rapid though caution must be exercised when working near the silage face to avoid being trapped with an avalanche of grain.

For grain to be dry or steam processed, inbound grain may be stored on the farm or at the mill before it is processed. In some cases, drying of incoming grain is required and bin aeration may become part of the grain handling system.

Pre-processing systems. Before grain is physically processed, additional steps may be needed. They can include: (1) removing trash (larger particles) and metal, (2) sizing with screens, (3) adding moisture with or without tempering agents (Sindt et. al 2006), and (4) adding inoculants and mold or yeast control agents.

Removing trash, screening for size, and removing the fine particles and dust from grain can occur during grain delivery or immediately before the grain is processed. Removal of trash is a routine step in steam processing systems, but usually this trash is re-added to the flaked grain. In some cases, fine particles are not removed prior to steam flaking so that weed seeds present in the grain will be sterilized by the steaming process. Separating grain by kernel size, though ideal for steam flaking of sorghum grain, is rarely used. Sizing would be beneficial because small barley and wheat kernels and small sorghum grain berries, especially, are difficult to flatten with the flaking rolls; small berries or kernels often are not cut or ground with dry rolling flaking equipment. Thus, distribution in kernel size distribution may be more important than mean kernel size to obtain adequate and uniform processing of grain.

Moisture control can be used with all processing systems including dry rolling but becomes an essential step for moisture added systems such as HM operations and steam processing. Prior to flaking, moisture is added to speed and enhance processing of the grain. Though moisture can be added as steam in the steam chamber associated with the flaker, water also can be

added to the grain in steep tanks where grain is held for several hours prior to flaking. Uptake of water by grain is much more rapid from hot than from cold water. Tempering agents to speed water uptake often are used and other nutrients such as urea or chemical like calcium hydroxide can be added to grain at this point. For ensiled HM grain, the moisture content is particularly critical for proper fermentation of the ensiling process. The amounts of water required can be huge. For example, to increase one ton of grain from 29% to 30% moisture requires addition of 29 pounds of water. So in this case, nearly 1.5% of the initial grain weight must be added simply to add one point of moisture to the final product. For large operations that ensile 250,000 bushel in a 24 hour period, adding 1 point of moisture requires about 18 gallons of water per minute. To reconstitute this quantity of dry grain, increasing moisture from 15 to 30% require delivery of over 4.6 gallons of water per second.

Additives and inoculants often are added. Mold preventing chemicals and preservatives may be used for either dry grain or steam processed grain. Mold preventing agents can be added either when grain is received to be processed later or they can be added at the time of feeding to improve shelf life in the feed bunk. With grain flaked for dairy operations, preservatives usually are added after flaking to reduce the high energy costs associated with drying flakes.

Dry grain processing systems. Categories of dry processing include: (1) hammer mill grinding, (2) “burr” milling, (3) crimping/cracking (no differential grind), (4) dry rolling with a differential grinding action, (5) dry heat processing, (popping, micronizing, roasting,) (6) pelleting, (7) others (extruding, expanding).

The choice among methods of processing dry grain will depend on the grain and specific feeding and management factors. Finely processed grain may, if fed correctly, can yield better feed efficiency than coarsely cracked grain, particularly with sorghum grain.

Dry heat processing of sorghum, i.e., popping and micronizing, will improve feed efficiency, but

the risk of mill fires has reduced commercial interest in these processing methods.

Pelleted grain is rarely used as the primary energy source in high energy rations, but pelleting is recommended for grain screenings to sterilize most of the weed seeds. Pelleted grain often is combined with medium or high protein ingredients to form receiving rations.

Finely hammer milled sorghum grain was demonstrated to be effectively processed by Bob Totusek at Oklahoma State University more than 50 years ago. Jack Freeman of Texoma, Oklahoma was successfully feeding dry hammer milled sorghum grain with corn silage in the 1960s.

Even though sorghum grain often is lower in cost than corn grain, most cattle feeders prefer corn because it has more consistent quality and it is easier and less costly (but more noisy) to process than sorghum grain.

In contrast with sorghum grain, finely ground or rolled corn is not recommended for high energy feedlot rations because an increased incidence of digestive disorders associated with rapid ruminal fermentation of fine corn particles that tend to separate during grain handling or in the feed bunk as well as the high palatability of corn grain. However finely processed dry corn can be fed quite successfully with a wet roughage or wet grain co-products such as distillers grain or corn gluten feed or when sufficiently diluted with roughage in diets for starting feedlot cattle or dairy cattle.

Particle size reduction of sorghum grain with multiple stack roller mills

One important equipment innovation useful for dry grain processing of sorghum grain was the double and triple stack roller mill. John Brethour at the Hays Station of Kansas State University showed that finely rolled sorghum grain when processed with a double stack roller mill had 94% the value of corn (Brethour 1982; 1983). He recognized that cattle feeders and rancher in his area previously had been using roller mills with corrugations that were too coarse for grain sorghum processing (Brethour, 2006). For dairy cattle, dry corn processed through multiple stack roller mills has been widely accepted (Burge 2006).

Moisture added processing systems.

Most large feedlots process grain with added moisture. These systems include (1) steam rolling or crushing with minimum steam exposure, (2) steam flaking (cooling and drying systems may be added), (3) crushing with added water but without steam (often with tempering agents added).

Most moisture-added systems are steam flaking operations. Research with steam flaking has involved many researchers. In the early days, steam rolled barley and oats were used in the dairy and cattle feeding industry and this work stimulated adoption of this process for corn and milo.

The seminal research of feeding flaked corn was conducted at Michigan State University (Newland et al., 1950) and at University of Florida (Hentges, 1962). John Matsushima and co-workers, particularly Bob Montgomery and the late Donald Johnson at Colorado State University also were at the forefront of research with steamed flaked corn.

Bill (William) Hale and his team at the University of Arizona were the first to quantify and employ quality control standards for steam flaking and feeding sorghum grains. Because many California and Arizona feedyards already were feeding flaked barley, transition to flaked sorghum grain was primarily one of more extensive steam to ensure a flat flake with less than half of the original bulk density for sorghum grain (28 versus 56 pounds per bushel for USDA #2 sorghum grain).

Recent flaked grain research

Since 1995, three groups have studied the factors that influence production and feeding of flaked corn. Richard Zinn and co-workers at the University of California have evaluated numerous quality control factors including processing mechanics (Zinn et al., 2002). The team at Kansas State University led by James Drouillard has focused on combinations of flaked corn with corn co-products, flake density, site of digestion, tempering agents, and moisture addition (Sindt et al., 2006), while research at Nebraska has evaluated kernel traits as it impacts the energy cost of flaking and digestibility (Harrelson et al., 2006).

Roller mills for flaking and crushing grain

The original processing machines that were used for flaking or crushing of grain were modified from

the roller mills used for wheat flour milling. Those rolls were 18 inches in diameter and 36 inches long. Today, most rolls are 24 x 56 inches and some very large mills use 32 x 68 inch rolls. Most installations use 24 x 48 and 24 x 56 inch mills (Petrakos, 2006).

Steam generation

Steam generation equipment includes boilers and steam generators. “Marine” fire type boilers are the primary units for producing steam, however steam generators also are used. The “Vaporator®” system which injects both the steam and the exhaust gases from the steam generator into the steaming/conditioning chamber also was developed with exhaust gases helping to sterilize the grain.

A Clayton steam generator was used for producing the original flaked sorghum grain research by Hale at the University of Arizona. An up-to-date steam generator now is available from Clayton Industries (Clayton Industries 2006).

Steam chamber for moisturizing grain

Specialized steam chambers (“steam chests”) were developed by suppliers of milling equipment. Mounted above the roller mills, these chambers have evolved over time to reduce separation of grain flowing through the chamber and to insure proper moistening of the grain before it is steam rolled or flaked (Gearn, 2006; Petrakos, 2006).

Heat and moisture removal from flakes

Flaked grain leaving the flaker can be pulled by draglines into bins for storage or delivery or vacuumed with an airlift system into storage. An airlift system cools the flakes and removes a slight amount of moisture. Removal of heat helps reduce starch retrogradation whereas moisture removal will permit longer-term flake storage and simplify handling. Cooling flakes for material handling reasons can use horizontal or vertical equipment modified from devices used for production of pelleted feed. Gearn Incorporated (Gearn, 2006) developed a system for cooling flakes for dairy and beef rations using perforated plates that allow air to flow through the flaked grain. Other cooling and dry equipment will pull water through a steam-heated radiator that warms the air that is blown through the flakes (Petrakos, 2006).

Tempering agents and moisture control

With very dry grain, water usually is added to the grain before the grain is dry-rolled or flaked. Specialized moisture monitoring and control equipment has been developed that monitors moisture content of the grain and incorporates the proper amount of water into the grain to attain a specified moisture content before the grain is processed. Tempering agents may be included with water to speed uptake of moisture and improve “toughness” of the flakes. Some tempering agents also can improve utilization of the grain. Such agents usually are added with the specialized moisture control equipment and tempering agent suppliers often provide and maintain the application equipment. Often, grain processing is delayed for several hours after the grain is moistened to allow more moisture to be added and for moisture to penetrate more deeply into the grain. For addition of moisture for several hours before flaking, a “soak tank” or a “day tank” is used.

Three different types of tempering agents or their combinations are available. These include (1) acid based products, (2) plant extracts that are natural surfactants, and (3) biodegradable detergent type surfactants.

Ensiled high moisture processing systems.

Ensiled HM corn feeding to livestock was used initially in the farming areas of the United States and Canada; it probably evolved from the practice of soaking grains for “slopping” the hogs. Whole or ground corn was stored in tower silo or oxygen limited silos. This whole HM corn either was crushed with crimping roller mills before feeding or fed whole. Ear corn with or without the husk was ground and ensiled in open topped tower silos.

Categories of high moisture grain processing

There are several categories of high moisture grain. These include: (1) hammer mill ground and ensiled, (2) roller mill processed and ensiled, (3) ground or kernel processed high moisture ear corn with or without the husk (commonly called earlage), (5) whole grain stored in oxygen limited structures (corn and sorghum grain), (6) reconstituted whole grain stored in oxygen limiting structures (particularly sorghum grain), and (7) reconstituted ground or rolled grain stored in bunker silos (particularly sorghum grain).

Early research: the 1976 High Moisture Grain Symposium

A symposium that summarized the early research with high moisture grains was held at Oklahoma State University in July 1976 (Gill et. al, 1976) and is now available on the internet from OSU. Conference participants included many of the early research workers. Among these animal scientists was T. W. Perry from Purdue University and Jimmy Clark from the University of Illinois who studied HM corn for dairy cattle. Others included H. L. Self, Doug Ware and Rich Vetter from Iowa State University. Dr. Vetter later worked with the Harvestore® group. Wise Burroughs, H. L. Self and Mitch Geisler reviewed their research at the 1971 Iowa State University Grain Feeders Seminar. W. C. (Wally) Koers was one of the early researchers at the University of Nebraska. At the University of Minnesota, high moisture corn research was led by Dick Goodrich and Jay Meiske. While at Minnesota, John Thornton studied the effect of corn maturity on composition in classical research publications (Thornton 1969a and b). Individuals at Oklahoma State University including Don Wagner, Don Gill, Fred Owens and many others evaluated ground ensiled HM corn. The initial studies from OSU were published in 1968 by Jock Buchanan-Smith, Bob Totusek, and A. D. Tillman (Buchanan-Smith et. al 1968).

Two intriguing papers from the symposium included Ed Prigge’s explanation of the importance of moisture content of ensiled HM corn (Prigge et al., 1976) and Jim Sprague’s discussion of protein solubilization during the fermentation process (Sprague, 1976). Discussions about effects of moisture level on energy value and of particle size on fermentation and of storage time on protein solubility were presented by John Thornton (Thornton, 1976).

Conclusions from the 1976 symposium...moisture is critical for ensiled grain

The consensus of speakers at the symposium was that ground ensiled HM corn must have adequate moisture (above 30%), be adequately processed for packing and feeding, can be stored in various structures (open top, bunker, or oxygen limited) with very limited weight loss, and has a feeding value for cattle superior to that of dry rolled or ground grain. Likewise with high moisture ensiled sorghum grain, moisture appears critical if one expects to dramatically improve energy and protein utilization when compared with dry sorghum grain.

Management consideration for harvest, processing and storage high moisture grain

Below is a list of processing and storing considerations for harvest and management to make high moisture grain ideal for feeding:

Ideal moisture content at harvest is over 30%. Speed during harvest and processing is necessary to obtain grain that is moist enough for proper storage and has a high feeding value. Holding high moisture corn overnight prior to storage allows aerobic yeasts to multiply; these germinate when re-exposed to oxygen during feeding and will increase the loss of readily available energy (oxidizing lactic acid) and cause the grain to heat.

Add moisture as needed. Note that 1.5 percentage of the weight of grain as water is needed to increase moisture content by 1%.

Particle size reduction for air exclusion during packing and to avoid air penetration into the silage face during feeding.

Narrow width of the bunker to match the feeding rate of grain's exposure to oxygen on the face of the bunker. This will prevent losses associated with volatiles and heating at the exposed surface of the bunker, particularly during warm months. Very wide silos often are split for feeding to decrease the time that the feeding face is exposed to air.

Prompt covering to prevent surface spoilage.

Detailed management from harvest to the feeding of HM grain.

Covering ensiled grain

The surface covering of ensiled HM grain in bunker silos has gradually evolved. Methods include:

- A thick layer of ensiled silage
- A layer of silage covered by plastic sheets weighted with tires
- Plastic sheets placed directly on the silage covered with wet hay silage
- White or black plastic sheets only, held with tires (or clean soil with soil removed when grain is removed from the bunker.) White plastic, though typically slightly more expensive and often thicker than black

plastic, reduces heat uptake from solar radiation and has a lower rate of deterioration than black plastic sheets. Thicker, oxygen excluding covers and even edible coverings have been developed that can reduce surface losses from silage bunkers even further.

Reconstitution of Grain.

The early research concerning reconstitution of sorghum grain was reviewed by Ray Hinders at the 1976 High Moisture Grain Symposium (Hinders, 1976). His review indicated that if adequate moisture was added at reconstitution, the product had feed efficiency, starch digestibility, and protein digestibility that were superior to dry processed sorghum grain.

Later, quality control of reconstituted sorghum grain was studied in four experiments that were summarized at the University of Arizona Cattle Feeders Day in 1982 by Bill Hale and his colleagues (Hale et al., 1982; Prouty et al., 1982; Prouty, 1983). For reconstitution, water was added to dry sorghum grain in a two-step process to bring moisture content of the grain up to 30%; this was allowed to ferment in an oxygen-limiting structure (Harvestore®) for 20 to 30 days. (With a single step wetting process, sorghum grain will expand. Expansion of reconstituted sorghum has caused oxygen limiting upright structures to split open!) Before feeding, the grain was crushed with a large roller mill. These trials demonstrated that reconstituted sorghum grain produced a feed efficiency comparable to steam flaked sorghum grain (Prouty, 2006). Because many believed that the benefits associated with reconstitution were due to berry changes during the germination process, sorghum was stored whole, and to avoid spoilage of whole grain, oxygen-limiting structures were considered to be required to produce reconstituted grain.

Late harvested sorghum grain with water added

Prior to harvest, grain remaining on the plant is much more exposed with sorghum than with corn grain. Hence, sorghum grain dries faster. This shortens the time window for harvest at an ideal moisture content. The short harvest time window for harvesting sorghum grain at the proper moisture level has reduced commercial interest in production of high moisture sorghum grain. However, water can be added readily to dry ground grain after harvest. Ground, moistened sorghum grain packed into storage will ferment but, being ground, such grain will not germinate. A

processing method similar to reconstitution but with ground sorghum grain was developed by cattle feeders in Colorado and Kansas. Late harvested sorghum grain (15 to 30% moisture) is processed with a roller mills (with differential speed rolls to produce a grinding action). Water is added to the ground grain as it is ground to attain a moisture content of over 30% moisture, preferably 35% moisture. The processed grain is stored in bunker silos covered with plastic sheets. Tested at the Garden City Experiment Station of Kansas State University by Huck and others (Huck et al., 1999), this processing method produced feed efficiencies equal to that for steam flaked corn (Huck, 2007).

Equipment for Handling processed grain.

The equipment for physically handling of processed grain has evolved with time to alleviate problems (“bridging” in bins) associated with the low bulk density of processed grains.

Dry processed grain can be stored in flat storage, in overhead bins, or in “live bottom” bins until it is fed. However, steam flaked grains typically are conveyed to bulk flat storage or into specially designed “live bottom” bins. The methods used for handling flaked grain include: (1) belt or auger conveyers to move flakes into flat storage, (2) conveying with vacuum “airlifts” into live bottom bins, and (3) producing the flakes at an elevated level so that flakes dropping directly into flat storage. Care should be taken in handling processed grain to avoid separation of fine particles. Separation can alter moisture and nutrient composition of the product.

Feeding and management impacts processing applications.

The preferred grain processing system will be impacted by several aspects of the feeding programs. These include (1) the roughage source, level, and moisture content, (2) availability of wet grain co-products that will add moisture and reduce separation of fine particles, and (3) the bunk management strategy that will alter feed bunk residence time and thereby influence its potential to spoil.

Dry roughages work well with fermented grains. Silages and wet grain co-products, such as distillers grains, help with mixing and enhance palatability of

rations with dry processed grains. With moist ingredients included in the diet, a finer particle sizes will be tolerated and can be used to increase digestibility and feed efficiency.

Two animal nutritionists that pioneered the art and science of bunk management are Bob Lake of the Hitch Industries of Oklahoma and Kansas (Lake, 1976) and John Thornton, a feedlot consultant formerly with Hitch’s Garden City operation. Proper feed mixing and handling is one of the primary training activities of consulting nutritionists and feedlot management people, and training and supervision of the employees that call bunks and deliver feed to the cattle is critical to achieve optimum feed intake by the cattle.

Special grain processing equipment.

The manufacturers of feed processing equipment have developed custom products and techniques to improve grain processing. These include:

- Special configuration of hammers and screens for hammer mills and tub grinders.
- Roller mill corrugation specifications (lands and groves) are available from 4 to 12 per inch and various surface cuts (the Stevens and the Deep V cut being the most common for flaking corn grain).
- In-line moisture control equipment.
- Large diameter roller mills with greater nip for flaking grain.
- Specially designed large capacity and tall steam chambers for moisturizing grain.
- Heat and moisture removal equipment for steam flaked grain.

Special pre-processing treatments.

- Scarification machines to damage the pericarp of sorghum grain and speed water uptake before flaking was tested but is no longer being used.
- Coarsely cracking corn followed by steam rolling.
- Moisture conditioning augers used at pellet mills are now used to moisten grain prior to steam flaking.
- The use of “day tanks” or bins for temporary storage of grain for moisture uptake before the grain is flaked.
- In-line moisture monitoring with automatic controls for moisture additions.
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IMPLICATIONS

Research and experience by university and industry animal scientists as well as innovative consultants and producers have developed sophisticated methods and equipment for processing grain for feeding beef and dairy cattle.

The reasons why livestock operators might alter their grain processing systems are attempts to (1) increase speed of feeding, (2) improve material handling for efficiency and worker safety, (3) reduce the cost of purchased energy, (4) improve grain utilization, (5) reduce costs for maintenance (e.g., re-surfacing flaker rolls) and for personnel, (6) reduce shrinkage from wind loss, and (7) attract customers with modern efficient equipment to minimize livestock production costs. Although grain processing and handling equipment often represent an immense physical and financial investment, every

progressive feedlot manager and consultant will monitor their operations and equipment and will alter their diet and grain processing method when economic advantages dictate. Changes are more frequent when feedlots expand or when grain prices change abruptly. Innovation and change is why every feedlot has a “junk yard” for used equipment and a “dead file” filled with logical ideas that did not work.

Utilization of energy from grain can be increased by more extensive grain processing when coupled with the appropriate management of the feeding program. However, grain processing is only one segment of a livestock production system that must be totally integrated financially. The economic balance between feed utilization and the cost of feed processing usually will dictate when changes in grain processing methods are needed and should occur.

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NUTRIENT COMPOSITION OF UNPROCESSED GRAINS AND PROCESSED GRAINS

Larry L. Berger, Ph.D.
Department of Animal Sciences
University of Illinois
llberger@uiuc.edu



ABSTRACT

Nutrient composition of commercial corn grain appears to have changed little in the last 10 to 15 years. Although the data for sorghum grain and barley are more limited, no dramatic changes in nutrient composition were apparent. Flaking corn appears to reduce the crude protein concentrations, perhaps because water used for starch gelatinization is not released during drying. Harvesting and storing corn grain as high-moisture increases the protein solubility and rumen degradation of corn grain protein. In contrast, flaking corn decreases protein solubility and ruminal protein degradation. Flaking corn may increase phosphorus availability by increasing ruminal phytase activity.

INTRODUCTION

Nutrient composition of grains can be quite variable. Although the variation is less with grains than with forages or byproduct feeds, grains comprise the majority of most feedlot diets so small changes in nutrient composition become very important. The sources of variation in nutrient composition can be divided into processing and non-processing factors. Most of the processing effects relate to energy value of the grains. Because several speakers have discussed how processing variables affect the energy values of different grains, that topic will not be discussed here. Effects of processing on protein and mineral availability will be discussed later.

NON-PROCESSING VARIATION

Non-processing factors that can affect the nutrient composition of grains include, but are not limited to, year, variety, fertilization, and management factors. In the last 10 to 15 years grain producers have made substantial changes in varieties (genetics), fertilization programs, and management practices. This review will examine whether such changes have altered grain composition.

Grain nutrient composition data collected for the 1996 Beef NRC publication (NRC, 1996) were from grains produced in the early 1990s. Data were collected from approximately 40 different laboratories in North America. Grain samples from most states and Canadian provinces were included in that database. The Dairy One feed analysis laboratory in Ithaca, New York provides excellent

public access to a database that can be used to examine nutrient variation. This laboratory receives grain samples from throughout the United States and Canada. These data have not been screened to remove outliers, so the standard deviations are greater than found in other data sources. The Dairy One data base is robust because it contains a large number of samples analyzed for many nutrients that were received between May 2000 and June 2006. All nutrients are expressed on a dry matter basis and can be accessed at <http://www.dairyone.com/Forage/FeedComp/disclaimer.asp>. Through comparing the nutrient composition data from the 1996 Beef NRC and the current Dairy One database, large changes in nutrient profile over the last 10 to 15 years can be detected.

Corn is the primary grain fed to cattle and has the largest number of samples in the data base. With over 3500 samples in both data sets, corn in the Dairy One data set averaged 9.51% crude protein; in the early 1990s corn averaged 9.80% protein (Table 1). Whether this is a trend or just random variation, is impossible to determine. However, when we select corn varieties for increased yield or alcohol production, a decrease in protein concentration would not be surprising.

Based on more than 2200 samples, corn NDF values also have tended to decrease (10.8% vs. 9.78%) during the past 15 years. Since most of the fiber is in the seed coat, it is possible that as we select for increased yield, kernel size could increase resulting in the seed coat being a smaller fraction of the weight.

Table 1. Current corn nutrient composition compared with that reported in the 1996 Beef NRC.

Item	Dairy One ^a			1996 Beef NRC		
	N	Mean	Std. Dev. ^b	N	Mean	Std. Dev.
Dry matter %	4135	90.32	3.64	3708	90.00	0.88
Crude protein %	3578	9.51	1.65	3579	9.80	1.06
Ether extract, %	1829	4.35	1.35	134	4.06	0.64
Neutral detergent fiber, %	2250	9.78	3.23	2488	10.80	3.57
Calcium, %	1923	0.04	0.13	3516	0.03	0.07
Phosphorus, %	1916	0.32	0.10	3515	0.32	0.04
Magnesium, %	1902	0.12	0.10	3437	0.12	0.03
Potassium, %	1906	0.41	0.11	3437	0.44	0.06
Sulfur, %	1451	0.10	0.10	382	0.11	0.02
Zinc, ppm	934	23.6	16.8	1743	24.2	11.1
Copper, ppm	934	2.83	3.08	1743	2.51	1.98
Manganese, ppm	926	9.02	13.8	1741	7.89	7.10

^a<http://www.dairyone.com>.

^bStandard deviation.

Mean mineral concentrations were very similar for corns raised in the early 1990s and those analyzed in more recent years (Table 1). In general, the standard deviations tended to be larger for the Dairy One data set than was reported in the 1996 Beef NRC. It is not known whether the mineral content of corn is becoming more variable, or whether some samples in the Dairy One data set may have been contaminated with other grains.

Sorghum grain is the second most common grain fed to cattle in the U.S. Because of the small number of samples analyzed, it is more difficult to detect compositional changes (Table 2). Mean crude protein has decreased from 12.6% in the 1996 Beef NRC to 10.35% in the current Dairy One database. With only 128 samples assayed for crude protein in the current data, one must be cautious about concluding that sorghum grain protein concentrations are decreasing. Mineral concentration data were not compared because of the small number of samples analyzed.

Table 2. Current sorghum grain nutrient composition compared with that reported in the 1996 Beef NRC

Item	Dairy One ^a			1996 Beef NRC		
	N	Mean	Std. Dev. ^b	N	Mean	Std. Dev.
Dry matter, %	147	89.07	2.12	226	90.00	2.29
Crude protein, %	128	10.35	2.23	230	12.6	1.99
Ether extract, %	58	3.46	1.06	68	3.03	0.66
Neutral detergent fiber, %	109	11.43	9.23	7	16.1	3.35

^a<http://www.dairyone.com>.

^bStandard deviation.

Barely is fed commonly to cattle in the Northern U.S. and Canada. Mean crude protein concentrations of barely decreased from 13.20 to 12.72% between the early 1990s and the current samples (Table 3). With 769 and 1884 samples for the Dairy One and Beef NRC data sets respectively, this difference may

be of actual trends. In contrast, mean NDF concentrations tended to increase (18.10 vs. 19.49%) over the past 15 years. Drought stress that has occurred in the barley producing areas of the U.S. the past few years may explain this trend.

Table 3. Current barley nutrient composition compared with that reported in the 1996 Beef NRC

Item	Dairy One ^a			1996 Beef NRC		
	N	Mean	Std. Dev. ^b	N	Mean	Std. Dev.
Dry matter, %	992	90.04	3.43	1743	88.1	0.86
Crude protein, %	769	12.72	2.10	1884	13.20	1.50
Ether extract, %	492	2.56	1.03	8	2.2	0.44
Neutral detergent fiber, %	627	19.49	6.47	1216	18.10	4.80

^a<http://www.dairyone.com>.^bStandard deviation.

PROCESSING VARIATION

Processing of grains would not be expected to change nutrient concentrations. However, analysis of 3,578 samples of cracked corn, 10,350 samples of high-moisture corn, and 278 samples of flaked corn, revealed, crude protein concentrations that averaged 9.51, 9.18, and 8.38%, respectfully in the Dairy One database. Flaking should not volatilize nitrogen resulting in a reduction in crude protein. However, testimonials indicate that flaking will lower crude protein concentrations. It is possible that during starch gelatinization, water is added to the starch matrix that is not lost during drying. Measured as an increase in dry weight, this would dilute the nitrogen and thereby reduce the crude protein concentration. An increase in mass of 13.5% would be required to dilute the protein from 9.51 to 8.38%. An increase in weight of this magnitude seems unlikely. The relatively low number of flaked corn samples (278) may be part of the explanation. However, region of origin of the flakes, selection for high test weight, using high starch hybrids for flaking, scalping of grain prior to flaking, and un-representative sampling of flakes, also might be involved.

Storage and processing of grains can affect the degradation of protein in the rumen. Using in the *Streptomyces griseus* enzymatic digestion procedure (Dairy One, 2006), rumen protein degradation for 1,027 samples of cracked corn, 7,299 samples of high-moisture, and 74 samples of flaked corn averaged 31.5, 41.8 and 25.8%, respectfully (Dairy One, 2006). In the 2001 Dairy NRC (NRC, 2001), readily degraded “A” fraction proteins were estimated to comprise 23.9, 27.9 and 1.7% of the protein in cracked, high-moisture, and flaked corns, respectfully.

Little data in the scientific literature shows grain processing changes the amount or availability of other nutrients. However, this may not always be the case. Guyton et al., (2003) showed that dairy cows fed steam flaked corn had greater ruminal phytase activity resulting in less phosphorus being excreted in the feces compared to cows fed dry ground corn. Using rumen fistulated cows they found that flaking the corn increased the degradation of phytate added to the rumen. The mechanism by which flaking corn might increase ruminal phytase activity is not known.

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QUESTIONS AND ANSWERS

Q: Larry, do you believe the Dairy NRC with regard to availability of protein from flaked grain for the A, B, and C fractions you mentioned? I assume that these were determined in situ and they seem questionable to me. Protein in the lower 8's for flaked grain seems reasonable based on geographical issues, but if 15% of the protein is not digestible, that doesn't leave much for the animal.

A: The C fraction is 15% of the total crude protein. With 9 or 10% protein in corn, 1.5% protein would be indigestible. Those numbers are a percent of the total protein. Those numbers presumably are a result of a literature review of a variety of work, some being animal work and some being solubility work. One can argue how much variation there is and how repeatable those numbers are.

- Q:** Larry, if you consider the response of steam flaked corn diets to high urea levels, a higher level of the C indigestible protein fraction makes sense.
- A:** Excellent point. Others here will be discussing the impact of distillers' grains and possible associative effects with different grain processing methods. If we are supplementing flaked grain with high ruminal starch availability but low protein availability with something like distillers' grains that have slow protein degradability in the rumen, it makes sense that we may restrict digestion in the rumen. Part of the interaction between grain processing (flaking) and utilization of high fiber byproducts with lower values with flaked grain may relate to the slow rate of ruminal protein degradation from grain byproducts.
- Q:** Larry, how much of the difference between the flaked and normal grain in starch and protein content is due to sampling problems with flaked grain? Based on personal sampling of these materials, as one grabs a sample of the flaked grain, the fat content often is only half that of the whole grain before it is flaked. How much of a problem is sampling of flaked grain?
- A:** Sampling always is an issue. Certainly, labs only can analyze the sample that is submitted. Sampling is of concern, particularly when small amounts are submitted. DairyOne appears to do an excellent job of subsampling and analysis. Certainly, sampling is a greater problem with flaked than whole grain or ground grain. Sampling presents an error that is hard to characterize.
- Q:** Larry, we see similar reductions in the field when we compare protein level in whole grain and compare it to protein level in flaked grain. Starch chemists indicate that at 100% gelatinization, one may gain 8% to 10% dry matter as starch. If we have 50% gelatinization with flaking, the increased starch content can be causing that reduction in protein because protein will be a smaller piece of a larger pie. I personally question that idea, but if that is not happening, someone needs to explain how I can take a 14% whole corn and add 6% moisture to it but come up with a 9 to 10% inventory gain when none of my other commodities are out of whack. So I have to believe that the starch content grows during flaking, as bizarre as that sounds.
- A:** Protein is simply measured as Kjeldahl nitrogen. Unless we are changing nitrogen by processing the starch, I don't know why changes in gelatinization of the starch structure should affect the amount of nitrogen. To my knowledge, there is no reason to believe that steam flaking will volatilize nitrogen. Only 279 samples are in this data set, so some differences may be due to the relatively small number of samples in the data set. We may be changing the starch structure, but that should not change the nitrogen level of the grain.
- Additional comment from Tim McAllister:** The questioner has a good point. This may relate to my discussion about how enzymes degrade starch. An enzymatic procedure is used to measure starch. Gelatinized starch is more susceptible to enzymes, so recovery will be greater for material that is more gelatinized. Anybody who has attempted to measure starch in the laboratory can attest that starch analysis is not a simple procedure; one does not get consistent results from sample to sample.

STARCH TYPE, STRUCTURE AND RUMINAL DIGESTION

T. A. McAllister, D. J. Gibb, K. A. Beauchemin and Y. Wang
Agriculture and Agri-Food Canada
Lethbridge, AB T1J 4B1
mcallistert@agr.gc.ca



ABSTRACT

The rate and extent of ruminal digestion of cereal starch depends on a number of complex interactions among rumen microorganisms, grain kernel structure, and the method of grain processing. The pericarp of cereal grains is the foremost barrier to microbial digestion and its destruction via processing (i.e., grinding, rolling) or mastication is essential for efficient starch utilization in ruminants. Upon exposure of the endosperm, rumen microbes readily digest endosperm cell walls, but their ability to digest the protein matrix surrounding starch granules depends on the type of cereal grain. Corn and sorghum contain dense protein matrices within the vitreous endosperm that surround starch granules and limit the access of amylolytic microbes to starch granules. In contrast, the protein matrices of wheat and barley are more diffuse and do not impede the access of rumen microbes to granules. More severe processing methods such as steam-flaking disrupt the protein matrix of corn and sorghum and increase the rumen availability of starch within the vitreous endosperm. In contrast, starch from barley and wheat is readily digested with less extensive processing. Once free of the protein matrix, starch granules from all grains are digested readily by rumen microbes, which reflects the myriad of amylases produced by these diverse strains of microbes that can digest starch. However, the “inside-out” method of microbial digestion is more prevalent for starch granules from corn and sorghum than for starch granules from wheat or barley. This strategic difference may reflect differences in surface lipids and/or proteins among starch granule types. Steam-flaking effectively disrupts barriers to microbial starch digestion; the degree of gelatinisation is highly correlated with the destruction of the protein matrix. Post flaking reductions in ruminal starch degradation likely reflect reformation of starch-protein complexes rather than starch retrogradation. An increase in extent of ruminal digestion of starch often results in improved growth and feed efficiency because by-pass starch often results in a decline in total tract starch digestibility. Future strategies aimed at enhancing starch digestion in ruminants must include a deeper appreciation for the microbial processes involved in cereal grain digestion.

CEREAL GRAIN STRUCTURE

The outer surface of cereal grains consists of a thick, multilayered pericarp that protects the inner germ and endosperm from microbial onslaught (Figure 1.1). High concentrations of lignin are deposited during secondary thickening of the pericarp and wax esters often are associated with the surface as a further deterrent to microbial invasion and water uptake. In addition to the pericarp that accounts for 3-8% of the total kernel weight, barley and oats have a fibrous hull or husk that may amount to up to 25% of total kernel weight (Evers et al., 1999). Chemically, the pericarp and husk are composed of about 90% fiber and, due to their highly lignified nature, their digestion is likely limited to less than 40% (Van Barneveld, 1999). Ruminal digestibility of the hull and pericarp likely is impaired further by the low ruminal pH (i.e., < 6.2) commonly associated with high grain diets. The endosperm consists of two distinct tissues, starchy endosperm (60-90% of kernel weight) and

aleurone (2-7% of kernel weight); the aleurone consists of 1 to 3 layers depending on the type and genetics of the cereal grain (Kent, 1983). Endosperm cell walls of wheat and corn are composed primarily of arabinoxylans, whereas those in oats and barley are predominately composed of (1→3, 1→4) - β -glucans. Endosperm cell walls are largely devoid of lignin and, given the high arabinoxylanase and β -glucanase activity of rumen microbes (McAllister et al., 2001), are unlikely to be a significant barrier to starch digestion. Endosperm cell walls surround starch granules embedded within a protein matrix (Figure 1.2). The endosperm has two distinctly different regions in both corn and sorghum grain. In the vitreous endosperm region, starch granules are densely compacted within a protein matrix, whereas in the floury endosperm region, starch granules are only loosely associated with the protein matrix. In corn, starch granules are so tightly associated with the protein that the granules frequently fracture upon grinding; this exposes the concentric rings that are formed during the deposition of starch in the

granule during kernel development (Figure 1.3). In barley and wheat, the protein matrix is loosely

associated with starch granules throughout the entire endosperm (Figure 1.4).



Figure 1. Scanning electron microscopy of (1) the pericarp (P) of corn (2) endosperm cells in wheat (3) horny endosperm of corn with starch granules (s) and (4) the endosperm of wheat with starch granules (s) Bars = 10 μ m. (From McAllister and Cheng, 1996).

The principal carbohydrate in the endosperm is starch. Starch is composed of linear and branched glucose polymers called amylose and amylopectin (French, 1973). The glucose units in amylose are linked by α -(1-4) bonds; in amylopectin, additional α -(1-6) linkages are present which result in branch points. Starch is deposited in granules within the endosperm. Depending on the grain type, granules vary widely in their shape (round, lenticular, polygonal), size, size distribution (uni- or bi-modal), and association either as individual (simple) or granule clusters (compound) (Table 1, Tester et al., 2004). Starch granules are formed by the deposition of growth rings that consist of alternating semi-crystalline and amorphous layers. These rings extend

from the centre of the granule (hilum) towards the surface of the granules in a manner analogous to the layers of an onion (Figure 1.4). The amorphous regions in starch granules are thought to represent the amylopectin branch points whereas the crystalline area represents the more compact double-helical structure of amylose. Starches are defined as waxy when the ratio of amylose to amylopectin is low < 15%, normal when the amylose makes up 16-35% of the granule, and high-amylose when amylose content exceeds 36% of the granule. Although several studies have shown that the amylose/amylopectin ratio is negatively correlated with starch digestion in non-ruminants (Svihus et al., 2005), the impact of the ratio on starch degradation by ruminal microorganisms is less certain.

Table 1. Characteristics of starch granules from different cereals¹

Cereal source	Distribution	Shape	Size, μ m
Barley	Bimodal	Lenticular (A-type) Spherical (B-type)	15 – 25 2 – 5
Corn	Unimodal	Spherical/polyhedral	2 – 30
High amylose corn	Unimodal	Irregular	2 – 30
Millet	Unimodal	Polyhedral	4 – 12
Oat	Unimodal	Polyhedral	3 – 10 (single) 80 (compound)
Rye	Bimodal	Lenticular (A-type) Spherical (B-type)	10 – 40 5 – 10
Sorghum	Unimodal	Spherical	5 – 20
Triticale	Unimodal	Spherical	1 – 30
Wheat	Bimodal	Lenticular (A-type) Spherical (B-type)	15 – 35 2 – 10

¹Adapted from Tester et al. (2004).

Starch Granule Digestion by Rumen Microorganisms

As a result of their numerical predominance and metabolic diversity, ruminal bacteria are likely responsible for the majority of the starch digestion in the rumen. *Streptococcus bovis*, *Ruminobacter amylophilus*, *Prevotella ruminicola*, *Butyrivibrio fibrisolvens*, *Succinimonas amylolytica* and *Selenomonas ruminantium* are the principal starch-digesting bacteria in the rumen (Cotta, 1988). Recent work using molecular techniques has suggested that less than 10% of the bacteria in the rumen lend themselves to culture under anaerobic conditions in the laboratory (McAllister et al., 2006). This raises the possibility that many amylolytic bacterial species within the rumen may remain to be identified and

characterized. Although starch granule type can have considerable influence on the ability of isolated amylolytic enzymes to digest starch (Zhang et al., 2006), this variation in digestion is less marked when isolated starch granules are subject to digestion by a mixed rumen microbial population (McAllister et al., 1993a; Fondevila and Dehority, 2001).

This likely reflects the wide diversity of amylases produced by rumen microorganisms as well as the formation of complex microbial consortia that frequently are observed on the surface of starch granules (Figure 2A). This microbial consortium can more readily produce the array of enzymes required to overcome additional digestive barriers that exist on the surface of starch granules such as lipids and proteins

(Tester et al., 2004). Microbial digestion of starch granules from wheat and barley radiates from a central point of microbial attachment on the surface of the granule (Figure 2B). In contrast, with corn starch granules amylolytic bacteria tunnel into the interior of corn starch granules (Figure 2C) such that corn starch granules are digested from the inside out. As a consequence, as digestion nears completion, the granule interior often is hollow with only the outer surface layer remaining (Figure 2D). Although differences in the microbial approach to digestion of different types of starch granules do exist, their overall impact on rate and extent of starch digestion pales in comparison to the influence of more recalcitrant barriers to starch digestion such as the protein matrix in some grains and the pericarp and husk.

Both Holotrich and Entodiniomorphid protozoa are capable of degrading starch; protozoa may be responsible for as much as 50% of the starch digestion in the rumen (Jouany and Ushida, 1999). Protozoa readily engulf starch granules at a rate inversely related to the size of the starch granule (Figure 3A). Consequently, the engulfment of starch granules by *Entodinium exiguum* is more rapid for the small rice starch granules (diameter 3-8 μm) than for the larger corn starch granules (with diameter 9-30 μm ; Fondevila and Dehority, 2001). To date, no studies have determined if differences in granule composition alter the ability of protozoa to utilize starch.

Perhaps the most significant impact of protozoa on cereal grain digestion is their ability to modulate pH (Ushida et al., 1991) as a result of their capacity

to sequester starch granules intracellularly and their ability to be predatory toward amylolytic bacteria (Nagaraja et al., 1992). Engulfed starch granules may require up to 36 h to be completely metabolized by protozoa (Coleman, 1986). Protozoal numbers typical increase when grain is included in forage-based diets (Hristov et al., 2001) and their number also may be sensitive to the type of grain fed or if mixed grains are included in the diet (Mendoza et al., 1999). Inclusion of very high concentrations of grain in the diet (i.e., >90%) may cause the diversity and number of protozoa to decline, a factor that may exacerbate a low ruminal pH and increase the risk of acidosis in cattle fed these types of diets. A decline in protozoa during the first eating bout of a high grain diet may make cattle more susceptible to acidosis during the second eating bout.

Although ruminal fungi are often considered only in relation to the digestion of recalcitrant plant cell walls, their contribution to rumen biomass increases when grains are included in the diet (Faichney et al., 1997). Our laboratory conducted studies that showed three species of ruminal fungi, *Orpinomyces joyonii*, *Neocallimastix patriciarum* and *Piromyces communis* digested starch in corn more than in wheat and barley (McAllister et al., 1993b). The rhizoids in ruminal fungi are capable of penetrating directly through the protein matrix in corn, enabling complete digestion of encased starch granules (Figure 3B). Although ruminal fungi are not a major contributor to ruminal starch digestion, many fungal species exhibit amylase activity and logically lead one to conclude they will digest starch under some circumstances. Their characteristic ability to penetrate through recalcitrant barriers may make their role more prevalent for digestion of more vitreous rather than flourier endosperm grains.

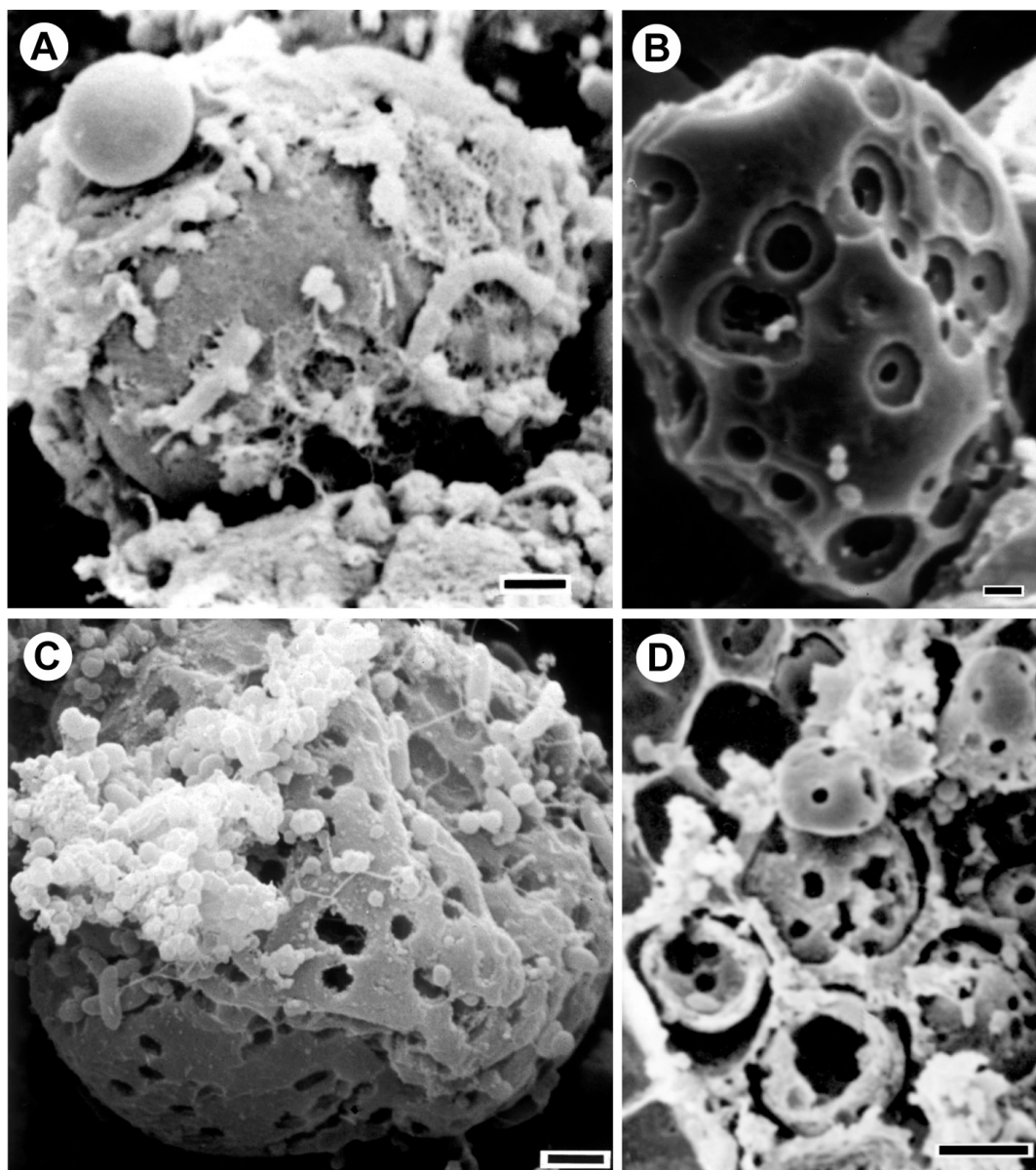


Figure 2. Scanning electron microscopy of (A) formation of a microbial biofilm on the surface of a wheat starch granule (Bar = 3 μm); (B) formation of concentric digestive rings on the surface of a wheat starch granule (Bar = 10 μm); (C) microbial biofilm on the surface of a corn starch granule, notice absence of rings observed in (B) (Bar = 1 μm) and (D) hollow corn starch granules after microbial digestion (Bar = 5 μm); (Adapted from McAllister et al., 1990a and 1990b).

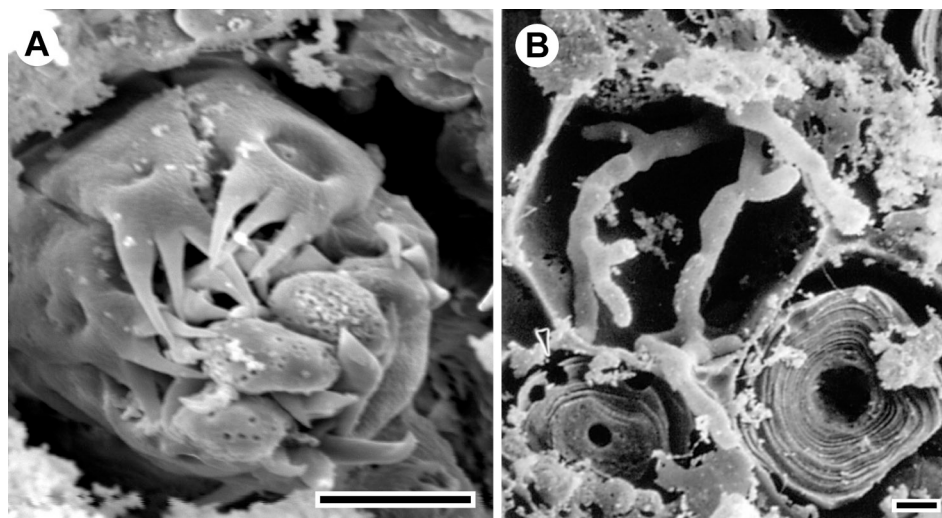


Figure 3. Scanning electron microscopy of (A) Rumen protozoa in the process of engulfing corn starch granules (Bar = 15 μ m) and (B) rhizoids of ruminal fungi penetrating the protein matrix of corn (Bar = 2 μ m); (A) Wang and McAllister, unpublished data; (B) From McAllister et al., 1993b.

Enzymology of Starch Digestion

Several enzymes are involved in the digestion of starch (Table 2). Although there is a plethora of information on the ruminal enzymes involved in the digestion of plant cell walls, only a handful of studies have examined the nature of ruminal amylases. The majority of these have focused on alpha-amylases from *S. bovis* (Clark et al., 1992; Cotta and Whitehead, 1993; Satoh et al., 1993) with

only a single report of an alpha-amylase from *B. fibrisolvens* (Rumbak et al., 1991). Studies to isolate and identify amylases capable of hydrolyzing the α -(1-6) linkages in amylopectin have not been conducted, but given that free starch granules are rapidly hydrolyzed in rumen fluid (Cone, 1991), such amylases presumably do not represent a rate limiting step to microbial starch digestion in the rumen.

Table 2. Enzymes involved in the hydrolysis of starch¹

Enzyme	Bond specificity	End product
Phosphorylase	α -(1-4)-glucosyl	Glucose-1-phosphate
Alpha-amylase	α -(1-4)-glucosyl	Linear and branched oligosaccharides
Beta-amylase	α -(1-4)-glucosyl	Maltose and limit dextrins
Amyloglucosidase	α -(1-4)-glucosyl and α -(1-6)-glucosyl	Glucose
Isoamylase	α -(1-6)-glucosyl	Linear α -(1-4)-glucan chains
Pullulanase	α -(1-6)-glucosyl	Linear α -(1-4)-glucan chains

¹Adapted from Tester et al., 2004.

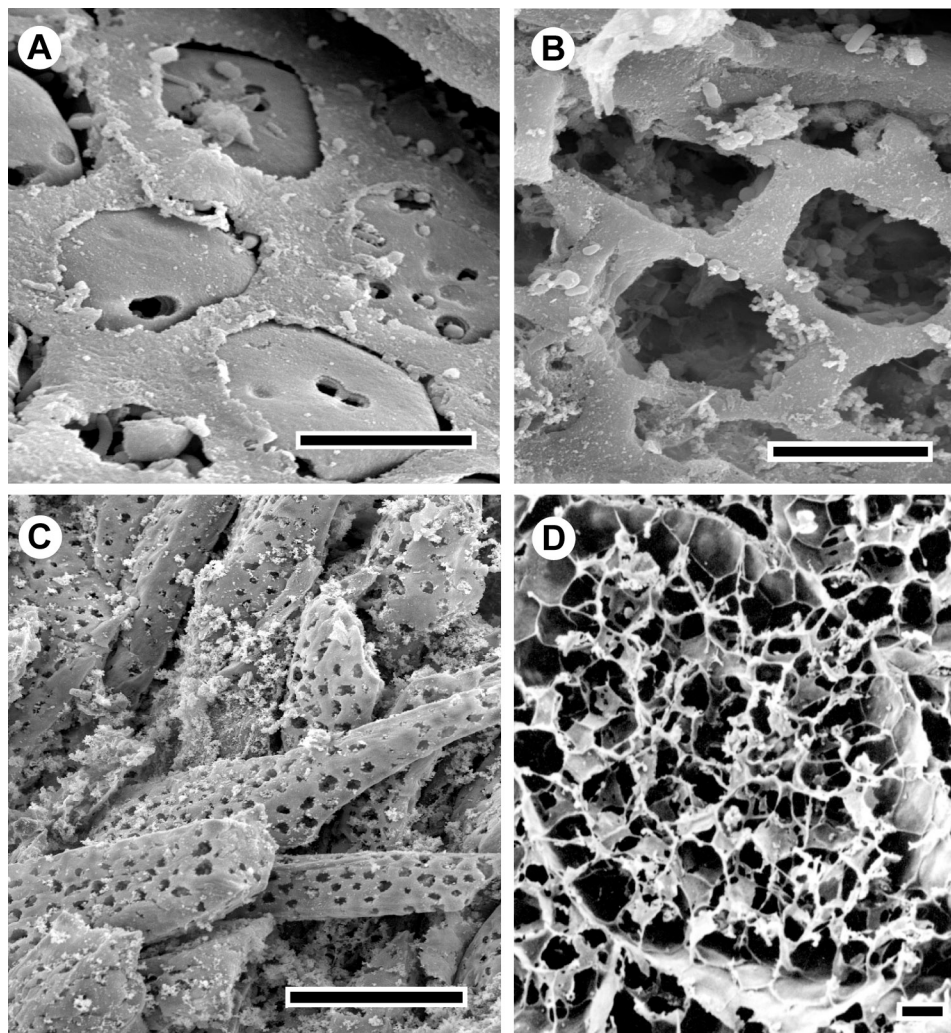


Figure 4. Scanning electron microscopy of (A) Starch granules embedded in the protein matrix of corn. Note that bacteria are preferentially colonizing and forming digestive pits on the surface of starch granules (Bar = 7.5 μm); (B) Protein matrix showing the locations previously occupied by starch granules (Bar = 7.5 μm); (C) Vitreous endosperm cells from corn. Note that the majority of the starch granules have been digested from the protein matrix (Bar = 75 μm); (D) Corn endosperm cell in which all of the starch granules have been digested and only the protein matrix and the endosperm cell wall remains (Bar = 10 μm). (A), (B), (C) Wang and McAllister, unpublished data; (D) From McAllister et al., 1990a.

Role of the Protein Matrix in Starch Digestion

For those cereal grains that are commonly fed to cattle, the nature of the protein matrix that surrounds starch granules has a far greater impact on the rate and extent of starch digestion than the properties of the starch itself (McAllister and Cheng, 1996). The yellow dent corn typically fed to cattle in North America arose as a result of crossing flint and floury genotypes. Flint corn contains high concentrations of vitreous endosperm and is less rapidly digested in

the rumen than corn that contains higher concentrations of floury endosperm, based on *in situ* measurements (Philippeau and Michalet-Doreau, 1997). Rumen bacteria preferentially colonize exposed starch granules that are embedded within the vitreous protein matrix (Figure 4A). As digestion proceeds, they hydrolyze the starch granules, tunnelling into the interior of the endosperm cells but leaving the protein matrix intact (Figure 4B) and the shape of the endosperm cell readily discernable (Figure 4C). With prolonged exposure to

rumen bacteria, all of the starch granules are digested and only the surrounding protein matrix and endosperm cell wall remain (Figure 4D). Properties of the protein matrix also may be related to the type or location of proteins, given that starch digestibility is negatively correlated with zein proteins but positively correlated with glutelins (Philippeau et al., 2000). Opaque 2, a corn genotype selected for its low zein concentration, exhibits a more rapid rate of ruminal starch digestion and a higher total tract starch digestibility than its isogenic counterpart when both genotypes are dry rolled (Ladely et al., 1995). Similar relationships between endosperm vitreousness and starch digestion also have been identified for sorghum (Kotarski et al., 1992). Many of the differences in digestion between more slowly fermented grains (e.g., corn, sorghum) and those that are more rapidly fermented (e.g., wheat, barley) can be attributed to differences in the properties of the protein matrix between these grains (McAllister et al., 1990b).

Impact of Grain Processing on Starch Digestion

Processing of cereal grains, whether by grinding, rolling, pelleting, tempering (i.e., addition of water prior to rolling), steam rolling (i.e., exposure to steam prior to rolling) or steam flaking (i.e., longer duration of exposure and higher grain temperature), breaks down recalcitrant barriers such as the hull, pericarp and protein matrix and allows microbes access to the starch harbored within endosperm cells. Furthermore, these processes reduce the particle size of the grain, increasing the surface area available for microbial attachment and colonization; combined, these actions increase the rate and extent of starch digestion (McAllister et al., 1994). Steam rolling and steam flaking expose grain to moisture and heat. At temperatures above 80°C, a portion of the starch in grain is gelatinized. Differential scanning calorimetry can be used to measure the extent of starch gelatinization and often is used to assess the effectiveness of steam conditioning. Steam conditioning and flaking gelatinizes less than half the starch (i.e., < 20%); extent of gelatinization increases with exposure to a higher temperature for a longer period of time (Svihus et al., 2005). Exposure of grain to temperatures above 120°C, such as those encountered during autoclaving, eliminates any

differences in the rate and extent of microbial digestion of starch between corn and wheat (McAllister et al., 1991).

The performance of feedlot cattle fed barley, which has a readily digestible protein matrix, was not improved as a result of steam processing as opposed to dry-rolling (Engstrom et al., 1992). In contrast, in corn, steam flaking as opposed to dry-rolling eliminated the adverse affects of increasing endosperm vitreousness on total tract starch digestibility in steers (Corona et al., 2006). This observation indicates that the benefits of steam flaking on digestion of corn are related not only to gelatinization of the starch, but also to enhanced destruction of the protein matrix. Recent work with high-moisture corn hybrids that differed in degree of vitreous endosperm supports this hypothesis. Szasz et al. (2007) found that ruminal, intestinal and total tract digestibility of starch in high-moisture corn were at least equal or in some instances higher for a vitreous hybrid than for a floury hybrid. In that experiment, all hybrids were rolled without steam conditioning, thus gelatinization of starch should not be a significant factor in determining the efficiency of starch digestion. Surprisingly, after rolling the high moisture corns, the particle size was smaller for the vitreous than the floury hybrid, exposing 15.8% more surface area for microbial colonization and enzymatic digestion (Szasz et al., 2007). We also have found that a large degree of the variation in ruminal starch digestion among barley varieties can be attributed to the degree to which the kernels shatter during processing and to the size of the processed particles (McAllister et al., unpublished). Consequently, a processing method × particle size interaction may be a major factor that determines the relative efficiency of starch utilization among varieties within a cereal grain species and between cereal grain species. With this point in mind, it seems logical that defining the factors within and among grain types that are responsible for the post-processing variation in particle size would be a prudent means of predicting the value of a processing method and of different batches of cereal grains for ruminants.

Post-processing Changes in Starch Digestion

Gelatinized starch can undergo a process known as retrogradation whereby starch molecules reassociate and form tightly packed structures stabilized by

hydrogen bonding. Retrograde starch resists digestion by amylases. This phenomenon is primarily associated with amylose, because retrogradation of amylopectin takes weeks or months to develop (Lii et al., 2004). Consequently, cereal grains that contain starch granules with a high amylose content (e.g., high amylose corn) are more subject to retrogradation than those that contain starch granules with a low amylose content. Storage of grain at higher temperatures can dramatically accelerate the rate of amylose retrogradation (Jouppila et al., 1998). However, under commercial production conditions in feedlots, the duration of storage is likely too short and the temperature too low for significant retrogradation of starch to occur.

Although retrogradation may be most prevalent in high amylose grains exposed to high temperatures, researchers have reported a “retrograde response” in steam-flaked corn held at temperature for much shorter periods of time (Ward and Galyean 1999; McMeniman and Galyean 2007). Thus, the amount

of available starch in corn subjected to various processing procedures may be described as portrayed in Figure 5. Heat treatment at low moisture levels can decrease the digestibility of starch due to the formation of starch-protein complexes (Ljokjel et al., 2003), but it is not known to what extent similar complexes may be formed in grain subjected to steam processing. The formation of these complexes may also impede the precise measurement of starch in feed byproducts such as distillers grains. At this point it is not known if rumen microbes can hydrolyze these complexes and make the starch available for ruminal fermentation, but others have observed no difference in ruminal or total tract starch digestion between fresh and air-dried steam flaked corn (Zinn and Barajas, 1997). Consequently, if such a phenomenon does occur, this type of “retrograde starch” is unlikely to limit starch digestion in ruminants. In light of the expanding use of corn and wheat distillers grains in feedlot diets, studies on the potential impact of these complexes on the performance of feedlot cattle are warranted.

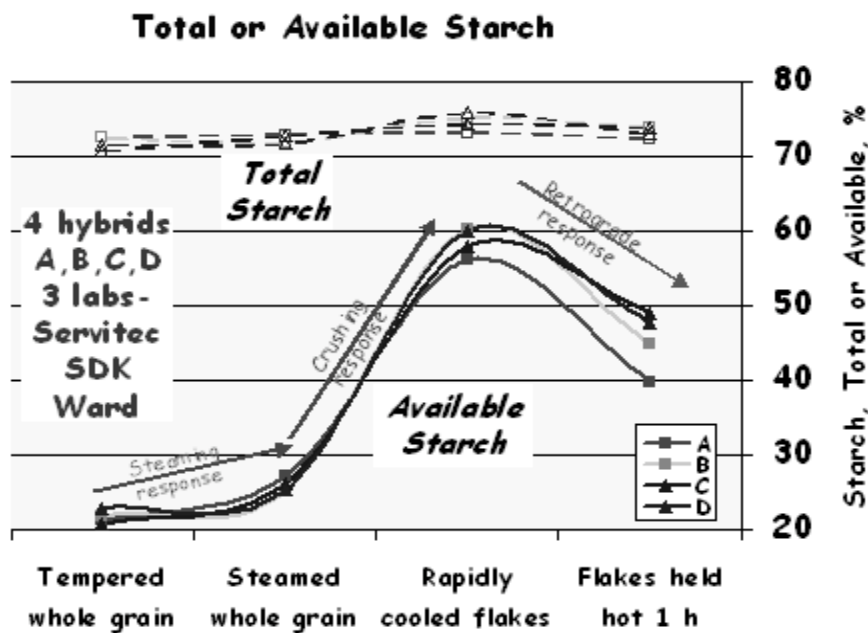


Figure 5. Changes in total or available starch in four corn hybrids as a result of tempering, steaming and crushing of corn. Note that an apparent “retrograde response” was observed in flaked corn that was held at temperature for 1 h. Data adapted from Ward and Galyean (1999) by Owens (personal communication).

SUMMARY AND IMPLICATIONS

The utilization of starch in cereal grains by ruminants is limited primarily by kernel structures

rather than the nature of the starch itself. Presence of the pericarp restricts bacterial and enzymatic access so that whole cereal grains are poorly digested. The pericarp

must be disrupted by processing or mastication for starch digestion to proceed. Once endosperm cells are exposed, starch digestion can still differ among cereal grains, limited by a dense protein matrix surrounding the starch granules. Processing techniques, such as steam flaking, that involve the application of heat and shear force are more effective than dry rolling for exposing the starch within the vitreous endosperm to digestion. Particle size also plays a key role in determining the

efficiency of starch digestion because smaller particles have a larger surface area and consequently are more susceptible to digestion by both microbial and mammalian enzymes. Characterization of the properties of cereal grains that influence particle size distribution such as kernel uniformity, chemical composition, moisture content, and degree of shatter upon processing may provide a reliable index by which relative ruminal digestibility of starch from cereal grains can be predicted.

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QUESTIONS AND ANSWERS

Q: Tim, based on your photomicrographs, the protein of corn seems quite indigestible in the rumen. Because corn byproducts and distillers' products concentrate those fractions, the amount of protein degraded in the rumen must be quite low for such products.

- A:** Lower ruminal protein degradation matches with higher protein bypass for distillers' grain. With wheat distillers' products from Canada, the energy availability is greater than what we initially expected, so the level that we can substitute into the diet without having negative effects is much greater. Whether you have seen this with corn is not known.
- Q:** Tim, you commented that if protein barriers limit the accessibility of starch to enzymes in the rumen, then mammalian enzymes similarly are not likely to digest that starch either. But once you expose the product to the low pH and pepsin of the abomasum, doesn't that change the structure of that protein so that you are looking at a different organizational structure than you have in the rumen?
- A:** Good point. Nobody has looked at that. Someone should collect samples from the small intestine of cannulated animals and examine the protein matrix with an electron microscope. When you are dealing with a product that has a high ruminal protein bypass because of its resistance to microbial enzymes, you may get some recovery of starch postruminally, but the starch will never become as available as when the grain is steam flaked that makes all the starch available.

GRAIN PROCESSING: PARTICLE SIZE REDUCTION METHODS

Leland J. McKinney
Kansas State University
Manhattan, KS
lelandm@ksu.edu



INTRODUCTION

Cereal grains generally are the primary source of energy in feedlot diets. Availability of energy from the grain depends largely on the type of grain used as well processing of that grain (Owens et al., 1997). A variety of grain processing techniques are used including grinding, steam flaking, and compiling high moisture corn to ferment. Each processing method differs in its nutritional efficacy (Owens et al., 1997) and each has a unique associated cost (Macken et al., 2006). For grain processing to be effective, a positive balance between processing equipment and maintenance costs, labor availability and skill level, energy efficiency, cattle management practices, and cattle performance must be achieved.

Depending on the size of the feedlot and the type and availability of feedstuffs, simply rolling or grinding grain can be the most effective processing technique to improve nutrient utilization and cattle performance. Four basic physical principles are involved with grinding or particle size reduction. These are: (1) *Compression*; (2) *Impact*; (3)

Attrition; and (4) *Shear*. Most grinding equipment employs a combination of these principles that ultimately defines the equipment's suitability for certain situations. The two most common types of grinders used in the cattle feeding industry today are hammermills and roller mills. These same two processing methods are used to process high moisture corn into storage and to roll steamed corn to produce steam flaked or steam rolled corn. Hammermills primarily grind by impact and attrition whereas roller mills utilize shear and compression to reduce particle size. Consequently, both grinder-types have positive and negative attributes depending on the situation. The purpose of this paper is to review hammermills and roller mills and to discuss the factors that influence the efficiency of hammermill and roller mill operation.

HAMMERMILLS

Hammermills consist of a rotor assembly made from two or more rotor plates fixed to a main shaft and enclosed in a screened grinding chamber (Heiman, 2005; Figure 1).

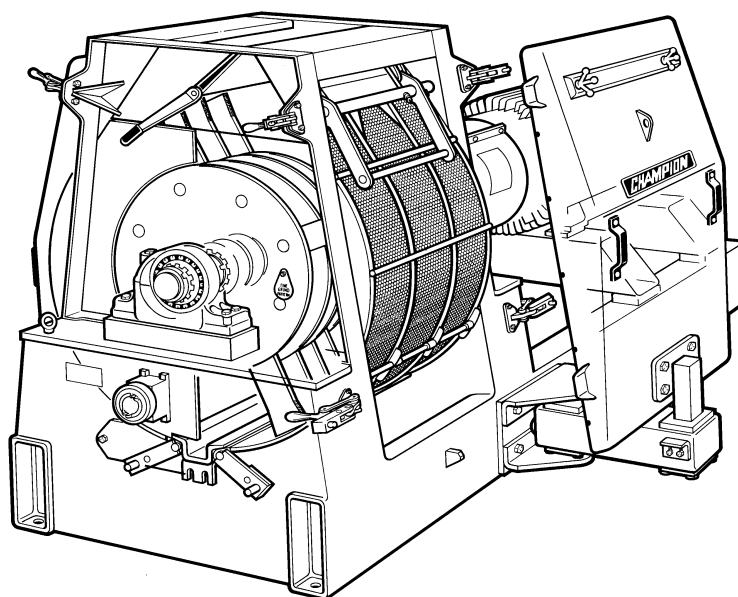


Figure 1. Illustration of a hammermill (Heiman, 2005).

Numerous grinding chamber designs exist including a half circle, a full circle, a teardrop and a spilt screen. Hammers, either fixed or free-swinging, are attached to the rotor assembly. As the rotor assembly rotates, the hammers impact and consequently shatter the feed. Because hammermills grind primarily by impact, a minimum critical "tip speed" is needed to provide the needed energy to shatter the feed in the grinding chamber. Hammermills generally operate at a tip speed of 17,000 to 25,000 ft/minute; a mill with a small diameter mill must turn at a higher RPM than a mill with a large diameter mill to obtain the same tip speed.

The size of the screen hole size has the greatest influence on the particle size of the product. The screen prevents the ground feed from leaving the grinding chamber until it reaches an appropriate size. In split screen designs, screens with smaller holes are placed the "down" side while screens with larger holes are on the "up" side.

Modern hammermills become much more efficient when an "air assist" system is added. An "air assist" places the grinding chamber under negative pressure so that air flows through the screen with the ground feed. This increases throughput reduces the heat retained within the grinding chamber. Most mills can be retrofitted with an air assist system, but it must be designed and installed properly to be effective. Some modification to the mill may be needed to direct air into the grinding chamber.

ROLLER MILLS

The design of a roller mill varies considerably depending upon its application. Roller mills are often named for the work they do--such as crackers, crimpers, crimper-crackers, flakers, crumblers, grinders, crushers, and, more simply, just rollers. This illustrates the great versatility of roller mills. Roller mills can consist of a single, double, or triple pair of rolls that are stacked and enclosed in a steel frame (Figure 2).

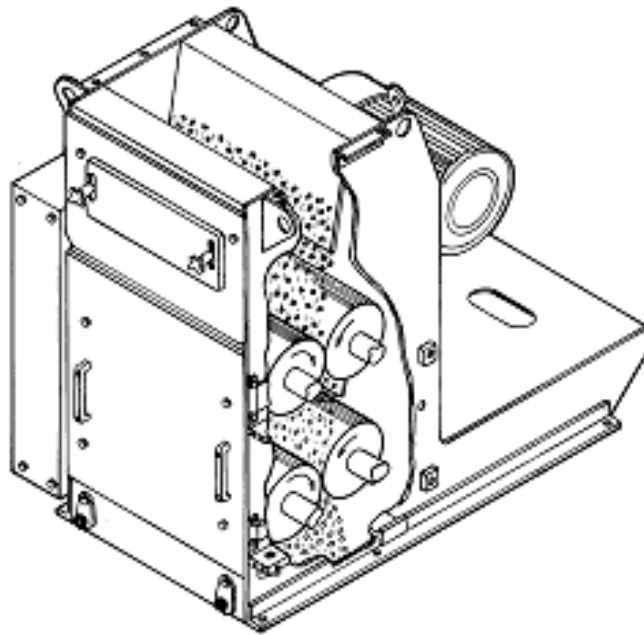


Figure 2. Illustration of a roller mill (Heiman, 2005).

Feed passing between the rolls is sheared and compressed to reduce the particle size depending on the speed differential between the rolls. The greater the differential in speed of the rollers, the greater the shear force that is applied to the feed. A feeder roll

ahead of the grinding rolls regulates the feed rate and drops the product evenly into the nip of the rolls where the product size is reduced. The rolls are usually grooved or corrugated and driven by belts connected to an electric motor. The rolls turn about

600 RPM. Alterations in roll grooving and machine design can make the roller mill useful in a very wide range of work requirements.

HAMMERMILL AND ROLLER MILL DIFFERENCES

In general, either grinder performs well with common grains including corn, grain sorghum, or wheat depending on their moisture content. However, roller mills do not grind fibrous materials efficiently; therefore, they are not typically used for finely grinding oats, barley, or other fibrous grains or ingredients. Grain moisture content will dramatically affect either mill. With more moisture, the endosperm of grain becomes elastic and absorbs the impact or crushing energy by deforming rather than shattering. Excessive moisture in hammermill ground grain can result in high heat due to friction and, because of the heat, moisture will be lost. A roller mill with differential speed of the rolls can generally handle high moisture grain more readily than a hammermill depending on the particle size desired.

A roller mill produces a less dusty, product that is more uniform in particle size than a hammermill does. This is because the product is crushed and sheared rather than shattered by impact. Impact grinding often results in excessive amounts of fine particles and dust, particularly with wheat and with very dry grain (<11% moisture).

Roller mills often are considered to be more energy efficient than hammermills. This statement must be qualified depending upon the target particle size. Roller mills are extremely efficient for producing a product with a large particle sizes (+1800 microns); however, as product size is reduced, energy consumption (or electrical efficiency) of the two types of mills becomes nearly equal when the target particle size is 600 microns or below. So depending upon the target particle size, energy efficiency may or may not be an important criterion for selecting a mill type.

Generally, roller mills are higher in cost than a hammermill with equal capacity; however, when the total installation cost is considered, cost of the two mills can be comparable. Hammermills usually require a larger, more expensive motor, a switch gear,

and controls, an air assist system, and more elaborate noise abatement. Hence, the installed cost for either system usually is comparable.

Generally, hammermills produce particles with more spherical shape whereas roller mills produce particles with a cubic shape. After a kernel shatters in a hammermill, abrasion rounds off the sharp edges of the particle; this makes the particle more spherical and results in more dust generation. It seems unlikely that particle shape will influence on animal performance, but grain handling and mixing can be changed dramatically. For example, the bulk density of roller mill ground grain typically is lower (by about 5%) than hammermill ground grain of similar mean particle size. This can affect volumetric proportioning operations as with a portable grinder-mixer. In addition, the mixer can be overloaded (if batch weight is not adjusted) that this reduces the efficiency of the mixer.

Roller mill ground grain does not mix with vitamins, drugs, and minerals as readily as hammermill ground grain. This likely is due to the shape of the particle. This may increase the amount of power required for mixing. Again, this likely is due to the differences in flow characteristics of cubic versus round shaped particles. These areas need additional research before definitive quantitative recommendations can be made.

CONCLUSION

Depending on the size of the feedlot and the type and availability of feedstuffs, rolling or grinding of grains both can be effective processing technique to improve nutrient utilization and cattle performance. The two common types of grinding systems used by the cattle feeding industry today are hammermills and roller mills. Both grinder-types have positive and negative attributes depending on the situation and application. Roller mills are most appropriate for cereal grains being ground to a larger particle size. However, the roller mill is more versatile and can be modified for application to a wide range of feeds and particle sizes and shapes. Hammermills are more suitable for grinding fibrous material or when grain is being ground to a very fine particle size.

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STEAM FLAKING GRAINS FOR FEEDLOT CATTLE: A CONSULTANT'S PERSPECTIVE

Steve Armbruster

Steve Armbruster Consulting, Inc.

sarmbruster@beeftech.net



INTRODUCTION

Several excellent recent reviews of grain processing are referenced at the end of this article. Thus, the focus of this discussion is limited to the implications and the applications of research on steam flaking, citing selected studies that illustrate salient items. The emphasis is on high-concentrate diets fed to growing/finishing cattle.

In this article, steam flaking frequently is compared to dry rolling while recognizing that other processes (i.e., high-moisture or whole corn) often are viable alternatives. Within processing method, grain attributes can vary considerably, such as degree of gelatinization after steam flaking and grain particle size after dry rolling.

For simplicity, “steam flaking” hereafter will be called “flaking.” For this discourse, flaking is considered the process of steaming whole grain at atmospheric pressure, typically for 20 to 40 minutes, and then rolling it to a flake density from 24 to 32 lb/bushel. This causes sufficient disruption of the

starch-protein matrix to result in starch digestibility of 80% to 90% in the rumen and 98% to 99% in the total tract. Consequently, one might expect a greater response to flaking with grains that contain more starch; also, response to flaking should be more consistent for grains that are less variable in starch content. The mean and standard deviation for starch content (% of DM) for various cereal grains from DairyOne (2007) were: corn 70.5 ± 5.1 ; sorghum grain 64.5 ± 14.2 ; wheat 62.7 ± 9.6 ; and barley $54.6 \pm 9.5\%$.

GROWTH PERFORMANCE

Flaking Corn

Compared to dry rolling or ensiling, flaking appreciably improves energetic efficiency of corn (Table 1); these differences were summarized in a review of grain processing by Owens et al. (1997). Among criteria for including data in their summary were 1) roughage less than 15% of diet DM, 2) grain more than 55% of diet DM, and 3) a single grain and processing method within a given diet.

Table 1. Least squares means for corn processed by various methods*

Process	ADG, lb	DMI, lb/d	F:G	ME, Mcal/lb
Dry Rolled	3.20 ^a	20.8 ^a	6.57 ^a	1.46 ^a
High Moisture	3.02 ^b	19.2 ^b	6.43 ^a	1.56 ^b
Steam Flaked	3.15 ^a	18.4 ^c	5.87 ^b	1.68 ^c

Owens et al. (1997).

*ADG, average daily gain; DMI, dry matter intake; F:G, feed to gain ratio; ME, metabolizable energy.

^{a,b,c} ($P < 0.05$).

When these data are interpreted for feedlot application, variation in efficiency within a processing method can be quite large, particularly with high-moisture or dry-processed corn. Regarding high-moisture corn, Owens et al. (1997) reported that ME values ranged from 1.32 to 1.58 Mcal/lb DM depending on the moisture content and form of processing of the corn.

Summarizing four trials comparing flaked with dry-rolled or -ground corn, Zinn et al. (2002) noted that flaking improved NE_g values from 15.9 to 25.9%.

Some of this large variation in flaking response probably was due to differing efficiencies of dry-processed corn because particle characteristics (size and uniformity) of dry rolled corn can vary widely.

Two recent research reviews (Table 2) indicate that the energetic response to flaking corn, as compared to dry rolling, is considerably greater than summarized in NRC Beef (1996). Zinn et al. (2002) offered two reasons for this difference between research and NRC values, 1) tabular NE values for dry-rolled corn have been overestimated and 2)

tabular NE values for flaked corn have been underestimated, perhaps due to failure to consider the increased digestibility of the non-starch organic matter associated with flaking.

Improvements in growth performance of feedlot cattle that result from flaking corn can be explained largely by increased ruminal, post-ruminal and total-

tract digestion of starch (Table 3). Also important is the increased digestibility of non-starch organic matter that appears similar in magnitude to the enhancement in starch digestion (Zinn et al., 1995). A protein matrix encapsulates unprocessed cornstarch granules. Zein normally ferments slowly in the rumen. Flaking denatures zein, and this contributes to the improved digestion of starch and nitrogen.

Table 2. Advantage (%) of flaking corn, compared to dry rolling*

Reference	NE _m	NE _g
Owens et al. (1997)	16.7	22.2
Zinn et al. (2002)	14.2	17.3
NRC, Beef (1996)	4.0	4.5

*NE_m, net energy for maintenance; NE_g, net energy for gain.

Table 3. Digestibility (%) of starch in corn

Process	Rumen, % Intake	Postrumen, % Entering	Total Tract
Dry Rolled	61 – 76	68 – 69	89 – 92
Steam Flaked	84 – 85	93 – 94	99

Huntington (1997), Owens and Zinn (2005).

In addition to improving starch utilization, Huntington (1997) reported that flaking corn reduces the variation in starch digestibility throughout the GI tract (Table 4). Thus, one can infer logically that the

animal growth response is more consistent with flaking than dry rolling. However, as previously emphasized, dry rolling is a nebulous term due to wide distribution of particle sizes.

Table 4. Digestibility (%) of starch in corn

Process	Rumen, % Intake	Postrumen, % Entering	Total Tract
Dry Rolled	76 +/- 8	69 +/- 18	92 +/- 3
Steam Flaked	85 +/- 4	93 +/- 4	99 +/- 1

Huntington (1997).

Flaking Sorghum

Compared to dry rolling, flaking also substantially improves energetic efficiency of sorghum grain (Table 5) as summarized in the review by Owens et al.

(1997). As with corn, flaking sorghum improves growth performance of feedlot cattle by increasing appreciably the ruminal, post-ruminal and total-tract digestion of starch (Table 6).

Table 5. Least squares means for sorghum processed by various methods

Process	ADG, lb	DMI, lb/d	F:G	ME, Mcal/lb
Dry Rolled	3.15	23.1 ^a	7.43 ^a	1.32 ^a
Steam Flaked	3.09	19.1 ^b	6.33 ^b	1.59 ^b

Owens et al. (1997).

*ADG, average daily gain; DMI, dry matter intake; F:G, feed to gain ratio; ME, metabolizable energy.

^{a,b} ($P < 0.05$).

Huntington (1997) did not report the degree of trial-to-trial variation in starch digestibility for flaked sorghum, as was noted with corn, presumably due to the small number of trials with sorghum. However,

one can deduce that flaking sorghum, as with flaking corn, should reduce the variation in digestion and animal performance.

Table 6. Digestibility (%) of starch in sorghum

Process	Rumen, % Intake	Postrumen, % Entering	Total Tract
Dry Rolled	60 +/- 12	62 +/- 11	87 +/- 5
Steam Flaked ¹	78	90	98

Huntington (1997).

¹Variation around means not reported.

Huntington (1997) noted that flaking increased ruminal digestibility of starch more for sorghum (19 percentage units) than for corn (13 percentage units). The protein matrix encapsulating raw sorghum starch is even more resistant to microbial degradation than the matrix in corn. Because flaking degrades this matrix, benefits of flaking, in terms of starch digestion and animal performance, are greater for sorghum than for corn. Compared to dry rolling, Owens et al. (1997) reported steam flaking improved ME values for sorghum and corn by 20.5% and 15.1%, respectively.

Although the response (on a percentage basis) to flaking is higher from flaking sorghum, flaked corn

remains superior to flaked sorghum in absolute starch digestion throughout the digestive tract (Table 7). These different coefficients are the principle reason that the ME value is 5.3% lower for flaked sorghum than flaked corn (Owens et al., 1997) even though these grains often have a similar starch content.

Theurer et al. (1996) suggested that optimal ruminal starch digestibility for corn and sorghum were near 80% and 85%, respectively, for feedlot cattle on high-grain diets. Research studies summarized in Table 7 suggest that achieving this target is more feasible with corn than sorghum without causing some potential negative consequences of over-processing.

Table 7. Digestibility (%) of starch

Process	Rumen, % Intake	Postrumen, % Entering	Total Tract
Flaked Corn	84 – 85	93 – 94	99
Flaked Sorghum	78 – 79	89 – 90	97 – 98

Huntington (1997), Owens and Zinn (2005), Swingle et al. (1999), Theurer et al. (1999).

Flaking Wheat

In their review, Owens et al. (1997) reported that flaking wheat, compared to dry rolling, improved body weight-adjusted ME by 13% as compared with improvements in ME of 15% and 21% for flaked corn

and flaked sorghum, respectively. Flaking wheat reduced feed intake but had no impact on daily gain (Table 8). In contrast, Zinn (1994) reported that flaking wheat tended to increase dry matter intake and increase daily gain.

Table 8. Least squares means for wheat processed by various methods*

Process	ADG, lb	DMI, lb/d	F:G	ME, Mcal/lb
Dry Rolled	3.04	19.8 ^a	6.59 ^a	1.49 ^a
Steam Flaked	3.04	17.9 ^b	5.92 ^b	1.70 ^b

Owens et al. (1997).

*ADG, average daily gain; DMI, dry matter intake; F:G, feed to gain ratio; ME, metabolizable energy.

^{a,b} ($P < 0.05$).

These differing conclusions probably are due to variation in physical attributes of processed wheat. Dry-rolling wheat creates fine particles; flour can reduce intake and gain and increases the potential for acidosis and bloat. The same appears true for thin, fragile flakes. Conversely, thicker flakes as described by Zinn (1994) improved “diet acceptability” compared to dry rolling; improved acceptability and

increased intake may account for much of the improvement in feed efficiency noted from flaking of wheat.

Flaking has far less impact on starch digestion from wheat than from corn or sorghum (Table 9). Yet the improvement in energetic efficiency from flaking wheat approaches that for corn. This supports the

concept that much of the benefit from flaking of wheat is associated with an improved physical form or

increased digestibility of non-starch organic matter.

Table 9. Digestibility (%) of starch in wheat for feedlot cattle

Process	Rumen, % Diet	Postrumen, % Flow	Total Tract
Dry Rolled	86.0	84.6	97.9
Steam Flaked	91.6	85.2	98.8

Owens and Zinn (2005).

Flaking Barley

Owens et al. (1997) reported no improvement in body weight-adjusted ME from flaking barley compared to dry rolling (Table 10) despite sizable improvements from flaking corn (15%), sorghum (21%) and wheat (13%). However, in that review, far fewer studies were available for barley than for the other flaked grains.

Summarizing least squares means from research trials, Owens and Zinn (2005) reported a trend for improved starch digestion by cattle fed flaked barley as compared to those fed dry-rolled barley (Table 11). Flaking enhances the rate of enzymatic starch digestion in barley, particularly when flakes are thin (Zinn, 1993).

Table 10. Least squares means for barley processed by various methods*

Process	ADG, lb	DMI, lb/d	F:G	ME, Mcal/lb
Dry Rolled	3.20	19.8	6.25	1.62
Steam Flaked	2.93	18.2	6.19	1.61

Owens et al. (1997).

*ADG, average daily gain; DMI, dry matter intake; F:G, feed to gain ratio; ME, metabolizable energy.

Table 11. Digestibility (%) of starch in barley for feedlot cattle

Process	Rumen, % Diet	Postrumen, % Flow	Total Tract
Dry Rolled	86.2	81.6	97.1
Steam Flaked	89.2	90.5	99.1

Owens and Zinn (2005).

As with wheat, interpretation of the response to flaking of barley is difficult considering the low number of trials. Often not well described were important attributes such as particle size with dry rolling and gelatinization with flaking. Depending on flake thickness, Zinn (1993) observed that flaking of barley increased NE_m from 2.8 to 7.0% and NE_g from 3.4 to 8.8%.

flaking. For each grain, the question was “Compared to dry rolling, what is the average percentage increase in grain NE_g (DM basis) from steam flaking?”

Criteria for answers were those used by Owens et al. (1997) including 1) roughage DM < 15% diet, 2) grain of interest > 55% of diet DM, 3) free choice access to feed, 4) single grain source, 5) flaking as only process, and 6) feedlot cattle > 99 days on feed. Results of this survey are summarized in Table 12.

Industry Perspectives

This author surveyed feedlot nutritionists for their perception of the net energy response to steam

Table 12. Increase (%) in grain NE_g from steam flaking: Industry survey

Grain	No. Responses	Mean, %	Range, %
Corn	12	11.6	8 to 14
Sorghum	11	15.4	8 to 19
Barley	6	4.5	0 to 5
Wheat	10	4.5	2 to 10

Carcass Value

In an analysis of data from published literature, Owens and Gardner (2000) reported that cattle fed flaked grains had heavier carcass weights than those fed dry-rolled, high-moisture, or whole grains, when averaged across grains (corn, sorghum and wheat). When other attributes were adjusted for carcass weight differences, cattle fed flaked grains had larger longissimus areas and greater subcutaneous fat thickness but lower marbling scores and quality grades than cattle fed dry-rolled grains. The authors suggested that higher subcutaneous fat deposition in cattle fed flaked grains is related to less escape of dietary starch from the rumen.

When finished cattle are marketed on a carcass basis, value depends carcass weight, quality grade and/or yield grade. Considering the carcass performance data reported by Owens and Gardner (2000), economic return from flaking is determined far more by carcass weight, and efficiency of carcass growth, than by carcass quality or yield grade.

MANAGING THE PROCESS

Zinn et al. (2002) prepared an excellent treatise on processing mechanics and quality standards. Although the focus of that review was flaking of corn, their commentary also is applicable to flaking sorghum. With the objective of improving animal performance, the primary purpose of flaking is optimizing starch digestion by 1) disrupting the protein matrix that encapsulates starch granules, and 2) damaging starch granules that in their native state are densely compacted.

As previously noted, benefits from steam flaking are greater with corn and sorghum than with wheat and barley. The same is true of the challenges with steam flaking. Although there are differences among varieties within a grain, corn and sorghum have more vitreous (hard) endosperm whereas wheat and barley contain a higher percentage of floury (soft) endosperm. In addition, the protein matrices of corn and sorghum inherently are more resistant to degradation than are proteins of wheat and barley.

As outlined by Zinn et al. (2002) the essential mechanics of flaking are 1) hydrate starch with moist heat to create irreversible swelling (gelatinization) of granules and 2) compress starch between rolls at a close tolerance to rupture granules and shear the

protein matrix. A proper combination of moisture, heat and pressure is necessary to achieve full benefit from flaking. Implemented alone, hydrating, steaming or rolling has less impact on starch digestion.

Moisture Addition

In most feedlots, water (with or without conditioner) is applied to whole grain during transfer of grain from dry storage to holding bins. Adding water after cleaning of grain is preferred because foreign material will wick moisture away from grain. Adequate mixing in a blending auger is essential for uniform uptake of moisture. Inconsistent absorption of water by whole grain causes variation in flake quality and uneven wear of rolls.

Depending on moisture of incoming grain and the target moisture for flakes, 5 to 7% water typically is applied. Steeping time for wetted grain ranges from 30 minutes to 12 hours based on facility design. Steaming further increases grain moisture by 2 to 4 %-units. The increase in moisture from steaming is influenced by moisture content of grain entering the chest and the time of steaming (retention time). Depending on these variables, flakes will range from 19 to 24% moisture as they exit from the rolls.

The effect of flake moisture on starch digestibility has received limited research attention. The same is true regarding interactions of moisture with density and retention time. With corn, Zinn et al. (2002) suggested that adding 5% moisture was sufficient when retention was about 30 minutes.

Also with corn, Sindt et al. (2006) indicated that adding moisture (up to 10% to whole grain initially at 11%) increased flake moisture and durability but had no effect on enzymatic starch availability. With sorghum, McDonough et al. (1997) reported that higher flake moisture, achieved by adding more water during tempering, improved both the structural integrity of flakes and extent of gelatinization of starch.

Routine measurement of flake moisture is important because it provides insight about the consistency of flakes and composition of ration dry matter. Daily testing of flakes beneath each roll helps achieve consistency among rolls. Flake moisture also can change from rolls to feed bunks depending on how flakes are conveyed (airlift vs. drag) and stored

(closed bin vs. open bunker). Samples obtained as flakes exit from storage provide the best estimate of moisture in bunks.

Retention Time

Time in steam chests varies among grains and across feedlots. Typical retention times are 30 to 40 min for corn, 40 to 50 min for sorghum and 20 to 30 min for wheat and barley. Zinn et al. (2002) noted that little research was available concerning the minimum retention time for optimal flaking but they suggested that a 30-min steaming was adequate for corn.

Feedlots usually steam for a longer time with sorghum than with corn grain, presumably due to the thicker protein matrix that surrounds starch granules of sorghum. Steaming of wheat and barley is for relatively short periods because the flaking emphasis with these grains is more on physical form than on starch digestion.

Estimating retention time in a steam chest is an important protocol that can be measured using a dye test or measuring the emptying rate of the cabinet. Injecting a food-grade dye at the top of a chest and timing its appearance at the bottom provides insight on retention time and uniformity of flow. Measuring each chest in a feed mill is essential because seemingly identical units can have different retention times. Further, measuring retention is important whenever there is change in grain source or cabinet design.

Flake Thickness (Density)

The most important variable affecting extent of processing is flake thickness, measured indirectly in feedlot mills as density (bushel weight). In studies summarized by Owen and Zinn (2005), flaking corn to lower densities for feedlot cattle increased starch digestion at all sites, particularly the small intestine. Results with varying density of sorghum have been similar, with one notable exception. Lower density with sorghum failed to increase starch digestion in the small intestine (Swingle, et al., 1999; Theurer, et al., 1999; Xiong et al., 1991). These data suggest that the protein matrix in sorghum remains as an impediment to small-intestinal starch digestion.

Owens et al. (1997) summarized the influence of flake thickness on cattle performance for corn,

sorghum and barley. Flakes of medium thickness (23 to 29 lb) tended to result in superior cattle performance, compared the thinner (< 23 lb) or thicker (> 29 lb) flakes. They reported flake weights as “dry” densities. One must be cautious extrapolating data in their review to feedlots because roll operators often weigh flakes hot and moist.

Consistency within a mill (among operators, across rolls and over time) is essential. As noted, flakes weigh more when hot and moist than when cool and dry. Intact flakes weigh less than fines. Differences in weighing protocol can easily result in 2- to 3-lb difference in bushel weight.

Regarding optimum density, one size does not fit all; it varies among feedlots and even among rolls within a mill. Flaking to a similar density does not necessarily assure that flakes are similar in terms of starch availability.

Other Considerations

McDonough et al. (2004) reported that accelerated aging of corn and sorghum at 50^o C for up to 15 days increased hardness index of the grain by 12 to 15%. During aging, floury endosperm became more corneous. As the grain hardened, strong associations between starch and protein developed, causing the endosperm to fracture through endosperm cells instead of along cell walls. These observations suggest that flaking is more beneficial, and extensive flaking more useful, for grain stored long periods than for grain freshly harvested. As a practical matter, optimum flake weight probably differs by period of time grain is stored and conditions during storage.

When flaked grains are stored in warm, moist conditions, gelatinized starch molecules can re-associate to form retrograde starch. Retrograde starch is “enzyme resistant” when incubated in the presence of starch-digesting enzymes such as amyloglucosidase. However, the capacity of rumen microbes to ferment or solublize enzyme-resistant retrograde starch is unclear. Ward and Galyean (1999) compared flaked-corn samples collected beneath rolls to samples collected as flakes exited storage bins. Bin samples were much lower in enzymatic starch availability, compared to roll samples. However, sampling site did not affect rate or extent of in vitro dry matter disappearance (IVDMD). In a study with similar design, McMeniman et al.

(2007) also reported lower starch availability in bin samples compared to roll samples. In contrast to the findings of Ward and Galyean (1999), these authors reported rate and extent of IVDMD were lower for bin samples. Whether retrograde starch impacts feedlot performance is unknown, but the subject merits further study.

OPTIMUM PROCESSING

Owens and Zinn (2005) and Zinn (1990) indicated that net energy reached a maximum when flake density of corn resulted in 99% total tract digestion of

starch. Theurer et al. (1996a) suggested that optimum processing resulted in 80% and 85% ruminal starch digestion for corn and sorghum, respectively.

Processing beyond this optimum tends to increase rate more than extent of starch digestion, thereby increasing risk. Illustrated in Table 13, risk includes increased acidosis, reduced DMI, and poorer efficiency (Reinhardt et al., 1997). Other consequences of over-processing are an increased incidence of bloat, laminitis and feed aversion.

Table 13. Degree of processing and performance of cattle fed sorghum

Item*	Density			SEM
	28	25	22	
Retention time, min	50	70	90	
Gelatinization, %	58.7	74.3	85.7	0.05
pH*hours				0.21
Below 5.0	3.9	7.3	9.6	1.88
Below 5.5	18.2	25.2	28.0	1.75
DMI, lb/d	19.0	18.8	18.4	0.20
F:G	5.92	6.10	6.13	0.045

Reinhardt et al. (1997).

*DMI, dry matter intake; F:G, feed to gain ratio.

It is a practical challenge to determine the density (thickness) at which optimum processing is achieved. Zinn et al. (2002) reported strong relationships of density to solubility ($r^2 = 0.87$) and enzyme reactivity ($r^2 = 0.79$). However, a considerable lag time exists between the production of flakes and their laboratory evaluation. Further, relationships of density to ruminal ($r^2 = 0.22$) and total tract ($r^2 = 0.52$) starch digestion were not so strong.

Fecal starch, perhaps a more suitable measure of starch digestion, explained 91 to 94% of variation in total-tract starch digestion, and 68% of variation in ruminal starch digestion for corn in feedlot cattle (Zinn et al., 2002; Owens and Zinn, 2005). Numerous studies with corn, sorghum and barley have shown that fecal starch as a percentage of fecal DM is less for cattle fed flaked grain than for cattle fed dry-rolled grain. Further, among flaked grains, lower flake density typically reduces fecal starch.

Owens and Zinn (2005) suggested that optimum processing of flaked corn occurred in feedlot cattle when fecal starch was 4% to 5% of DM. Despite encouraging research, most feedlots do not routinely

monitor fecal starch. Thus, we know very little about inherent variation in fecal starch, either among individuals within a pen or pens within a feedlot.

OTHER FACTORS

Compiling data from studies directly comparing starch digestibility to animal performance, Theurer et al. (1996a) reported that ruminal and small-intestinal starch digestibility accounted for 54% and 35%, respectively, of variation in feed efficiency. These data confirm the importance of grain processing and also illustrate that factors besides grain processing can significantly influence performance. Some of these factors have been studied in research trials; others are apparent from experience at feedlots. Some remain speculative.

Roughages

Roughage (forage NDF) contributes little digestible energy to high-concentrate diets. On the other hand, roughage aids in mixing the diet, stimulating saliva production, diluting acids, and encouraging rumination. Unfortunately, we do not understand all the complex interactions between roughage and grain processing.

Owens et al. (1997) reported that alfalfa was superior to corn silage in body weight-adjusted ME response for flaked corn, sorghum and wheat. Owens and Zinn (2005) indicated that optimum forage NDF range was 5% to 9% for cattle fed growing/finishing diets and suggested that values outside this range compromise energy intake and daily gain. Theurer et al. (1999b) noted that at a constant forage NDF, there were no interactions among dry roughage sources and response to flaking sorghum grain to various densities.

Based on intuition and experience, this author believes there is an important inverse relationship between level of forage NDF and extent of grain processing. Specifically, the more extensively that flaked grain is processed, the higher the level of roughage necessary to sustain DM intake and minimize digestive disorders.

In addition to level of roughage, physical form also is important. Coarser processing results in less ration fines, stimulates chewing and rumination, and these help to maintain intake and minimize acidosis.

Concentrates

Associative effects among concentrates are important in determining benefit from flaking and optimum degree of processing. One example is combining high-moisture corn with flaked corn or sorghum. Rate of ruminal starch digestion is faster with high-moisture corn than flaked grain. Thus the presence of high-moisture corn might justify flaking more conservatively.

Another example is incorporating wet ethanol by-products. When finishing diets contain large amounts of corn wet distillers grains (CWDG), research suggests that the advantage of steam-flaked corn over dry-processed or high-moisture corn is reduced (Vander Pol et al., 2006; Corrigan et al., 2007). However, rather than diminishing the energetic efficiency of flaked corn, added CWDG appears to improve relative values of dry-processed and high-moisture corn.

Bunk Management

Pritchard and Bruns (2003) authored an excellent treatise on bunk management. Appropriately, they stated “the causes of variable results in bunk management research can be ambiguous.” The same is true for practices in feedlots. Evaluating results is difficult, partly because daily variation in feed intake by a pen provides little insight about animal-to-animal differences within a pen.

Emphasized by Prichard and Bruns (2003), the primary considerations in bunk management are 1) controlling intake and 2) minimizing metabolic disorders. Because these also are important factors in grain processing, bunk management and steam flaking are inherently associated.

However, studies of this association are limited. One can presume that if bunk management minimizes intake variation, then it facilitates more extensive processing of grain. Conversely, practices that induce or fail to control intake variation require more conservative grain processing.

Defined by differences in providing access to feed, bunk management programs include ad libitum, clean bunk, and restricted (or limited) feeding. Often debated, merits and drawbacks of each program have not been studied sufficiently.

What is known or surmised is that the bunk management program affects a) level and variation of intake, b) rate and efficiency of growth, c) incidence of binging or aversion, and d) frequency of digestive disorders. Grain processing will affect these same parameters. In this common context, there is an inextricable link between flaking grain and managing bunks.

Feed Additives

Monensin fed in high-grain diets increases average rumen pH, reduces feed intake variation, increases meal frequency while diminishing meal size, and reduces bloat. Monensin also interacts with the bunk management program to affect rumen pH and eating behavior (Erickson et al., 2003). Unfortunately, the relationship between monensin and grain processing has received only very cursory examination in research studies.

In finishing rations devoid of monensin, such as those fed in “natural” programs, typical diet formulas include a higher amount of roughage to control acidosis and minimize bloat. When such rations contain flaked grain, particularly corn or sorghum, another means for managing digestive disorders is to process grain conservatively. When reducing ruminal starch fermentation, potential tradeoffs are less total-tract digestion and subsequent loss of efficiency. In terms of animal performance, cost effectiveness of this exchange is unclear.

A similar conundrum exists between extent of grain processing and feeding antibiotics such as tylosin. Tylosin greatly reduces the incidence of liver abscesses and their negative impact on performance of cattle fed high-grain rations (Nagaraja and Chengappa, 1998). In the absence of tylosin, higher roughage levels in finishing rations will reduce the incidence of abscesses. It is unknown whether more conservative processing of flaked grain results in a similar benefit.

Environment

Eng (personal communication, 2006) stated that: “improvements from steam flaking are greater in more temperate and more stable climates.” Climate, season, weather, and breed type all can affect level and pattern of consumption. Therefore, it seems reasonable that these factors can influence not only the response to flaking, but also the optimum degree of processing. Framed in a practical context, flaking for a Brahman calf in the Southwest is different from flaking for a Continental yearling in the Midwest.

SUMMARY

Compared to all other methods of grain processing, flaking improves growth performance of cattle fed growing-finishing rations. Flaking improves energetic efficiency of corn and sorghum more than barley and wheat. For corn and sorghum, most of the benefit from flaking is due to improved ruminal and total tract digestion of starch. For barley and wheat, the principle advantage from flaking is higher feed intake, due to improved physical attributes of the grain.

Optimum processing usually maximizes net energy intake. For optimum results, flaking needs to be more extensive for corn and sorghum than barley and wheat. Inadequate processing corn and sorghum will compromise efficiency due to poor starch digestion. In contrast, excessive processing will reduce intake and gain, harm efficiency, and increase the prevalence of digestive and metabolic disorders.

Variables affecting steam flaking include grain type and variety, processing conditions, other diet ingredients, bunk management, feed additives, environment, and cattle type. Regarding processing conditions, flake thickness (density) has more impact than any other variable. Also important are retention time in the steam chest and moisture content at rolling. Laboratory evaluation provides only limited insight about processing. Fecal starch is a valuable tool, but it is not used widely. Other useful criteria include DM intake and digestive disorders. Compared to other methods of processing, flaking requires a greater investment in equipment, energy and labor. Costs of steam flaking to compare with its benefits are addressed elsewhere in this publication.

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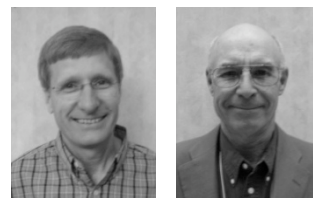
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HIGH MOISTURE CORN QUALITY CONTROL AT HITCH

R. Britt Hicks* and Robert P. Lake†

*Oklahoma Panhandle Research and Extension Center, Oklahoma State University, Goodwell and †Hitch Consulting Services, Guymon, OK
britt.hicks@okstate.edu



INTRODUCTION

Feed conversion becomes more important to the cattle feeder as the price of grain increases. As a result, the quality control procedures followed in harvesting and processing high moisture corn (HMC) become of even greater importance. The level of moisture in HMC and its processing can affect performance greatly. A review by Owens et al. (1997) clearly illustrated how both the moisture content and processing form (ground, rolled or whole) of HMC affects feedlot performance. In that review, performance (gain and efficiency) increased as moisture content increased and was greater for ground than for rolled HMC. Regression of daily gain against the percentage of moisture of HMC fed in all grain forms indicated that daily gain should reach a maximum at between 30 and 31% moisture. The maximum efficiency with HMC is attained when digestion is maximized without causing acidosis (Secrist et al., 1995). The ideal particle size of HMC represents a balance between digestion and acidosis. For maximum digestion, large particles should be avoided, but to reduce the incidence of acidosis, small particles also should be avoided.

Since 1973, Hitch Enterprises has purchased more than a quarter of a billion bushels of high moisture corn. This paper will review the quality control procedures that Hitch Enterprises developed for harvesting and processing HMC over the last 40 years at their feedyards.

QUALITY CONTROL AT HITCH ENTERPRISES

Receiving and Processing

Quality control at Hitch during HMC harvest has changed since the early 1970's. Hitch has used WHO hammer mills to process high moisture grain before ensiling since 1967. In 1967, 30% moisture milo was ensiled at Hitch Feedlot and the cattle performance was excellent. Gains were good, feed conversions were low, and cost of gain was low. Ladd Hitch said, "A bushel of 30% moisture ground ensiled milo is worth the same as a bushel of dry rolled milo." In

1968, HMC and high moisture milo were ensiled with quite different results. HMC ensiled at 27% to 30% moisture resulted in good performance. Milo ensiled was in the low 20% moisture range due to an early frost and the cattle performance was poor. The next two years, the success with high moisture milo was variable while success was consistent with high moisture corn. Since 1971, only high moisture corn has been ensiled at Hitch.

Today most feedlots use roller mills to process high moisture corn because it is easier to manage rolled than hammer milled high moisture corn at the feed bunk. But due to the tremendous volume of HMC that Hitch receives during corn harvest season, hammer mills are used to process the corn; milled corn packs tighter and faster resulting in less spoilage and fermentation loss. With proper handling and covering of HMC pits, Hitch kept shrinkage (dry matter loss from ensiling to feeding) below about 1.5% of DM. Feeding rolled HMC as compared to ground HMC simplifies bunk management while increasing DMI and ADG. In the past, some rolled HMC was fed at Hitch Feeders II in Garden City, KS; they observed that feed conversions suffered unless the rolled HMC was quite wet (30-35% moisture). In theory, ensiling and feeding a mixture of both ground and rolled HMC should optimize not only the packing and ensiling process but also cattle performance. Hitch currently feeds up to 75% of the grain dry matter as HMC with the remainder being steam flaked grain (typically corn, but occasionally milo or wheat).

Because the incidence of acidosis might increase when feeding ground rather than rolled HMC, the goal at Hitch has been to process ground HMC to reduce the rate of digestion without reducing the extent of digestibility. Hitch's goals for HMC corn harvest and receiving are listed in Table 1. The target moisture level for HMC is 28 to 30%. Water is added to the ground HMC when the moisture content drops below 27.5%. At receiving, HMC with a minimum of 24% moisture is accepted provided enough higher moisture corn is being received so that the HMC blend will meet target moisture levels. Similarly, at

receiving, HMC with a moisture content below 33% is accepted provided it can be blended with enough dryer corn to meet target moisture levels. The moisture content is monitored with a Dickey-John Grain Analyzer.

The screen size that Hitch uses on a hammer mill in processing HMC will vary within a harvest season due to corn kernel size, moisture level of the received HMC, hammer conditions, and the number of hours that the screen has been used. Using a WHO hammer mill with an 84 inch cylinder grinding HMC at a rate

of 1300 bu/hr, Hitch has found that screens will last about 80 hrs or 1,000,000 bu.

To reduce the number of times that the crop is irrigated, some corn growers plant shorter season hybrids and can deliver such grain several weeks before full season grain is harvested. Hitch usually steam flakes this early season hybrid corn due to the low volume received. Early season hybrids may be received as HMC if hail has damaged a grower's field and thus, the field is harvested early.

Table 1. Goals for high moisture corn harvest at Hitch

-
- One pack tractor per 5000 bu per hr capacity
 - Grind daily corn within 18 hours after arrival
 - Maintain moisture level of 28 to 30%
 - Whole corn less than 2.5%
 - Fines less than 20%
 - Shake samples a minimum of four times daily
 - **SAFETY:** "Don't get run over by a pack tractor while taking samples"
-

The profile of HMC changes as it ages in pits after ensiling. Much of the debate over the feeding value of HMC has centered on the fact that much of the protein in HMC is solubilized during ensiling (Soderlund, 1995). Soluble N is highly correlated with moisture level and increases with storage time (Prigge, 1976; Thornton, 1986; Stock et al., 1991). In addition, major differences in nitrogen solubility can exist when the high moisture grain is stored whole rather than ground (Prigge, 1976). This early data showed that at 56 days of ensiling, 38% of the nitrogen was in the soluble form for ground whole shelled corn as opposed to 15% for non-ground corn. The increase in soluble protein after ensiling indicates that the protein matrix around starch continues to be broken down as the grain ages in the pit (Owens et al., 1986). That review indicated that soluble protein is a good indicator of digestibility in high moisture corn.

Recent reviews evaluating the influence of corn processing on site and extent of digestion in cattle (Owens, 2005; Owens and Zinn, 2005) indicated that two factors are critical for maximum feed efficiency and ruminal starch digestion from HMC: adequate moisture (preferably 26 to 31%) and a sufficient duration of fermentation. Recent research (Benton et al., 2005) indicated that in situ dry matter digestibility (ISDMD) of HMC increased rapidly during the first 28 days of ensiling with a more gradual increase

during the remaining storage period (ranging from 298 to 372 days of total storage). In this trial, changes in ISDMD paralleled increases in degradable intake protein (DIP: expressed as percentage of CP) as length of ensiling increased. This trial also indicated that ISDMD and DIP increased both for HMC and reconstituted corn as corn moisture content increased.

Quality control samples analyzed for Hitch have shown that the percent soluble protein (expressed as percentage of CP) ranges from 10 to 15% for dry corn versus 60 to 80% for ground HMC. Soluble protein levels in rolled HMC in the Hitch data ranges from 50 to 60%. Similar to observation by Benton et al. (2005), soluble protein increased rapidly during the first one to two months of storage but increased more gradually thereafter. In data from the Dairy One library (2007; Table 2), soluble protein content of high moisture shelled corn averaged about 30% as compared to 20% for dry shelled corn and 11% for steam flaked corn in the samples they analyzed over the last seven years. Those values for soluble protein content of high moisture shelled corn are considerably lower than observed at Hitch. This difference may be due to differences in the grain form (whole vs ground) and the fact that length of ensiling in the Dairy One data is unknown. In the Dairy One library, soluble protein ranged from 19 to 42% in HMC.

Table 2. Summary of Dairy One data (accumulated crop years: 5/01/2000 through 4/30/2007)*

Grain	DM, % ¹	CP, % ¹	Soluble Protein, % of CP ¹
Steam Flaked Corn	87.76 (405)	8.39 (308)	10.68 (198)
Shelled Corn	90.07 (4,745)	9.40 (4,064)	20.17 (1,939)
High moisture Shelled Corn	71.92 (12,358)	9.11 (11,890)	30.57 (11,280)

*DM, dry matter; CP, crude protein.

¹Number in parentheses is number of samples.

Further analysis of data from the DairyOne database (New York samples) separated by month that the sample of high moisture shelled corn was

analyzed readily displays an increase in protein solubility with time after harvest (Figure 1).

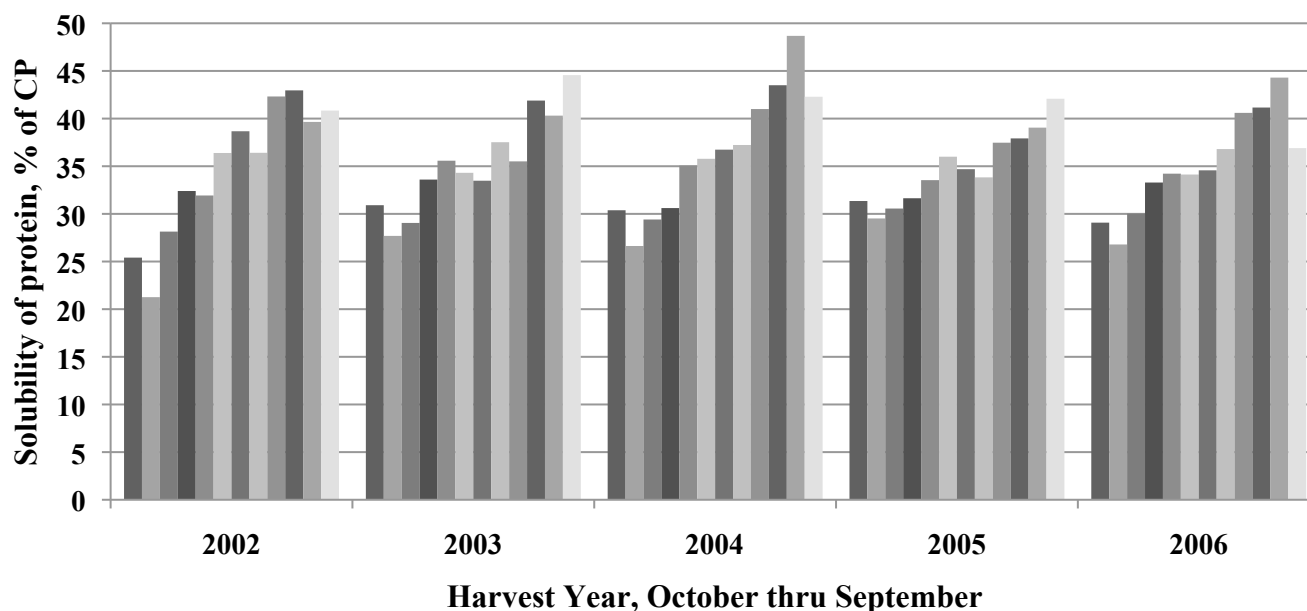


Figure 1. Influence of month of analysis on mean protein solubility of high moisture shelled corn analyzed by Dairy One Analytical Laboratory (New York samples).

Quality Control Testing

In 1973, quality control at Hitch consisted of detecting a maximum of five kernels of whole corn in a double handful of freshly ground HMC (< 1.2% whole kernels). The High Moisture Grain Symposium held at Oklahoma State University in 1976 illustrated that high moisture corn is only a generic term. So in 1976, Hitch's quality control procedures were refined to manually shaking HMC using two screens and a pan. The screens from Burrows used a 12/64 scalper screen on top and 2 ½/64 bottom screen and a shake time of about three minutes. Whole corn kernels were less than 1.5% by weight and fines (material in pan) were more than 25% by weight. Incidence of digestive upsets by cattle indicated that the rate of ruminal digestion of this corn was quite rapid.

In 1980, Hitch quality control procedures were changed to manually shaking HMC using three screens and a pan and a shake time of 3 minutes. The screens were: top screen - 12/64 scalper, middle screen - 1/12, and bottom screen - 2 ½/64. The hammer milled high moisture corn had less than 2.5% whole corn kernels and fines were less than 20%. As the fines were reduced, the incidence of digestive upsets decreased.

In 1995, Hitch started using a W.S. Tyler Sieve Shaker (Model RX-86) with three screens, a pan and a timer at their feedlots in their quality control program. The screens used are USA standard #18 (1.00mm), #10 (2.00mm), and #4 (4.75mm). These screens are similar to the 12/64, 1/12, and 2 ½/64 screens previously used at Hitch. The procedures followed with the sieve shaker are listed in Table 3.

Table 3. Current sieve shaker procedures for HMC at Hitch

• SAMPLE SHOULD REPRESENT THE GRIND
• Pull 1000 gram sample and mix
• Shake duplicate 400 to 500 gram samples
• Shake for 3 minutes by timer
• Separate whole corn from 4.75 mm Screen and weigh
• Weigh ground corn on the different sieves
• Weigh the “fines” from the pan
• Calculate the percentages and record the date, time, pit, WHO and RPM

For the past two harvests (2005 and 2006), Hitch Feeders I at Hooker, OK has been working with Wes Miller of Stratford, TX in developing a combination WHO hammer mill/roller mill design to process high

moisture corn. The goal at Hitch is to decrease the prevalence of both whole corn and fines during processing without affecting production capacity. Two sizes of equipment are being evaluated (Table 4).

Table 4. Processing equipment being evaluated at Hitch

Caterpillar Engine	Horsepower	WHO Cylinder, in.	Roller Size, in.	Electric Horsepower
3412	880	60	52	50
3508	1000	84	72	75

The HMC particle size breakdown results collected to this point using the Tyler Sieve Shaker with the various processing equipment are shown in Table 5. Processing HMC using only a roller mill increased particle size. Results did not appear to be altered by roller size. Processing with a hammer

mill/roller mill combination resulted in smaller particles with about 2.5% whole corn. The larger particle size observed when using only the roller mill should reduce the incidence of acidosis but feed conversion also might be reduced.

Table 5. HMC particle size distribution at Hitch Feeders I using different processing equipment

Equipment	Whole Kernels, %	Sieve Size, mm			
		4.75	2.00	1.00	Pan (fines)
-----Retained on sieves, % of total weight-----					
52 in. Roller Mill	---	24.7	59.5	9.1	6.7
72 in. Roller Mill	---	25.1	59.0	9.3	6.6
60 in. WHO and 52 in. Roller	2.8	16.7	51.2	15.0	14.4
84 in. WHO and 72 in. Roller	2.3	12.9	50.0	17.8	17.0

The HMC particle size breakdown distribution using the Tyler Sieve Shaker Tyler Sieve Shaker for 2004, 2005 and 2006 at Hitch Feeders are shown in Table 6. The HMC harvested in 2004 had large kernels and was processed using only a 60-inch hammer mill. The HMC harvested in 2005 also had larger kernels and was processed using a combination of the same hammer mill used in 2004 and a 52-inch roller mill. The HMC harvested in 2006 had small to normal kernels (some popcorn size) and was processed the same as in 2005. These data suggest that using the hammer mill/roller mill combination as compared to using only the hammer mill can reduce

the percentage of fines in HMC. These results also show how kernel size can affect quality control and how it varies from year to year. Similarly, a review by Soderlund (1995) showed that HMC is not a consistent or uniform product. Stock et al. (1991) also noted that HMC is not a consistent grain and should be characterized as much as possible before being fed to finishing cattle. These researchers suggested that important characteristics to consider are moisture level, particle size, method and length of storage and rate of digestion.

Table 6. HMC particle size distribution at Hitch Feeders I over the last three years

Year	Kernel Size	Moisture (%)	Whole Kernels, %	Sieve Size, mm			
				4.75	2.00	1.00	Pan (fines)
				Retained on sieves, % of total weight			
2004 ¹	Large	27.8	2.6	12.5	47.7	17.2	20.0
2005 ²	Large	27.4	2.7	16.5	50.8	15.4	14.6
2006 ²	Small to Normal ³	28.2	3.3	13.7	49.0	16.5	17.5

¹Processed using WHO 60 inch hammer mill with 3412 Caterpillar (880 horsepower).

²Processed using WHO 60 inch hammer mill (880 horsepower) and 52-inch roller mill (50 electric HP).

³Some popcorn size.

SUMMARY

Quality control procedures used in receiving and processing HMC at Hitch Enterprises have evolved over time in an effort to better quantify and process HMC in an attempt to reduce rate of digestion without reducing extent of digestion. Due to the tremendous volume of HMC that Hitch receives during corn harvest season, hammer mills are used to process the corn because compared to rolled corn, milled corn can

be packed more tightly and more quickly. In addition, feed conversions generally are better for ground HMC than for rolled HMC. Hitch's target moisture level for HMC is 28 to 30%. A sieve shaker system is used to monitor particle size in the ground HMC with a goal of less than 2.5% whole kernels and less than 20% fine particles. Meeting these goals has helped maximize cattle performance while minimizing the incidence of digestive upsets.

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QUESTIONS AND ANSWERS

Q: John Thornton, how were those high moisture corn and high moisture milo from feedlots processed and stored in your study where fecal starch was measured?

A: The HMC was stored whole in an oxygen-limiting silo and processed before feeding. The milo was stored in a bunker.

Q: Was particle size different?

A: The milo would have the largest particle size. That could explain part of the difference, but also milo also had the lowest moisture.

Q: For Steve or John, when comparing feeding values of dry and high moisture corn, does the method being used for dry matter determination bias this comparison? Do you have any comparison among various dry matter techniques? How much variation would you expect depending on the method you use to determine dry matter?

A: All of my measurements are determined by oven drying. Values from Servitec would be the same. Some organic volatiles are lost from high moisture corn giving it an unjust advantage in feed efficiency.

CORN HYBRID BY PROCESSING METHOD CONSIDERATIONS

Steve Soderlund and Fred Owens
Pioneer Hi-Bred International Inc.
Johnston, IA
steve.soderlund@pioneer.com



SUMMARY

The nutritional value of corn grain is influenced by numerous factors. These included the growing conditions, storage and handling, processing techniques and genetics. Corn hybrids differ in both physical and chemical characteristics that can influence feed value. Nutrient content and availability are influenced by both physical and chemical differences that are discussed throughout these Proceedings. The most important chemical factor that impacts the feeding value of corn grain is the amount and type of starch in the kernels. Commercial corn hybrids differ in the proportion of vitreous and floury endosperm; this is related directly to rate and degree of starch availability of the raw grain. Vitreous starch granules are highly compact being embedded in a protein matrix with a high amount of zein protein. Zein protein, being resistant to ruminal microbial digestion, reduces accessibility of the starch contained in these cells (McAllister 1993). More extensive processing such as steam flaking or high moisture ensiling will minimize hybrid differences largely due to disruption of this protein matrix and allow greater access of starch to microbial and enzymatic digestion. Studies conducted by several researchers indicate the presence of an interaction between hybrid starch type and processing method in determining their feeding value (Owens, 2002; Harrelson et al., 2006; Macken et al., 2003; Szasz et al., 2006). Soft-textured hybrids, because they have more floury endosperm generally have greater feeding value than the harder textured, more vitreous endosperm hybrids when fed as dry rolled grain. However, no difference is apparent when the grain is steam flaked or fed as ensiled high moisture corn.

Physical characteristics also are related to the feeding value of corn hybrids. Absolute density, determined by fluid displacement and measured as grams per ml, is highly correlated with the degree of vitreousness; thus it can be used to predict feed value for grain fed as dry rolled corn (Phillippeau et al., 1999; Correa et al., 2002; Jaeger et al., 2004). Bulk density (test weight usually measured as

pounds per bushel or kg per hl) is a poor predictor of the feeding value of dry rolled corn because both kernel size and kernel density influences bulk density. Kernel weight (mg/kernel) appears more reliable and can be determined easily by weighing a representative number of kernels (generally greater than 100). Kernel weight is correlated positively with feed efficiency for corn fed as dry rolled corn. This has several potential reasons. Small kernels often have a thicker pericarp layer, usually are richer in protein and fiber and thereby lower in starch, often have more vitreous starch, and, due to their small size, they may escape processing if the roll gap is not very narrow. Larger kernels with high density are preferred for steam flaking because they produce durable flakes with less fines and faster grain flow through the flaker than soft textured hybrids (Owens Personal Communication). Pioneer and Nebraska research both indicate that the difference among hybrids in total tract starch digestion is very small after flaking and starch digestibility approaches 100%. However, the site of starch digestion still can vary considerably. Hybrids with a higher density appear to have greater percentage of their starch digested post-ruminally than softer textured hybrids. When selecting hybrids for high moisture ensiling, kernel size and texture appears unimportant if the grain is ensiled above 28% moisture (Szasz et al., 2006). During the ensiling process much of the protein is solublized and starch availability increases. However, as with dry rolling, large kernels are preferred when rolling high moisture corn to assure that all kernels are adequately processed.

Research has shown hybrids differ in feeding value and that differences are largest when the grain is minimally processed. As feed costs increase and feeders face greater competition from industrial processors, economics will make maximum feed efficiency and low processing cost even more. Selecting corn hybrids that have high yields and are nutritionally suited for the operation can help livestock producers stay competitive. Operations that can grow, store and feed their own grain are ideally suited to capitalize on a deeper understanding of the nutritional differences between corn hybrids.

BACKGROUND

Corn grain is a commodity traditionally graded and traded on rather ambiguous quality standards including test weight, kernel damage and foreign material. Yield and agronomics have been the primary drivers for hybrid selection by farmers, and nearly all the recent biotechnology developments have focused on insect protection, herbicide resistance, and drought tolerance. With the exception of food corn, plant breeders have given little attention to the end-use value of corn grain.

Seed companies now are beginning to characterize their corn hybrids for such traits as high extractable starch (HES) for the wet milling industry, high total fermentables (HTF) for the ethanol industry, and high available energy (HAE) for non-ruminant feeds. The development of NIR calibrations that permits rapid and cost effective screening of corn hybrids for these traits has allowed end-users to quantify value and thereby improve productivity or efficiency in their operations (Haefele et al., 2004).

Ruminant animals currently consume an estimated 1 billion bushel of grain in the U.S.; this is approximately 19% of the total U.S. production. In addition, ruminants consume the majority of the grain byproducts produced by industries. To date, no NIR calibrations for estimating metabolizable energy or the net energy value of corn grain for ruminants have been released. The complexity of the ruminant digestive system and the multitude of processing techniques utilized in ruminant diets have prolonged the development of rapid assay technology to estimate the true feeding value of corn grain for this use.

This paper will review the chemical and physical factors that can influence feeding value of different corn hybrids and illustrate the need for greater characterization of corn hybrids in order to optimize the feeding value of corn grain for ruminants.

NUTRIENT COMPOSITION

The nutrient composition of corn grain is determined largely by the relative proportions of different kernel parts. Figure 1 illustrates the corn kernel anatomy. The largest portion of the kernel, the endosperm, normally represents between 80 to 85% of the total mass of the kernel. The endosperm

is composed primarily of starch (80 to 85%). There are two types of starch in the endosperm. The vitreous or horneous endosperm is the dark yellow fraction located on sides of the kernel that sometimes is called the grit. As shown in the electron microscope picture in the upper right of Figure 1, vitreous starch is highly compacted in honey comb-shaped cells and embedded in a protein matrix. The floury endosperm located near the center of the kernel is more opaque in color. The starch granules contained in the floury endosperm shown in the upper left in Figure 1 are large spherical granules that are loosely organized and not embedded in a protein matrix. The proportion of vitreous to floury endosperm varies between hybrids being influenced largely by amount of flint genetics in the parental lines. Flint grains, grown mostly in Europe and South America, contain a much higher proportion of vitreous starch than the dent genetics typically grown in North America. Within the US, the shorter season corn hybrids tend to have a greater proportion of vitreous endosperm than fuller season hybrids presumably due to a heritage that is predominately from Northern Europe.

The germ or embryo located near the tip to the kernel typically represents 10 to 12% of the total kernel mass. With over 30% oil, the germ provides nearly all of the oil in the kernel. Hybrids with a larger proportion of germ have higher oil content. The germ also contains approximately 20% protein; richer in lysine and tryptophan, this protein has greater nutritional value than protein from the endosperm.

The pericarp, also sometimes called the bran, is the layer of cells that cover the outside of the kernel; typically the pericarp represents less than 5% of the total kernel mass. However, pericarp thickness varies among hybrids and appears associated with the rate that corn will lose moisture as it matures. Low test weight corn usually has a thinner pericarp layer than high test weight corn. The primary defense against insect and fungal damage to the kernel, the pericarp and is composed mainly of NDF. Thus hybrids having thicker pericarp or a greater proportion of pericarp will tend to have higher NDF content. Because shape and size will influence the ratio of surface to volume, larger and more circular kernels have less percentage of pericarp and less NDF than smaller, more irregular kernels.

The hilum or tip cap attaches the kernel to the cob that is the point of black layering. The black layer consists of several cell layers that collapse during grain

maturation. Once these cells have collapsed, nutrient translocation to the kernel will cease. Representing

less than 1% of the total kernel mass, the hilum is composed mainly of NDF.

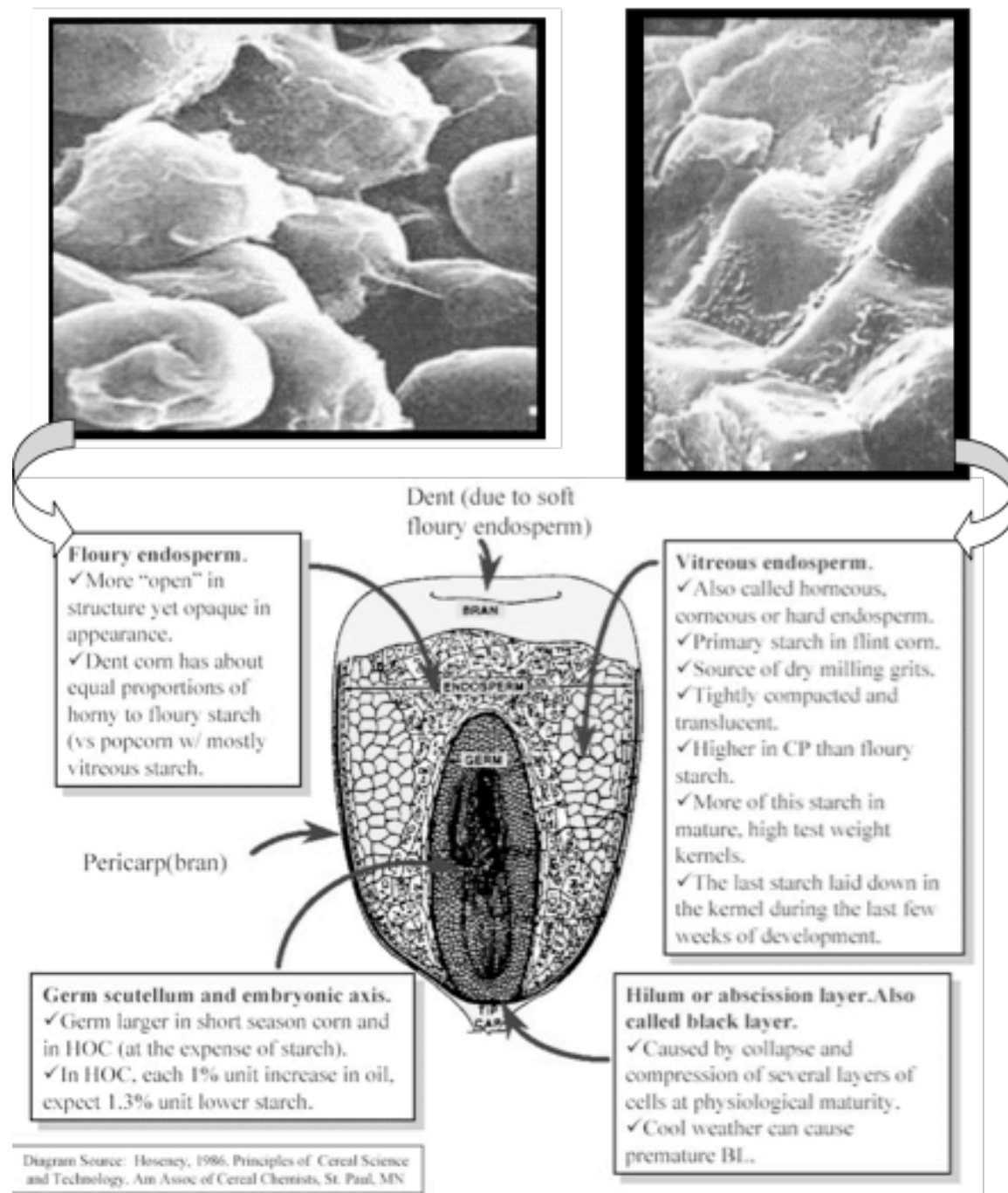


Figure 1. Diagram with electron microscope illustrations.

The nutrient composition for corn grain is discussed in detail by other authors in these

proceedings. In general, corn hybrids with a higher percentage of starch will have less protein and oil.

Figure 2 shows Pioneer starch, protein and oil data from nearly 30,000 samples across 306 commercial Pioneer corn hybrids. Starch content ranged from 70.5 to 73.0% with a mean of 71.8% and a standard deviation of .43%. Crude protein ranged from 8.2 to 10.4% with a mean of 9.25% and a standard deviation of .43%. Protein and starch content across hybrids were negatively correlated ($R^2 = 0.3955$). Oil

content ranged from 3.5 to 4.6% with a mean of 3.92% and a standard deviation of .22%. Oil was negatively correlated with starch ($R^2 = 0.19$). These data support the concepts that as the proportion of endosperm within a hybrid increases, the proportion of germ declines as the reciprocal. However, compositional changes associated with genetic differences across hybrids may differ those attributed to environmental or maturity factors.

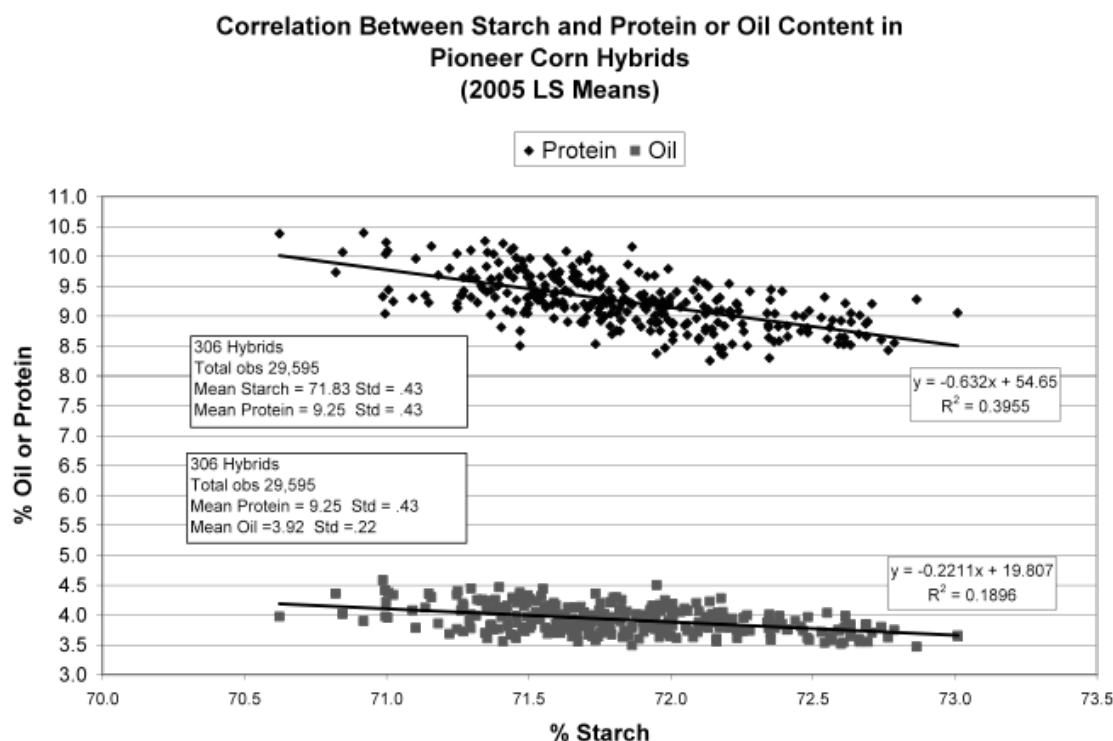


Figure 2. Correlation between starch and protein or oil content in Pioneer corn hybrids. (2005 LS means).

To examine seasonal effects, the impact of year on composition of shelled corn, flaked corn, high moisture corn grain, and high moisture ear corn, analyses of commercial corn samples were examined using information from the Dairy One Forage Lab (2007). Effects of year on the sample was analyzed (mean of samples from May through April of the years 2000 through 2006) on nutrient compositions as well as effects of form were examined simultaneously. Year effects were detected for crude protein (higher in 2001 and 2002 than thereafter, perhaps due to differences in N fertilization), NDF [highest in 2000 and linearly decreasing ($P < 0.05$ since)], and phosphorus content [lowest in 2005 with a tendency to decrease ($P < 0.10$) over time]].

Within each forms of corn, standard deviations were provided. For comparing means (dry matter basis) and standard deviations among forms, each year was considered to be a replicate. Means for are shown in Tables 1 and 2.

As expected, DM content was lower and variability was greater for high moisture corn grain and high moisture ear corn than for shelled and flaked corn. Crude protein was lower for flaked and high moisture corn grain with the highest variation in crude protein being for shelled corn. Fermented products had a higher fraction of the crude protein in a buffer soluble form. Flaking decreased protein solubility as expected from denaturation of protein by heat. Due to presence of the cob and possibly some husk, high moisture ear corn

contained more NDF and ADF than shelled or flaked corn; these did not differ in NDF or ADF.

However, NDF content was greater for high moisture corn than for flaked corn samples.

Table 1. Dry matter, protein, soluble protein, ADF, and NDF means and standard deviations for corn harvested or processed by different methods*

Form	DM	DM(SD)	CP	CP(SD)	SolCP	(SCPSD)	ADF	ADF(SD)	NDF	NDF(SD)
Shelled	89.4 ^a	2.58 ^c	9.31 ^a	1.48 ^a	20.3 ^c	5.44 ^c	3.49 ^b	1.44 ^b	9.84 ^{bc}	3.13 ^b
Flaked	88.0 ^a	2.00 ^c	8.38 ^b	0.78 ^b	11.4 ^b	6.64 ^c	3.62 ^b	0.99 ^b	9.18 ^c	1.89 ^c
HMC	71.8 ^b	6.35 ^b	9.15 ^a	0.82 ^b	30.7 ^b	11.35 ^b	3.56 ^b	1.17 ^b	10.3 ^b	2.25 ^c
EARHMC	64.5 ^c	7.51 ^a	8.42 ^b	0.93 ^b	36.5 ^a	14.34 ^a	9.27 ^a	3.64 ^a	20.7 ^a	6.63 ^a

*DM, dry matter; SD, standard deviation; CP, crude protein; SolCP, soluble CP; ADF, acid detergent fiber; SD, standard deviation; HMC, high moisture corn; EARHMC, high moisture ear corn.

^{a,b,c}Means with different superscripts within a column are different ($P < 0.05$).

Table 2. Starch, fat, and phosphorus means and standard deviations for corn harvested or processed by different methods*

Form	Starch	Starch(SD)	Fat	Fat(SD)	Phosphorus	Phosphorus(SD)
Shelled	70.5 ^b	4.25 ^b	4.37 ^a	1.33 ^a	0.32 ^a	0.10 ^a
Flaked	72.2 ^a	3.91 ^b	3.95 ^{ab}	1.66 ^a	0.24 ^c	0.08 ^a
HMC	70.1 ^b	3.08 ^b	4.15 ^{ab}	0.59 ^b	0.32 ^a	0.03 ^b
EARHMC	59.3 ^c	6.91 ^a	3.70 ^b	0.51 ^b	0.30 ^b	0.03 ^b

*SD, standard deviation; HMC, high moisture corn; EARHMC, high moisture ear corn.

^{a,b,c}Means with different superscripts within a column are different ($P < 0.05$).

Starch, fat, and phosphorus contents were lowest and starch content was most variable for high moisture ear corn due to dilution of grain with differing amounts of cob. However, starch content was greater and phosphorus content was lower for flaked than for shelled and high moisture corn grain. The higher starch and lower protein, fat, and phosphorus content of flaked than of shelled or high moisture corn might reflect differences in sample origin (and hybrid) or loss of fine particles during field sampling of flaked grain. On a percentage basis when compared with shelled corn, flaking increased starch by 2.4% and this alone cannot explain the 7% decrease in NDF, the 10% decrease in protein and fat, and the 25% decrease in phosphorus content. Variation in phosphorus content was lower for wet products, perhaps due to phytase degradation during storage increasing extractability of the starch.

Stepwise regression revealed that starch content across sample types and across years was driven primarily ($R^2 = 0.97$) by NDF content, with starch decreasing by 1.1% for each 1% increase in NDF. Even when high moisture ear corn was removed from the data set, NDF remained the factor most closely related to starch ($R^2 = 0.54$). Compared with

cleaned grain from hybrids discussed above, commercial grain samples are more likely to be diluted with foreign matter that would be rich in NDF. This may explain the difference in relationships of components of cleaned hybrid corn and commercial samples of corn grain.

Monthly information also is available for samples analyzed at Dairy One (Dairy One Forage Laboratory, 2007). Using only samples from New York state, solubility of protein is plotted for samples analyzed different months from grain presumably harvested from 2002 through 2006 breaking the harvest season at September (Figure 3). Solubility of protein was consistently lowest in November when new crop samples would be predominant. Thereafter, protein solubility increased reaching a peak in August or September that should represent grain that had fermented for a longer time period. High soluble protein and increases in protein solubility with high moisture corn over time have been noted by Thornton (1976), Prigge et al. (1976), and Benton et al. (2005). If starch availability increases with protein solubility, the rate and extent of ruminal digestion must be increasing markedly during storage of high moisture corn. This may require re-formulation of diets to avoid acidosis.

Similar means for solubility of protein from corn silage are shown in Figure 4. In contrast with high moisture corn, solubility increased for 4 to 5 months and remained relatively stable thereafter.

Consequently, once corn silage has been stored for several months, it should be more consistent as a feed ingredient than high moisture corn is.

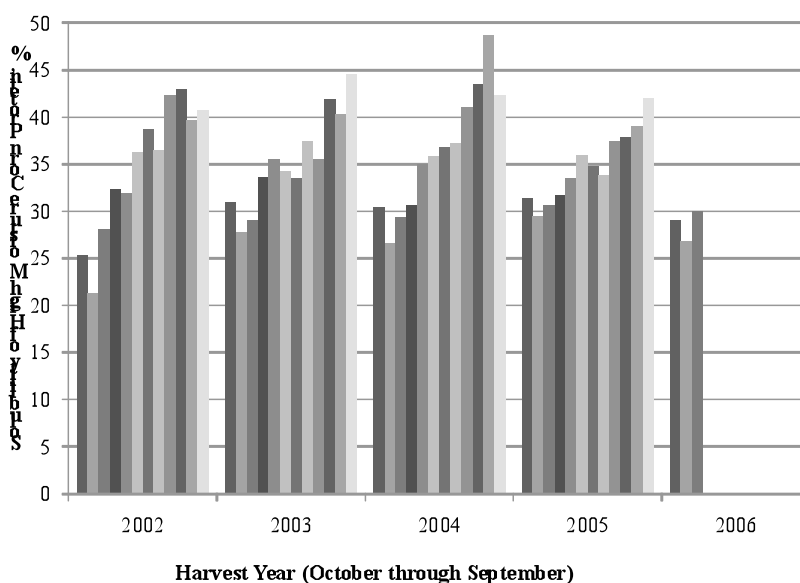


Figure 3. Solubility of protein in high moisture corn samples from New York analyzed each month at Dairy One (Dairy One Forage Lab, 2007).

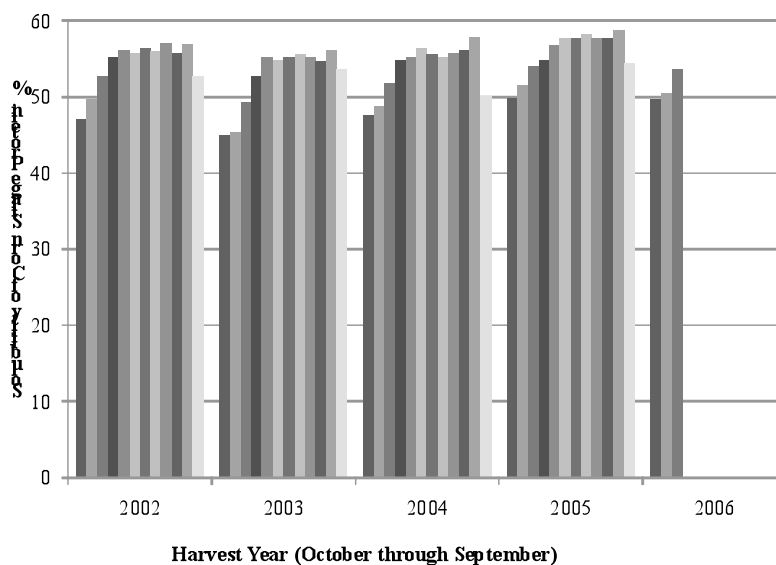


Figure 4. Solubility of protein in high moisture corn samples from New York analyzed each month at Dairy One (Dairy One Forage Lab, 2007).

STARCH TYPE AND STRUCTURE

Two primary starch polymers are found in corn. Amylose, a straight chain polymer of glucose units, usually comprises between 24 to 30% of the total starch in yellow dent corn while amylopectin, a branched polymer makes up the remaining 70 to 76% of the total starch (Owens, 2005). The amylose:amylopectin ratio generally increases with increasing maturity and may be greater in floury than vitreous starch (Owens, 2005). Due to the high degree of branching, amylopectin is more susceptible to enzyme hydrolysis than amylose; thus corn hybrids having higher proportion of amylopectin may have greater ruminal starch digestion. However, steer feeding trials evaluating waxy corn; which typically contains 98% amylopectin, have shown inconsistent response in improving animal performance. Waxy corn has generally shown a positive response in ADG and feed efficiency when fed in dry rolled or whole corn diets but shown no advantage when fed in steam flaked diets (Owens and Zinn, 2005).

Several research studies have shown that corn grain samples containing a greater proportion of vitreous to floury endosperm has lower *in situ* starch digestion when dry rolled (Correa et al., 2002, Philippeau 1997). Greater *in situ* disappearance of floury hybrids has led to the suggestion that extent of ruminal digestion will be greater for a floury than a vitreous hybrid when the grain is fed dry rolled. This concept was verified with dry rolled corn fed to steers by Jaeger et al., 2004; they observed that hybrids with more floury starch produced the best gain efficiency ($r = 0.83$).

However, close examination of Dacron bag disappearance curves from *in situ* studies reveals that virtually all of the increased *in situ* loss for the floury hybrids is lost even before fermentation begins (wash loss). Indeed, floury hybrids when dry and ground, generate more fine particles during grinding, and fine particles readily escape through pores in Dacron bags. The nutritional merit of fine particles may vary depending on the diet. Higher total tract digestibility of small versus large particles should be beneficial, and some fine and dense particles will be flushed rapidly through the rumen with fluids to increase the starch supply to the intestines. However, because small particles are fermented very rapidly in the rumen, fine particles

from the floury endosperm may also increase the risk of acidosis. Unfortunately, particle size alone, without knowledge of composition, can prove misleading. Fine particles generated during steam flaking, originating from selective removal of the germ, are likely to be rich in oil and protein. In contrast, fine particles generated during dry milling or over mixing of grain are more likely to be rich in starch and would have greater potential to cause acidosis.

KERNEL PHYSICAL CHARACTERISTICS

Kernels from corn hybrids that differ genetically will vary considerably in their kernel size, density, shape and texture. Test weight (bulk density) of commercial hybrids typically ranges from 53 to 63 lb per bushel, absolute density as measured by a pycnometer will range from 1.2 to 1.4 g/cc and kernel weight will range from 250 to 450 mg. Several studies have assessed the relationship of physical properties of kernels to digestibility of these same corn grain samples. It is not appropriate to consider such measurements as being representative of a specific hybrid because numerous environmental and harvest factors also can influence these physical measurements except to appraise differences associated with types of grain that have extreme differences (flinty, floury, waxy, etc.). Philippeau et al., (1999) reported that ruminal starch degradability of dry rolled grain was highly correlated to the degree of vitreousness ($r^2 = 0.89$) and vitreousness could be predicted by combining absolute density with 1000 kernel weight ($r^2 = 0.91$). Owens (2002) noted that absolute density of the whole kernel was highly correlated ($r^2 = 0.79$) to 18 hr *in situ* DM disappearance for dry rolled corn. Jaeger et al. (2004) also found that 1000 kernel weight, Stenvert time to grind, and Stenvert proportion of soft to coarse particle all were highly correlated to feed efficiency when evaluating samples of seven different dry rolled corn hybrids. However, in more recent study conducted by Harrelson et al., (2006) who evaluated seventy-two commercial corn hybrids, test weight was the only kernel trait that related to *in situ* DM disappearance ($P = 0.07$) and even there, the relationship was weak ($r = 0.04$). Contrary to previous results reported by Jaeger et al. (2004), the relationship between the percent Stenvert soft particles in the kernels and *in situ* DM disappearance was weak and not significant ($P = 0.27$).

PROCESSING INTERACTIONS

Although hybrid texture and density have been shown to be negatively correlated to *in situ* digestibility

and cattle performance when fed as dry rolled corn, this relationship does not hold true for grain that is processed more extensively, e.g., steam flaked and high moisture corn. Owens (2002) evaluated samples of 10 different commercial Pioneer hybrids all having a large sales volume fed as either dry rolled, steam flaked, or high moisture corn to steers in a digestion trial (Figure 5). Diet DM digestion was significantly ($P < 0.05$) altered by processing methods with a significant ($P < 0.01$) processing by hybrid interaction noted. Across hybrids, diet digestibility was slightly greater for high moisture

than flaked corn, and much greater for flaked than dry rolled corn. However, the advantage to processing differed among hybrids. Hybrids with a softer texture tended to have higher digestibility than more vitreous hybrids when fed dry rolled whereas compared with softer hybrids, harder textured hybrids tended to have the greatest digestibility when the grain was steam flaked. No single hybrid was best for all processing methods. A similar hybrid by processing interaction was reported by Harrelson et al. (2006) who compared 12 Golden Harvest corn hybrids that were either dry rolled or steam flaked.

Diet DM Digestibility
(Steer Indigestible Marker Study - Pioneer Livestock Nutrition Center 2002)

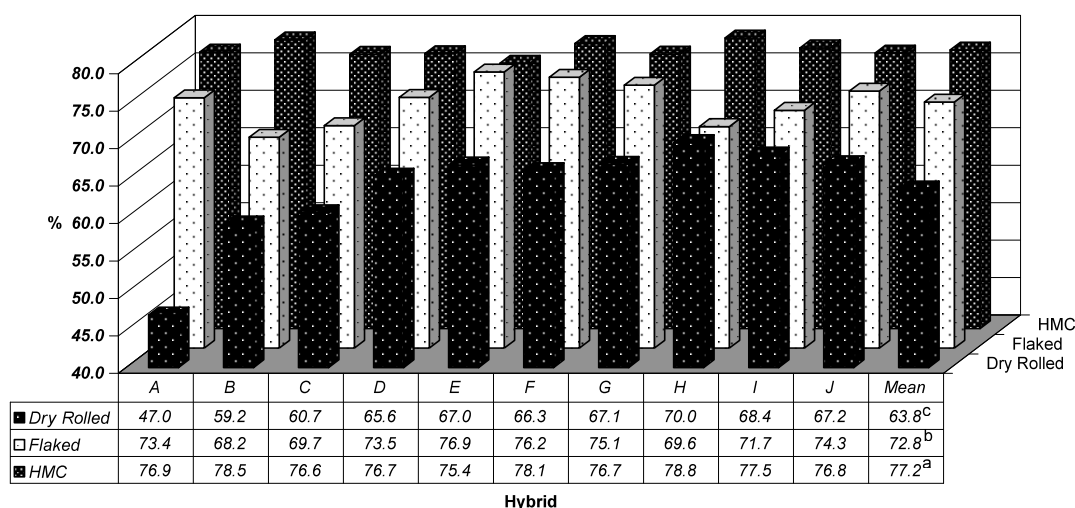


Figure 5. Diet DM Digestibility.

Owens (2002) also noted that when being flaked, hybrids that were floury generated fragile flakes, more fine particles, and tended to flake less rapidly at the same flaker settings than more vitreous hybrids. He noted with dry rolled corn diets, most of the difference in digestibility between samples of hybrids could be explained by the differences in total tract starch digestion. In contrast, most of the difference in diet DM digestion noted when hybrid samples were either steam flaked or HM ensiled was due to differences in protein or fiber digestion because starch digestibility with flaked and HM samples all exceeded 98%.

Using in situ and in vitro methods Owens (2002) observed processing method altered in situ and enzymatic disappearance of dry matter and that samples of different corn hybrids also differed in their site of digestion (Figure 6). Most of the difference in starch digestion between dry rolled and corn flaked at 28 lb per bushel could be attributed to an increase in enzymatic (presumably post-ruminal) digestion. Flaking corn to a lower density (25 lbs per bushel) tended to increase ruminal starch digestion beyond that observed with either dry rolled or corn flaked at 28 lb per bushel. These data suggest using in situ DMD alone to predict total tract DM digestion or animal performance can be misleading with dry rolled corn.

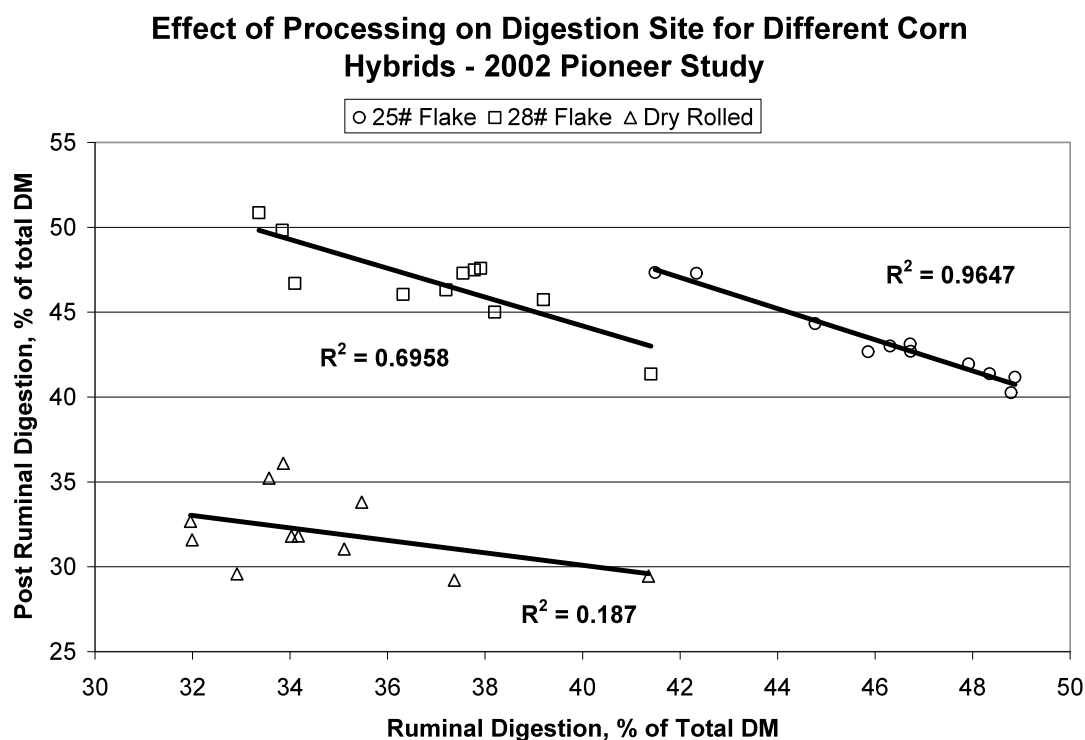


Figure 6. Effect of processing on digestion site for different corn hybrids. 2002 Pioneer study.

Macken et al. (2003) fed feedlot steer diets based on floury or vitreous corn with corn endosperm type factorized across processing method (i.e., dry-rolled or high moisture ensiled). When the corn was fed dry rolled, steer fed the floury endosperm corn, as compared with steers fed more vitreous endosperm corn had a superior feed to gain ratio (5.55 vs. 5.88). However; when the corn was fed as high moisture ensiled, feed:gain ratios were identical (5.36 vs. 5.37) for steers fed floury or vitreous corn. In a recent study conducted by Szasz et al. (2006) using high moisture corn (28% moisture) prepared from either a vitreous or a floury corn hybrid, digestibility of starch both in the rumen and the total digestive tract surprisingly tended to be superior for the vitreous hybrid. The authors noted that, contrary to previous findings with dry rolled corn, the more vitreous corn when rolled wet had a smaller geometric mean particle size and 15.8% greater calculated surface area than the floury corn did. The researchers postulated that the floury corn kernels when moist were more pliable and thereby were less damaged by the rolling process. In contrast, vitreous corn kernels when moist were

more brittle and shattered into finer particles when rolled with a high moisture content.

In summary, compared with more vitreous or flint hybrids, floury dent hybrids are more extensively digested by ruminants when fed after simply being coarsely rolled. However, this starch digestibility advantage for more floury hybrids is NOT apparent for corn grain that is processed for ruminants by other methods (steam rolled or flaked or fermented alone or in corn silage).

FUTURE IMPLICATIONS

Commercial corn hybrids differ both chemically and physically and hybrid selection can alter nutritional characteristics and economic value for cattle feeders. However, evaluating the feeding value of different corn hybrids for ruminants is a daunting and an expensive proposition because of interactions between grain characteristics and processing method. No single trait can fully explain the differences observed in digestibility and in subsequent animal performance. Therefore, nutritionists and cattle feeders must consider the dynamics between the kernel characteristic, processing methods, and ration formulation in order to

fully exploit the differences between corn hybrids. Consequently, in the immediate future, hybrid selection for cattle must still be based primarily on grain production economics, specifically obtaining maximum yields obtained through reliable genetics, good agronomics, and disease and insect resistance. In the future as the nutritional factors that contribute to the feeding value of corn hybrids are defined,

more reliable and rapid assay technologies will be developed to predict the metabolizable or net energy value of corn grain based on physical and chemical characteristics of hybrids and the responses to grain processing. Such knowledge will permit corn producers to select hybrids based on nutritional traits and corn breeders to develop hybrids most useful for those cattle producers that use a specific grain processing method.

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QUESTIONS AND ANSWERS

Q: What is the correlation between the pH of high moisture corn and its starch digestibility?

A: Generally, pH is lower with wetter high moisture corn and starch digestibility also will be greater with wetter high moisture corn, so one has an inverse relationship.

Q: For Steve or John, when comparing feeding values of dry and high moisture corn, does the method being used for dry matter determination bias this comparison? Do you have any comparison among various dry matter techniques? How much variation would you expect depending on the method you use to determine dry matter?

A: Certainly we are losing some volatiles with oven drying, probably 1 or 2%.

Additional comment by Owens: We compared various drying procedures for freshly harvested high moisture corn containing from 13 to 38% moisture. Note that these samples had NOT been fermented. We compared drying at 62 C for a minimum of 24 hours, 103 C and 130 C and compared values with estimates from an NIR (a Dickey John and another NIR machine) as well as the Karl Fischer dry matter procedure. Certainly, with drying at 62 C, about 4% moisture remained in the freshly harvested whole kernel corn grain. The agreement between 103 C and NIR procedures was quite close. We also compared moisture content of kernels from the tip versus the base of the cob. Compared with kernels at the tip, kernels at the base of the ear had 3 to 5% greater moisture. Though it sounds simple, moisture content is one of the more complex measurements we have. Certainly, loss of organic volatiles, being greater for fermented than fresh grain, presents a problem in data interpretation with all fermented products.

Q: Is kernel size be correlated with endosperm type.

A: About 40 to 50% of endosperm type can be explained by differences in pure density, but test weight is not a particularly good measure of pure density. We use a pycnometer to measure pure density by displacement. Kernel size is important, particularly with dry processing, because it will influence the ideal gap setting and particle separation. Also, wet corn will fracture differently from dry corn. Particle size of rolled corn will vary tremendously with different corn types, particularly with a floury versus a more vitreous product. Being in the seed business, we routinely count kernel size because we sell seed corn in various kernel sizes. Sizing can be done. We have an automated 100 kernel counter so 100 kernel weight could be measured in about the same time it takes to do test weight. The automated kernel counter costs several thousand dollars. But I would rather have 100-kernel weight than test weight because kernel weight provides an index of both kernel size and density.

Q: If we have a huge variability in starch availability among hybrids, do people feeding rolled corn need to be rolling to a finer density?

A: Definitely. If you have small kernels, anything below about 300 mg, and test weights above 60 pounds per bushel, use finer processing. Logistics of fine grinding can get complex in a large lot. But smaller feedlots that roll grain daily and can measure particle size probably can pick up significant improvements in efficiency by adjusting their grinding to obtain a specific small particle size.

ADVANTAGES AND DISADVANTAGES OF FEEDING WHOLE SHELLED CORN

Steven C. Loerch and Milton Gorocica-Buenfil
The Ohio State University
Wooster, OH
loerch.1@osu.edu



ABSTRACT

Feeding whole corn is a viable option for cattle feeders. Dry processing (cracking, rolling) has only small effects on starch digestion. For long-fed calves (greater than 170 days), feeding whole corn may result in better gains and efficiencies than feeding dry processed corn.

INTRODUCTION

Corn is included in feedlot diets to increase the energy concentration of the diet. Nutritionally, starch is the most important component of corn, and mechanical processing is used to increase extent of starch digestion in the rumen. Corn processing is used widely in the feedlot industry to increase starch digestibility and cattle performance (Galyean, 1996) even though the benefits of corn processing have been debated by feedlot nutritionists for years (Pritchard and Stateler, 1997). Corn processing has been reported to increase starch digestibility (Galyean et al., 1979; Turgeon et al., 1983) and feedlot performance (Cole et al., 1976; Zinn et al., 2002) although results have not been consistent for all processing methods. In extensive reviews of published trials, dry corn processing did not improve starch digestibility (Owens et al., 1986) or feedlot performance over whole shelled corn (Owens et al., 1997).

In some trials, cattle fed whole shelled corn diets had similar ADG and FE (gain/feed) to cattle fed processed corn diets (Vance et al., 1972; Ørskov et al., 1974; Owens et al., 1997). However, whole corn is not used commonly in large commercial feedlot diets. This could be attributed to the fact that when whole corn is fed, whole kernels often are observed in feces leading to the conclusion that the whole corn was not well digested (Ørskov, 1986).

Most experiments reporting that starch digestibility is greater for processed than for whole corn diets have been conducted with yearling animals (Ørskov et al., 1974; Galyean et al., 1979; Turgeon et al., 1983); in contrast, feedlot performance trials with weanling steers usually have failed to prove advantages for processing corn (Loerch and Fluharty, 1998). The difference may be due to extent of chewing. Chewing capacity is much greater for

younger cattle (weanlings) than older cattle and yearlings (Nicholson et al., 1971; Morgan and Campling, 1978). Digestibility of whole corn is increased by extensive chewing of the diet because the cuticle will be disrupted and this allows ruminal bacteria access to the corn starch for fermentation (McAllister et al., 1994). This review will discuss the advantages and disadvantages of dry processing corn grain.

DISCUSSION

According to the 1996 Beef NRC (NRC, 1996) whole and dry rolled corn both have an NE_g-value of 68.0 Mcal/cwt; NE_g values for cracked and steam flaked corn are higher (70.3 and 73.5 Mcal/cwt, respectively).

Owens et al. (1997) reviewed data from 164 feeding trials reported in journals, experiment station publications, and cattle feeder's day reports in which various grain sources, processing methods, roughage sources, and roughage levels were reported. The ME content of corn was calculated from cattle performance. Mean ME concentrations for whole, dry rolled, and steam rolled corn were 3.56, 3.26, and 3.73 Mcal/kg, respectively.

Owens et al. (1997) also reported rates of gain, feed to gain ratio and dry matter intakes of cattle fed whole versus processed corn diets. The results for whole, rolled and steam rolled corn are presented in Table 1. Steam flaking reduced ADG slightly but not significantly. This could be attributed largely to reduced DMI. Reduced DMI of rapidly fermented grain sources and extensively processed grain has been attributed to excessive rates of acid production in the rumen and subclinical acidosis (Fulton et al., 1979a,b) that will increase the day-to-day variation in DMI (Stock et al., 1995).

Table 1. Least squares means for rate of gain (lb/d), dry matter intakes (lb/d), and feed efficiency (feed/gain) of feedlot cattle fed corn processed by various methods (*Modified from Owens et al., 1997*)

Processing method	Rate of gain	Dry matter intake	Feed conversion
Whole	3.20 ^a	18.9 ^{ab}	5.95 ^a
Dry roll	3.20 ^a	20.8 ^c	6.57 ^b
Steam roll	3.15 ^a	18.4 ^b	5.87 ^a

^{a,b,c}Means within a column with different superscripts differ ($P < 0.05$).

Reduced DMI of processed grain diets also could be due to greater starch digestibility with ground or steam-flaked corn. With increased starch digestibility, the energy content of the ration is increased so the animals does not need to eat as much feed to meet its need for net energy. Feed efficiency also is improved by increasing the energy density of the diet because animals eat to meet their energy requirement (Conrad et al., 1964). Therefore, compared to cattle fed whole corn, cattle fed processed grains usually have similar NE intakes and similar ADG while consuming less feed.

Feed to gain ratio was not always improved simply by grinding or rolling corn for cattle (Theurer, 1986; Owens et al., 1997). Indeed, the energetic efficiency of whole shelled corn diets was superior ($P < 0.05$) to that of diets containing dry rolled corn (Owens et al., 1997). This feed efficiency advantage for whole over dry-rolled corn diets may be ascribed largely to the fact that a lower percentage of roughage (sometimes zero) usually is included in the diet for cattle fed whole corn grain than for cattle fed processed corn grain (Owens et al., 1997). There are very few reports that directly compare grain processing methods and the interactions between grain processing and dietary forage level.

In contrast to these reports showing excellent utilization of diets containing whole shelled corn, several trials have reported an advantage for corn processing both for improving starch digestibility and animal performance (Theurer et al., 1999; Zinn et al., 2002). Digestibility of whole shelled corn can be influenced by numerous factors. These would include forage source and level, age of the animal, protein source, dietary protein concentration and pH of the rumen, and perhaps grain characteristics (kernel hardness, kernel moisture, concentration of foreign matter). The effects of chemical and physical properties of grains (and strategies to alter these characteristics) on digestion were discussed in an excellent review by Kaiser (1999). Relative

importance of these factors has not been extensively researched. Nevertheless, cattle age and forage level seem likely to be among the most important factors influencing whole shelled corn digestibility and performance of cattle fed diets based on whole shelled corn.

Most experiments that have reported that starch digestibility is greater for processed than whole corn diets were conducted with yearling animals (Ørskov et al., 1974; Galyean et al., 1979; Turgeon et al., 1983); feedlot performance trials with weanling steers failed to show any advantage for processing corn (Loerch and Fluharty, 1998). Chewing capacity appears greater for weanlings than yearlings. Digestibility of whole corn increased by chewing because the cuticle is disrupted allowing ruminal bacteria access to the corn starch inside the kernel so it can be fermented. Differences in extent of chewing of whole grain explain much of the variation found in the literature about the feeding value of whole corn and provide insight into procedures that might enhance the value of whole shelled corn in practical diets. When cattle were limit-fed no roughage diets, digestibility of whole corn-based diets was lower than for rolled corn-based diets (Murphy et. al., 1994). Limit-fed cattle consumed their daily ration in less than one hour. Rate of feed consumption may have reduced extent of mastication and therefore, whole corn digestibility.

Gorocica et al. (2005) measured digestibility of whole and ground corn with weaned calves and with yearlings. Surprisingly, cattle age did not affect starch digestibility or the recovery of whole corn kernels in the feces (8% of the whole kernels that were fed). This indicates that extent of mastication in this study probably was similar for calves and yearlings.

One of the biggest factors that limits use of whole corn in feedlot cattle diets is the visual presence of whole corn kernels in feces. We quantified the excretion of whole corn kernels as affected by diet

forage level (Gorocica et al., 2005). Although cattle ate about 39,000 kernels of corn per day, they

excreted only about 500 kernels per day (Table 2).

Table 2. Effect of forage level on whole corn kernel excretion, digestibility, and whole corn kernel excreted composition

Item	Forage Level ^a		SEM ^b
	High	Low	
No. of steers	4	4	
Whole corn kernels			
Intake	39,555	37,729	3353
Excretion, kernels/d	489	562	397
Disappearance, %	98.8	98.5	1.4
Starch, % ^c	73.3	61.1	6.5

^aHigh – 18.2% corn silage; Low – 5.2% corn silage of the diets, DM basis.

^bStandard error of the mean.

^cFor kernels recovered in feces.

Regardless of level of forage in the diet (18% vs 5% corn silage), less than 2% of the kernels consumed appeared in feces. Thus, despite high visibility, only a small percentage of kernels escaped digestion. The

study detected no forage level by corn processing interactions for starch digestibility. Starch digestibility for both cracked and whole corn diets was 95% (Table 3).

Table 3. Main effects of corn processing method (PM) and two different (High = 18.2% corn silage; Low = 5.2% corn silage of the diets, dry matter basis) forage levels (FL) on feed intake, excretion, and apparent digestibility of dry matter (DM), starch and crude protein (CP) of steers fed feedlot corn-based diets

Item	Forage level		Corn processing		SEM*	FL	PM	FL × PM
	High	Low	Cracked	Whole				
	Least squares means					P-value		
Intake, kg/d								
DM	8.7	8.6	8.9	8.4	0.49	0.82	0.43	0.56
Starch	5.1	5.5	5.5	5.1	0.31	0.44	0.41	0.58
CP	1.2	1.2	1.2	1.2	0.07	0.82	0.73	0.62
Excretion, kg/d								
DM	1.6	1.6	1.6	1.5	0.13	0.95	0.84	0.17
Starch	0.3	0.3	0.3	0.3	0.07	0.63	1.00	0.81
CP	0.3	0.3	0.3	0.3	0.02	0.52	0.73	0.07
Apparent digestibility, %								
DM	82.4	81.6	82.3	81.7	0.92	0.56	0.65	0.08
Starch	95.2	94.4	94.8	94.8	0.96	0.59	0.97	0.64
CP	78.5	77.2	78.0	77.7	0.79	0.27	0.77	0.02
Fecal starch, %								
of fecal DM	15.88	19.07	18.03	16.92	2.76	0.43	0.78	0.94

*Standard error of the mean.

We also investigated the effects of diets on feedlot performance (18% vs 5% corn silage and whole vs cracked corn) (Gorocica et al., 2005, Table 4). Neither affected daily gains or feed conversion. Steers fed 18% corn silage with whole corn had lowest daily DM intakes (19.2 lb/d) while steers fed cracked corn at

either forage level and whole corn with 5% corn silage had slightly greater DM intake (20 lb/d). In this trial, we had four weight blocks. Heavier cattle were fed fewer days than lighter cattle. Interaction between number of days fed and corn-processing method for both growth rate and feed efficiency was detected.

Figures 1 and 2 illustrate days fed \times corn processing interactions for growth rate ($P = 0.07$) and feed efficiency ($P = 0.01$).

For cattle fed cracked corn, the growth rate was greatest for the heaviest weight block (4.12 lb/d at 129 DOF) with growth rate being progressively slower for the lighter weight blocks (3.53 lb/d at 185 DOF). Feed efficiency remained consistent across weight blocks for cattle fed cracked corn diets (.191 vs .190 lb of gain/lb of feed for cattle fed 129 and 190 DOF, respectively). Conversely, when whole corn was fed, growth rate remained largely unchanged among weight blocks (3.89 vs 3.62 lb/d at 122 and 192 DOF, respectively), but feed efficiency was superior for the lighter weight cattle that were fed more days (188 vs 207 lb of gain/lb of feed at 122 and 192 DOF, respectively).

For the heaviest weight block (cattle with the shortest time on feed), cracking corn increased ADG by 4% when the low-forage diet was fed and by 8.5% when the high-forage diet was fed. Cracking corn resulted in a similar ADG improvement for cattle in the second largest weight block that were fed high forage. In contrast, there was no ADG advantage from cracking corn for cattle in this weight block that were fed the low-forage diet. For cattle in the medium and small weight blocks (longest time on feed) cracking corn resulted in a 5 to 7% decrease in ADG. This illustrates that cattle in the heavier weight blocks that were fed high forage benefited from cracking corn whereas cattle in the lighter weight blocks did not benefit from cracking corn. These cattle were from Ohio State University herds and were all from 8 to 10 months of age.

Table 4. Effect of forage level and corn processing on cattle performance (Adopted from Gorocica et al., 2005)*

Item	18% silage		5% silage		SEM
	Cracked	Whole	Cracked	Whole	
ADG, lb/d	3.86	3.73	3.88	3.97	0.09
DMI, lb/d	20.5 ^x	19.2 ^y	20.3 ^x	20.1 ^x	0.2
Feed/gain lb/lb	5.35	5.13	5.18	5.08	0.08

*SEM, standard error of the mean; ADG, average daily gain; DMI, dry matter intake.

^{x,y}Means bearing different superscripts differ ($P < 0.10$).

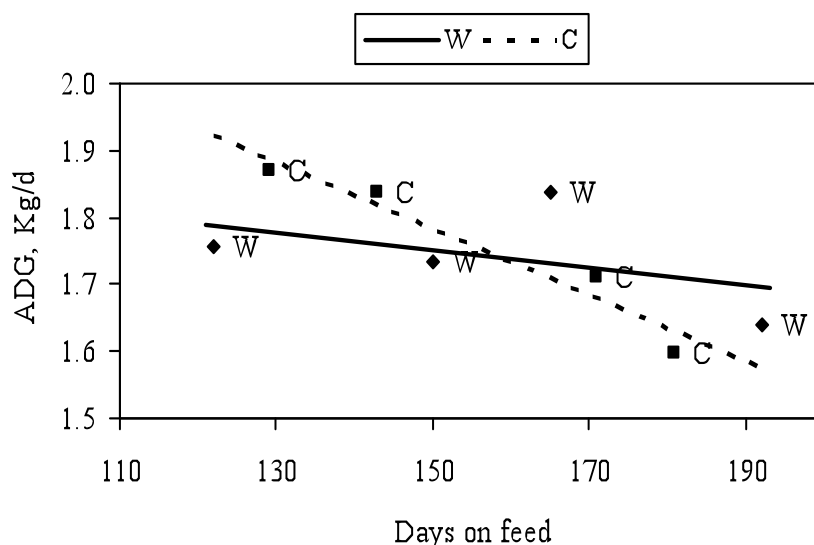


Figure 1. Effect of days on feed and corn processing on average daily gain (ADG) in Exp. 2 (interaction; $p < .10$). Corn was fed either cracked (C) or whole (W).

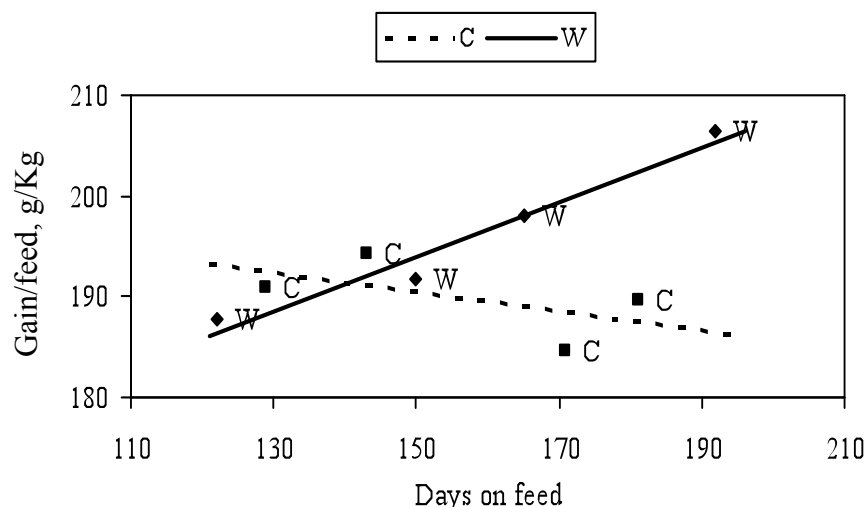


Figure 2. Effect of days on feed and corn processing on feed efficiency in Exp. 2 (interaction; $p < .01$). Corn was fed either cracked (C) or whole (W).

Lack of a performance response to cracking the corn for cattle fed for more days may have been due to long-term, cumulative effects of more rapid starch fermentation (Huntington, 1997; Beauchemin et al., 2003). Subacute acidosis (Fulton et al., 1979a,b) and decreasing integrity of ruminal epithelial tissue (Bartle and Preston, 1992) may have contributed to the response observed. This interaction of time on feed and grain processing may explain partly the conflicting responses to grain processing reported in the literature. Further research specifically designed to test the interactions between corn processing and days on feed is warranted.

Forage level and corn processing effects on carcass characteristics were presented by Gorocica et al. (2005). Cattle fed less forage had heavier HCW reflecting the higher energy concentration of their diets. Grain processing affected marbling score. When averaged across forage levels, marbling scores were 376 and 347 points (low choice = 300; medium choice = 400) for cattle fed cracked corn and whole corn, respectively. However, this effect on marbling score did not translate into effects on the percentage of

carcasses grading Select or above low Choice. In addition, processing corn did not improve yield grades. The number of cattle marketed through quality and yield grids has increased dramatically during recent years (USDA, 2003). Considering that the most common standards to receive price premiums and avoid discounts are quality grades of at least Choice, with a yield grade not greater than 4, feeding corn whole rather than cracked certainly did not diminish the carcass value of the animal.

In a review by Owens et al. (1986), ruminal starch digestibility was reported to average 59% for whole corn, 78% for ground corn, and 83% for steam flaked corn. These differences in ruminal starch fermentation would affect the requirement for ruminally degraded protein. Although protein levels commonly fed in the industry are in the 13-14% range where processed grains are fed, cattle fed whole corn should have a lower protein requirement. This fact has environmental implications because cattle only retain about 30% of the protein they consume (Table 5).

Table 5. Published measurements of starch digestibility with corn whole, ground, or steam flaked (Modified from Owens et al., 1986)

Processing method	Rumen	Small intestine	Large intestine	Total tract	Gain/feed
Whole	58.9	17.0	2.8	91.7	0.146
Ground	77.7	13.7	4.3	93.5	0.145
Steam flaked	82.8	15.6	1.3	97.8	0.158

One final consideration regarding grain processing deals with ration condition and uniform mixing of ingredients. With whole corn, it is difficult to obtain and maintain a mixture with certain ingredients, e.g., chopped hay and unpelleted dry protein supplement. Including ensiled feeds or adding liquids, e.g., water, molasses, or fat, and providing the protein-mineral-vitamin supplement as a liquid or a small pellet (to avoid sorting) helps avoid separation of fine particles from whole corn. Grain quality and cleanliness also may be important when selecting a source of corn grain to feed whole. Fine particles usually are more prevalent in lower quality grades of corn due to the dilution during grain handling or the shatter of kernels, especially of over-dried grain, during handling or storage. Avoiding or removing the fines and small grain particles to avoid particle separation in a feed bunk should help reduce the

incidence of acidosis. Also, a less vitreous hybrid is more likely to yield fine particles during chewing than a very dense, vitreous type and larger kernels are more likely to be chewed. Consequently, a floury, light test weight corn with few small kernels would seem the most preferable type to feed as whole grain.

IMPLICATIONS

Feeding whole corn eliminates processing costs. Improvements in performance from rolling or cracking corn grain often are not sufficient to offset a 5 to 10% processing cost. Whole corn may actually be advantageous, particularly for long-fed calves. Whole corn also should be considered for specific applications such as in starter rations, limit-feeding situations, when forage is less than 5% of the diet, and when "Natural" feeding programs prohibit use of ionophores and feed grade antibiotics.

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QUESTIONS AND ANSWERS

- Q:** Steve, why is dressing percentage often 1% lower for cattle fed whole shelled corn than for cattle fed rolled or dry processed corn diets? Is this due to a difference in subcutaneous fat, in omental fat, or in gut fill?
- A:** I don't think the lower dressing percentage is due to a difference in composition of gain. Gut fill may differ. For example, with more forage in the diet, gut fill should be greater. However, more forage usually is fed with rolled corn than with whole corn diets, so this would result in exactly the opposite of the change actually seen dressing percentage.
- Q:** Steve, how does moisture content impact the advantage or disadvantage for processing and feeding value of whole corn?
- A:** I would speculate that moisture (10% for grain from a drier versus 15% field dried corn) may influence feeding value. However, vitreousness and kernel density probably have a greater impact on feeding value. A larger the kernel size and a greater amount of floury starch leads to greater mastication so that bacteria can more readily penetrate the seed coat and digest the grain. Grain usually is the cheapest component of the diet. Why we worry about grinding and processing corn to increase its digestibility and ignore the forage puzzles me. Forage usually costs more per pound than grain and we have no information about how we should processing that forage or how processing can influence the feeding value of roughage.
- Q:** Steve, what is the starch content of feces from cattle fed whole shelled corn?
- A:** In our digestion trials where we counted corn kernels, we looked at differences in fecal starch. We saw small but not significant differences in fecal starch concentrations. Fecal starch is a great tool, but many things can affect it. It is only one component of digestibility. If you add forage to the ration, you will dramatically reduce fecal starch even if starch digestibility is not altered. You need to keep factors that influence output of feces in mind when making comparisons; you need to make comparisons that are not confounded with other factors.
- Q:** Steve, do you have any measurements of methane losses with ground versus whole corn grain?
- A:** No.
- Q:** Steve, what percent of the feedlot cattle in the US are fed whole corn and what is the nature of those feedlots or feeding programs.
- A:** I don't have hard numbers, but more people feed whole corn than will admit it. Whole corn has a stigma. We see more feeding of whole corn by people feeding Holsteins, particularly lightweight Holsteins. In general, whole corn is used most frequently by farmer-feeders, small lots, by those feeding calves for a long time, and

more in the Corn Belt. They will feed corn silage or may not feed any roughage with their whole corn. They may add distillers' grain. Feeding dry forage with whole grain is a difficult challenge.

Additional comment by Lalman: We don't have many farmer-feeders in Oklahoma, but we have a large and growing number of stocker producers who use and prefer whole corn for programmed feeding. Whole corn makes that program user-friendlier.

Q: Steve, do people that feed whole corn have steam flakers?

A: No, but they might like to sell water at the price of corn.

FLAKED GRAIN VARIABLES: CONTROL POINTS AND EVALUATION OF FLAKED GRAINS

Jim Drouillard, Chris Reinhardt
Kansas State University
Manhattan, KS
jdrouill@k-state.edu



INTRODUCTION

With recent increases and the volatility in the costs of feed grains and of natural gas (Figure 1), it is more important than ever for feedyards and their

consultants to scrutinize their steam-flaking operation for potential sources of inefficiency.

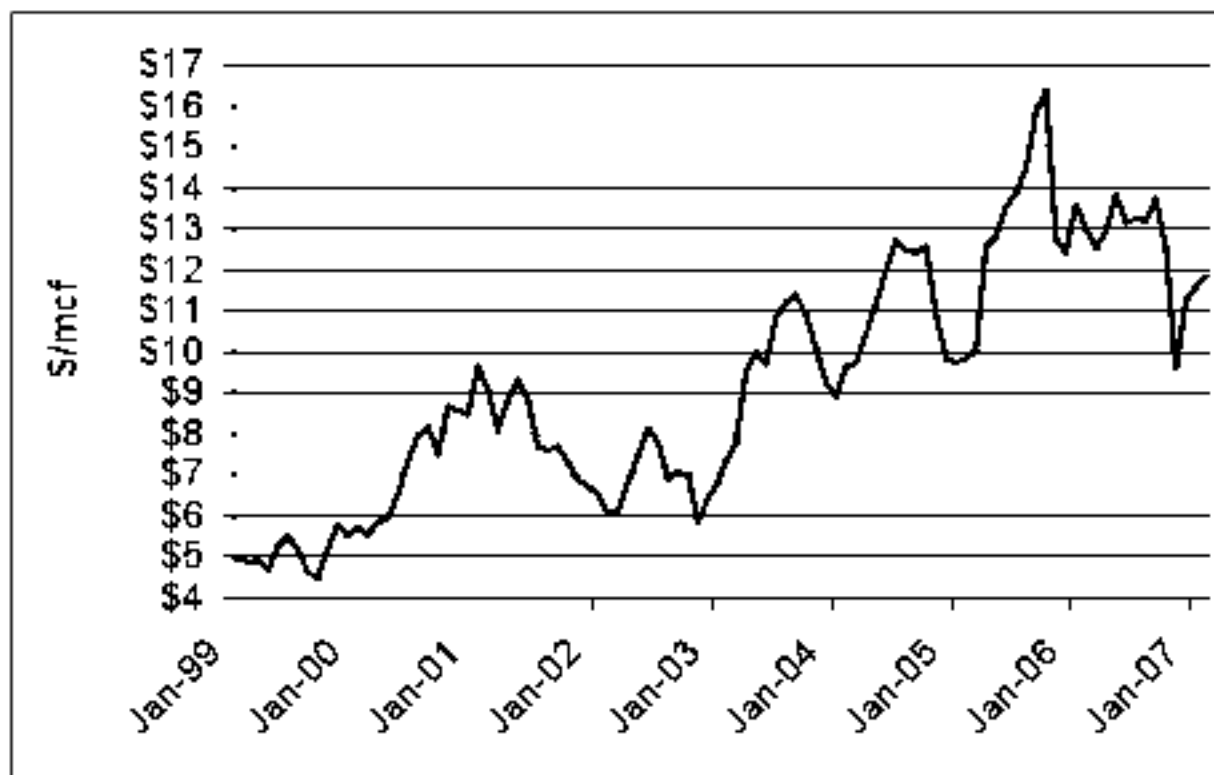


Figure 1. Price (dollars per thousand cubic feet) of natural gas, Kansas (<http://tonto.eia.doe.gov/dnav/ng/hist/n3020ks3m.htm>).

Perhaps the most obvious direction to look for cost-return optimization is in flake density. Studies evaluating feedlot performance at various flake densities of corn, sorghum, and wheat date back through several decades (Potter et al., 1971; Martin and Wagner, 1974; Theuer, 1986). However, the economic feasibility of flaking to any particular

degree changes with fluctuating energy costs, so this topic warrants re-examination. With an increased degree of processing, starch availability increases both for corn (Zinn et al., 1990a; Sindt et al., 2006b) and sorghum grain (Reinhardt, et al., 1997; Swingle et al., 1999; Figure 2).

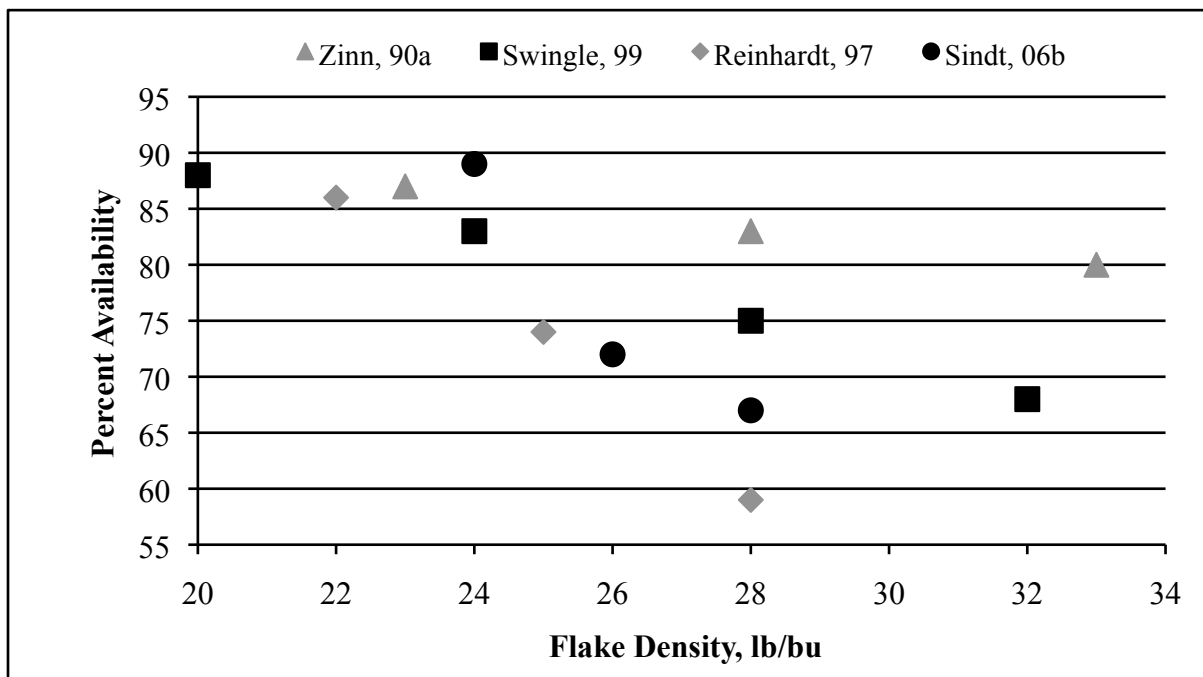


Figure 2. Starch degradability with increasing flake density of corn and sorghum (Zinn, 1990a: corn; rumen disappearance; Swingle et al., 1999: sorghum using enzymatic reactivity; Reinhardt et al., 1997, sorghum; differential scanning calorimetry; Sindt et al., 2006b, corn; *in vitro* gas production).

Theoretically, this should translate into improved feed efficiency for the more highly processed grain. However, while Xiong et al. (1991) observed a linear decrease in feed:gain (increased efficiency) when sorghum grain flake density was

increased from 20 to 30 lb/bu [VALUES IN FIGURE 2 FROM XIONG DO NOT MATCH VALUES FROM JAS 69:1711], Reinhardt et al. (1997) reported a linear increase in F:G (decreased efficiency) from 22 to 28 lb/bu (Figure 3).

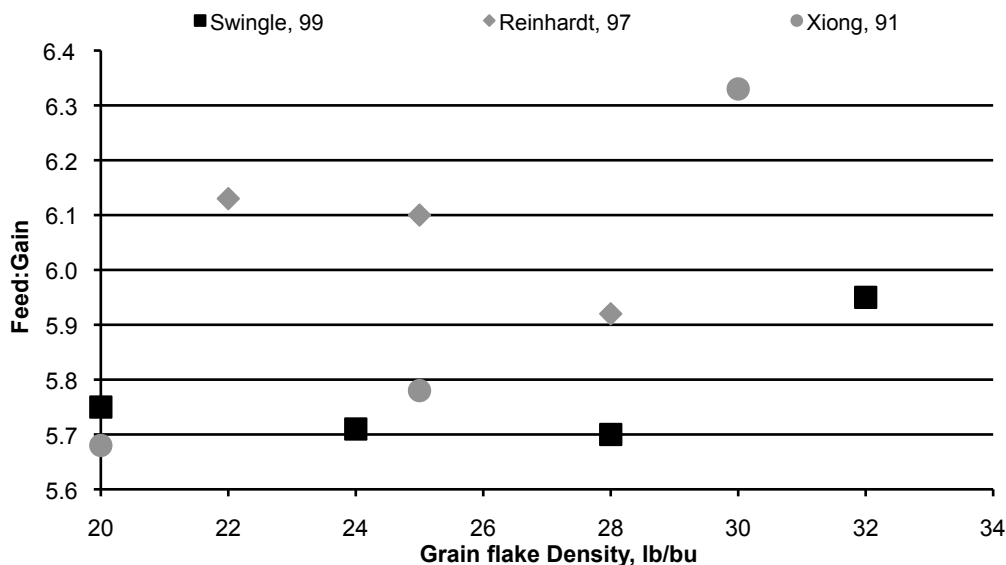


Figure 3. Effects sorghum grain flake density on feed:gain (Swingle et al., 1999; Reinhardt et al., 1997; Xiong et al., 1991)

Swingle et al. (1999) reported no change in feed efficiency from 20 to 28 lb/bu, but a 4.9% increase in F:G (decreased efficiency) from 28 to 32 lb/bu. When feeding corn, Zinn (1990a) reported a quadratic response in feed conversion, with an improvement in efficiency from 20 to 24 lb/bu and a

subsequent increase in F:G (decrease in efficiency) from 24 to 28 lb/bu (Figure 4). Likewise, KSU researchers (unpublished) have observed a linear increase in F:G (decrease in efficiency) from 28 to 36 lb/bu.

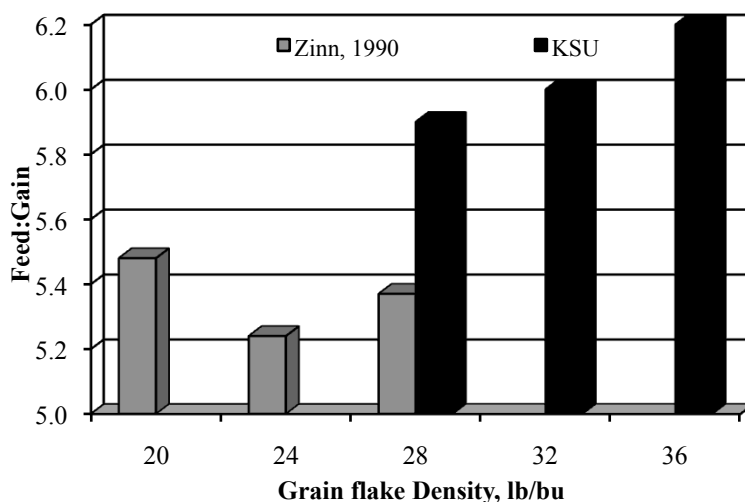


Figure 4. Effects of corn flake density (lb/bu) on feed:gain (Zinn et al., 1990a; KSU, unpublished).

The optimum level of grain processing also may change with different costs for grain, natural gas, and electricity. Reinhardt et al. (1997) reported that mill throughput was increased by 66% when sorghum grain flake density was increased from 22

to 28 lb/bu, and KSU researchers (unpublished) recently found a 63% increase in tonnage processed through the mill when corn flake density was increased from 28 to 36 lb/bu (Figure 5).

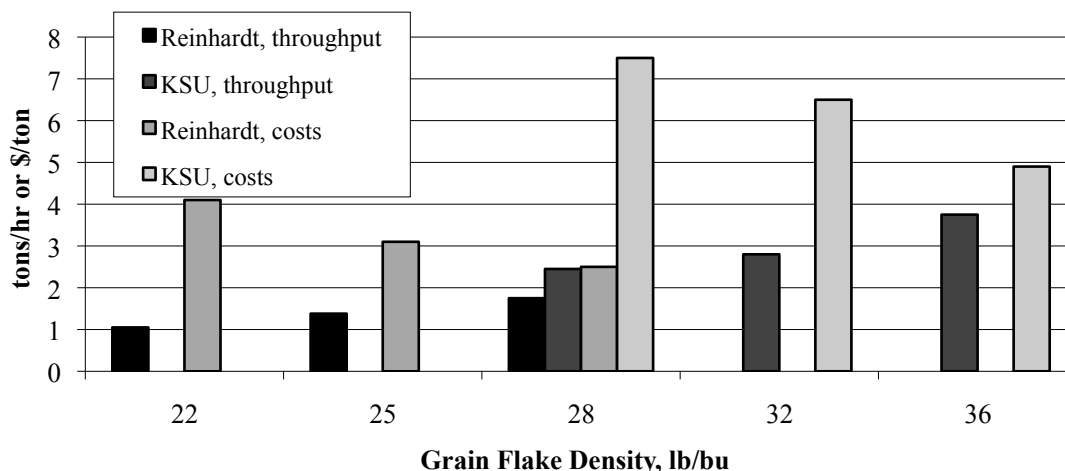


Figure 5. Effect of steam-flake density of corn (KSU, unpublished) or sorghum grain (Reinhardt et al., 1997) on mill throughput (tons/hr) and utility costs (\$/ton).

These increases in milling throughput correspond to 40 and 35% reductions in utility cost for flaking. With increasing processing input costs, the performance benefits of flaking to a given density may give way to opportunity costs of reducing the overall cost of the milling operation. Conversely, escalating grain costs may justify greater utility input costs to optimize efficiency of grain conversion.

Another concern within some feeding operations is the effect of storage conditions on changes in nutritive value of flaked grains. The temperature of the grain on the fringe of a pile of flaked grain cools very rapidly, rarely exceeding 140°F, and falls to below 100°F within 12 hours (Figure 6; Sindt, 2004).

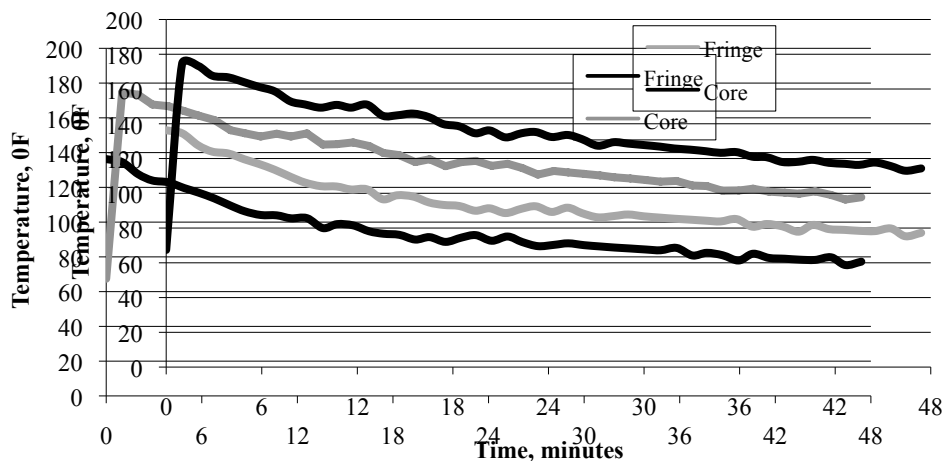


Figure 6. Temperature change of flaked corn during storage (Sindt, 2004).

However, the temperature at the core of the pile may remain above 140°F for more than 17 hours, permitting insoluble protein-sugar complexes to form (Figure 7). Also, the trapped moisture along

with the relatively slow decline in temperature may permit retrogradation of the starch, where starch chains re-align and create a less available form of starch than present in freshly flaked grain (Donovan, 1979).

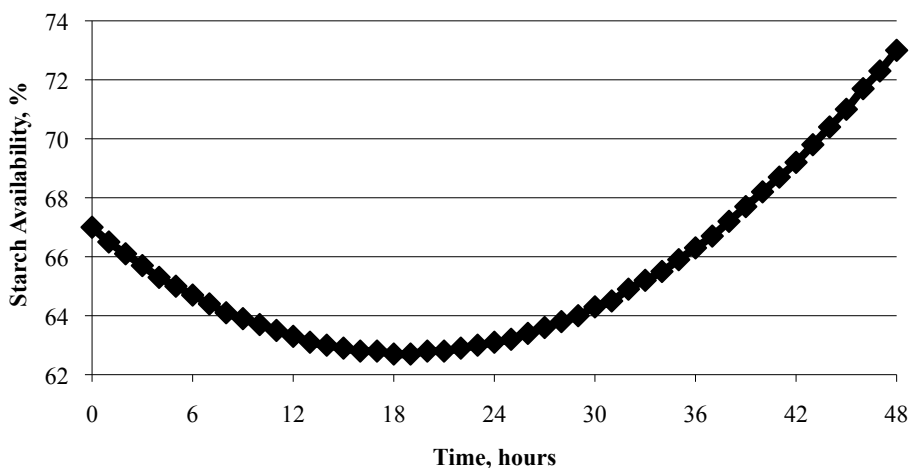


Figure 7. Starch availability (refractive index following 15-min incubation in glucoamylase) of steam-flaked corn stored in a pile as affected by time of storage (Sindt, 2004).

When dry-rolling or grinding, increasing the surface area available for microbial and enzymatic digestion is the goal; therefore, particle size reduction is critical for improving ruminal digestion. Such is not the case with steam-flaking. We

measured particle size distribution of corn flaked to a density of 28 lb/bu and determined that greater than 75% of the particles exceeded 4.75mm. In the case of dry rolled corn, more than 75% of grain had a particle size of less than 4.75 mm (Figure 8).

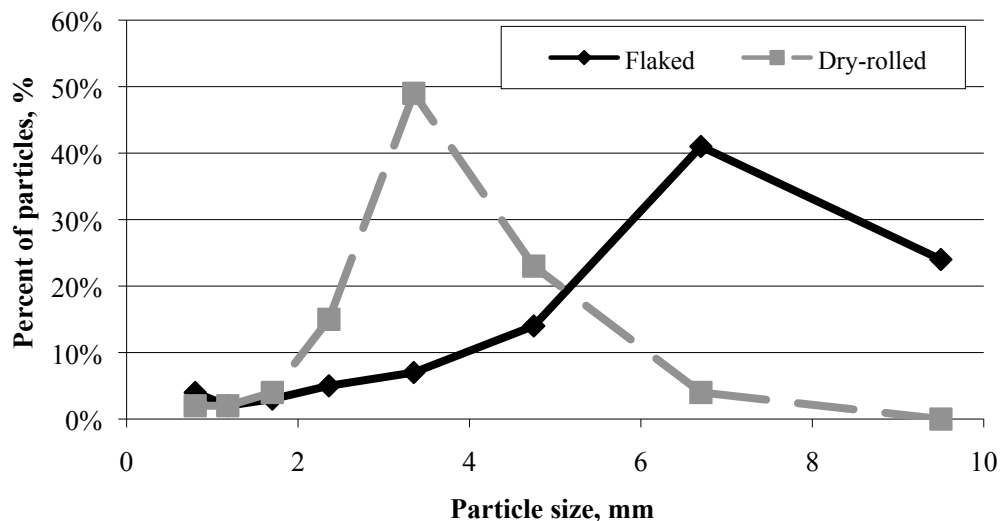


Figure 8. Distribution of grain sizes for dry rolled or steam-flaked corn (KSU, unpublished).

However, *in vitro* gas production for large particles of flaked grain was similar to that of small particles of either dry-rolled or steam-flaked corn; in

contrast, large particles of dry-rolled corn (whole or half kernels) were associated with much lower gas production than the smaller particles (Figure 9).

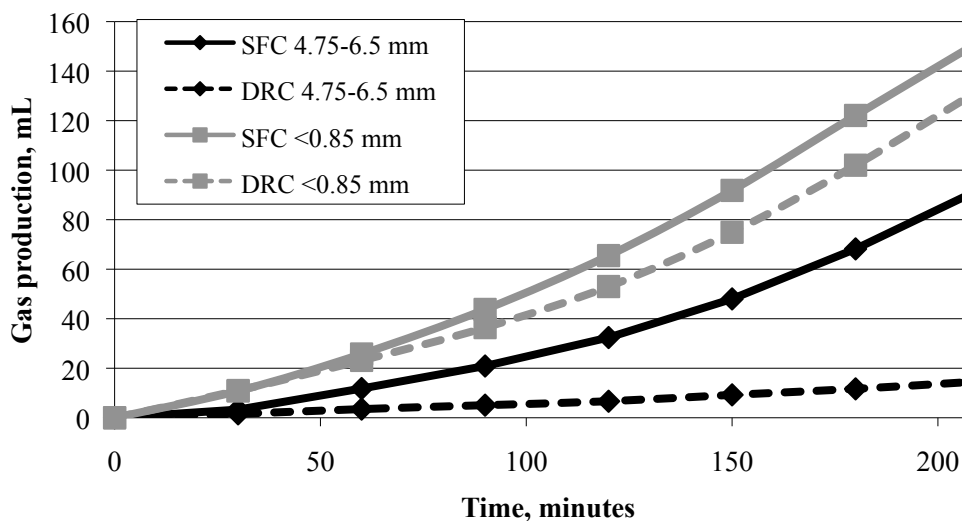


Figure 9. Effects of particle size on *in vitro* gas production of steam-flaked corn (SFC) and dry-rolled corn (DRC; KSU, unpublished).

While insufficient mixing will cause reductions in efficiency due to inconsistent nutrient intake, excessive mixing of the final diet containing flaked grain will cause flake damage and reduction of particle size of the steam-flaked grain; this may cause digestive upsets. Sindt (2006b) found that mixing steam-flaked corn for 15 minutes reduced average particle size (Figure 10). DMI was numerically reduced (19.4 vs. 20.5 lb; $P = 0.13$)

when grain was mixed for 15 additional minutes compared to no additional mixing time. While no differences were observed in ADG or F:G, the percentage of cattle grading Prime and Choice was reduced (42% vs. 65%; $P = 0.10$). More extensive ruminal digestion of starch may markedly reduce the supply of starch flowing to the small intestine. This reduced supply of glucogenic compounds may ultimately affect quality grade.

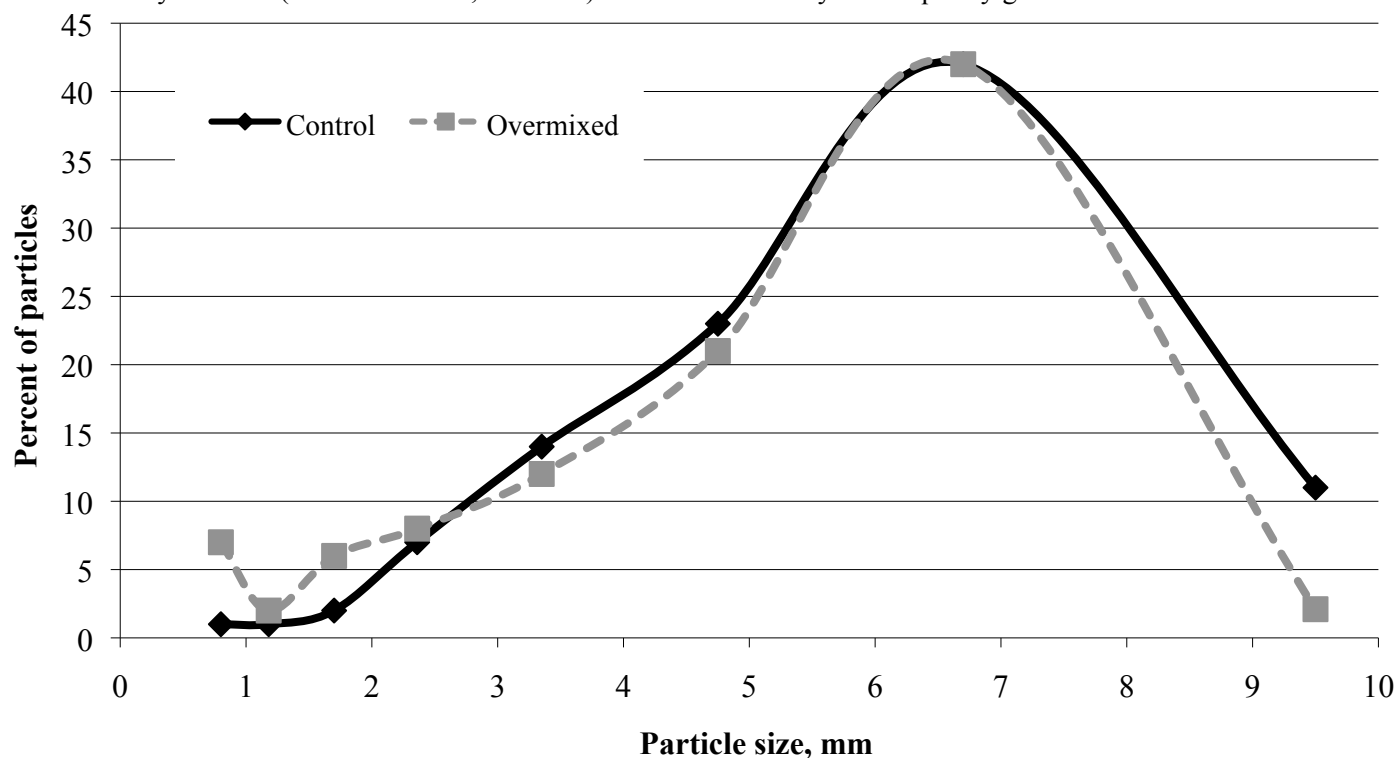


Figure 10. Effects of mixing on particle size reduction of steam-flaked corn portion of finishing diet (Sindt, 2006b).

Moisture content of flaked grain also can alter ruminal digestibility of grain. In one study, Sindt and coworkers (2006a) tempered corn with 0, 6, or 12% (wt/wt) water and flaked the grain to 24 or 28 lb/bu. Flaking to the lighter test weight increased starch availability, and increasing tempering moisture content also linearly increased starch availability. However, while increasing moisture content increased DMI and reduced F:G for cattle fed grain flaked to 28 lb/bu, the 12% moisture level actually caused a 0.8 lb reduction in DMI and a 1 unit increase in F:G ($P < 0.01$) compared to the 6% level in cattle fed the grain flaked to 24 lb/bu. In a separate study, Sindt et al. (2006b) found that when

corn had a final post-flaking moisture content of 36%, DMI (17.6 vs 18.9 lb; $P = 0.02$) and ADG (3.44 vs 3.70 lb; $P = 0.05$) both were lower when compared to those of cattle fed flaked corn containing 18% moisture.

Sindt and co-workers (2006b) evaluated the following grain processing treatments: tempering to 6, 10, or 14% moisture pre-steaming, addition of a yucca-based surfactant, steaming for 40 minutes vs. 20 minutes, or flaking to 24, 26, or 28 lb/bu. While only flake density affected starch availability, increased tempering moisture level, the addition of the surfactant, longer steaming time, and lighter

flake density all positively affected flake durability ($P < 0.10$). Increasing the steaming time also can increase the moisture content of the flakes (Zinn, 1990b), but that change is relatively small when compared to adding water in the tempering step. These data suggest that any method for optimizing moisture content of the final flaked grain may improve flake durability, diminish the particle size reduction during diet mixing, and ideally, improve animal performance. Interactions between moisture content and flake density on starch availability may impose practical limits to the improvements in animal performance based on moisture content of the flaked grain.

In summary, increasing the degree of processing increases ruminal availability of starch, but this

increase does not always translate into improved feed efficiency. This may reflect an inability of some animals to deal with the rapid acid accumulation in the rumen during fermentation of highly processed grain. While particle size reduction is essential for improving digestion of dry-processed grain, fine particles of flaked grain may increase the incidence of digestive upsets and reduce performance. For this reason, flake durability becomes an important consideration. Increasing the moisture content of flaked grain can improve the durability or “toughness” of flaked grain and reduce the amount of flake damage during mixing and feeding. Once again, with respect to steam-flaking of grain, “optimization” may be more important than “maximization.”

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QUESTIONS AND ANSWERS

Q: Would you comment on the role of surfactants in grain processing?

A: Other people here could answer that question better than me. Surfactants have been studied for many years. Jim Drouillard has generated some nice data regarding flake durability that matches information on moisture uptake and gelatinization. These factors all can alter the ability of the flake to hold together.

HIGH MOISTURE GRAINS: HARVESTING, PROCESSING AND STORAGE

Terry Mader¹ and Steve Rust²

¹University of Nebraska, ²Michigan State University
tmader1@unl.edu



INTRODUCTION

High moisture grains can be an economical feed source due to high grain yields and elimination of the cost for drying grain. Rather than simply a processing system, high moisture grain requires alteration in harvest and storage of the grain but by processing the grain into storage, it can eliminate processing of grain at the time of feeding. Other grains including sorghum and wheat have been utilized as high moisture, but corn is the principal grain harvested and stored in high moisture forms. High moisture corn (HMC) can be harvested and stored as whole shelled corn, the grain can be rolled or ground into storage, or larger sections of the plant can be harvested and ensiled to form high moisture ear corn with or without the husk. High moisture grain production has several agronomic and economic advantages. These include: harvest several weeks earlier than harvest for dry storage and this contributes to a decrease in field and harvest losses of 3 to 6 percent; elimination of drying costs; and a reduced commodity cost associated with seasonal grain prices and discounts equivalent to drying and elevator dockage charges. Disadvantages of harvesting high moisture grain include: loss of marketing flexibility compared to dry grain; additional equipment may be needed for harvesting, handling, and packing high moisture grain; storage facilities are needed for a large quantity of grain; harvest and ensiling can prove hectic; and storage losses can be large if the grain is not properly ensiled and removed from storage at an adequate rates.

Optimum Maturity and Harvest Moisture

Feed grains are considered physiologically mature when yield of dry matter is at the maximum point. Corn kernels continue to accumulate dry matter until moisture content decreases to about 35% although some hybrids may be mature at a moisture content near 40%. Postponing harvest to decrease moisture further will not increase yield of DM or energy per acre and often results in an increased field losses due to ear drop. For corn, kernels started to dent at about 50% moisture and are at a medium

soft stage but not mature. Twelve to 16 days usually are needed to reduce kernel moisture from 50 to 40%. During this time, yield can increase at a rate of 0.25 to 0.75 bushel per acre per day.

The optimum moisture for corn and grain sorghum will allow easy harvest and low field loss but still adequate for proper fermentation and near maximum animal performance. The moisture content that best satisfies all these requirements occurs shortly after physiological maturity of the grain is reached. An acceptable range for grain moisture content is between 25 to 33 percent. Once grain reaches physiological maturity, corn grains will lose about 1/2 to 1% moisture per day in the field although a hard freeze will speed this drying process. Because sorghum grain is more exposed, rate of drying can be much faster than for corn grain. Field loss at harvest can be affected substantially by grain moisture content. Harvesting and handling becomes easier as moisture content falls, but delaying harvest increases ear drop or loss of grain from a sorghum head, and the prevalence of downed stalks will increase due to wind, stalk rot, and insect damage. These losses can be minimized by proper adjustment of harvest machinery and initiating harvest when grain is at or slightly above 30% moisture and completing harvest before moisture reaches 25%. If corn contains less than 25% moisture, spoilage losses increase (Mader and Erickson, 2007) and feed efficiency will suffer. If all grain is to be harvested within 5 points of moisture and moisture content decreases at a rate of 1% per day, a hybrid must be harvested within a short (5 day) time window. To extend harvest time, hybrids can be selected with early to later maturity dates and hybrids with slower field drying of the grain. Slow field drying of grain conflicts directly with that of producers of dry grain who prefer rapid field drying so that grain can be harvested earlier. To reduce the number of irrigations needed or to produce multiple crops in a season, some growers will plant and grow shorter growing season hybrids than normally produced in their region at some sacrifice in grain yield.

High Moisture Grain Storage

Two storage methods are used commonly for high moisture grains. Ground grain can be stored in bunker or trench silos whereas whole grains often is stored in upright oxygen limiting structures. Ground or coarsely rolled grain can also be stored in upright structures. Large bagging systems that have been primarily used for encasing silage can also be used to store high moisture grains. In addition, corn and sorghum can be harvested dry and reconstituted by adding water to allow the grain to ferment in any of these storage units. Because the dominant grain stored in a high moisture form is corn, the following discussion will relate mainly to corn grain.

Fermentation loss of DM for high moisture corn averages 3 to 4% of the initial dry matter ensiled, but loss can be 2 to 3 times this level if grain is ensiled at the wrong moisture for the type of structure being

used. For storage in bunker silos, the preferred harvesting moisture is above 27 percent. Corn stored in bunkers should be ground or rolled and thoroughly packed into the silo. Since proper packing depends on the moisture and particle size, corn to be stored in a bunker silo can be coarsely ground with as much as 20 percent whole corn. However, as moisture of the corn decreases to near 25 percent, a finer grind may be necessary to achieve proper packing. Finer grinds also permit a feedout rate to be slower once the silo is opened. If the feeding rate is sufficiently fast (> 3 inches removed daily from the face of the bunker) to prevent deterioration as the grain is fed, a coarser grind is recommended.

Dry matter recovery of ensiled grains depends on the type of storage structure and form of the grain being stored (Table 1).

Table 1. Approximate dry matter fermentation and storage losses of high moisture corn

Losses	Bunker corn silage	High moisture corn		
		Bunker processed	Harvestore whole	Stave whole
Total	8 – 25%	4 – 10%	4 – 12%	8 – 16%
Fermentation	5%	2%	?	?
Storage	10%	4%	6%	10%

For high moisture grain that is properly processed and packed in bunker silos, dry matter losses from fermentation will average about 2%, with an additional storage surface loss of 3 to 5%. Exclusion of oxygen is critical for efficient ensiling. Aerobic deterioration (mold growth, etc.) associated with whole grain storage and uncovered/unsealed processed grain storage units can result in total DM loss during storage of 10% in bunker silos and 10 to 15% in structures used to store whole corn. Bagging or covering large bunker silos with plastic often held down with tires can hold total DM loss to under 5% of the total dry matter ensiled.

Deterioration of the exposed face of a bunker of stored grain will occur with slow removal rates and extensive exposure (i.e., when grain is removed from longitudinal sections of the bunker silo at different times). Dry matter losses from the face will vary with firmness of pack, particle size, and moisture. Nevertheless, in aerobic stability studies, Young et al. (1982) ensiled HMC at 22 to 28% moisture and reported respective DM losses from untreated (no

preservatives added) coarse rolled HMC (4 lb samples taken from stave silo) of 0.9, 1.3, 1.6, and 2.7% after 2, 5, 7, and 16 days of exposure to air in May and respective DM losses of 2.7, 3.1, 3.2, and 2.8% for samples exposed to air in July. Comparable losses were also found with rolled high moisture grain sorghum (Heidker et al., 1982). Loss of dry matter may underestimate energy loss during exposure to oxygen; in the Heidker et al. (1982) study, loss of lactate plus acetate after 3 days totaled 1.7% though dry matter loss was less than 1%. Presumably, this reflects loss of volatile compounds during determination of dry matter during oven drying. Clearly, the rate of deterioration and dry matter losses are influenced by ambient temperatures. However, peak dry matter losses appeared to be limited to approximately 3% of the dry matter after more than two weeks of exposure despite elevated temperatures. Orientation of the bunker face and exposure to direct sunlight would also influence surface moisture and dry matter losses. In addition, losses from the face of a well-packed bunker silo may be less than those found in a

small sample under laboratory conditions. However, other environmental influences, such as rain and wind, could increase the magnitude of these losses.

High Moisture Grain Feeding Value

Relative differences among various grain type and processing methods were outlined by Owens et al. (1997). In general, more extensive processing of grain reduces ADG. This reduction can be attributed largely to reduced dry matter intake (DMI). Reduced DMI of grain sources that are extensively processed and rapidly fermented has been attributed to an

excessive rate of acid production in the rumen and subclinical acidosis that will increase day-to-day variation in DMI.

Feed to gain ratios generally are lower (improved) with high moisture ensiled grain when compared to dry rolled grain (Table 2). Metabolizable energy contents of the grain alone, without or with adjustment for final weight of test cattle, are greater for high moisture grain than dry rolled grains.

Table 2. Feed to gain (F/G) and metabolizable energy (ME, Mcal/lb) for feedlot cattle fed dry rolled vs high moisture corn and milo (Owens et al., 1997)

Processing method	F/G		ME, Mcal/lb	
	Corn	Milo	Corn	Milo
Dry roll	6.57	7.43	1.48 ^a	1.33
High moisture	6.43	7.12	1.55 ^b	1.35
Change, %	-2.13	-4.17	4.60 (6.84)*	1.36 (10.00)*

^{a,b}Means within a column with different superscripts differ ($P < 0.05$).

*Adjusted for final weight.

On a body weight-adjusted ME basis, high-moisture corn and milo had 6.8% to 10.00% greater ME than dry-rolled corn and milo, respectively. Performance of cattle fed high-moisture corn grain harvested and stored at various moisture contents

and ground, rolled, or unprocessed (left whole) are shown in Table 3. Only the middle range in moisture content for whole corn was available; presumably, this represents grain stored in oxygen-limiting structures.

Table 3. Performance of cattle fed high moisture corn grain at various moisture contents and processed by various methods prior to storage (Owens et al., 1997)*

Moisture content, %	Ground		Rolled		Whole
	23 – 26	>27	23 – 26	>27	23 – 26
ADG, lb/d	2.91	2.80	2.23	2.56	3.06
DMI, lb/d	19.91 ^a	18.06 ^b	19.05	18.28	20.04
Feed/gain	7.2	6.5	8.6	7.2	6.6
ME, Mcal/lb	1.45 ^a	1.58 ^b	1.36	1.49	1.50

*ADG, average daily gain; DMI, dry matter intake; ME, metabolizable energy.

^{a,b}Means in a row and processing type with different superscripts differ ($P < 0.05$).

Although the number of observations limits statistical power for comparison, ADG numerically was greater with the wettest rolled grain and with whole grain. The wetter corn grain resulted in lower DMI. To numerically maximize efficiency of feed use, lower moisture grain should be ground rather than rolled; overall, for optimum gain and efficiency, wetter grain is more desirable. Regressions of daily gain and body weight-adjusted ME against the percentage of moisture of high

moisture grain fed in all forms revealed that both ADG and ME should be maximum at about 40% moisture (Owens, et al., 1997). Presumably, this increase in ME is a function of DM digestibility; digestibility tends to increase with moisture content.

The potential benefits of using high moisture corn stored in the whole form have been reported by Mader et al. (1991) and are summarized in Table 4.

Table 4. Performance of cattle fed high moisture corn (HMC) finishing diets (3 trial summary; Mader et al., 1991)

Item	Dry whole corn	HMC			SE*
		Whole	Ground (bunker)	Rolled (stored whole)	
Daily gain, lb ^a	3.18	3.13	2.80	3.00	0.09
Daily intake, lb ^a	21.63	21.26	20.22	19.54	0.51
Feed/gain ^b	6.90	6.90	7.34	6.68	0.21

*Standard error.

^aWhole vs processed ($P < 0.05$).

^bGround vs rolled ($P < 0.10$).

Daily gain of cattle fed dry whole corn (DWC) was similar to performance of cattle fed whole high moisture corn (WHMC). Daily gains of cattle fed whole corn (DWC and WHMC) were greater than daily gains of cattle fed ground high moisture corn (GHMC) and rolled high moisture corn (RHMC). Feed intakes followed a similar pattern. As the percentage of processed corn in the diet increased, intakes tend to decrease. More desirable animal performance may be produced from WHMC than RHMC because of increased DMI and improved nitrogen utilization as a result of the lower organic acids and less soluble nitrogen associated with corn stored as WHMC.

Efficiency of feed conversion (feed to gain ratio) was similar among cattle groups fed whole corn. Because of lower gains for cattle fed GHMC, feed to gain ratios tended to be greater (worse) for cattle fed GHMC than for cattle fed RHMC. In this study, cattle fed GHMC tended to have more liver abscesses than other cattle groups. More highly processed grain sources including high moisture grains tend to increase the incidence of liver abscesses.

The increased incidence of liver abscesses may be attributed to a rapid ruminal digestion of the corn starch that will increase the likelihood of digestive disturbances and acidosis. Other research conducted at the University of Nebraska Northeast Research and Extension Center has shown that the decreased performance observed with ground HMC occurred primarily during the step-up or diet adjustment period, the very period when cattle most frequently develop acidosis. Once cattle were adapted to their high concentrate rations, performance was similar regardless of grain type fed. Numerically, the lowest feed to gain ratios were found with cattle fed RHMC

that was stored whole in an oxygen limiting structure but rolled prior to feeding.

Limited data indicates that steers fed HMC stored whole and fed whole tended to gain faster and are approximately 5 percent more efficient than steers fed DRC in high concentrate finishing rations. In addition, rolling whole HMC prior to feeding resulted in a 1 to 2 percent improvement in feed efficiency over steers fed whole HMC (Mader and Erickson, 2007). However, storage losses of corn stored whole typically are greater than for corn stored in a bunker silo as GHMC. High moisture corn can also be stored whole by treating it with organic acids. Organic acids also can be used to treat HMC to be stored outside in areas where loss associated with rainfall will be low. Gains and feed efficiencies may be improved 1 to 3 percent over DRC when corn is treated with organic acids, but the cost of the acid and its application must be considered.

Performance benefits of ensiling grain can partially be attributed to enhancement of protein solubility and starch availability. Early reviews found that soluble N, as a % of total N in ground HMC, was increased from 16% on day 0 to 38% on day 56 of ensiling (Prigge, 1976). Prigge (1976) also reported that energy availability based on CO₂ products was increased by approximately 20%. Benton et al. (2005) reported in situ dry matter digestibilities (ISDMD) of 37.7 and 61.3%, for 24% and 30% moisture HMC, respectively, following 28 days of ensiling. The rates of change in ISDMD, 28 days post-ensiling, were 0.44 and 0.38%/day for the 24 and 30% moisture HMC. Degradable intake protein (DIP) as a percentage of crude protein were 41.6 and 68.1% for the 24 and 30% moisture HMC, respectively, while respective rates of change in

degradable intake protein, 28 days post-ensiling, were 0.51 and 0.44%/day. Although rates of change in ISDMD and DIP were greater for the lower moisture corn, the magnitude of initial post-ensiling levels of ISDMD and DIP were greater for the higher moisture corn. Clearly, a positive relationship between changes in ISDMD and DIP is apparent. In addition, changes in starch digestibility and protein solubility appear to continue throughout the period the grain is being stored in a fermentative state. Mahanna (2007) attributed these continuous increases in starch digestion and related changes in energy content of ensiled corn to “spring acidosis” which is assumed to be found more frequently in cattle fed grain ensiled for a long (> 6 months) period of time.

Cooper et al. (2002) also found greater DIP (67.1 vs 31.1%), greater rate of starch digestion (4.8 vs 3.0%/hr), and greater ruminal starch digestion (68.4 vs 52.0%) for HMC vs DRC. Interestingly, steam flaked corn had a numerical DIP level very similar to DRC but, as expected, a ruminal starch digestion very similar to HMC. In grain sorghum studies, Defoor et al. (2000) reported insoluble CP (% of total CP) to be 7.68 in 30% moisture ensiled (105 d) grain sorghum, and 9.03% for dry rolled grain sorghum. Starch availability (% of total) was enhanced with ensiling from 36.5% to 51.6%. Thus, ensiling ground grain sorghum increased protein solubility and starch availability in a manner similar to that found in HMC.

RECONSTITUTION

A summary of research conducted in South Dakota, Indiana and Nebraska has found little if any improvement in gain and feed efficiency from reconstituting corn when fed in high concentrate rations. With the extra cost incurred in drying corn and then reconstituting it, harvesting HMC from the field and storing it in its native form seems more logical and economical than reconstituting dry corn. Adding enough moisture for adequate fermentation can be a problem because a moisture content above 25% is desirable for proper reconstitution but is often difficult to achieve. Reconstitution of milo is much more beneficial than reconstituting corn. However, reconstitution of grains can add flexibility to the feeding operation because less inventory of grain needs to be maintained when compared with traditional HMC systems.

Ground Ear Corn or Ground Snapped Corn

Ground ear corn (corn and cob only) appears to have 6 to 10 percent greater feed value when stored as high moisture feed than when fed dry. This improvement may be due largely to increased palatability of the feed. Ear corn can be easily harvested by adjusting combine fan speed and concave clearance to retrieve the ground cob and corn. Hill et al. (1995) found that a diet consisting of ground high moisture ear corn diet produced steer performance equivalent to that from a high moisture ground corn diet that contained 8% alfalfa. Snapped ear corn is another type of ear corn that normally is harvested by attaching a corn combine head to a silage chopping unit. Either ear corn or snapped corn provides a relatively inexpensive roughage source in feedlot diets. Between 8 to 15% of the dry matter of high moisture ground ear corn is found in the cob depending on hybrid and stage of maturity at harvest whereas ground snapped ear corn may contain 20% or more roughage from the cob, husks, and other plant materials. This is likely to be more roughage than preferred to achieve a maximum rate and efficiency of gain in finishing rations. Thus, for optimal cattle performance, additional grain must be added to most ground ear corn or snapped ear corn rations once cattle are adapted to their finishing ration. For best results, cob pieces need to have a diameter less than 1/2 inch to assure good packing and adequate consumption when fed. Ear corn will require 25 to 35 percent more storage capacity than grain alone. Where storage capacity is limited or more expensive structures are used, the improvement in feed utilization and the feed value of the cob may not offset the additional cost of harvest and storage.

SUMMARY

Harvesting, processing and storing grain at moistures between 25 and 30% can provide a more economical energy source in feedlot diets than dry processed grain. However, care must be exercised to minimize fermentation and storage losses that can offset the economic gains associated with early harvesting. In general, covering bunker silos will hold storage dry matter loss to under 5%. In addition, harvesting the cob with the corn and storing the product as ensiled ear corn offers a viable and relatively inexpensive source of both energy and roughage source for feedlot cattle. Grain that is

properly ensiled not only has increased protein solubility and starch availability compared to dry grain, but both protein solubility and starch

availability appear to continue to increase during storage.

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QUESTIONS AND ANSWERS

- Q:** Where did your data come from that shows a higher feeding value of high moisture grain stored whole and rolled at feeding time versus high moisture grain rolled into storage?
- A:** Our data were published in the *Journal of Animal Science* in about 1984. That was a summary of three studies. I understand that your data does not support the idea that corn stored whole and rolled at feeding time had no greater value than corn rolled into storage. These are our results.
- Q:** For Terry, what is the energy value of fermented snapped ear corn in terms of an NE_g value or its feeding value relative to corn?
- A:** Ear corn silage or fermented ear corn can be of three different types and feeding values. With the cob alone, you have a value relative to corn of about 94 to 95%, add husks and you drop this value by 5 to 8%. Snapped ear corn includes ear, the husk, and tops of some plants. One can calculate feeding value based on fiber or roughage content of the product. Snapped ear corn has about 25% roughage, the ear with the cob and the husk is about 20% roughage; the cob alone will provide about 10% roughage. You can put net energy values on the roughage to calculate net energy values from this and include associative effects as well, if you wish.

RECONSTITUTION OF GRAIN SORGHUM FOR RUMINANTS

Paul J. Defoor¹, Mike S. Brown², and Fred N. Owens³

¹Cactus Feeders, ²West Texas A&M University, and ³Pioneer Hi-Bred International
paul.defoor@cactusfeeders.com



ABSTRACT

The mechanisms by which reconstitution increases rumen degradation of grain sorghum and relevant studies that have measured effects of reconstitution on growth performance by finishing cattle were reviewed. The growth performance data summarized indicate that reconstitution of sorghum improved feed efficiency by 15% when compared to dry-rolled sorghum with a 7.6% increase in rate of gain. Individual trial responses to reconstitution have varied greatly both for feed efficiency and rate of gain. The extent to which differences in reconstitution techniques have contributed to this inconsistency is not clear, but laboratory trials indicate that the impact could be large. Laboratory data indicate that an aerobic germination period of 1 to 5 d with grain whole prior to anaerobic storage is a critical step in the reconstitution process. This germination period allows initiation of endogenous starch hydrolysis through gibberellin-like hormones that migrate to the aleurone layer and cause protease and amylase enzymes to be released. Endogenous starch hydrolysis ceases under anaerobic conditions, but grain nitrogen becomes increasingly soluble as the duration of both germination and ensiling increase; this increases microbial access to starch granules. Access of starch granules for microbial attack is not readily reflected by enzymatic starch availability measurements.

INTRODUCTION

Cereal grains fed to growing and finishing cattle typically are processed to increase ruminal digestion by increasing the rate of digestion (K_d) in the rumen relative to the rate of passage (K_p) from the rumen. The K_d of cereal grains can be increased by several mechanisms including particle size reduction (e.g., grinding, rolling), solubilization of the protein matrix surrounding starch granules of the endosperm (e.g., fermentation during storage), and gelatinization of endosperm starch in concert with physical disruption of the protein matrix surrounding starch granules (e.g., steam flaking, popping, extruding, micronizing). For fermentation, grain can be harvested before it dries in the field (high moisture harvest) or water can be added to dry grain (reconstitution) with this material being allowed to ferment. The harvest window during which grain moisture remains within the range ideal for production of high moisture *corn* lasts 7 to 14 days; for *sorghum grain* this period lasts only 2 to 5 days due to direct exposure of the grain in the sorghum head to the environment. Because of this short harvest window, reconstitution has been the preferred method to achieve fermentation with sorghum grain. Traditionally, reconstitution has been defined as the process of rehydrating dry grain (12-15% moisture) to approximately 30% moisture, storing the whole wet grain under oxygen-limiting conditions for approximately 3 weeks for

fermentation, and rolling or grinding the fermented grain prior to feeding. Storage time will dictate the extent to which fermentation progresses. The objectives of this paper are to review the mechanisms by which reconstitution increases the K_d of grain sorghum, and to review relevant studies that have measured the effects of reconstitution on growth performance by finishing cattle.

Growth Performance Studies: Prior to 1976

Hinders (1976) reviewed much of the performance data with reconstituted grain sorghum conducted prior to 1976. He differentiated between grain that was reconstituted whole and stored in an oxygen-limited environment versus grain that was rolled or ground prior to storage. Particle size reduction before reconstitution allows the product to be stored in bunker silos. Relative rates of gain and relative feed efficiency for reconstituted grain sorghum relative to dry rolled grain sorghum from the individual studies reported by Hinders (1976) are shown in Figures 1a and 1b; data summarized across studies are in Figure 1c. In most studies, feed efficiency and rate of gain were improved when sorghum was reconstituted in the whole form but the magnitude of improvement varied considerably across trials. Three studies conducted during or prior to 1976 that were not included in this review were those of Schake et al. (1972), Riley et al. (1975), and Bolsen and Riley (1976).

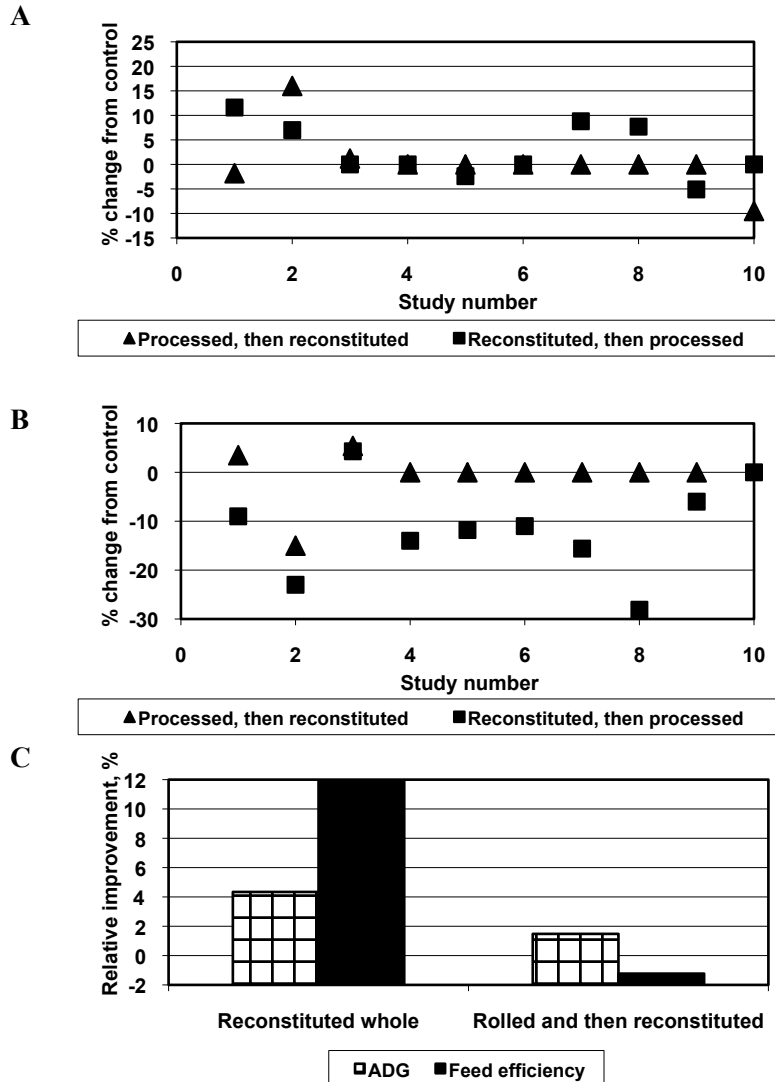


Figure 1. Effects of grain sorghum reconstitution on relative average daily gain (1a) and relative feed efficiency (1b) of individual trials and summarized across trials (1c; Hinders, 1976).

Schake et al. (1972) reconstituted both dry whole and dry-rolled grain sorghum to approximately 30% moisture and evaluated feeding performance relative to a steam-flaked grain sorghum control. Both of the reconstituted grains were stored in oxygen-limiting structures. The whole grain was stored for 14 d prior to initial feeding and was rolled prior to feeding. The reconstituted rolled grain was stored for 30 d prior to initial feeding. Rate of gain was not affected by treatment (*P*-value not reported) but feed efficiency tended to be improved for cattle fed the reconstituted whole grain sorghum rolled versus the reconstituted rolled grain (*P*-value not reported). This study had 75 steers per treatment but only 2 pens/treatment. The studies of

Riley et al. (1975) and Bolsen and Riley (1976) reported that there was no difference in cattle performance between those fed reconstituted grain sorghum and those fed dry rolled grain sorghum, but these studies had limited replication. Details of the reconstitution process were not fully described in these studies.

Using a body weight-adjusted ME approach in his review of grain processing, Owens et al. (1997) stated that in eight trials directly comparing steam-rolled milo with reconstituted milo, the reconstituted milo had higher body weight-adjusted ME than steam-rolled milo. However, it is not clear from the older literature or in the review of Owens et al. (1997) how closely the

“steam-rolled” grain that was used would compare to steam-flaked grain produced today. Furthermore, many of the earlier studies used only 2 or 3 replications per treatment. In addition, the exact steps involved in reconstituting milo in most of the older literature are not fully described. This makes it difficult to relate performance results to grain handling techniques or physical and chemical characteristics of the processed grain.

Growth Performance Studies: Since 1976

Huck et al. (1999) compared growth performance of finishing heifers fed 1) reconstituted grain sorghum rolled prior to reconstituting and ensiling 2) grain sorghum harvested at 25% moisture that was rolled prior to ensiling, and 3) a steam-flaked corn control. The reconstituted grain sorghum was harvested at 14% moisture, rolled, and reconstituted to either 30 or 35% moisture before ensiling. Rate of gain was not affected by processing method, but feed efficiency was superior ($P < 0.10$) for the 35% compared with the 30% moisture reconstituted grain sorghum. Feed efficiency was poorer (4%) for the 35% moisture reconstitution treatment relative to the steam-flaked corn control. Consistent with expectations, feed efficiency was poorer (9%; $P < 0.10$) with the 30% moisture reconstituted grain sorghum than with steam flaked corn. Performance of cattle fed the rolled high-moisture grain sorghum was similar to that of cattle fed the 30% moisture reconstituted grain sorghum.

Simpson et al. (1985) evaluated the effects of several reconstitution methods using yearling steers. Their treatments included: 1) dry-rolled grain sorghum, 2) whole grain sorghum soaked in water 21 h that was rolled prior to feeding, 3) whole grain sorghum soaked in water 21 h and exposed to air for 21 h that was rolled prior to feeding, and 4) whole

grain sorghum soaked in water 21 h, exposed to air for 21 h, ensiled in air tight polyethylene bags for 5 d and then rolled before feeding. Each grain was fed at 88% of ration dry matter. In the 138 d feeding trial (3 pens/treatment), dry matter intake by cattle fed the reconstituted grain was similar to that of cattle fed the dry rolled grain. Feed efficiency was not different ($P > 0.12$) among the treatments with added moisture, but feed efficiency was improved dramatically (15.4%, $P < 0.12$) for steers fed reconstituted grain compared to steers fed dry-rolled grain sorghum.

A meta-analysis using mixed procedures of SAS (SAS Institute, Cary, NC) was conducted on selected growth performance studies published since the review by Hinders (1976) to provide quantitative estimates of the response to reconstituting grain sorghum. Studies included in our analysis must have included at least dry-rolled and reconstituted grain sorghum; fewer studies were available in which both steam-flaked and reconstituted grain sorghum were fed. The data set included the six reconstitution studies summarized by Owens et al. (1997) conducted between 1982 and 1986 as well as data from Simpson et al. (1985). Based on these data (Table 1), the improvement in feed efficiency from reconstituting grain sorghum was surprisingly large (15%). A performance improvement of this magnitude would require reconstituted sorghum to contain an optimistic 0.72 Mcal of NE_g/lb if dry-rolled sorghum contained 0.61 Mcal of NE_g/lb and was included as 80% of diet dry matter. Perhaps destruction of tannin during the fermentation process as demonstrated by Reichert et al. (1980) may have contributed to the improved feeding value of reconstituted sorghum in these studies. If so, reconstitution should be of less benefit with modern sorghum varieties produced in the US because no modern varieties contain high levels of tannin.

Table 1. Growth performance by feedlot cattle fed processed grain sorghum

Item	Dry-rolled	Reconstituted	Standard Error
Trials, n	7	7	-
Days on feed	126	126	-
Initial weight, lb	656	653	-
Dry matter intake, lb/d	20.0 ^a	18.1 ^b	1.0
Average daily gain, lb/d	2.62 ^a	2.82 ^b	0.19
Feed efficiency	7.68 ^a	6.52 ^b	0.3

^{a,b}Means differ ($P < 0.05$).

More recent research conducted by Ponce et al. (2006) evaluated the effects of a modified reconstitution process that was applied to corn, not grain sorghum. The objective of their process was to solubilize the protein matrix of dry-rolled corn using a solution of urea and water and to enhance hydrolysis of starch by adding amylase enzyme. Dietary treatments contained 91% concentrate based on 1) dry-rolled corn (DRC), 2) dry-rolled corn treated with urea, amylase, and water (DRT), and 3) steam-flaked corn (SFC). Diets were formulated to contain similar percentages of protein from NPN. Because the DRT grain contained 0.55% added urea, 0.55% urea was added to the remaining diets. In addition, the equivalent of 0.32% urea was added from a steep:molasses blend; the equivalent of 0.1% urea was added to all diets from ammonium sulfate. The DRT diet was prepared each afternoon and held under ambient conditions until being fed the next day.

Steers receiving SFC consumed less DM than steers fed either DRC (5.8%) or DRT (7.3%). Steers receiving DRC tended to gain weight less rapidly on a carcass-adjusted basis (4.7%; $P < 0.15$) than steers receiving the DRT diet. Carcass-adjusted feed efficiency was poorest ($P < 0.10$) for steers receiving DRC, but efficiency was improved above that for DRC by 3.1% by feeding DRT and an additional 6.3% by feeding SFC. The authors stated that this improvement in feed efficiency from treating the dry-rolled corn with urea, amylase, and water would be conservative because the study was conducted during the cool fall and winter months, and catalytic activity of amylase is dependent on ambient temperature.

Kernel Characteristics

At the time most of the reconstitution studies were conducted, the mechanisms by which reconstitution improved growth performance were not clear. Sullins et al. (1971) proposed that softening of the kernel and fermentation changes involving degradation of the protein matrix were involved. Their microscopic analysis revealed that the structure of the endosperm of reconstituted grain was modified and this increased accessibility of the starch granules. Others proposed that lactic acid-producing flora found on grain sorghum were responsible for the benefit attributed to reconstitution (Pflugfelder et al., 1986).

Interestingly, Van der Walt (1956) identified eight species of lactic acid bacteria responsible for the souring of South African sorghum beer. These bacteria produce an exo-polysaccharide shell from sucrose. Pflugfelder et al. (1986) suggested that the ability of these and other slime-producing organisms to convert soluble sugars into an insoluble storage polysaccharide might account, in part, for the effective conservation of dry matter reported during conventional reconstitution.

Between 1971 and 1981, several studies (Sullins et al., 1971; Wagner et al., 1974; Hibberd et al., 1981) indicated that the onset of germination could explain the chemical changes observed in reconstituted grain sorghum. Sullins et al. (1971) detected the release of gibberellin-like hormones that can migrate to the aleurone layer to stimulate the release of protease and amylase enzymes. Girdling the aleurone layer of barley prior to steeping inhibited degradation of the endosperm because the hormone-like substances were unable to move from the embryo to the aleurone layer to activate these enzymes. Grinding or rolling prior to reconstitution destroys this signaling pathway and inhibits much of the autolytic process (Sullins et al., 1971). However, some enzymes present in the particles of ground grain still were activated when water was added; this could result in some enzymatic degradation (Sullins et al., 1971).

Pflugfelder et al. (1986) examined the impact of germination and anaerobic storage on sorghum reconstitution. In their study, grain moisture content was increased to 30-35% by steeping for 16 h in 18° to 20°C tap water. The steeped grain was allowed to germinate at room temperature under aerobic conditions for 0, 0.5, 1.0, 1.5, or 2.0 d prior to anaerobic storage for 0, 5, 13, or 21 d. The combination of 0 d for germination with 21 d for anaerobic storage simulated conventional reconstitution procedure. Surprisingly, this treatment combination produced little increase in nitrogen solubility above that of untreated controls. Each additional 12 h of germination time resulted in the solubilization of approximately 10% more nitrogen, reaching approximately 50% solubilization for the 2-d germination after 21 d of anaerobic storage; nitrogen continued to be solubilized during anaerobic storage. Starch hydrolysis also was increased with germination periods of 1.5 and 2.0 d, but anaerobic storage did not alter starch hydrolysis. These observations indicate that the endosperm matrix protein could be degraded during both germination and anaerobic storage, but at least 24

h for germination was needed to initiate starch hydrolysis. The authors concluded that short periods of germination prior to anaerobic storage of reconstituted sorghum should greatly accelerate the anaerobic fermentation process and improve digestibility for ruminants. Dry matter loss during the entire process (germination + anaerobic storage) ranged from 2% to 18%.

More recently, Balogun et al. (2005) studied the effect of aerobic and anaerobic treatments on laboratory characteristics of grain sorghum. Samples of grain were either dry-rolled or soaked whole. Soaked grain was 1) rolled after soaking, 2) stored anaerobically for 21 d and then rolled, 3) stored aerobically for 5 d to allow germination and then rolled, or 4) stored aerobically for 5 d to allow germination and finally stored anaerobically for 16 days and then rolled. As occurred in the study of Pflugfelder et al. (1986), treatments that involved

aerobic storage to allow germination significantly increased the solubility of nitrogen and carbohydrate as well as extent of fermentation and degradation of the reconstituted grain. The combination of aerobic and anaerobic treatments increased fermentability and degradability of reconstituted grain. Balogun et al. (2005) concluded that incorporating an aerobic phase that allows germination to occur prior to anaerobic storage could take advantage of the activity of both endogenous and microbial enzymes to improve the digestibility of grain sorghum. Work by McNeill et al. (1971) indicates that reconstitution of sorghum will increase the extent of ruminal starch digestion (Table 2) compared to dry-rolling primarily due to greater accessibility of starch because reconstitution did not alter in vitro starch availability (Table 3; McNeill et al., 1975). Ruminal protein digestion of reconstituted sorghum also is markedly higher than for dry-rolled sorghum (Table 4; Potter et al., 1971).

Table 2. Ruminal, post ruminal, and total tract digestion of starch from reconstituted grain sorghum (McNeill et al., 1971)

Item	Dry Ground	Reconstituted	Steam Flaked	Micronized
Ruminal Digestion, %	42.03	66.67	83.41	42.99
Post Ruminal Digestion, %	94.42	98.42	98.42	95.00
Total Digestion, %	96.76	99.47	99.74	97.14

Table 3. Susceptibility of processed sorghum grain to amyloglucosidase (McNeill et al., 1975)

Item	Glucose release, mg/g dry matter
Dry Ground	118.6
Reconstituted	139.3
Steam Flaked	615.5
Micronized	232.7

Table 4. In situ loss of feed protein as affected by processing (Potter et al., 1971)

Item	Ruminal Breakdown, %
Dry Ground	51.28
Reconstituted	79.48
Steam Flaked	62.16
Micronized	36.11

These data provide one plausible explanation for performance benefits sometimes observed from reconstituting grain sorghum; however, the extent of germination in most studies is unclear. Disparity in procedures probably explains the variability in response associated with reconstitution.

SUMMARY

Addition of 15 to 18 percentage points of moisture to field-dried, unprocessed (whole) sorghum grain generally requires multiple additions of small increments of water on more than one occasion or other modifications to achieve uniform

moisture distribution before ensiling. [For corn grain, water uptake is much faster if water is *hot* rather than *cold*.] In contrast, water absorption by ground or rolled sorghum grain occurs within minutes. Germination requires an intact seed plus oxygen and warmth and is an important factor for improving feeding value in the reconstitution process. Germination could be initiated before ensiling and continue until oxygen within the storage structure is depleted if environmental conditions are favorable. Germination for 24 hours will initiate endogenous starch hydrolysis, but this process ceases under anaerobic conditions. Nevertheless, grain nitrogen becomes increasingly soluble as the length of either germination or ensiling increases; this increases

accessibility of starch granules to ruminal microbes. Growth performance data indicates that reconstitution of sorghum can improve feed

efficiency by 15% when compared dry-rolled sorghum, but confirmation of these data is needed using current sorghum grain varieties and production practices.

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QUESTIONS AND ANSWERS

Q: Mike, why was urea added when you reconstituted your grain?

A: We were hoping for some urea hydrolysis and ammoniation of the grain. Based on starch availability measurements, we did not get any benefit from the amylase enzyme. We did see a slight improvement in performance with the urea treatment, likely from slightly greater starch accessibility. In addition, we conducted this study in the wintertime to determine if under those ambient conditions we would see any benefit from the added enzyme.

Q: Mike, what are the logistical challenges for reconstituting grains at a commercial feedyard to increase the feeding value of dry grain?

A: Size will impact the logistics. Bob Lake pointed out the extensive nature of their effort involved with ensiling high-moisture corn. The key factors with reconstitution are hydrating the grain and then allowing sufficient time for enzymatic or bacterial activity. The logistics of reconstituting a large quantity of grain in a short time and storing it for a sufficient time under the favorable ambient conditions to get the optimum response would present a huge logistical challenge for a large feedlot.

FERMENTATION AIDS FOR HIGH MOISTURE CORN

William. M. Rutherford
Pioneer Hi-Bred International, Inc
Johnston, IA
william.rutherford@pioneer.com



INTRODUCTION

Harvesting and ensiling corn as a high moisture product offers an excellent alternative to dry grain for the feeding of domestic livestock. Preservation of high moisture corn (HMC) typically is accomplished through ensiling, defined as the preservation of a perishable feedstuff for use at a later time. The predominant factor in the ensiling process is the reduction of pH due to production of organic acids, predominantly lactic acid, from soluble sugars due to bacterial fermentation. Numerous silage additives have been developed to aid ensiling and to reduce storage losses. Although various types of fermentation aids may prove useful in different situations, this review will focus on the addition of bacterial inoculants that can favorably

affect the outcome of the microbial fermentation in high moisture corn.

THE ENSILING PROCESS

The ensiling process, although appearing quite simple, is a complex dynamic process encompassing a number of interrelated factors. In essence, various substrates (soluble sugars under ideal circumstances) are converted by bacteria to various products with loss of weight and energy. Specific fermentation (anaerobic) as well as oxidation (aerobic) reactions together with loss of mass and energy during conversion from substrates to products are shown in Table 1. The ensiling process can be divided into six different phases (Figure 1; McCullough, 1984).

Table 1. Weight and energy lost during fermentation (absence of oxygen) or oxidation (aerobic)

Fermentation type	Substrate	Product(s)	Weight loss, %	Energy loss, %
Homolactic	Glucose	2 Lactate	0.0	3.1
Acetic (Heterolactic)	Glucose	Lactate + acetate + CO ₂	16.7	20.4
Propanediol (Heterolactic)	Glucose	Acetate + 1, 2 propane diol + CO ₂	24.4	4.8
Butyric	Glucose	Butyrate + 2CO ₂	51.1	22.1
Ethanol	Glucose	Ethanol + 2CO ₂	48.9	2.6
Oxidation	Any organic compound	CO ₂ , H ₂ O	100.0	100.0

Phase 1 (Aerobic)

The first phase begins when the plant is harvested. During this phase, indigenous aerobic microorganisms convert water-soluble carbohydrates to carbon dioxide, water and heat. The production of carbon dioxide, water, and heat continues as long as respiration occurs in the harvested plant material and ceases when oxygen in the silage mass is depleted or the supply of water soluble carbohydrates is exhausted. Under optimal conditions, phase 1 is completed quickly, but it can last for several days depending on moisture, compaction, and the epiphytic microbial load. At surfaces unprotected from oxygen penetration,

oxidation can continue with sizeable losses of both weight and energy.

Phase 2 (Anaerobic)

Oxygen becomes depleted either due to use by microbes or plant tissue or due to displacement by dense carbon dioxide. With depletion of oxygen, the initial aerobic ensiling phase ends and anaerobic heterofermentation of phase 2 begins. The term "hetero" refers to the assortment of fermentation end products that are generated by bacteria that can tolerate the heat produced during phase 1. These bacteria are inefficient (Table 1) and produce relatively small amounts of typical fermentation products (acetate, lactate, propionate and ethanol)

plus heat when compared to the nutrients consumed. Uneconomical fermentation by these organisms can

result in a sizeable nutrient and energy loss from the silage mass.

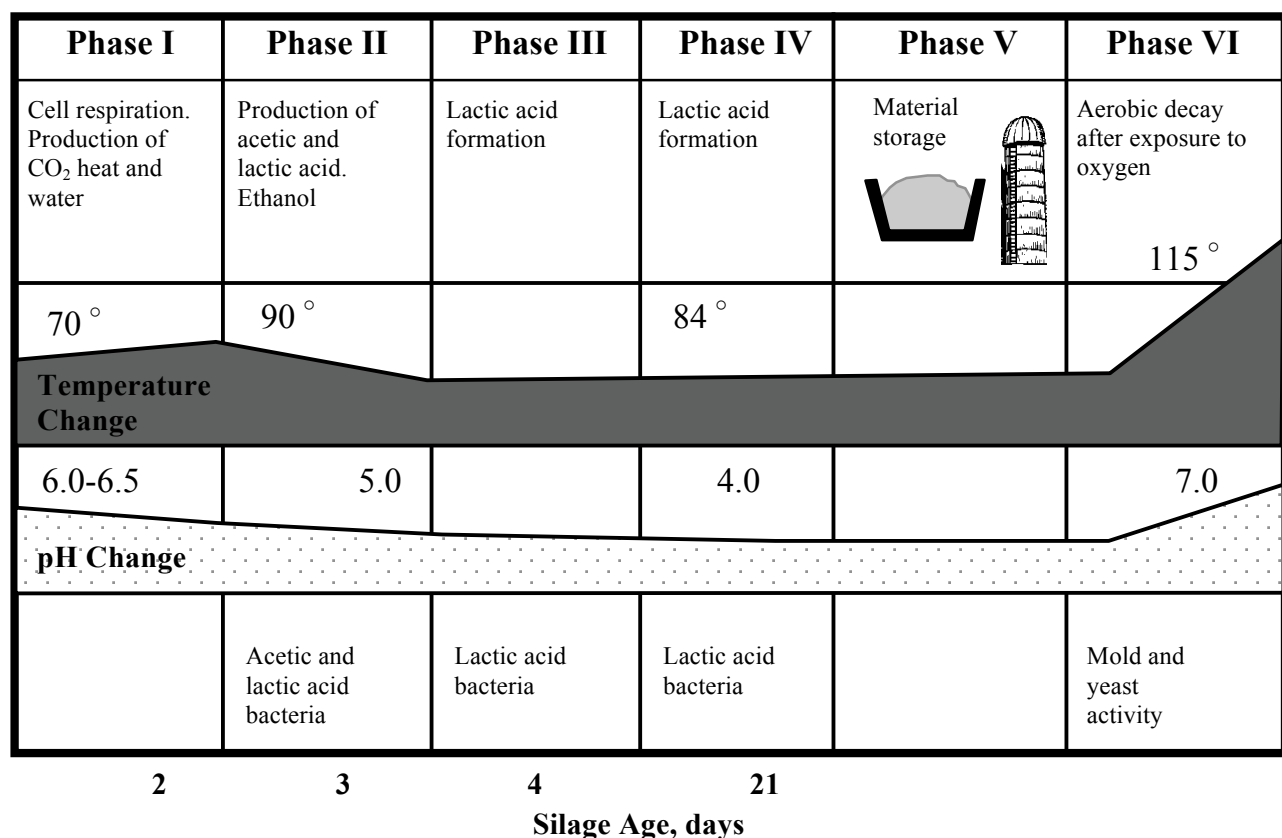


Figure 1. Six Phases of silage fermentation and storage.

The aerobic bacteria that are dominant during phase 2 are relatively active above pH 5, but their production of acid reduces the pH to near 5; this inhibits their activity. Depletion of oxygen coupled with the reduction in pH shifts metabolism to from homofermentative (“homo” referring to single product) bacteria which thrive at pH 5 and below.

Phase 3 (Anaerobic)

Phase 3 also is a short-lived transitional phase that usually last only about 24 hours. During phase 3 the populations of efficient homofermentative lactic acid-producing bacteria (Table 1) increase rapidly. These bacteria are considerably more efficient for conservation of energy, producing mainly lactic acid that drives the pH even lower. These organisms are less tolerant to heat than the anaerobic heterofermentors that dominant phase 2 but are more heat-tolerant than those dominating in

Phase 4. As the silage mass cools, these organism give way to another group of homofermentative lactic acid-producing bacteria that continue to produce lactic acid but remain active at a lower pH and temperature.

Phase 4 (Anaerobic)

Often considered a continuation of phase 3, phase 4 is the period when silage temperature stabilizes and the predominant lactic acid bacteria (*Lactobacillus plantarum*) continue to convert water-soluble carbohydrates to lactic acid. The conversion of the carbohydrates to lactic acid is highly desired. The strongest of the organic acids produced during fermentation, lactic acid is efficient for reducing pH. This reduced pH conserves silage nutrients and the lactic acid present that can be utilized as a source of energy by ruminants.

Phase 4 continues until the pH is sufficiently low to limit the growth of all organisms. The limited growth

and metabolism of the silage organisms results in little further change in pH and the silage mass remains in a preserved state. Silage pH serves as an indicator that the crop has been stably preserved, but it tells nothing about the rate and quality of the fermentation.

Phase 5 (Anaerobic)

Phase 5 is considered the stable phase; it lasts throughout the duration that the silage is stored. Although often considered stable, phase 5 still is dynamic; changes continue to occur in the silage mass depending upon environmental conditions, the epiphytic populations present on the forage at harvest, and the number and activity of the dominant populations of lactic acid producing bacteria. The amounts of fermentation substrates remaining and the variety of fermentation acids present dictates what changes occur during this phase.

Phase 6 (Aerobic)

Phase 6, the final phase, occurs when silage is removed from storage for feeding. It begins when silage is exposed to air. Initially, organic acids including lactic acid will be catabolized by yeast and other aerobic organisms producing carbon dioxide and water (Table 1); this causes pH to rise that permits spoilage organisms such as molds and bacillus to proliferate.

Aerobic activity of the microorganisms in the silage mass causes silage to heat and reduces the palatability of silage and availability of nutrients. The degree of spoilage in the silage mass depends upon the number and activity of the spoilage organisms present and the amount of residual carbohydrates remaining. Spoilage can account for a loss of 1.5-4.5% of DM per day in affected areas of corn silage (Oude-Elferink, 2002).

IMPROVING HMC WITH BACTERIAL INOCULANTS

Bacterial inoculants can have a profound effect on fermentation of HMC. Microbial inoculants insure that a sufficient number of organisms with the proper activities are present to direct the fermentation and provide an environment suitable for long-term storage. The use of bacterial

inoculants can alter the fermentation process in several ways to improve the feed value of the stored crop.

Generally, bacterial inoculants will compress phases 1-4. These phases can last as long as 3 weeks in uninoculated silage, but an appropriate inoculant can reduce this time to less than one week. Because terminal pH is reached sooner, the undesirable fermentation steps are avoided and preservation of the silage is enhanced. The more rapid reduction in pH provided by an inoculant will reduce respiration from harvested grain and limit the extent of inefficient fermentation of phases 1 and 2. Swift progression through the early phases causes more rapid transition to efficient lactic acid fermentation to preserve more nutrients and dry matter.

The most obvious response to the compression of the initial phases of silage fermentation is an increase in dry matter recovery (Bolsen et. al., 1989a, 1989b; Hoffman and Muck, 1999). In a survey of 35 trials, corn silage dry matter recovery was increased an average of 1.7% by inoculation (Bolsen et. al., 1989b). Similar improvements in dry matter recovery have been evident both with high moisture shelled corn and high moisture ear corn in controlled research settings (Pioneer, unpublished; Soderlund, 1997; Wardynski et. al., 1993).

In addition to having effects at the onset of fermentation, inoculation can alter the later phases of fermentation. Phase 5, the storage phase, often is regarded as a maintenance phase when nutrients are preserved indefinitely with little, if any, microbial activity. However, advances in silage microbiology have shown that silage at phase 5 still is dynamic with shifting populations and changing metabolic activities. Nutrient utilization by livestock fed inoculated silage appears to be a result of alterations during phase 5 of the fermentation. Using an automated *in vitro* system adapted from Schofield and Pell (1995), we observed that inoculant-treated ground HMC ensiled at 29% moisture had a slightly slower rate of gas formation but a considerably higher extent of fermentation than untreated HMC similar in moisture content (Figure 2). Fellner et. al. (1993) also have shown detected differences in ADF digestibility between inoculated and uninoculated high moisture ear corn.

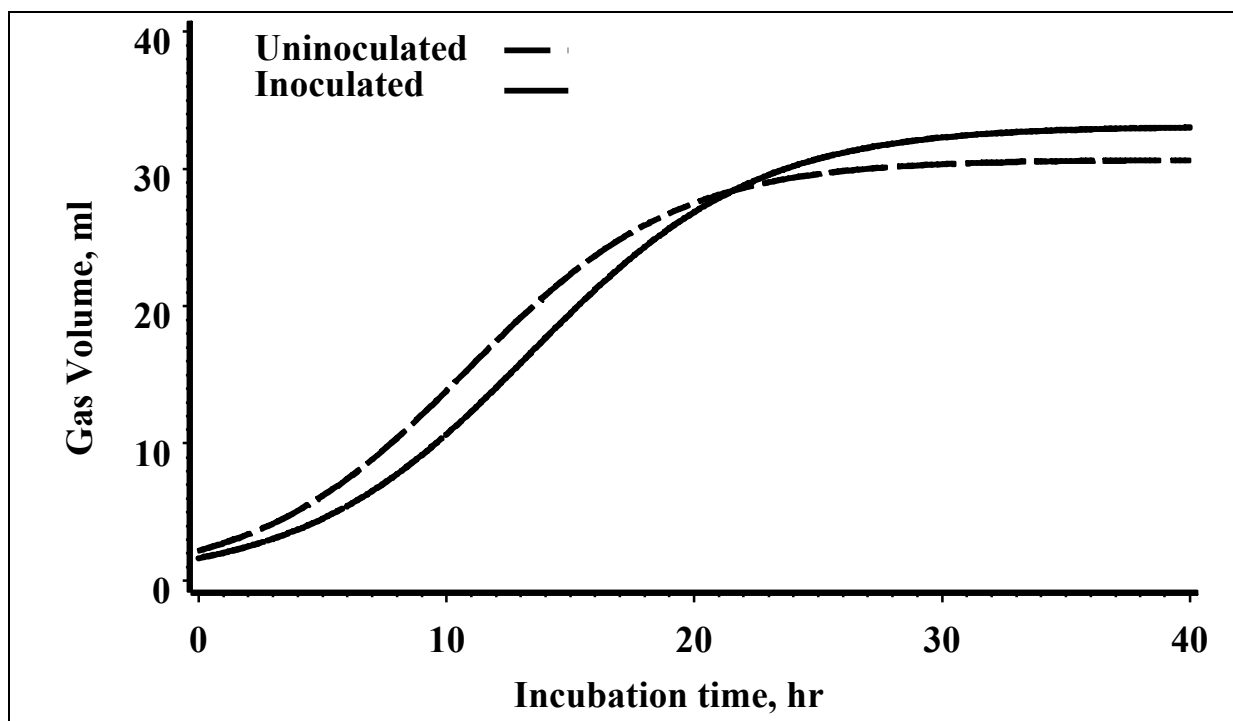


Figure 2. Effect of inoculation on high moisture shelled *corn in vitro* digestion. Samples of high moisture shelled corn were ensiled at 29% moisture in 4" x 14" PVC silos for 88 days. Gas production was evaluated via an automated *in vitro* system according to the methods of Schofield and Pell (1995). Microbial inoculant was applied at 1×10^4 colony forming units per gram forage ensiled. Uninoculated controls were treated with equal volume of water.

It has been observed that starch availability continues to increase in ensiled corn with longer ensiling periods. It is not known if this increased starch availability is a function of the chemical action of high acid content and low pH or if it is an active process facilitated by the ever changing metabolic activities of the microorganisms present. (Benton et. al., 2004; Pringle, 1976).

The most recent development in microbial inoculants addresses one of the most challenging areas of silage fermentation, deterioration of the silage mass when exposed to air. In the past, aerobic deterioration upon exposure of silages to air was prevented by adding specific chemicals, typically short chain organic acids such as acetic and propionic acid (Phillip and Felner, 1992; MacDonald et. al., 1991; Weinberg and Muck, 1996; Kung et. al. 2004). In the past 10 years, attention has been focused on the use of the heterolactic bacteria, *Lactobacillus buchneri*, for the prevention of aerobic deterioration in silage. Inhibition of aerobic spoilage

by this organism appears to be due to this organism's ability to convert lactic acid to acetic acid and 1,2 propanediol. These in turn significantly reduce the yeast population of silage (Driehuis et. al., 1997, 1999; Oude Elferink et. al., 2001). The inhibition of yeast growth during exposure to air can extend phase 6 from as little as 24 hours to as long as 5 days before silage begins to heat. Reduced heating and lower yeast and mold counts result in cooler silage with less aerobic losses than either untreated or silage inoculated with traditional homofermentative silage inoculants.

Improvements in high moisture corn aerobic stability have been reported following the use of *L. buchneri* inoculants. Taylor and Kung (2002) observed a marked increase in the aerobic stability and reduced population of yeast that was proportional to an increased acetic acid content. Data from our laboratory with HMC using *L. buchneri* combined with selected strains of *L. plantarum* indicate that total dry matter loss is decreased (Figure 3) and that populations of yeasts and molds were reduced by nearly 100-fold (Figure 4)

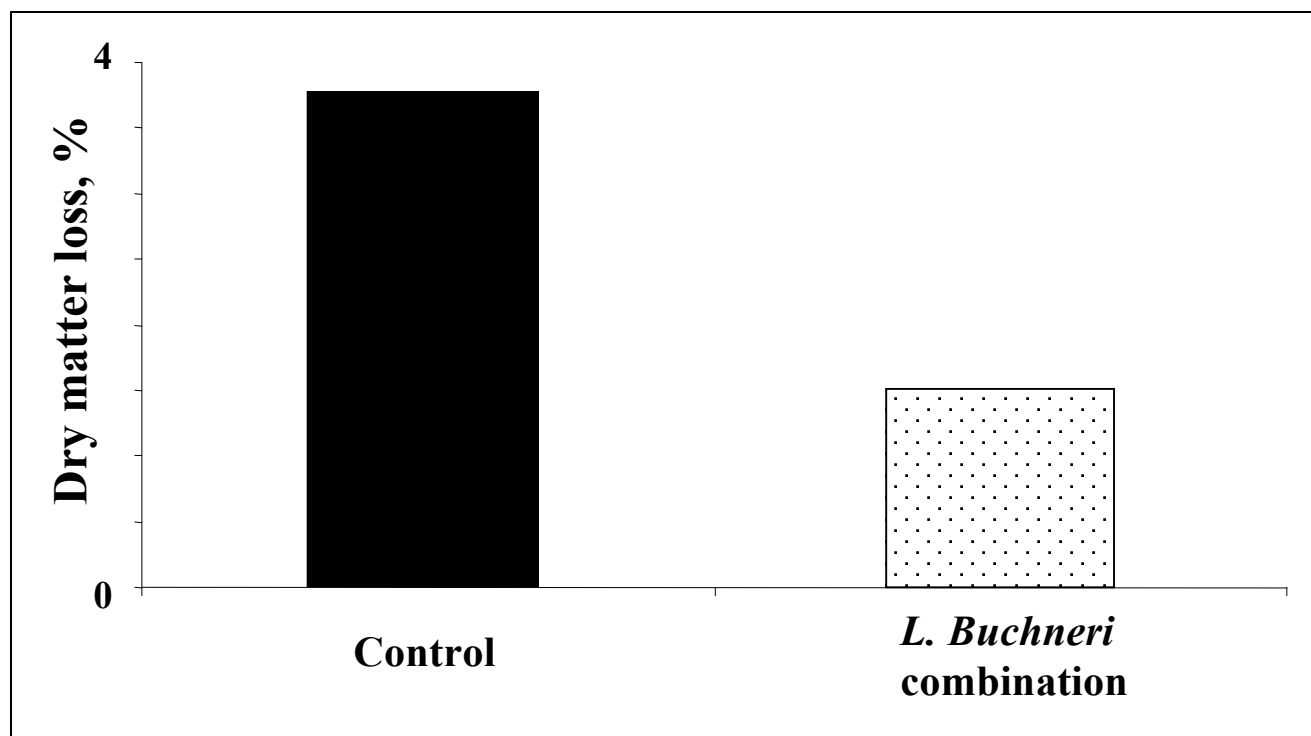


Figure 3. Reduced total dry matter loss in high moisture shelled corn with *Lactobacillus buchneri* combination inoculants. Comparisons were made between inoculated and uninoculated high moisture corn ensiled at 30% moisture for 60 days. Total dry matter loss is the sum of the losses occurring throughout ensiling plus the aerobic loss upon exposure to air as determined by the methods of Honig (1985). *L. buchneri* combination (mixture of *L. buchneri* and *L. plantarum*) was applied at a rate of 1×10^4 colony forming units per gram forage ensiled and compared to an uninoculated control treated with an equal volume of water.

Concerns have been raised about the use of heterolactic rather than homolactic inoculants because their less efficient metabolism could lead to excessive dry matter losses. In addition, high concentrations of acetic acid in the silages might depress animal intake. Current research has not supported these concerns. The increases in dry matter loss have been small and no negative effects on animal intake or performance have been observed among cattle fed high moisture corn treated with *L. buchneri* (Kendall, et. al., 2002; Combs and Hoffman, 2003). Indeed, except for lactic acid, ruminal concentrations and yields of organic acids far exceed concentrations in fermented silages. For example, dilution of 10 kg of DM from corn silage in 50 L of ruminal contents would add 0.25 mM lactate, 0.1 mM acetate, and 0.03 mM propionate. Typical ruminal concentrations of these acids are about 5 mM lactate, 60 mM acetate, and 30 mM propionate.

Alterations in fermentation by microbial inoculants results in improvement in other important attributes of the silage. The target for inoculants is to enhance the productivity of livestock fed silages. Kung and Muck (1996) have reported that positive responses to microbial inoculants on gain and milk production in studies comparing treated and untreated silages were detected in approximately 50% of the trials reviewed and seldom if ever were negative effects detected. These responses were observed across all silage crops, dry matters and inoculation levels.

Positive animal production responses also have been noted for high moisture corn treated with microbial inoculants. Fellner and co-worker (2001) found that weight gain was greater for steers fed inoculated high moisture ear corn than for steers fed an untreated control. A summary of 10 feeding trial with high moisture shelled and ear corn inoculated with microbial inoculants have show an average

improvement in daily gain of more than 8% and a feed efficiency improvement of more than 6% (Pioneer, unpublished). These performance

responses are above and beyond the increase in dry matter recovery usually seen with bacterial inoculants.

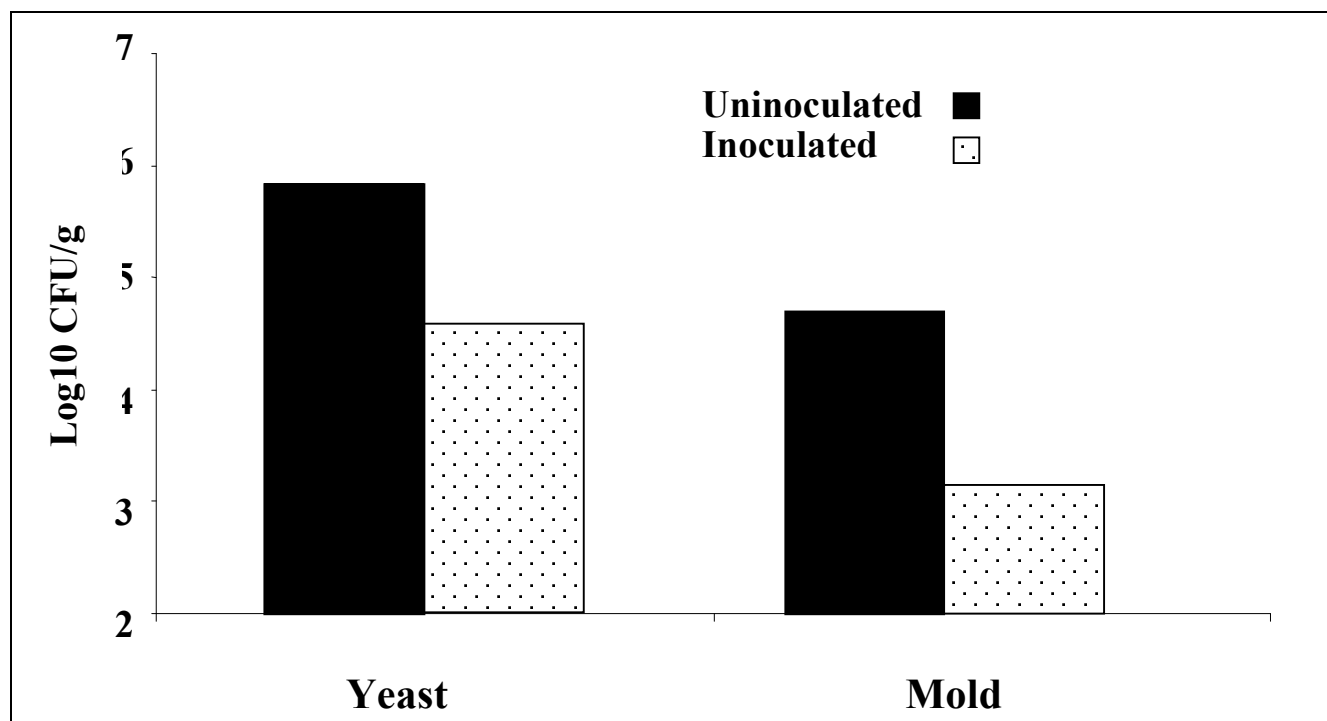


Figure 4. Reduction of yeast and mold level in high moisture shelled corn by treatment with Lactobacillus combination product.). *L. buchneri* combination (mixture of *L. buchneri* and *L. plantarum*) was applied at a rate of 1×10^4 colony forming units (CFU) per gram forage ensiled and compared to an uninoculated control treated with an equal volume of water. Yeast and mold levels were determined according to Taylor and Kung (2002).

SUMMARY

Microbial inoculants can consistently improve high moisture corn preservation and feeding value. Traditional homofermentative inoculants improve dry matter recovery primarily by accelerating the early fermentation process and can improve the availability of nutrients from the ensiled feedstuff. The newer *L. buchneri* inoculants have proven to effectively reduce the aerobic deterioration and heating that occurs upon exposure of silage to air during feeding. Combined, changes in the fermentation process achieved with active and effective inoculants can increase efficiency of

energy conservation and the efficiency of livestock production.

Microbial fermentation aids are no substitute for proper silage management. The key to success in the use of microbial inoculants is attention to proper management. These would include harvesting and ensiling at the proper moisture, adequate packing of the silage mass to exclude as much air as possible, and use of a suitable cover to protect the ensiled grain from air and the environment. Strict attention to proper silage management techniques can maximize the beneficial effects of microbial additives.

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ANALYTICAL VARIATION OF PROTEIN, STARCH, FIBER AND FERMENTATION PROFILES

Dave Taysom
Dairyland Laboratories
Arcadia, WI
dtaysom@dairylandlabs.com



Variation in nutrient content of feeds and forages is a natural and unavoidable phenomenon. It exists for two reasons: 1) feeds and forages inherently vary in their chemical and biological make up due to genetic and environmental effects, and 2) laboratories use different analytical procedures. If no variation existed among feeds, analytical labs would not be needed and book values for nutrient content would suffice to predict animal performance. However, analytical variation adds noise to the data and must be minimized.

Because variation can never be eliminated, unnecessary variation must be controlled. Statisticians employ the term “error” to explain variation, however that word has the connotation that a mistake was made or someone did not perform their tasks correctly. Numerous studies have documented that the analytical variation of feeds and forages generally is quite small when compared to variation involved with sampling, feed preparation and mixing.

Before discussing laboratory analytical variation, three terms should be defined. *Accuracy* – is a measure of the ability of a procedure to measure, or predict the “true” or agreed upon values. For feeds and forages, accuracy implies how closely the analytical value of the sample submitted, compares to the true value of the feed. *Precision* – or *repeatability* – is a measure of the ability of a procedure to repeatedly provide the same result for a particular sample. *Bias* – is a systematic distortion from the known or consensus value.

Both precision and accuracy are important for nutritional analyses. Accuracy insures that the analytical measurements are useful for establishing the value of a feed and thereby in formulating diets. Precision is needed to gain confidence in the

sampling, the analytical method used, and the laboratory performing the analysis.

Horwitz (1982) analyzed the results of AOAC collaborative studies and observed that the among-laboratory relative variation (standard deviation divided by the mean) was proportional to the mean concentration of the analyte over a wide range of methods. This likely occurs because methods and equipment are more sensitive when the concentration or the analyte is small. Horwitz further concluded the with-in laboratory variation is only about half of among-laboratory variation for most methods. (Mertens 2006).

Mertens in 2002 conducted a study using 5 forage materials sent to 11 laboratories. For aNDF the mean concentration was 52.2 with SD repeatability of .84 and SD Reproducibility 1.10. (Table 1). The 95% confidence interval of with-in laboratory replicates was 2.36 and the 95% confidence interval of among-laboratory analyses was 3.08. Using the Horwitz equation (1982) to calculate analytical coefficients of variation and standard deviations, Mertens compiled coefficients of variation (HCV)-based on the percent concentration typically found in feed and forage analysis. (Table 2).

Note that certain procedures (DM, ash, protein) can be measured quite accurately whereas assays for fiber fractions and digestibilities are considerably more variable. Because the repeatability for different analyses differs, altering diet formulation for certain nutrients based on a single analysis of a feed will prove reliable. But for nutrients where analyses are more variable, reformulation of diets should be based on a running average of a feedstuff over time, not the assay at a single time point.

Table 1. Expected analytical reproducibility of aNDF using Horwitz's (1982) equation to calculate analytical coefficients of variation (HCV) and standard deviations (HSD) (Mertens, 1982)

% Con.	HCV (%)	HSD	Anylate/Source*	OBS.SD	NFTA
5	3.14	0.16	Ash, Lignin	ADL = 0.62	0.46
10	2.83	0.28	Ash, Lignin	Klas.Lig. = 0.80	0.54
15	2.66	0.40	CP forages		0.62
20	2.55	0.51	CP forages		0.70
30	2.40	0.72	ADF forages		0.86
40	2.30	0.92	ADF for. NDF leg.	ADF for. = 1.13	1.02
50	2.21	1.11	NDF legumes	aNDF for. = 1.10	1.18
60	2.16	1.30	NDF grasses	TDF bp = 1.59	1.34
70	2.11	1.48	NDF grasses		1.49
80	2.07	1.65	NDF straws		1.65

*CP, crude protein; ADF, acid detergent fiber; NDF, neutral detergent fiber.

Table 2. Expected analytical variation (Mertens, 2006)*

Constituent	SD (R)	Avg. Conc.	95% CI	Min ^a	Max ^a
Ash, DM (Moisture)	0.5	10	1.40	9.3	10.7
Crude protein	0.5	20	1.40	19.3	20.7
Lignin	0.7	7	1.96	6.0	8.0
ADF, NDF	1.0	40	2.80	38.6	41.4
NDF	1.3	60	3.64	58.2	61.8
NDF	1.8	80	4.48	77.8	82.2
IVdNDF (%DM)	1.3 ^b	20	3.64	18.2	21.8
IVNDFD (%NDF)	2.6 ^b	40	7.28	36.4	43.6
IVdNDF (%DM)	2.6	20	7.28	16.4	23.6
IVNDFD (%NDF)	5.2	40	14.56	32.7	47.3

*DM, dry matter; ADF, acid detergent fiber; NDF, neutral detergent fiber; IVdNDF, *in vitro* digestible NDF; IVNDFD, *in vitro* NDF digestibility.

^a19 out of 20 analytical results should fall between the minimum and maximum confidence limits.

^bStandard deviation of reproducibility in one laboratory over 7 months – SD of reproducibility would be expected to be 2 to 3 times this value.

One major source of variation among laboratories is moisture content. Measuring moisture sounds simple in theory, but in reality there are sizeable differences in methods used by different labs. Most methods estimate moisture by measuring the loss of weight from oven drying. During oven drying, volatile substances in addition to water are lost and reactions will occur during heating. Windham et al. (1988) and Thiex and Van Erem (1999) have indicated that methods for measuring moisture have not improved for over two decades. For all the documented problems with oven-drying methods, they remain the primary method of choice because they are relatively fast and inexpensive to perform. Thiex and Richardson (2003) recommended that results obtained using oven methods not be termed "Moisture" but rather be called "Loss on Drying."

When comparing analysis among laboratories it may be better to use as-is or as-received values, rather than dry basis: to remove lab differences in dry matter measurement. Although values on a dry basis contain the variation of both moisture content and nutrient analysis, diets for ruminants generally are formulated on a dry matter basis to avoid wide swings in composition associated with changing moisture content of moist feeds.

Other sources of analytical variation:

- 1) Sampling of the material to be analyzed (Probably the major source of within lab variation).
- 2) Sample preparation – drying, grinding, sub-sampling.
- 3) Methods of analysis.
- 4) Expertise and experience of analytical technicians.
- 5) Equipment, calibrations, reagents and environment.

- 6) Calculating and reporting of test results.
- 7) Interpretation of test results.

For feeds and forages, sampling in the field and in the lab probably is the weakest link in the analytical process. Shenk (1991) measured the standard error associated with sample collection of hay samples (Table 3).

Table 3. Standard error associated with sample collection (Shenk 1991)

Quality Factor	Standard Error
Crude protein	1.57
Acid detergent fiber	2.43
Neutral detergent fiber	4.20

While it may be the largest source of variation, sampling is no excuse for poor laboratory

performance. There are several organizations that provide check samples that provide laboratories with the tools to evaluate the accuracy and precision of the analysis they report. These organizations also evaluate laboratories regarding their accuracy and precision relative to other analytical labs. Laboratories should be willing to share this information with clients.

CONCLUSIONS

Analytical variation of feeds and forages can be minimized but never eliminated. The primary reason for requesting laboratory analysis is to determine the degree to which a sample differs from a typical sample of a feed and to employ this knowledge to properly formulate or supplement diets. Analytical variation is highly correlated with the average concentration of the analysis.

Acknowledgement: The information supplied by David Mertens is greatly appreciated.

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PROCESSING ADJUSTMENT FACTORS AND INTAKE DISCOUNTS

Noah B. Litherland
Oklahoma State University
Stillwater, OK
noah.litherland@okstate.edu



ABSTRACT

Processing adjustment factors (PAF) and intake discounts are two adjustments made in the NRC (2001) for dairy cattle to more accurately assess energy availability of feeds for dairy cattle. When a processing method improves feed digestibility, a constant PAF that exceeds 1.0 is assigned to that feed that in turn increases the energy value of the feed based its non-fiber carbohydrate (NFC) content. Thus, the PAF allows nutritionists to adjust energy value for a feed based on the feed processing method. Intake discounts are an attempt to account for reduced digestibility of nutrients at high levels of feed intake. As cows consume a larger amount of feed, the efficiency with which nutrients are absorbed decreases; this reduces the total digestible nutrients of the feed proportional to intake (typically as a multiple of maintenance energy intake). Although increased feed intake increases productive efficiency due to increased dilution of maintenance energy needs, higher feed intakes decrease digestive efficiency. The extent to which digestibility of the diet decreases depends on complex relationships among rate of passage, rate of digestion and associative effects among feeds. Without this reduction in digestive efficiency, the energy values of feeds for high producing cows would be overestimated. Elevated feed intake also reduces methane loss, which may partly compensate for the reduction in digestibility. New information from UC Davis, Robinson (2007), suggests that the digestibility depression associated with high intake levels, if it exists, excessively reduces net energy estimates of diets. Indicating NRC, (2001) may excessively discount energy intake in diets for high producing cows.

INTRODUCTION

Processing Adjustment Factors

Processing of grains can improve nutritive value by improving or altering the rate or site of digestion. Grinding and rolling of grains are used commonly to improve the nutritive value of grains. Despite this, quantifying the effects of processing on feeding value remains a challenge. Physical processing usually does not alter the nutrient composition of grains, but processing often increases the digestibility of starch and can alter the site of starch digestion that in turn can alter the efficiency of carbohydrate utilization. The processing adjustment factor (PAF) first introduced by the NRC publication for dairy cattle (NRC, 2001) is a factor that is multiplied by the non-fiber carbohydrate (NFC) of the feed to account for the effects of feed processing on energy availability. If processing a feed improves digestibility, a value higher than 1.0 is assigned to the feed that will increase the energy value of the feed and thereby of the diet. Processing adjustment factors are applied only to the NFC portion of the diet even though research studies indicate that digestibility of protein, fat, and fiber also are increased by certain processing methods. The PAF offers an empirical approach to account for the effect

of processing of grains on starch digestion by enhancing the TDN value from which NE_L values can be calculated. While the dairy cattle NRC (2001) refers to only NFC portions of nutrients, adjustments also could be made for the processing of forages and the final diet fed to dairy cattle. Processing adjustment factors for ingredients included in a TMR would be especially beneficial as particle size of the final diet dictates the cow response.

Intake Adjustment Factors

Accurately estimating digestible energy intake requires one to discount energy availability when cows eat large amounts of feed to support high rates of milk production. As cows eat more feed to support higher milk production, the proportion of digested energy that is captured in milk actually increases. But as cows consume more feed, digestive efficiency decreases (Tyrrell and Moe, 1975) due to changes in the dynamics of digestion in the rumen (Van Soest, 1994). Unfortunately, the magnitude of depression in digestibility has not been clearly characterized with high producing cows (Vandehaar, 1998). But because the conversion of gross energy to digestible energy is not constant, energy supply needs to be adjusted for level of intake. Tabular energy values of feeds are inaccurate without some adjustment for intake. The

extent to which digestibility is depressed vary with rate of passage, rate of digestion, and associative effects among feeds.

Correcting for effects of feed processing on starch digestibility as well as the effect of intake level on digestibility of energy should improve the accuracy of predicting the quantity of energy available to the dairy cow.

DISCUSSION

Processing Adjustment Factors

Processing adjustment factors provide an empirical approach to account for effects of processing on starch digestion. The PAF values were derived from in vivo digestibility data for which digestibility of NFC from unprocessed feed at a feed intake equal to three times maintenance was assumed to be 90%. The PAF value for a processed feed can be calculated by dividing in vivo NFC digestibility by 0.90. Figure 1 compares values for starch digestibility from literature summaries for corn grain processed by various methods fed to lactating cows at production levels of feed intake against PAF estimates from NRC (2001).

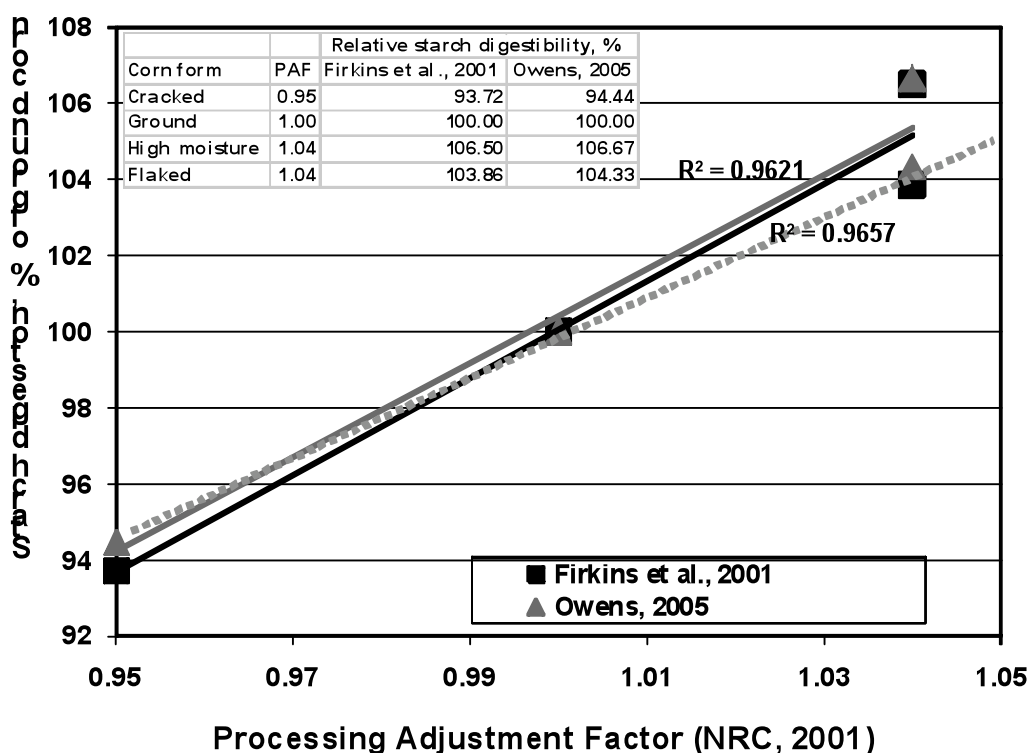


Figure 1. Relationship of starch digestibility from literature summaries to processing adjustment factors for corn grain processed by various methods. The dotted line would represent a perfect numeric fit between measurements.

Although PAF values are applied to all NFC, not simply starch, and starch comprises about 92% of NFC of processed and unprocessed corn grain [as calculated from DairyOne (2007) assays], PAF values would appear to underestimate the effects of processing corn grain, particularly for high moisture corn grain. The NRC (2001) cautions that PAF adjustment can overestimate the NE_L in some feeds being fed at maintenance because at a low intake

level, true digestibility of NFC for some processed feeds will approach 0.98. The PAF, however, is presumed by NRC (2001) to be correct for cows fed at three times maintenance energy intake. In addition, digestibility of starch can vary widely within a processing method (e.g., flakes differing in density; high moisture corn differing in test weight); ideally, these should be differentiated. Processing not only alters the digestibility of grains, but of forage as well.

Forage processing can alter the site, rate, and extent of digestion of forage. Most forages listed in NRC (2001) have a PAF of 1.0 but response of forage to processing may vary with forage maturity. Certainly, variables such as length of chop and kernel processing will alter the digestibility of corn silage; these should be considered when diets are formulated. Some researchers have questioned whether PAF values reflect the effects of processing on digestibility and fermentation in the rumen or the total digestive tract. Based on their derivation, PAF values were not designed to account for differences in site of digestion; they were developed as an index of effects of processing on total tract digestibility of NFC. Despite a general correlation between ruminal and total tract digestibility, variation is much greater for ruminal digestion of starch (50 to 90%) than in total tract digestion of starch (typically 85 to 95%). The variation in PAF among feeds should be equal to the variation in total tract digestion. A limited amount of more recent data has been published that tend to support the concept that the PAF values properly predict changes in NFC digestibility of

grains. In contrast, no new NE_L estimates have been published in the last ten years. Hence, the precision of NE_L estimates with versus without adjustment for PAF remains uncertain.

For high producing dairy cows, over half of the truly digested energy is derived from dietary starch. Cereal grains contain from 45 to 80 percent starch. Response to processing will vary with the source of starch (the grain), level of feed intake, forage type, and level of NFC in the diet. The NFC is digested faster from wheat, barley and oats than from corn and sorghum.

Evaluating Particle Size

Particle size of grain is measured by sieving grain through a series of sieves with sequentially smaller mesh size with a pan underneath for collecting fines. Grain screens are a useful on farm diagnostic tool to evaluate the extent of processing of grain. Fractions retained on screens, their relative size, and physical characteristics are shown in Table 1.

Table 1. On farm Particle Size guidelines using a simple, four-screen stacking sieve and pan

Screen	Size	Description
#4 screen	>4500 microns	whole or coarse corn
#8 screen	>2200 microns	cracked corn
#16 screen	>1100 microns	ground corn
#30 screen	>500 microns	finely ground corn
Pan	<500 microns	feed grade starch

Particle size typically is expressed as the geometric mean diameter (GMD) of particles based on the proportions of the total mass that is retained on individual screens. A spreadsheet program for calculating the geometric mean diameter (GMD) from weights of grain retained on individual sieves is available at (<http://tarwi.lamolina.edu.pe/~cgomez/mf2051.pdf>) from Baker and Herrman at Kansas State and information regarding particle size at (http://www.afs.ttu.edu/home/mgalyean/lab_man.pdf) from M. L. Galyean at Texas Tech University.

Another index of grain processing, the processing index (PI), is used in Canada for measuring the degree of processing in steam processed barley. This method attempts to describe the extent to which starch is available for degradation by ruminal microbes. The PI is

calculated as the weight of a given volume of barley after rolling expressed as a percent of the weight of the barley before processing. A coarsely rolled grain has a higher PI than finely rolled grain. Though applicable for flaked grain, the PI, however, may not be applicable for ground grain or dry rolled grain because spaces between the larger ground grain particles often are filled with fines so that bulk density alone is not reliable as an index of particle size.

To justify the expense of grain processing, one must understand the impact of processing on grains and evaluate its usefulness. One objective in feeding dairy cattle is to optimize the site as well as the extent of starch digestion. Ruminal fermentation of carbohydrate drives microbial protein synthesis, but fermentation of starch to VFA in the rumen decreases the supply of starch to the small intestine. Intestinally digested starch is more efficiently used and can supply glucose for

lactose synthesis. Extent of ruminal starch digestion with different grain processing methods ranges from less than 49% to over 90% of starch intake. The extent of ruminal starch digestion depends on the processing of grains (fine processing > coarse processing), type of cereal grain (sorghum < corn < barley), intake/rate of passage, and the dilution rate of rumen fluid. To be useful, starch escaping the rumen and the starch in bacteria and protozoa that pass from the rumen to the small intestine must be digested in the small intestine. The topic of postruminal starch digestion has stimulated great interest and controversy among ruminant nutritionists. In theory, postruminal starch digestion is more efficient than ruminal fermentation with subsequent gluconeogenesis from propionate, primarily due to reduced loss of as fermentation gas (methane), and heat associated with ruminal fermentation. Quantitative limits in the capacity for intestinal starch digestion have been proposed to be 300 g/d in mature sheep (Ørskov, 1986), 480 to 960 g/d for steers (Kreikemeier, 1995), and 1300 g/day for dairy cattle (Pehrson and Knutsson, 1980). In contrast to these proposed limits, Callison et al., 2001 measured small intestinal NSC disappearance in lactating cows and had values with some diets that exceeded 2800 g/day. Undigested starch that flows to and is fermented in the large intestine will increase microbial growth in the large intestine and increased fecal nitrogen loss. Proposed reasons for the low recovery of glucose from intestinal starch digestion in ruminants may include, but are not limited to a) insufficient pancreatic amylase activity, b) limited small intestinal capacity for absorption of glucose, c) fermentation in the small intestine by acid-tolerant bacteria capable of starch fermentation, and d) increased glucose use by visceral tissues.

Knowlton et al. (1998) infused 1500 g/d of hydrolyzed starch into either the rumen or abomasum of dairy cows producing greater than 40 kg of milk daily. Results can shed some light on value of post-ruminal starch digestion; milk yield increased with either infusion. Ruminal infusion did not increase glucose irreversible loss rate, but it decreased glucose oxidation. Abomasal starch infusion increased the glucose irreversible loss and glucose oxidation. Additionally, mammary use of glucose accounted for approximately 30% of the increased irreversible loss rate. Data from this study imply that an increased intestinal supply increased

the amount of glucose absorbed or decreased gluconeogenesis. However, the benefits of postruminal starch digestion and an increase in the supply of glucose still is not fully resolved. Presumably, some unidentified optimal balance between ruminal and intestinal starch digestion exists. However, that optimum may vary with dietary protein (and the need for microbial protein), potential for acidosis or reduced ruminal fiber digestion associated with pH depression, time for ruminal starch digestion (that is altered by passage rate), and postruminal digestibility of starch (that varies with processing method).

Intake Discounts for Dairy Cattle

The objective of discounting the amount of available energy from a diet for high feed intakes is an attempt to account for the increase in fecal loss of energy when dry matter intake is very high. As cows eat more feed to support high rates of milk production, the proportion of digested energy captured in milk increases due to greater dilution of maintenance. In contrast, when cows consume more feed, diet digestibility decreases. The magnitude of depression in digestibility has not yet been characterized for cows at very high production levels (Vandehaar, 1998). In previous editions of the NRC for dairy cattle (1978 and 1989) the digestible energy content of a diet was discounted by 4% at each multiple increase above maintenance. In the NRC (2001) revision, energy discounts vary based on the energy level in the ration; energy discounts are greater for rations that are higher in TDN. The relationship between digestibility at maintenance and the percentage unit decline in digestibility per multiple of maintenance based on various NRC revisions are shown in Figure 2.

The decline in digestibility with feeding level typically is expressed in proportion to maintenance energy intake. The percent discount in TDN according to the NRC (2001) is projected to be $\%Discount = [(TDN1X - [(0.18 \times TDN1X) - 10.3]) \times Intake] / TDN1X$. In this equation, TDN is the percent of dry matter for the entire diet (not for individual feeds) when TDN is measured at a maintenance level of feed intake; low intakes often are used to measure digestibility. Intake is expressed as the incremental intake above maintenance (i.e., for a cow consuming 3 times maintenance, intake above maintenance is equal to 2). For example, a cow consuming a diet containing 74% TDN, with this TDN measured at maintenance, if consuming feed at three times maintenance would have

a discount factor of 0.92 $[(74 - [(0.18 \times 74) - 10.3]) \times 2]/74$. Therefore, TDN of this diet for this cow would be expected to be 68% (0.92 times 74%). However, as feed intake increases, loss of energy as methane will decrease by an estimated 1.6% of gross energy for each multiple of maintenance level of feed intake (Johnson and Johnson, 1995). This reduction in methane loss, partly associated with site of digestion and partly with a higher propionate to acetate ratio, should counteract about half of the reduction in energy availability associated with the reduced digestibility attributed to an increased feed intake level. Further, whether the digestibility depression with high intakes is evident with all types

of diets also is not clear. If the digestibility depression associated with elevated feed intake is due to reduced ruminal retention time, then the extent of depression in digestibility should vary with feed source and processing, being greater with ground than long fiber, with NDF than NSC, and with coarser than processed grains. In addition, ruminal NDF digestion should be depressed more with elevations in intake of low than of high concentrate diets because the feed intake level will have greater potential to depress ruminal intestinal pH with low concentrate diets. Grain processing also may have an impact, because starch flowing to the large intestine can depress pH therein and reduce compensatory NDF digestion at that site.

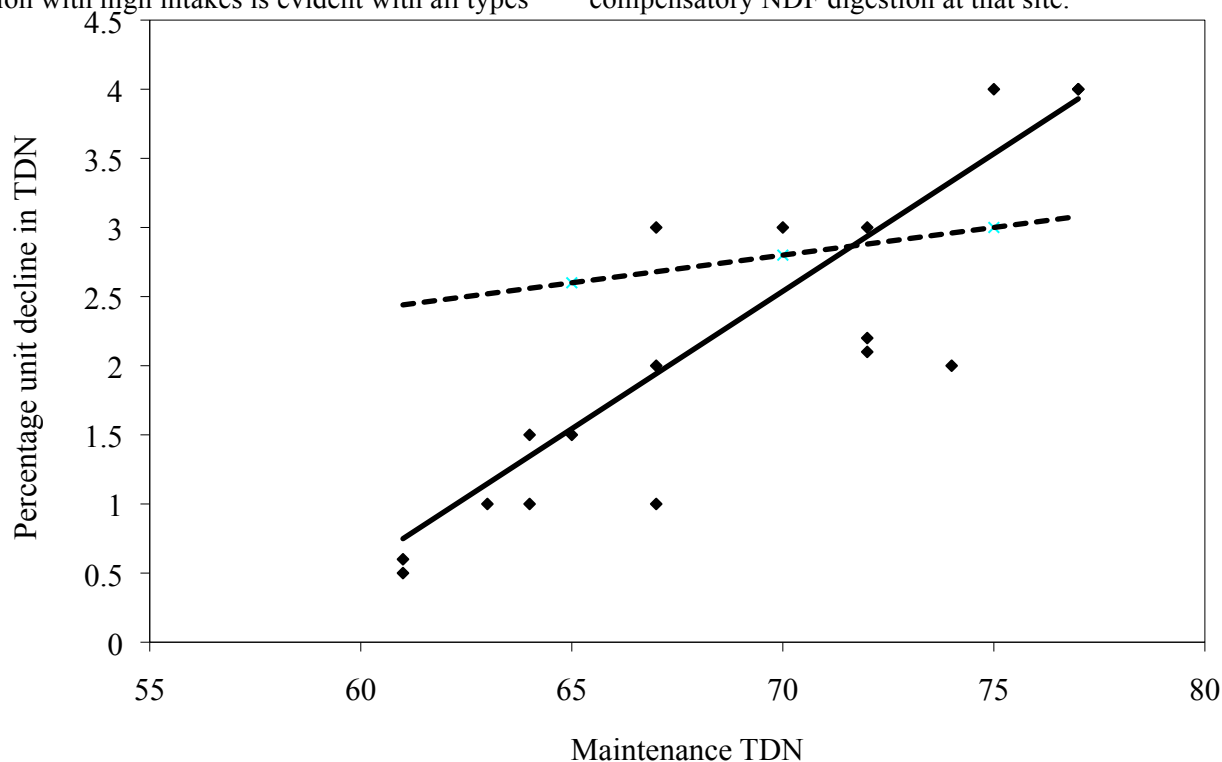


Figure 2. The relationship between total digestible nutrients (TDN) depression and intake expressed as multiple of the maintenance energy requirement. The unit decline in diet TDN (NRC, 2001) is shown in the solid line (TDN depression = $0.18 \times \text{TDN} - 10.3$, $r^2 = 0.85$) whereas the dotted line shows the depression as a constant 4% of TDN (NRC, 1978; 1989).

When diets contain less than 60% TDN at 1X, the discount appears negligible, so for diets with less than 60%TDN at 1X, the discount is set to 1 (no discount). The NRC, 2001 committee set this minimum so that feeds with less than 60% TDN would not be increased in TDN value when their discount equation is applied. Multiple of maintenance feed intake may exceed 4X for cows producing 35 to 45 kg of fat corrected milk. In

addition to this energy discount, associative effects of feeds may decrease digestibility. However, most studies conducted with lactating cows fed mixed diets of constant composition at several feeding levels have shown that digestibility decreased linearly as intake increased (Vermorel and Coulon, 1998). Discount models can be empirical, mechanistic, or the combination. The Cornell Net Carbohydrate and Protein System (CNCPS) relies on a variable discount model

that is based on passage rate and digestion kinetics of various feed fractions to discount the TDN content of the diet (Weiss, 1998).

Weiss and Wyatt (2004) measured digestible energy values of diets containing different fat supplements to determine the effect of fat supplementation on dietary digestible energy concentrations, to calculate digestible energy of two fat supplements, and to compare estimated (NRC, 2001) digestible energy with measured values. These researchers determined that measured digestible energy did not differ from digestible energy using NRC (2001). However, the NRC model did not accurately estimate TDN; predicted TDN values were 3.7 percentage units lower than directly measured values for the control diet. This indicates that the NRC (2001) model either underestimated TDN concentration at maintenance, or overestimated the discount factor.

Michigan State data, Oba and Allen, 2003, showed that lactating cows have a high capacity for starch digestion and increased intake may not reduce starch digestibility. This is likely due to the fact that starch ferments rapidly in the rumen and extensive starch digestion compensates for lower ruminal starch digestibility. A recent review of the literature by Robinson, 2007 revisited the area of energy discounts using data from 92 published studies. Robinson examined NE_L prediction equations from the NRC (1989), NRC (2001), and the UC Davis model and determined the models were

fundamentally incorrect in calculation NE_L concentrations of the diet based on NEL intake.

CONCLUSION

Adjustments for differences in energetic efficiency among nutrients, especially fat and fiber, play important roles in our understanding and modeling of energy efficiency and utilization. Physical characteristics of feeds can affect digestibility and passage of nutrients. The future of PAF values for grain in dairy cattle diets remains unclear. PAF values were devised for and incorporated into equations to calculate NE_L for dairy cattle by NRC (2001) because they were a simple and direct method by which the committee could adjust compositionally derived TDN values for the effects of grain processing. As newer data are generated and more advanced models are developed, PAF values may be refined or replaced by other measurements. Physical form of the diet for dairy cattle is important as new processing (for harvested forages; for flaking or steam rolling corn) and feed handling (TMR mixing equipment and times) become available. The nutritionist's challenge is to control fiber length, to maintain rumen pH and health, to optimize microbial growth, and to maintain dry matter intake to maximize milk production without causing metabolic problems. As DMI increases, cows become less efficient in capturing feed energy. Factors that attempt to adjust for differences in energy availability due to grain processing and feed intake level have been incorporated into current nutrient requirement models such as NRC (2001) but should become more refined, precise, and accurate with future research.

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RUMINAL AND POSTRUMINAL STARCH DIGESTION BY CATTLE

Fred Owens and Steve Soderlund
Pioneer Hi-Bred, a DuPont Business
Johnston, Iowa 50131

Fred.Owens@Pioneer.com; Steve.Soderlund@Pioneer.com



ABSTRACT

Grains are fed to livestock primarily to supply energy, and most of the digestible energy in cereal grains comes from starch. To maximize starch digestion by livestock, corn and sorghum grain must be processed. For non-ruminants, starch from finely ground grain is fully digested, but for ruminants fed high concentrate diets, finely ground grain often causes metabolic diseases. Hence, rather than finely grinding corn, processes including steam rolling, steam flaking and fermentation (high moisture storage) are used to increase extent of starch digestion from grains fed to ruminants. These processing methods usually increase starch digestion in the rumen, in the intestines (of starch reaching the small intestine), or at both locations. The lower the density (bushel weight) of flaked corn, the greater the digestibility of starch, particularly in the small intestine. For maximum ruminal starch digestion, a thinner flake is needed for lactating cows than for feedlot cattle because grain particles spend less time for digestion in the rumen of lactating cows than of feedlot cattle. This shorter ruminal retention time can explain why ruminal and total tract starch digestibility generally is lower for lactating cows than for finishing cattle. Ruminal escape of starch is greater with dry rolled and whole corn grain than with steam flaked and high moisture corn, but starch from dry rolled and whole corn grain is poorly digested in the small intestine. Averaged across processing methods, starch digestibility in the small intestine decreases as the quantity of starch entering the small intestine increased, but when grain processing methods are considered individually, disappearance of starch in the small intestine remains roughly proportional to starch entry rate. Due to reduced loss of energy as methane and heat, available energy supply for the ruminant is greater when starch is digested in the small intestine than when starch is fermented in either the rumen or large intestine. But if starch digestion in the small intestine is below about 70%, no energetic benefit from increasing ruminal output of starch will be achieved.

Characteristics that make a grain or a hybrid ideal for livestock differ with processing method. For whole and dry rolled corn, the combination of very fine grinding of grain with a floury endosperm, a thin or loose pericarp, and a low amylose:amylopectin ratio will maximize starch digestion. For fermented corn grain with adequate moisture content as well as adequately processed steam flaked corn, starch digestion usually exceeds 97% so any remaining differences in digestibility among corn samples (1 to 3%) are due to components other than starch (NDF, protein). For maximum feed efficiency, energy digestibility must be maximized. For dry rolled or ground corn, incomplete starch digestibility is of primary concern, but with more extensively processed grain, altering the starch content (more starch and less NDF and protein) is the simplest way to increase its content of digestible energy.

Key Words: Starch, Rumen, Small intestine, Processing, Grains

INTRODUCTION

The value of any livestock feed is the multiple of three factors: nutrient or energy content, feed intake, and digestibility. Nutrient and energy content of grain at harvest is influenced by genetic (hybrid and grain type) and environmental (soil fertility, growth conditions, maturity) factors and the interaction between genetics and environment. Blending or dilution with grain of lower nutritive value further alters the composition of commodity grains. The influence of corn genetics on composition and feeding value as well as the interrelationships among nutrients present in corn grain have been outlined elsewhere (Owens 2005a; Soderlund and Owens - elsewhere in these proceedings, 2007) and will not be discussed

further here. The second factor, dry matter or feed intake, usually is reduced by extensive grain processing primarily because energy availability of the grain has been increased. With high-concentrate feedlot diets, except for very low roughage diets, high moisture grains, and possibly with barley, metabolizable energy intake by cattle is not altered by grain processing (Buchanan-Smith –Elsewhere in these proceedings, 2007). The third factor, digestibility, is the point where livestock producers can increase the value of a feed through altering site and extent of digestion through grain processing.

Selection of a processing method must consider not only the animal performance response but also the

cost of grain handling and processing (Peters – Elsewhere in these proceedings, 2007). Ideally, optimal processing economically increases digestibility; processing also may alter the site of digestion but must not detrimentally affect ruminal pH and cause digestive dysfunction. In essence, grains are processed to enhance their nutritional value. However, the extent of processing often is slightly limited in an attempt to reduce the incidence of metabolic disorders. A higher grain price helps to justify more extensive and expensive grain processing methods.

Processing methods and responses in site and extent of digestion have been reviewed extensively (Nocek and Tamminga, 1991; Huntington, 1997; Theurer et al., 1999a; Rowe et al., 1999; Firkins et al., 2001; Harmon and McLeod, 2001, 2005; Owens and Zinn, 2005; Owens 2005a, 2005b; Huntington et al., 2006). This review will highlight the results of digestion trials with lactating dairy cows typically fed diets with 40 to 60% roughage and with feedlot cattle fed diets with less than 20% roughage. Because most grain processing trials have been conducted with yellow dent corn grain, information from that commodity will be emphasized. Compared to dent corn grain, flint corn grain and sorghum grain should respond more extensively to processing whereas cereal grains with less vitreous starch (oats, barley, wheat) will exhibit much less response. Because starch comprises over 70% of the dry matter of most cereal grains, starch will be the primary focus of attention.

GRAIN PROCESSING METHODS

Unprocessed grains can be fed to livestock. Kaiser (1999) and Loerch and Gorocica-Buenfil – Elsewhere in these proceedings (2007) have outlined the economic advantages and limitations of feeding cereal grains whole (without mechanical processing). With less vitreous grains (oats, barley, triticale, rice, wheat), with sheep and with young animals that chew their feed thoroughly, and with very low levels of dietary roughage or forage, extent of starch digestion usually is quite high for unprocessed grains. However, for corn and sorghum grains, particle size reduction, either by the animal or by mechanical processing of the grain prior to feeding, generally increases starch digestibility slightly. Adverse associative effects (interactions of grain with roughage) where added roughage depresses starch

digestion are most evident with whole or rolled grains. Presumably, higher intakes and higher roughage diets flush large corn particles through the rumen before the starch is fully digested (Wylie et al., 1990). To expose more surface area for digestion and to fracture the pericarp, most cereal grains are rolled or ground prior to feeding to cattle. For more mature feedlot cattle, dry corn grain usually is coarsely rolled or cracked yielding 4 to 10 particles per kernel of corn, but for lactating dairy cows, much finer grinding is used. Surprisingly, in some trials with feedlot cattle, starch digestibility and net energy value are greater for whole than for rolled grains (Owens et al., 1997). This may be attributed to longer ruminal retention time for whole than rolled corn. With mature corn silage, as well, some whole corn kernels will be found in feces unless feedstuffs have been adequately “kernel processed” during harvest to damage the kernels or the corn particles are adequately softened during fermentation to increase starch digestibility.

Grain processing typically involves kernel damage and a reduction in particle size either with or without addition of water or steam. Grinding or rolling to form dry rolled or dry ground grain, occasionally with addition of moisture to reduce fine particles and dust, is the most common method of grain processing. Fracturing kernels by high speed milling generally results in a very wide range in particle sizes; the crushing action involved with rolling the grain results in a much narrower range in particle sizes. However, moisture content can alter both the mean particle size and distribution of particles generated by either dry processing method. To increase digestion further, grains (whole, rolled or ground) can be fermented if adequate moisture (typically 24 to 35%) is present. The fermentation process appears similar whether the moisture is inherent to the grain due to early harvest to form high moisture grain or added to dry grain prior to fermentation to form reconstituted grain (Benton et al., 2005). To form steam rolled or steam flaked grain, dry whole grain is moistened with steam and crushed between corrugated rolls. Compared with steam flaked grain, steam rolled grain is steamed for a shorter time period, crushed flakes are thicker, and a smaller proportion of the starch will be gelatinized (fracturing of starch granules). Starch that is gelatinized is very rapidly and completely fermented within the rumen. However, amylose starch in flaked grain can retrograde (harden to form digestion-

resistant starch) if the grain is cooled slowly (Ward and Galyean, 1999).

Effects of processing on the site and extent of starch digestion will vary with processing conditions (grain moisture, screen size or roll gap; fermentation moisture and time; steaming time) as discussed by Zinn et al. (2002). The primary factor limiting the extent of digestion either in the rumen or the intestines is the extent to which surface area is exposed for microbial or enzymatic attack (e.g., primarily particle size). In addition, with more vitreous grain, encapsulation or imbedding of starch granules within a matrix of either protein or fiber delays or retards digestion. However, restrictions associated with vitreousness are removed readily by either fermentation or by heat processing. Consequently, for less extensively processed corn, feeding value will vary with vitreousness of the hybrid or variety, its maturity, and certain agronomic conditions for grain production (Philippeau and Michalet-Doreau, 1997; Philippeau et al., 1999; Shaver and Majee, 2002). In contrast, by markedly increasing the extent of starch digestion, fermentation (Szasz et al., 2007) and flaking (Corona et al., 2006) minimizes or completely obliterates differences among grain hybrids and grain types associated with vitreousness. Finally, chewing and rumination as well as bunk management can alter site and extent of digestion and rate of passage through the digestive tract; these in turn vary with animal age and background, diet composition, feeding frequency, and dietary forage or fiber (NDF) level.

IMPACT OF PROCESSING ON SITE AND EXTENT OF STARCH DIGESTION

A summary of trials published since 1990 where site of starch digestibility was measured either with lactating dairy cows or with feedlot steers or heifers initially compiled by Owens (2005b) has been updated in Tables 1 and 2. Many more trials have measured site and extent of starch digestion by feedlot cattle than by lactating cows. Lack of a strong research emphasis on grain processing for lactating cows seems surprising considering the huge opportunity to increase ruminal and total tract starch digestion by lactating dairy cows. Note that this literature summary includes information from all research trials regardless of the degree or extent of processing of the grain. For example, results from trials with rolled and ground grain were combined even though the mean particle sizes can differ greatly; all trials with steam

flaked and steam rolled grains were included regardless of flake density that alters site and extent of digestion; all grain called “high moisture corn” was included in the summary despite the marked effect that moisture content has on energy value of this product. How such factors can alter digestibility and feeding value within these processing methods have been discussed elsewhere (Zinn et al., 2002; Owens 2005b; Owens and Zinn 2005).

Within both feedlot and dairy cattle, ruminal and total tract starch digestion was greater for fermented than for dry rolled grain. Whenever the ruminal digestion of starch increases, the supply of postruminal starch decreases. However, postruminal digestion of starch leaving the abomasum was numerically greater for high moisture than for dry rolled corn grain. Steam processing of corn led to a marked increase in ruminal digestion by feedlot cattle, but surprisingly steam rolling or flaking did not significantly increased ruminal starch digestion by lactating dairy cows. Because ruminal digestion of flaked corn depends on flake thickness and bulk density, perhaps the extent of flaking was less in trials with lactating cows than with feedlot cattle. Compared with whole or dry rolled or ground corn, processed corn generally had greater digestibility in the total digestive tract indicating that its net energy value had been increased.

Grinding grain to a very fine particle size will increase starch digestibility. However, benefits in starch digestion from fine grinding are considerably less than those obtained from fermentation or heat processing (Firkins et al., 2001). Nevertheless, fine rolling or grinding has increased the feeding value of more vitreous grains for steers (Brethour, 1990) and lactating cows (Bush et al., 1972).

For lactating cows, less than 60% of the starch digested in the total tract was digested in the rumen with all corn processing methods except high moisture corn. This leaves a substantial supply of starch available for digestion in the small intestine or fermentation in the large intestine. The importance of postruminal starch digestion automatically increases when the extent of ruminal digestion is low and more of the dietary starch is flushed to the intestines. Due to reduced methane and heat losses, starch digested in the intestine has considerably greater energy value than starch fermented in the large intestine

(Huntington et al., 2006). However, as they ably illustrated, the impact that site of digestion has on energetic efficiency of the animal relies heavily on the degree to which starch is digested in the small intestine. Starch from high moisture and steam flaked corn was quite well digested in the small intestine of feedlot cattle, but despite large numerical differences, no significant effect of processing method on small intestinal starch disappearance by lactating cows was detected. Whether the lower digestion of starch in the small intestine of lactating cows than of feedlot cattle is due to larger size of grain particles (associated with less extensive processing or less efficient or thorough chewing or rumination of grain by cows), to less activity of starch-digesting enzymes by cows fed diets with more NDF associated with the roughage, e.g., amylase inhibitors in alfalfa products, or to some additional unidentified factors is not certain. A shorter retention time in the small intestine is unlikely to be responsible considering that Wylie et al. (1990) noted that increasing the NDF content of the diet failed to decrease retention time in the small intestine of cattle.

The quantity of starch digested in the small intestine is the multiple of starch flow and its digestibility. As a fraction of dietary starch, more starch was digested in the intestines of cattle fed whole, dry rolled, and steam rolled corn than for cattle fed high moisture corn. For feedlot cattle, two processing methods, high moisture preservation and steam flaking, shifted the fractional site of starch digestion away from the intestines but toward the rumen. But in addition, these two processing methods increased small intestinal digestibility of starch reaching the intestines. This supports the concept advanced by Rowe et al. (1999) that processing corn grain to enhance ruminal digestion also enhances the postruminal digestibility of the starch flowing to the intestines. This also supports the concept that similar factors (particle size and protein shielding) limit the extent of starch digestion at both sites.

Greater ruminal and intestinal disappearance of starch from high moisture and for steam flaked corn than for dry rolled or whole corn can be attributed to the reduction in particle size and alteration of the protein matrix by processing. Just as these factors limit starch access by ruminal microbes, as indicated by McAllister et al. –Elsewhere in these proceedings (2007), they presumably limit starch access by

intestinal enzymes. But in contrast with the suggestion that starch that resists attack by ruminal microbes also should resist digestion by intestinal enzymes, starch disappearance in the small intestine as a fraction (percentage) of that entering the small intestine consistently exceeded the percentage of starch digested in the rumen for some processing methods. Such was not the case for rolled or ground corn. Visual inspection of duodenal contents from steers fed rolled corn reveals both vitreous grain fragments and grain particles shielded by the pericarp. But because particle size reduction postruminally appears minimal, renewed starch digestion must be due to chemical changes. Indeed, exposure to acid, pepsin, and other proteases in the abomasum and to lipases of the intestine must increase the accessibility of starch in particles for enzymatic attack in the small intestine.

In contrast to the effects of grain processing on starch digestion in the small intestine, starch digestion in the large intestine, either as a fraction of the starch supply or as a percentage of starch intake, was decreased by grain processing. Although compensatory starch digestion in the large intestine serves to recover energy from grain, fermentation of starch in the large intestine is energetically less desirable (yielding undigested microbes, VFA, and heat) than either fermentation in the rumen (yielding VFA, potentially digested ruminal microbes, methane, and heat) or digestion in the small intestine (presumably yielding glucose). Quite extensive digestion of starch from less processed grain in the large intestine further indicates that some physical or chemical barriers to starch fermentation must be altered by physical or enzymatic actions in the abomasum or small intestine or that the large intestinal microflora has additional starch fermenting capability as could evolve with a consistent supply of resistant starch.

Table 1. Influence of corn grain processing on site and extent of starch and NDF digestion by lactating dairy cows

Processing method	Dry rolled	High moisture	Steam flaked	Steam rolled	SEm*
Starch digestion in the rumen, % of intake	49.20 ^b	76.34 ^a	51.79 ^b	55.70 ^b	9.89
Postruminal starch disappearance, % of supply	77.67	82.93	88.43	88.32	12.96
Fraction of starch digestion in the rumen, % of total	55.50 ^b	79.37 ^a	54.83 ^b	58.81 ^{ab}	10.78
Total tract starch digestion, % of intake	89.95	95.99	93.94	94.23	5.60
Starch digestion in the small intestine, % of supply	48.40	57.75		71.20	39.97
Starch digestion in the small intestine, % of intake	26.62	9.84		36.90	23.95
Starch digestion in the rumen plus small intestine, % of intake	79.82	93.87		89.10	14.53
Starch digestion in the large intestine, % of supply	42.00	51.58		62.00	31.86
Starch digestion in the large intestine, % of intake	8.55	3.03		8.17	8.00
NDF digestion in the rumen, % of intake	42.59 ^a	17.90 ^b	51.50 ^a	45.90 ^a	10.63
NDF digestion in the total tract, % of intake	56.47 ^a	38.48 ^b	61.99 ^a	52.95 ^{ab}	9.92
NDF digestion past the rumen, % of supply	17.41 ^a	24.05 ^a	13.89 ^{ab}	-0.36 ^b	9.05

*Standard error of the mean.

^{a,b}Means with different superscripts within a row are different ($P < 0.05$).**Table 2.** Influence of corn grain processing on site and extent of starch and neutral detergent fiber (NDF) digestion by feedlot cattle

Processing method	Dry rolled	High moisture	Steam flaked	Whole	SEm*
Starch digestion in the rumen, % of intake	63.80 ^b	86.55 ^a	84.05 ^a	68.34 ^b	3.38
Postruminal starch disappearance, % of supply	72.16 ^b	93.10 ^a	94.33 ^a	52.99 ^c	4.07
Fraction of starch digestion in the rumen, % of total	70.15 ^c	87.24 ^a	84.74 ^{ab}	79.20 ^b	3.64
Total tract starch digestion, % of intake	91.03 ^b	99.25 ^a	99.09 ^a	87.08 ^c	1.12
Starch digestion in the small intestine, % of supply	58.83 ^b	94.86 ^a	92.48 ^a	64.64 ^b	22.38
Starch digestion in the small intestine, % of intake	20.08	17.18	16.39	24.50	7.62
Starch digestion in the rumen plus small intestine, % of intake	83.67 ^b	99.07 ^a	98.48 ^a	86.60 ^{ab}	12.01
Starch digestion in the large intestine, % of supply	56.32 ^a	24.80 ^b	20.47 ^b	32.09 ^{ab}	22.25
Starch digestion in the large intestine, % of intake	11.66 ^a	0.23 ^b	0.42 ^b	4.30 ^b	5.42
NDF digestion in the rumen, % of intake	48.07 ^a	18.48 ^d	27.71 ^c	33.43 ^{bc}	8.18
NDF digestion in the total tract, % of intake	50.83 ^a	34.27 ^d	44.39 ^{bc}	38.10 ^{cd}	7.02
NDF digestion past the rumen, % of supply	9.95	15.50	19.89	2.43	15.06

*Standard error of the mean.

^{a,b,c}Means with different superscripts within a row are different ($P < 0.05$).

Table 3. Influence of animal class on site and extent of starch and neutral detergent fiber (NDF) digestion

Animal class	Lactating cows	Feedlot cattle	SEM*	<i>P</i> <
Starch digestion in the rumen, % of intake	58.48	75.34	2.37	0.01
Postruminal starch disappearance, % of supply	80.90	79.71	2.89	0.66
Fraction of starch digestion in the rumen, % of total	63.43	79.56	2.54	0.01
Total tract starch digestion, % of intake	92.45	94.55	0.96	0.02
Starch digestion in the small intestine, % of supply	63.26	78.77	12.26	0.07
Starch digestion in the small intestine, % of intake	25.75	21.85	5.46	0.31
Starch digestion in the rumen plus small intestine, % of intake	88.06	92.17	1.95	0.31
Starch digestion in the large intestine, % of supply	35.40	41.25	13.24	0.53
Starch digestion in the large intestine, % of intake	3.58	5.47	3.16	0.40
NDF digestion in the rumen, % of intake	33.70	34.84	4.85	0.74
NDF digestion in the total tract, % of intake	49.55	42.63	4.03	0.02
NDF digestion past the rumen, % of supply	14.36	8.39	7.00	0.25

*Standard error of the mean.

Starch digestion by cows and feedlot cattle has not been compared directly in any research trials. However, effects of cattle class can be examined when differences associated with processing methods are removed statistically (Table 3). Compared with feedlot cattle, lactating cows had considerably less dietary starch digestion in the rumen, the small intestine (as a percentage of abomasal starch), and the total digestive tract. This indicates that site of digestion differed with cattle class. As a fraction of dietary starch, almost twice as much starch (averages of 37% vs 20%) disappeared postruminally with lactating cows than with feedlot cattle. A faster solids dilution rate and reduced time for ruminal digestion associated with higher feed intakes and higher NDF content of the diet may explain why ruminal starch digestion was lower for lactating cows. Similarly, time for compensatory digestion of starch in the large intestine probably is lower with higher intakes of NDF leading to slightly lower large intestinal starch digestion by lactating cows.

One sidelight of altering site of starch digestion by grain processing is its impact on site and extent of NDF digestion. Combined with diets richer in forage and a higher ruminal pH, one would anticipate that extent of dietary NDF digestion in the rumen should be greater for lactating cows than for feedlot steers. Such was not the case. The greater NDF digestion in the total tract for lactating cows was due surprisingly not to increased ruminal but to increased postruminal digestion of NDF. Certainly, the source of NDF will

differ with cattle type and can markedly influence NDF digestibility; lactating cows typically are fed more digestible forages. However, in feedlot diets, much of the NDF is derived from grains and protein supplement; ruminal digestibility of NDF from fine particle forages, e.g., soybean hulls, is quite high.

Grain processing also altered site and extent of NDF digestion, but these responses tended to differ with animal class (Tables 1 and 2). With both cows and feedlot cattle, NDF digestion in the rumen and total tract was lower with high moisture than dry rolled corn, possibly due to inhibition of NDF digestion by a low ruminal pH. Conversely, compensatory NDF digestion past the rumen was lowest when starch digestion in the large intestine was greatest. This again may reflect pH reduction of digesta; starch digestion in the large intestine would reduce pH and inhibit fiber digestion therein. Consequently, although processing grain may reduce ruminal pH and inhibit ruminal fermentation of NDF, processing also reduced the supply of starch for fermentation in the large intestine; this allowed greater compensatory fermentation of NDF. This supports the concept that a low fecal pH reflects not only incomplete pre-cecal starch digestion, but also a reduction in compensatory fermentation of NDF in the large intestine. A fecal pH near neutrality should reflect both efficient pre-cecal starch digestion and greater NDF fermentation in the large intestine. Because many additional factors including level of feed intake and dietary buffers will influence fecal pH,

direct measurement of fecal starch would seem preferable to measuring fecal pH as an index of starch digestibility.

Because digestion of starch can be expressed as a fraction of available or of dietary starch, simple comprehension of the effects of grain processing on

site of digestion can prove confusing. To illustrate differences site of digestion of dietary starch with various processing methods, mean values for site of digestion from the published literature subdivided by animal class and grain processing methods are presented in Figure 1.

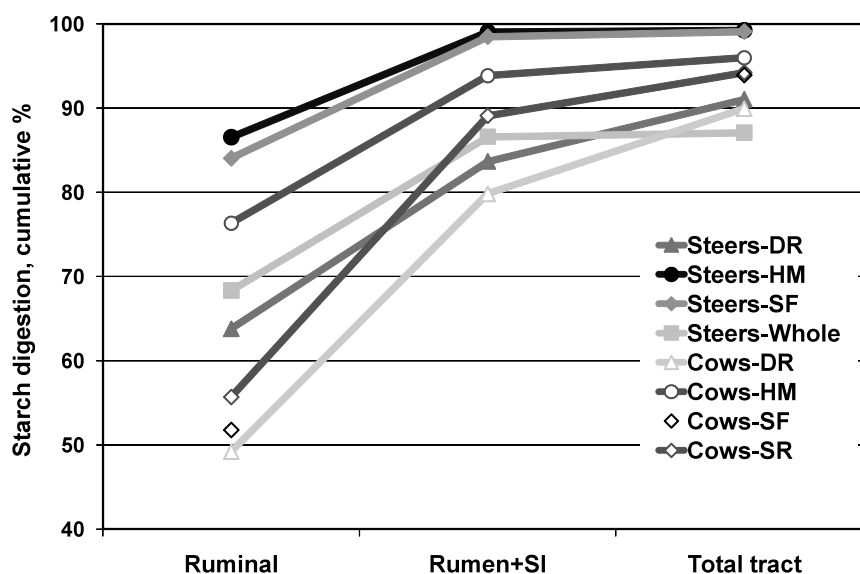


Figure 1. Site of digestion of dietary starch by feedlot cattle or lactating dairy cows fed corn grain processed by various methods. Open symbols are means for cows whereas closed symbols are for feedlot cattle. Triangles are for dry rolled corn, circles are for high moisture, and diamonds are for steam flaked corn grain.

Initial points on the left represent the extent of ruminal starch digestion. Relative slopes from ruminal to ruminal plus small intestinal points represent the quantities of dietary starch disappearing from the small intestine. Despite having a lower fractional digestion rate in the small intestine, rolled or whole grains provided quantitatively more starch to be digested in the small intestine. However, compensatory disappearance of dietary starch in the large intestine was greatest for dry rolled and steamrolled grain with very little additional starch disappearance from either high moisture or steam flaked grains (due to its extensive disappearance

before this point). Large intestinal disappearance of starch also was low for whole corn grain, presumably due to large particle size of the grain.

Values from literature summaries that have reported site and extent of digestion of starch for steers and for lactating cows are presented in Figures 2 and 3. Because these summaries probably were derived from a similar base of research data, high similarity in estimates of site and extent of starch digestion among trials both for total tract (Figure 2) and ruminal (Figure 3) disappearance should come as no surprise.

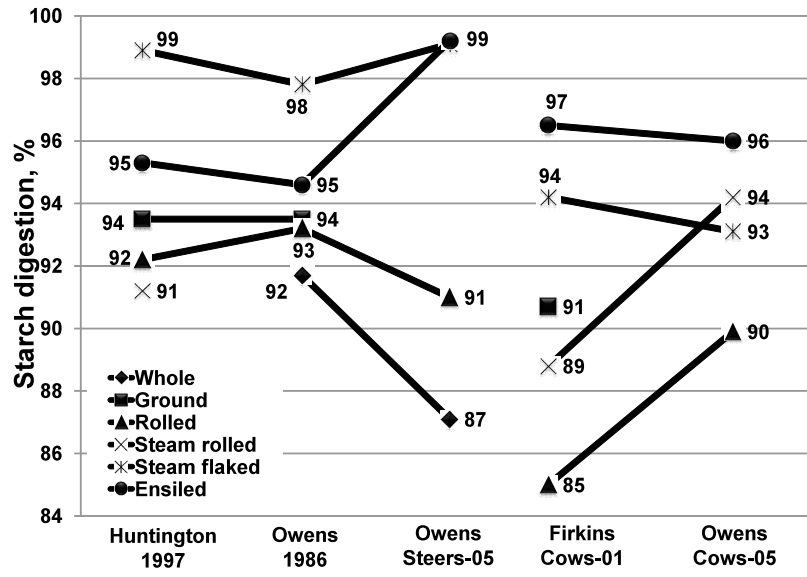


Figure 2. Total tract starch digestion from processed corn grain based on literature summaries for feedlot cattle and lactating cows.

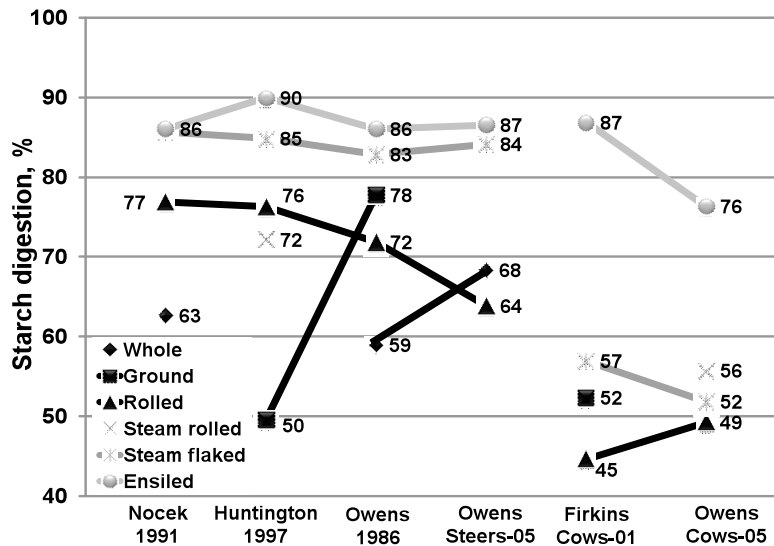


Figure 3. Digestion of dietary starch in the rumen of cattle from corn grain processed by various methods.

Such literature summaries of digestibility generally present the average of means from individual trials. An alternative approach to calculate starch digestibility is to regress disappearance (g) of starch against starch intake or starch entering a specific segment of the digestive tract. The regression line (disappearance/input) serves as an index of digestibility. Because starch output should be zero

when starch input is zero, this regression usually is forced through zero. In contrast with individual measurements of digestibility, this regression approach places greater emphasis on trials where input of starch is greater and the precision and reliability of the estimate should be greater. When plotted as in Figure 4, effects on digestion at different starch inputs can be visualized.

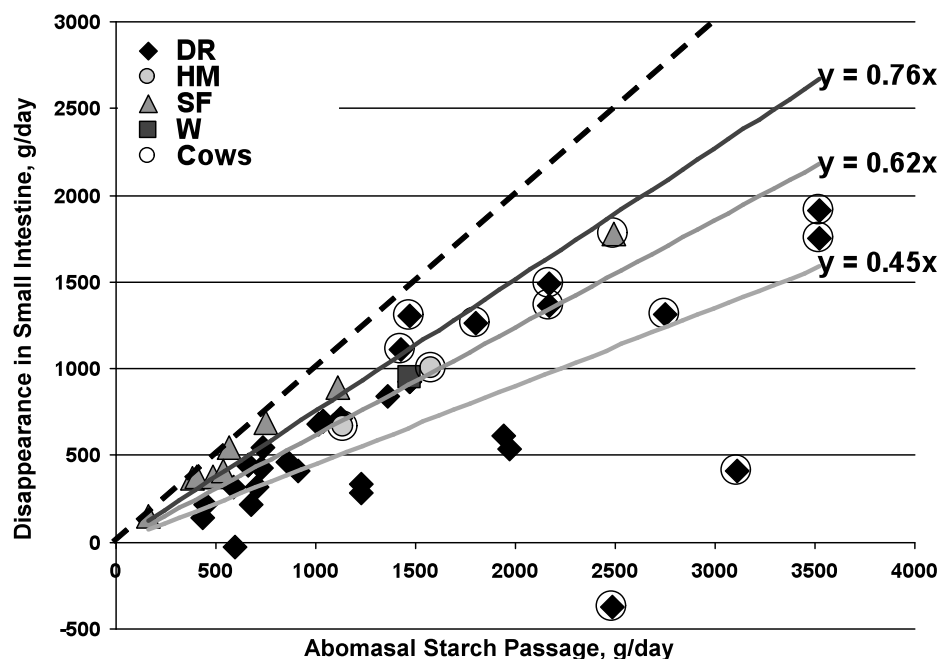


Figure 4. Disappearance of abomasal starch in the small intestine. The dotted line represents unity, where digestion would be complete (100%).

When regressed across cattle types, apparent intestinal digestibility of starch from steam processed, high moisture, and dry rolled grain averaged 76, 62, and 45%, respectively (Figure 4). These digestibility estimates differ slightly from the mean values from individual trials with feedlot cattle and lactating cows of 92 and 71% for steam processed corn, 95 and 56% for high moisture, and 58 and 48% for dry rolled grains; this illustrates how regression values are driven more strongly by trials with higher starch inputs. For steam processed and high moisture corn grain, no curvilinearity is apparent indicating that digestibility remained constant across all intake levels. However, digestion estimates from individual trials are scattered widely for dry rolled corn grain. In two trials, starch disappearance from dry rolled corn in the small intestine was negative, perhaps reflecting the difficulty in obtaining a representative digesta sample from the ileum when the digesta contains larger grain particles. Insufficient data are available to calculate

separate regression lines for feedlot cattle versus lactating cows.

In Figure 5, grams of starch disappearing in the rumen plus small intestine are plotted against grams of starch digested in the total digestive tract. Except for some deviant points from one trial with lactating cows, grams of starch in the rumen plus small intestine seems roughly proportional to grams of starch digested in the total digestive tract. This indicates that the differences in digestibility of starch in the large intestine associated with different processing methods quantitatively are small when compared with the total quantity of starch digested. The fact that processing methods that alter site of starch digestion do not deviate markedly from each other indicates that relative to total tract starch digestibility, site of digestion (rumen versus small intestine) may have only minor effects on energetic efficiency. Nevertheless, effects of site of digestion on energetic efficiency have been the subject of a considerable amount of discussion and research.

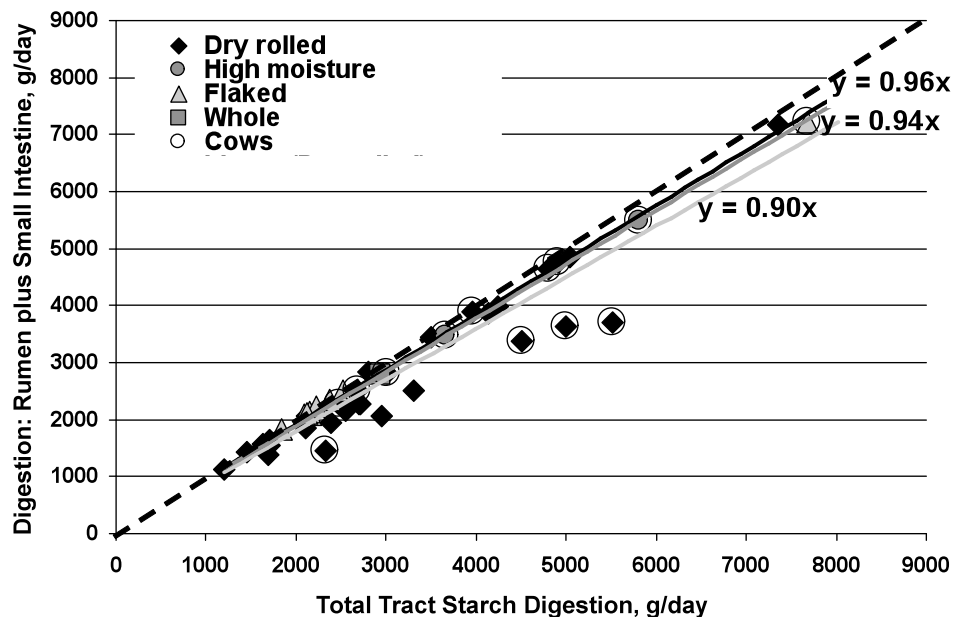


Figure 5. Digestion in the rumen plus small intestine versus total tract starch digestion by cows and feedlot cattle. Dotted line represents line for 100% digestion.

EFFECTS OF SITE OF DIGESTION ON ENERGETIC EFFICIENCY

Energetic efficiency is greater when glucose is infused into the abomasum or small intestine than when glucose is infused into the rumen (Harmon and McLeod, 2001; Huntington et al., 2006). Precisely where carbon and energy from glucose disappearing from the small intestine goes and whether it provides useful energy for the ruminant has been debated extensively because glucose recovery in the portal blood stream never is complete. Several studies have indicated that fat synthesis is increased when glucose is infused postruminally (Armstrong et al., 1968; Rust, 1992; McLeod and Harmon, - Elsewhere in this publication 2007). Armstrong et al. (1968) observed that 54% of ruminally infused energy was converted to fat whereas 71% of glucose abomasally infused was stored as fat. Similarly, 68 to 71% of the calories from sucrose or glucose provided to pigs and dogs was stored as fat. With ruminants, fat deposition in the omentum has increased when glucose has been infused either into the abomasum of sheep (Rust, 1992) or the small intestine of cattle (McLeod and Harmon, - Elsewhere in these proceedings 2007). Added glucose failed to increase lean mass or carcass weight but instead added to the intestinal mass.

Lipogenesis directly by the intestine or omentum also could explain why glucose disappearing from the intestine is not recovered in blood draining the intestines (the portal drained viscera). Increased omental fat and a lower dressing percentage matches observations at harvest of Holstein steers. This fits with the concept above if Holstein steers are similar to lactating cows (typically Holsteins) where ruminal starch outflow is large. If postruminal glucose merely increases fat deposition in and around the intestine, postruminal starch digestion would not prove useful for growth or lactation even though it avoids methane and heat losses associated with fermentation in the rumen. An increase in visceral fat would provide padding for protection of internal organs. All other things being equal, an increase in omental or small intestinal fat should decrease dressing percentage as these tissues are removed before hot carcass weight is measured.

What is the appropriate control to evaluate an increase in supply of energy from postruminally administered glucose? An increased intestinal supply of energy from protein, volatile fatty acids, or lipid might cause similar increases in omental fat deposition by ruminants of a similar magnitude.

Indeed, pigs and dogs given supplemental sucrose or glucose exhibit increased fat deposition (Armstrong et al., 1968). Intestinal tissue would provide an additional location for synthesis of fatty acids when the capacity for lipogenesis by other tissues is limited if the lipid synthesized at this site can be transported to other depot sites or to the mammary gland for secretion.

Further research studies concerning the impact of site of starch digestion on energetic efficiency of milk and meat production are warranted. But besides energetics, site of digestion can be important nutritionally. An increase in ruminal starch escape would reduce the amount of energy available for synthesis of microbial protein that is needed for young, growing animals and for cows at high levels of lactation. If fermented in the large intestine, fecal loss of nitrogen as well as energy would be expected. However, shifting the site of starch digestion from the rumen to the small intestine for digestion should reduce methane loss to the environment as well as the ruminal acid load; reducing the acid load should help to maintain a ruminal pH that is higher and more optimal for fiber digestion.

PREDICTING STARCH DIGESTIBILITY

Several laboratory methods for appraising or predicting starch digestion have been advanced in addition to the enzymatic starch availability measure used at commercial laboratories to evaluate flaked grain. These include gas production measures during incubation with yeast (as compared with corn flakes), microscopically appraised gelatinization (measuring prevalence of maltese crosses), the Degree of Starch Access (DSA) reported by Basel et al. (2006) that is being used with both silages and grains, and particle size measurements with grains and silages that are

based on the concept that starch found in particles larger than $\frac{1}{4}$ kernel (> 4.25 mm) from in corn silage are less extensively digested in vitro than smaller particles (Ferreira and Mertens, 2005). Ultimately, direct analysis of the starch content of feces should provide a direct measurement of indigestible starch as noted below.

STARCH DIGESTIBILITY BY PRODUCING RUMINANTS UNDER FIELD CONDITIONS

If feed starch input and fecal starch output are known, starch digestibility can be calculated. By employing either an inherent or an added marker, starch digestibility can be calculated for cattle under field conditions using a method recently described by Zinn et al. (2007). In turn, net energy values of grains can be predicted from starch digestibility. This would imply that fecal starch output, representing an energy loss, must be proportional to energy availability from starch in the rumen plus small intestine. To quantify this relationship, daily starch digestion in grams in the rumen plus small intestine for feedlot cattle and lactating cows was plotted against fecal starch divided by the mean indigestibility of starch in the large intestine ($100 - 47.8 = 52.2\%$) across all processing methods as shown in Figure 6.

Sampling variability among animals and days need further study, but fecal starch concentrations above 5% of fecal dry matter presumably reflect inadequate flaking of grains for maximum starch digestion or the presence of fecal starch from other sources (e.g., corn silage). Direct measurement of starch digestibility under field conditions should prove useful in the field to assess the veracity of laboratory indices of starch availability as well as the efficacy of grain processing methods being employed by livestock producers.

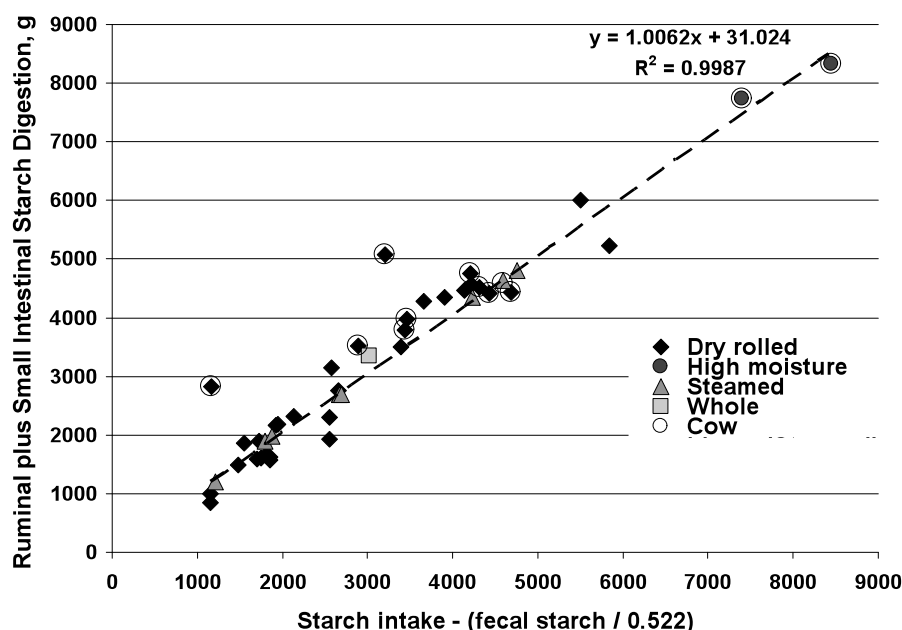


Figure 6. Relationship of digestion of starch in the rumen plus small intestine to starch intake minus fecal starch excretion divided by mean starch indigestibility.

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Table 1. Influence of corn grain processing on site and extent of starch and NDF digestion by lactating dairy cows

Processing method	Dry rolled	High moisture	Steam flaked	Steam rolled	SEm*
Starch digestion in the rumen, % of intake	49.20 ^b	76.34 ^a	51.79 ^b	55.70 ^b	9.89
Postruminal starch disappearance, % of supply	77.67	82.93	88.43	88.32	12.96
Fraction of starch digestion in the rumen, % of total	55.50 ^b	79.37 ^a	54.83 ^b	58.81 ^{ab}	10.78
Total tract starch digestion, % of intake	89.95	95.99	93.94	94.23	5.60
Starch digestion in the small intestine, % of supply	48.40	57.75		71.20	39.97
Starch digestion in the small intestine, % of intake	26.62	9.84		36.90	23.95
Starch digestion in the rumen plus small intestine, % of intake	79.82	93.87		89.10	14.53
Starch digestion in the large intestine, % of supply	42.00	51.58		62.00	31.86
Starch digestion in the large intestine, % of intake	8.55	3.03		8.17	8.00
NDF digestion in the rumen, % of intake	42.59 ^a	17.90 ^b	51.50 ^a	45.90 ^a	10.63
NDF digestion in the total tract, % of intake	56.47 ^a	38.48 ^b	61.99 ^a	52.95 ^{ab}	9.92
NDF digestion past the rumen, % of supply	17.41 ^a	24.05 ^a	13.89 ^{ab}	-0.36 ^b	9.05

*Standard error of the mean.

^{a,b}Means with different superscripts within a row are different ($P < 0.05$).**Table 2.** Influence of corn grain processing on site and extent of starch and neutral detergent fiber (NDF) digestion by feedlot cattle

Processing method	Dry rolled	High moisture	Steam flaked	Whole	SEm*
Starch digestion in the rumen, % of intake	63.80 ^b	86.55 ^a	84.05 ^a	68.34 ^b	3.38
Postruminal starch disappearance, % of supply	72.16 ^b	93.10 ^a	94.33 ^a	52.99 ^c	4.07
Fraction of starch digestion in the rumen, % of total	70.15 ^c	87.24 ^a	84.74 ^{ab}	79.20 ^b	3.64
Total tract starch digestion, % of intake	91.03 ^b	99.25 ^a	99.09 ^a	87.08 ^c	1.12
Starch digestion in the small intestine, % of supply	58.83 ^b	94.86 ^a	92.48 ^a	64.64 ^b	22.38
Starch digestion in the small intestine, % of intake	20.08	17.18	16.39	24.50	7.62
Starch digestion in the rumen plus small intestine, % of intake	83.67 ^b	99.07 ^a	98.48 ^a	86.60 ^{ab}	12.01
Starch digestion in the large intestine, % of supply	56.32 ^a	24.80 ^b	20.47 ^b	32.09 ^{ab}	22.25
Starch digestion in the large intestine, % of intake	11.66 ^a	0.23 ^b	0.42 ^b	4.30 ^b	5.42
NDF digestion in the rumen, % of intake	48.07 ^a	18.48 ^d	27.71 ^c	33.43 ^{bc}	8.18
NDF digestion in the total tract, % of intake	50.83 ^a	34.27 ^d	44.39 ^{bc}	38.10 ^{cd}	7.02
NDF digestion past the rumen, % of supply	9.95	15.50	19.89	2.43	15.06

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Table 3. Influence of animal class on site and extent of starch and neutral detergent fiber (NDF) digestion

Animal class	Lactating cows	Feedlot cattle	SEM*	<i>P</i> <
Starch digestion in the rumen, % of intake	58.48	75.34	2.37	0.01
Postruminal starch disappearance, % of supply	80.90	79.71	2.89	0.66
Fraction of starch digestion in the rumen, % of total	63.43	79.56	2.54	0.01
Total tract starch digestion, % of intake	92.45	94.55	0.96	0.02
Starch digestion in the small intestine, % of supply	63.26	78.77	12.26	0.07
Starch digestion in the small intestine, % of intake	25.75	21.85	5.46	0.31
Starch digestion in the rumen plus small intestine, % of intake	88.06	92.17	1.95	0.31
Starch digestion in the large intestine, % of supply	35.40	41.25	13.24	0.53
Starch digestion in the large intestine, % of intake	3.58	5.47	3.16	0.40
NDF digestion in the rumen, % of intake	33.70	34.84	4.85	0.74
NDF digestion in the total tract, % of intake	49.55	42.63	4.03	0.02
NDF digestion past the rumen, % of supply	14.36	8.39	7.00	0.25

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Starch digestion by cows and feedlot cattle has not been compared directly in any research trials. However, effects of cattle class can be examined when differences associated with processing methods are removed statistically (Table 3). Compared with feedlot cattle, lactating cows had considerably less dietary starch digestion in the rumen, the small intestine (as a percentage of abomasal starch), and the total digestive tract. This indicates that site of digestion differed with cattle class. As a fraction of dietary starch, almost twice as much starch (averages of 37% vs 20%) disappeared postruminally with lactating cows than with feedlot cattle. A faster solids dilution rate and reduced time for ruminal digestion associated with higher feed intakes and higher NDF content of the diet may explain why ruminal starch digestion was lower for lactating cows. Similarly, time for compensatory digestion of starch in the large intestine probably is lower with higher intakes of NDF leading to slightly lower large intestinal starch digestion by lactating cows.

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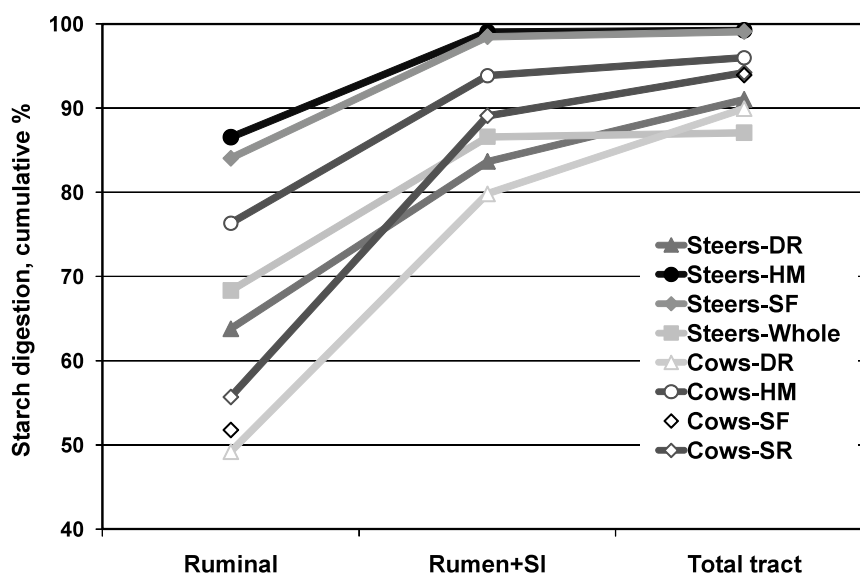


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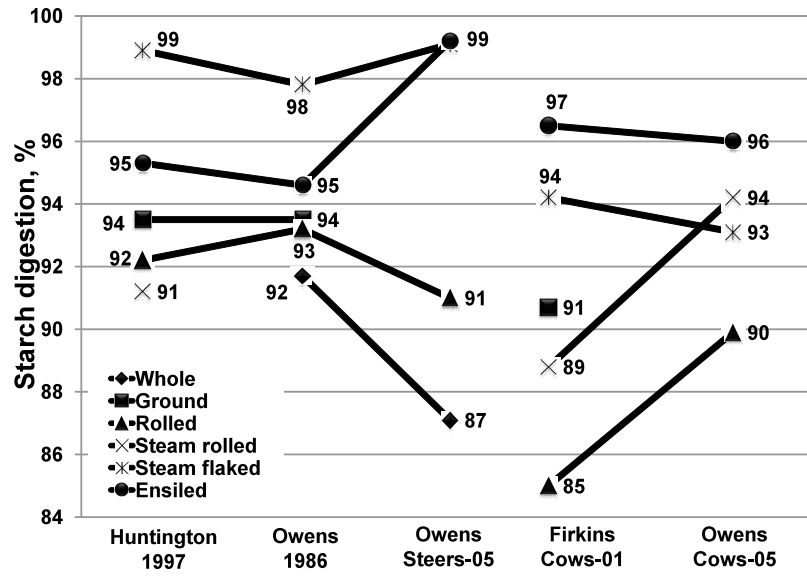


Figure 2. Total tract starch digestion from processed corn grain based on literature summaries for feedlot cattle and lactating cows.

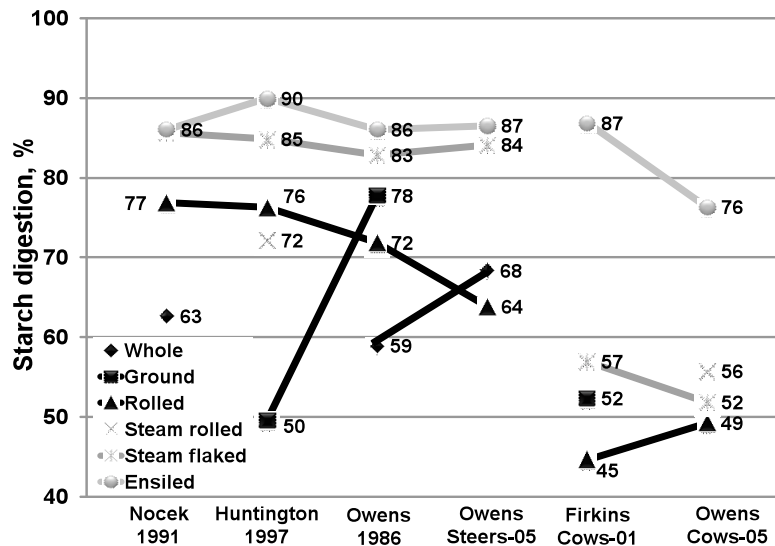


Figure 3. Digestion of dietary starch in the rumen of cattle from corn grain processed by various methods.

Such literature summaries of digestibility generally present the average of means from individual trials. An alternative approach to calculate starch digestibility is to regress disappearance (g) of starch against starch intake or starch entering a specific segment of the digestive tract. The regression line (disappearance/input) serves as an index of digestibility. Because starch output should be zero

when starch input is zero, this regression usually is forced through zero. In contrast with individual measurements of digestibility, this regression approach places greater emphasis on trials where input of starch is greater and the precision and reliability of the estimate should be greater. When plotted as in Figure 4, effects on digestion at different starch inputs can be visualized.

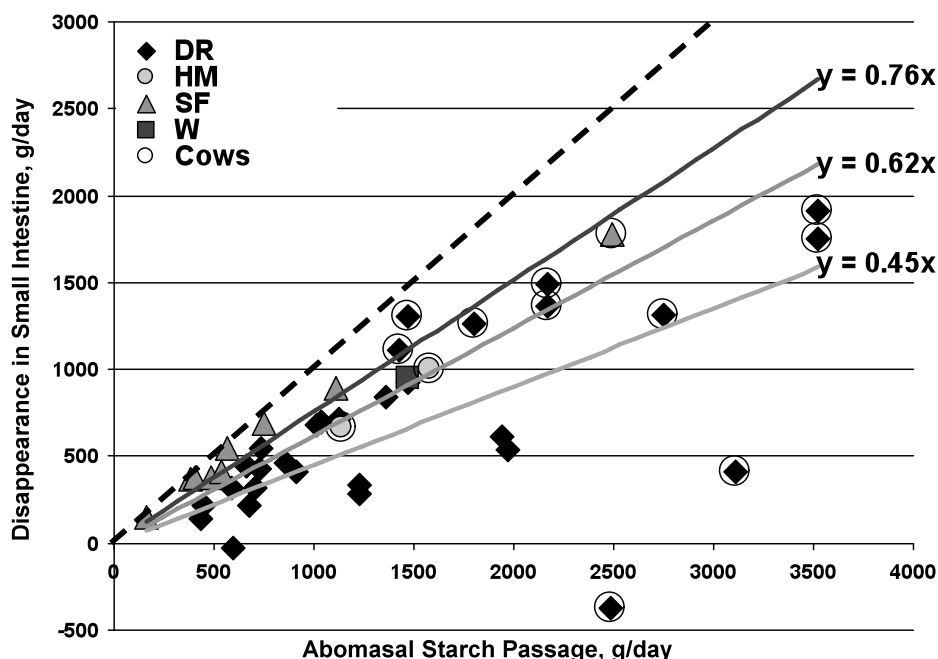


Figure 4. Disappearance of abomasal starch in the small intestine. The dotted line represents unity, where digestion would be complete (100%).

When regressed across cattle types, apparent intestinal digestibility of starch from steam processed, high moisture, and dry rolled grain averaged 76, 62, and 45%, respectively (Figure 4). These digestibility estimates differ slightly from the mean values from individual trials with feedlot cattle and lactating cows of 92 and 71% for steam processed corn, 95 and 56% for high moisture, and 58 and 48% for dry rolled grains; this illustrates how regression values are driven more strongly by trials with higher starch inputs. For steam processed and high moisture corn grain, no curvilinearity is apparent indicating that digestibility remained constant across all intake levels. However, digestion estimates from individual trials are scattered widely for dry rolled corn grain. In two trials, starch disappearance from dry rolled corn in the small intestine was negative, perhaps reflecting the difficulty in obtaining a representative digesta sample from the ileum when the digesta contains larger grain particles. Insufficient data are available to calculate

separate regression lines for feedlot cattle versus lactating cows.

In Figure 5, grams of starch disappearing in the rumen plus small intestine are plotted against grams of starch digested in the total digestive tract. Except for some deviant points from one trial with lactating cows, grams of starch in the rumen plus small intestine seems roughly proportional to grams of starch digested in the total digestive tract. This indicates that the differences in digestibility of starch in the large intestine associated with different processing methods quantitatively are small when compared with the total quantity of starch digested. The fact that processing methods that alter site of starch digestion do not deviate markedly from each other indicates that relative to total tract starch digestibility, site of digestion (rumen versus small intestine) may have only minor effects on energetic efficiency. Nevertheless, effects of site of digestion on energetic efficiency have been the subject of a considerable amount of discussion and research.

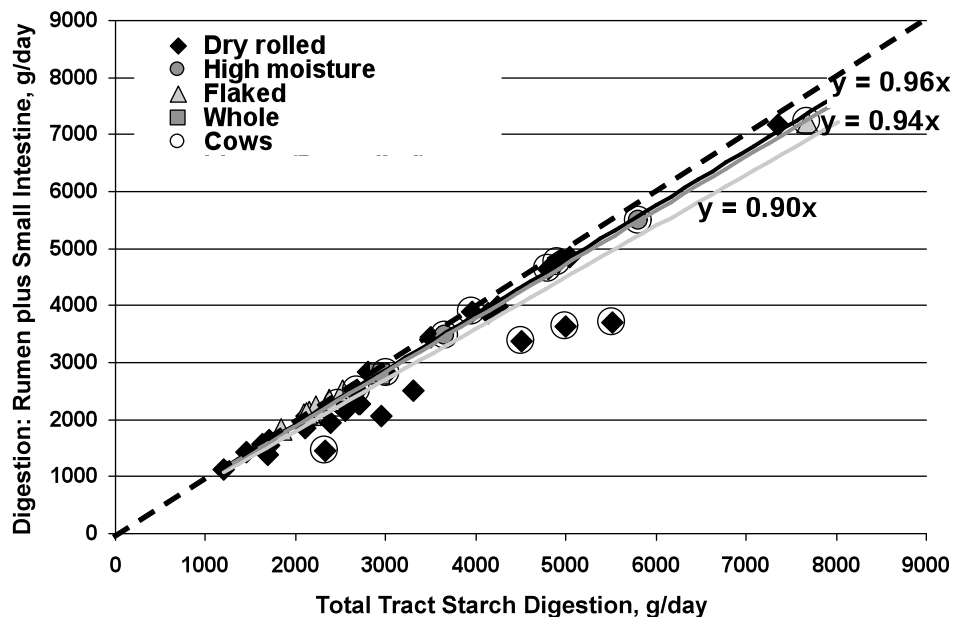


Figure 5. Digestion in the rumen plus small intestine versus total tract starch digestion by cows and feedlot cattle. Dotted line represents line for 100% digestion.

EFFECTS OF SITE OF DIGESTION ON ENERGETIC EFFICIENCY

Energetic efficiency is greater when glucose is infused into the abomasum or small intestine than when glucose is infused into the rumen (Harmon and McLeod, 2001; Huntington et al., 2006). Precisely where carbon and energy from glucose disappearing from the small intestine goes and whether it provides useful energy for the ruminant has been debated extensively because glucose recovery in the portal blood stream never is complete. Several studies have indicated that fat synthesis is increased when glucose is infused postruminally (Armstrong et al., 1968; Rust, 1992; McLeod and Harmon, - Elsewhere in this publication 2007). Armstrong et al. (1968) observed that 54% of ruminally infused energy was converted to fat whereas 71% of glucose abomasally infused was stored as fat. Similarly, 68 to 71% of the calories from sucrose or glucose provided to pigs and dogs was stored as fat. With ruminants, fat deposition in the omentum has increased when glucose has been infused either into the abomasum of sheep (Rust, 1992) or the small intestine of cattle (McLeod and Harmon, - Elsewhere in these proceedings 2007). Added glucose failed to increase lean mass or carcass weight but instead added to the intestinal mass.

Lipogenesis directly by the intestine or omentum also could explain why glucose disappearing from the intestine is not recovered in blood draining the intestines (the portal drained viscera). Increased omental fat and a lower dressing percentage matches observations at harvest of Holstein steers. This fits with the concept above if Holstein steers are similar to lactating cows (typically Holsteins) where ruminal starch outflow is large. If postruminal glucose merely increases fat deposition in and around the intestine, postruminal starch digestion would not prove useful for growth or lactation even though it avoids methane and heat losses associated with fermentation in the rumen. An increase in visceral fat would provide padding for protection of internal organs. All other things being equal, an increase in omental or small intestinal fat should decrease dressing percentage as these tissues are removed before hot carcass weight is measured.

What is the appropriate control to evaluate an increase in supply of energy from postruminally administered glucose? An increased intestinal supply of energy from protein, volatile fatty acids, or lipid might cause similar increases in omental fat deposition by ruminants of a similar magnitude.

Indeed, pigs and dogs given supplemental sucrose or glucose exhibit increased fat deposition (Armstrong et al., 1968). Intestinal tissue would provide an additional location for synthesis of fatty acids when the capacity for lipogenesis by other tissues is limited if the lipid synthesized at this site can be transported to other depot sites or to the mammary gland for secretion.

Further research studies concerning the impact of site of starch digestion on energetic efficiency of milk and meat production are warranted. But besides energetics, site of digestion can be important nutritionally. An increase in ruminal starch escape would reduce the amount of energy available for synthesis of microbial protein that is needed for young, growing animals and for cows at high levels of lactation. If fermented in the large intestine, fecal loss of nitrogen as well as energy would be expected. However, shifting the site of starch digestion from the rumen to the small intestine for digestion should reduce methane loss to the environment as well as the ruminal acid load; reducing the acid load should help to maintain a ruminal pH that is higher and more optimal for fiber digestion.

PREDICTING STARCH DIGESTIBILITY

Several laboratory methods for appraising or predicting starch digestion have been advanced in addition to the enzymatic starch availability measure used at commercial laboratories to evaluate flaked grain. These include gas production measures during incubation with yeast (as compared with corn flakes), microscopically appraised gelatinization (measuring prevalence of maltese crosses), the Degree of Starch Access (DSA) reported by Basel et al. (2006) that is being used with both silages and grains, and particle size measurements with grains and silages that are

based on the concept that starch found in particles larger than $\frac{1}{4}$ kernel (> 4.25 mm) from in corn silage are less extensively digested in vitro than smaller particles (Ferreira and Mertens, 2005). Ultimately, direct analysis of the starch content of feces should provide a direct measurement of indigestible starch as noted below.

STARCH DIGESTIBILITY BY PRODUCING RUMINANTS UNDER FIELD CONDITIONS

If feed starch input and fecal starch output are known, starch digestibility can be calculated. By employing either an inherent or an added marker, starch digestibility can be calculated for cattle under field conditions using a method recently described by Zinn et al. (2007). In turn, net energy values of grains can be predicted from starch digestibility. This would imply that fecal starch output, representing an energy loss, must be proportional to energy availability from starch in the rumen plus small intestine. To quantify this relationship, daily starch digestion in grams in the rumen plus small intestine for feedlot cattle and lactating cows was plotted against fecal starch divided by the mean indigestibility of starch in the large intestine ($100 - 47.8 = 52.2\%$) across all processing methods as shown in Figure 6.

Sampling variability among animals and days need further study, but fecal starch concentrations above 5% of fecal dry matter presumably reflect inadequate flaking of grains for maximum starch digestion or the presence of fecal starch from other sources (e.g., corn silage). Direct measurement of starch digestibility under field conditions should prove useful in the field to assess the veracity of laboratory indices of starch availability as well as the efficacy of grain processing methods being employed by livestock producers.

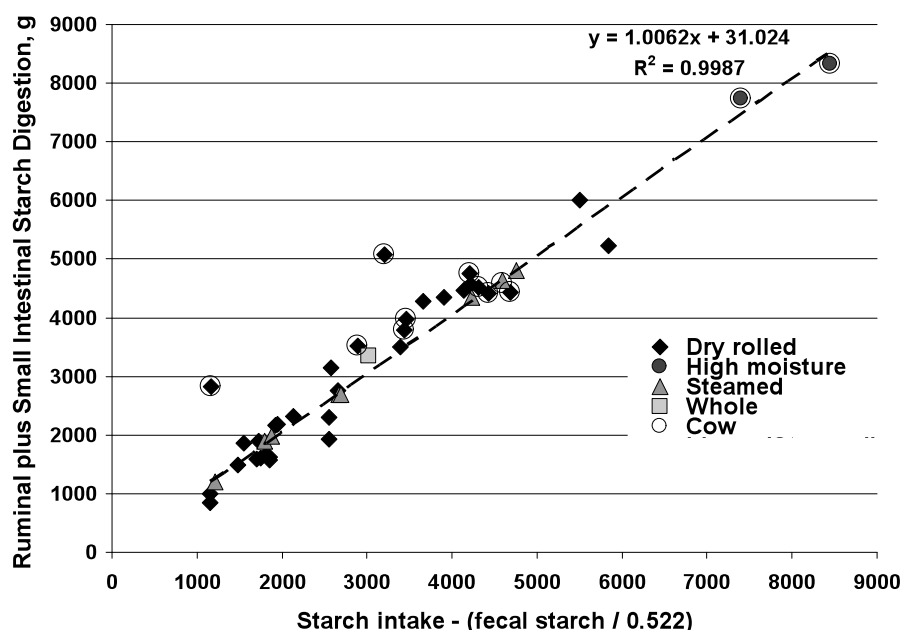


Figure 6. Relationship of digestion of starch in the rumen plus small intestine to starch intake minus fecal starch excretion divided by mean starch indigestibility.

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SITE OF STARCH DIGESTION: IMPACT ON ENERGETIC EFFICIENCY AND GLUCOSE METABOLISM IN BEEF AND DAIRY CATTLE

Kyle R. McLeod*, Ransom L. Baldwin†, VI, Samer W. El-Kadi*, and David L. Harmon*

*Department of Animal and Food Sciences, University of Kentucky

†Bovine Functional Genomics Laboratory, USDA, ARS

kmcleod@uky.edu



SUMMARY

Stoichiometric relationships and controlled infusion experiments clearly show that the efficiency of converting starch energy to tissue energy is enhanced when starch is digested in the small intestine rather than in the rumen. However, limitations in small intestinal starch digestion can prevent realization of this enhanced efficiency at productive levels of starch intake; this is due to incomplete digestion or energy losses associated with large intestinal fermentation. Nevertheless, delivery of starch or glucose to the small intestine increases net PDV glucose flux and glucose entry rate in cattle. In lactating cows, the fraction of the glucose entry rate that is used for lactose synthesis, versus that which is oxidized or incorporated into tissue, appears to be dependent upon the metabolic “pull” of the mammary gland for lactose synthesis and milk production. Alternatively, in growing beef steers, an increased glucose entry rate is associated with adiposity, particularly in the alimentary fat depots. However it is unclear whether this increase in adiposity is due to increased glucose oxidation that spares acetate carbon for lipogenesis, or a direct effect of glucose on the abundance and activity of rate-limiting lipogenic enzymes.

INTRODUCTION

Starch from cereal grains is the primary dietary energy source for highly productive cattle, representing up to 50 and 70% of the ration dry matter for lactating dairy cows and feedlot finishing cattle, respectively. Provided with the capacity to digest starch in both the rumen and intestines, cattle are equipped with the ability to digest large amounts of starch, often exceeding 90% of starch intake (Owens and Zinn, 2005). Although pregastric fermentation in cattle provides an advantage, particularly in forage systems, in that energy is derived from digestion of cellulosic feedstuffs and protein is synthesized from non-protein nitrogen, this advantage is tempered due to fermentative energy losses when high grain diets are fed. In contrast, heat loss associated with small intestinal starch digestion is minimal relative to ruminal and large intestinal fermentation. Estimates of small intestinal starch digestibility are highly variable and are generally indicative of limitations in the capacity to capture energy by cattle consuming high starch diets. Optimization of starch utilization in lactating dairy and growing and finishing beef cattle is impaired by our current inability to precisely predict site of starch digestion, and thus accurately assess the impact of absorption and metabolism of glucose vs. fermentative end products. The goals of this paper are to discuss 1) how site of digestion affects the net energy value of starch, in terms of energy and heat losses associated with starch digestion and subsequent

assimilation of substrate into tissue, 2) the integration of potential differences in energetic efficiency with site-specific capacities to digest starch, and 3) implications of increased glucose supply on metabolism and tissue synthesis by lactating cows and growing beef cattle.

ENERGETIC EFFICIENCY OF RUMINAL AND INTESTINAL STARCH DIGESTION

It generally is maintained that conversion of dietary starch energy to tissue energy is greater if assimilation occurs via intestinal glucose absorption rather than ruminal fermentation and subsequent VFA absorption. However, scientific data that directly supports this contention or quantifies the divergence in energetic efficiency associated with site of starch delivery is sparse. Nevertheless, inferences can be made regarding this divergence based upon estimates of energy or heat losses associated with the individual processes involved in digestion and assimilation of substrate into body tissue. Additionally, in vivo approaches have been used to develop total and partial efficiencies of converting ME supplied from purified carbohydrate sources to body tissue energy.

Methane, an end product of anaerobic fermentation, represents a fraction of carbon that is not available for reconversion into usable substrates by either the microbes or the host animal (Hungate, 1966). Accordingly, methanogenesis, 90 to 95% of

which occurs in the rumen, represents a net energetic loss in the conversion of dietary energy to animal tissues or milk. Based on *in vivo* measures (Blaxter and Clapperton, 1965; Moe and Tyrrell, 1980; Kreuzer et al., 1986) and the stoichiometric relationships between substrates and products (Hungate, 1966; Baldwin et al., 1970), energy losses associated with methane formation range from 3 to 18% of digestible energy. This wide variation is largely attributable to diet composition. Moe and Tyrrell (1980), summarizing data from 404 energy balance trials with dairy cows, reported that the variation in methane production across diets depended largely upon the carbohydrate fractions being digested; energy loss was greater when digestible energy was derived from structural carbohydrate (11-33.6%) rather than from soluble carbohydrate (6.5 %) fractions. These differences in methane formation due to carbohydrate fraction most likely reflect differences in the rumen microflora and in fermentation patterns. Diets rich in fiber support growth of cellulolytic-methanogenic bacteria, whereas diets rich in readily-available carbohydrates (e.g., starch) alter the fermentation pattern so that excess reducing equivalents are consumed for propionate synthesis rather than for reduction of CO₂ to methane. For a typical high-grain feedlot diet, Beever (1993) calculated that 0.38 mole of methane is produced per mole of starch fermented. Based on the heats of combustion of starch (672 kcal/mol) and methane (212 kcal/mol), this is equal to 12% of the DE from starch that would be lost as methane. This value is greater than the value of 8.5% of DE generated in an experiment in which partially hydrolyzed starch was infused into the rumen at a rate of 20% of dietary ME intake (McLeod et al., 2001). Nevertheless, these values indicate that a typical feedlot steer consuming 6.0 kg of starch (25.2 Mcal of intake energy), with a ruminal starch digestibility of 80%, would lose between 1.7 to 2.4 Mcal DE from starch or 6.8 to 9.6% of starch intake energy as methane from the rumen. This loss contrasts with essentially no loss of energy in the form of methane when starch is digested in the small intestine and absorbed as glucose; only negligible amounts of methane are produced in the small intestine (Hungate, 1966). However, given the similarities in fermentation end products between the rumen and large intestine, one would assume that any starch reaching the large intestine would incur a similar energy loss from methane production as that for ruminal fermentation.

Dietary energy also is lost as heat during fermentation as a result of the inefficiency of converting substrates to end products of fermentation. Heat of fermentation is calculated as the difference between the heats of combustion of the substrates used and products formed. Stoichiometric relationships describing the fermentation of starch to a typical ratio of VFA (62 acetate : 22 propionate : 16 butyrate) indicates that 6.4% of the fermentable starch would be lost as heat (Hungate, 1966). This calculation, however, assumes that the microbial mass is static with no capture of hexose energy by the microbiota. Because up to 30% of the hexose may be incorporated by microbial cells (Baldwin et al., 1970), this simple calculation overestimates heat loss to the degree by which hexose energy is incorporated into bacterial cells. However, for starch digested in the rumen, but not in the large intestine, a portion of hexose energy captured in the form of bacterial polysaccharides and amino acids subsequently would be released as heat as a result of bond breakage via enzymatic hydrolysis in the small intestine. Approaches using both *in vitro* and *in vivo* techniques provide estimates of heats of fermentation that range from 3 to 12% of DE from both purified substrates and mixed diets (Blaxter, 1962; Webster, 1980). This large variation and the deviation from stoichiometric estimates likely are due to differences in molar ratios of VFA end products and the precision of the experimental techniques used to quantify heat production. Heat of fermentation of starch in the small intestine is negligible; however, heat is released as a result of glucosidic bond cleavage by host enzymes. Given that the free energy of hydrolysis of glucosidic bonds is 4.3 kcal/mol of starch, it is estimated that heat released from digestion of starch in the small intestine would equal 0.6% of DE (Baldwin, 1968).

Absorption of VFA from the rumen and large intestine of ruminants is primarily a passive process; hence, the energy costs directly associated with absorption are negligible (Rechkemmer et al., 1995). Conversely, small intestinal absorption of glucose occurs via a Na⁺-dependent cotransporter coupled with Na⁺/K⁺-ATPase, an energy dependent process (Shirazi-Beechey et al., 1995). Providing that absorption of 1 mole of glucose (686 kcal) requires the use of 1 mole of ATP (18 kcal), 2.6% of glucose energy would be expended during absorption (Baldwin, 1968).

Aside from direct energy costs attributed to digestion and absorption, indirect costs such as synthesis of proteins necessary for digestion and maintenance of gut mass and cell ion balance must be considered. Estimated rates of digestive protein secretions in the gastrointestinal tract vary from 3.5 to 7.5 g/BW^{0.75} (Baldwin, 1995). Considering the average molecular weight of protein equals 110g / mole of amino acid in protein and 5 ATP equivalents are required per peptide bond synthesized, heat loss associated with the synthesis and secretion of digestive proteins of a 250 kg steer would equal 285 kcal/d or approximately 4% of maintenance energy. Although this cost is significant, the relative difference in the rate or quantity of digestive proteins secreted due to site of starch digestion gut is considered to be small. In contrast, the difference in costs of gut tissue maintenance between ruminal and small intestinal digestion may be substantial. McLeod et al. (2007) demonstrated that supplying ruminal starch at a rate of 20% of the dietary ME increased gut mass; however the increase in mass of the stomach complex was 12% greater than when an equal amount of starch was supplied to the small intestine. Although an increase in gut tissue mass increases heat losses associated with cellular processes such as ion balance and protein turnover, estimating such costs are difficult and it is not clear whether these changes in mass are a linear function of starch supply. Additionally, Richards (1999) demonstrated that hepatic glucose production was lower for beef cattle receiving abomasal versus ruminal starch infusion, implying that dietary glucose is insufficient when starch is digested in the rumen. Thus, additional metabolic costs of converting gluconeogenic carbon into glucose for essential function or lactose synthesis could also be considered. These costs range from 4% of the energy derived from propionate to 12% of the energy derived from glucogenic amino acids. Nevertheless, excluding indirect cost, stoichiometric relationships indicate that energetic losses associated with starch digestion and subsequent glucose transport in the small intestine equal 3.2% of starch DE or approximately 15-20% of the energy loss incurred if the starch were fermented in the rumen. These same relationships show that losses associated with ruminal fermentation of starch are only about 50% of those that would be incurred with glucose fermentation in the large intestine due to flow and subsequent digestion of bacteria in the small intestine.

The efficiency of converting energy from starch fermented in the rumen or digested in the small intestine to tissue energy is difficult to assess based on feeding studies with grain. Starch from grain is not digested in only one location within the digestive tract. Therefore, one cannot quantitatively deliver dietary starch to specific organs for digestion. To circumvent this problem, we infused a partial cornstarch hydrolysate into either the rumen or the abomasum of growing beef steers (McLeod et al., 2001). Steers were fed a basal forage diet at 1.5 times maintenance energy requirements; starch hydrolysate was infused at a rate of 20% of total ME intake [12.6 g/(d⁻¹ kg BW^{0.75})]. The partial efficiency (K_r) of converting ME from starch to tissue energy was calculated as the increase in retained energy above the basal diet divided by the ME supplied by the infused starch. Thus, K_r reflects both direct and indirect heat losses associated with digestion, absorption, and assimilation of substrate into tissue. Our K_r estimates averaged 0.48 and 0.60 for ruminally and abomasally infused starch, respectively. These K_r values are somewhat lower than those determined previously with sheep for ruminally-supplied (0.55) and abomasally-supplied (0.72) glucose (Armstrong et al., 1960). However, the relative increases in K_r observed (25 and 31%) for abomasal versus ruminal starch or glucose supply are reasonably consistent between studies. Branco et al. (1999) determined that 88% of duodenally-infused cornstarch hydrolysate disappeared from the small intestine of steers. Because we used a similar rate of infusion in our energy balance experiments, some of the abomasally-infused starch in our experiment may have escaped small intestinal digestion to be fermented in the large intestine. Adjusting the data set by 0.88 creates a theoretical maximum K_r value for small-intestinally supplied starch of 0.68. Therefore, the actual K_r value for small intestinally-supplied starch probably falls between the observed 0.60 and the calculated maximal value of 0.68. Based on these partial efficiencies, and an average loss of 10% of DE for methane formation, the total energetic efficiency of ruminally-fermented starch is only 65 to 72% of that for starch digested in the small intestine. Although the magnitude of the total energy loss seems greater, the differences in these efficiencies agree reasonably well with differences based on stoichiometric relationships of substrates and products and the cost of absorption. Therefore, both approaches indicate that accurate prediction of the energy values of cereal grains

requires quantitative data describing starch digestion in terms of the extent of digestion in the rumen, small intestine, and large intestine.

INTEGRATION OF ENERGETIC EFFICIENCY AND DIGESTION LIMITS

Cattle are efficient at and have high capacity for digesting starch from cereal grains. Owens and Zinn (2005) summarized results from published and unpublished trials that measured site and extent of starch digestion by lactating dairy and feedlot beef cattle. Across grain types and processing methods, total tract starch digestibility averaged 92% and 98% for lactating dairy and feedlot cattle, respectively. However, based on the calculations of energetic efficiency presented above, the net energy value of starch from grains can vary not only due to the extent, but also due to the site of digestion. Several excellent reviews have been published that discuss the capacity for and factors that affect ruminal and intestinal starch digestion by cattle (Huntington et al., 1997; Harmon and McLeod, 2001; Harmon et al., 2004; Owens and Zinn, 2005; Huntington et al., 2006); the reader is referred to these reviews for detailed discussions. This paper will briefly discuss potential limitations to starch digestion in the rumen and small intestine and how these limitations impact the net energy value of starch from cereal grains.

Using a data set generated from 16 published studies conducted in beef cattle ($n=79$) consuming 1 to 5 kg of starch per day supplied from varying sources of grain (corn, sorghum, and barley), Harmon et al. (2004) demonstrated a linear relationship between starch intake and ruminal starch digestion with a slope (i.e., digestion coefficient) of 0.77. This approach also revealed variation in ruminal starch digestion due to source of grain, with digestibility being higher for corn-based diets (0.80) than for sorghum-based diets (0.75). However, these authors found no relationship between starch intake and ruminal digestibility, indicating that ruminal starch digestion was not limiting, at least within the starch intake parameters of the data set. Owens and Zinn (2005), summarizing data from 49 trials, showed that ruminal digestibility of starch from corn, in both lactating dairy and feedlot beef cattle, was increased by processing corn with added moisture, mechanical pressure, and/or heat. When averaged across processing method and weighted by the number of observations, ruminal digestibility of starch from corn

in beef cattle was identical between the data sets (80%) used by Harmon et al. (2004) and Owens and Zinn (2005). In contrast to beef cattle, Owens and Zinn (2005) further reported that the ruminal fraction of total tract starch digestion that occurs in the rumen is substantially lower in lactating dairy cows. Again, averaged across processing method by using weighted means from the data set of Owens and Zinn, an average ruminal digestibility of 55% was calculated for starch from corn in lactating cows. It is unlikely that the lower ruminal starch digestibility by lactating dairy cows relative to beef cattle reflects a lower fermentation capacity, but rather a decreased rumen retention time due to higher feed or NDF intake, or to anatomical differences in the reticulo-omasal orifice (Owens and Zinn, 2005).

Postruminal starch digestion includes digestion in both the small and large intestines. As previously described in their summary of studies in beef cattle where intestinal starch digestibility was measured, Harmon et al (2004) reported that the digestibility of starch entering each segment averaged 62% and 47% for the small and large intestines, respectively. Additionally, these authors applied linear regression to the data and found a reasonable relationship between starch entering the large intestine and large intestinal digestion (slope = 0.44). In contrast, the linear fit for small intestinal entry and digestion was comparatively low ($r^2=0.36$; slope = 0.40), which reflects a tendency for small intestinal digestibility to decline at a higher starch intake. In an effort to further define the relationship between starch entry and digestion in the small intestine, these same data were subsequently fit to a nonlinear kinetic-based model (Huntington et al., 2006). Output from this model showed that the capacity for the small intestine to digest starch approached an upper asymptote between 600 and 700g/d. As a consequence, small intestinal digestibility was predicted to decrease from approximately 85% to 44% as the amount for starch entering the small intestine increased from 300 to 1,500 g/d. Parallel data describing intestinal starch digestion in lactating cows is extremely limited; however, similar limitations in digestion would be expected. Limitations in small intestinal starch digestibility have been ascribed to particle size or physiochemical properties of intact starch, insufficient pancreatic α -amylase and/or brush-border carbohydrases (Owens et al., 1986; Harmon et al., 2004). Conversely, low digestibility of starch in the

large intestine probably reflects the fact that starch particles, having resisted digestion in the rumen and small intestine, inherently are resistant to digestion.

Based on these capacity estimates of starch digestion in cattle, maximal net energy value of cereal grain is limited by small intestinal starch digestibility. Case-in-point, using a ruminal starch digestibility coefficient of 0.80 and the kinetic model of Huntington et al. (2006) to predict small intestinal digestibility, a feedlot steer consuming 5 kg of starch would have a postruminal starch flow of approximately 1200g/d. Of this amount only 50% would be digested in the small intestine, leaving 600 g to flow to the large intestine. Because of this large flow of starch to the large intestine and its associated energy losses, any advantage in energetic efficiency achieved by digesting starch in the small intestinal digestion relative to the rumen is lost. Huntington et al. (2006), using a simulation model, demonstrated that shifting starch digestion from the rumen to the small intestine would increase energy yield only when small intestinal digestibility exceeds 75%. Therefore, in order to capitalize on the energetic efficiency of shifting starch digestion from the rumen to the small intestine, starch flow to the large intestine must be minimized.

SMALL INTESTINAL STARCH DIGESTION AND GLUCOSE METABOLISM

Typically ruminants obtain the majority of their glucose supply from hepatic gluconeogenesis, which is derived primarily from propionate (43 to 77%) and amino acid (10 to 30%) carbon. One putative advantage conferred by postruminal digestion of grain starch is an increase in glucose absorption or a decreased need for de novo synthesis of glucose to meet demands of production. Indeed, Amaral et al. (1990) reported that the fractional contributions of propionate to hepatic glucose output decreased when dairy cows were infused intravenously with glucose. Data from experiments using short-term intravenous or intra-duodenal infusions of glucose would support this contention in that endogenous glucose synthesis was decreased (Bartley and Black, 1966; Leng, 1970). Relative to water infusion, long-term abomasal infusion of wheat starch (1200g/day) increases PDV appearance of glucose without decreasing hepatic output (Reynolds et al., 1998). Furthermore, in growing beef steers infused with 800 g of partially hydrolyzed starch ruminally or abomasally, net

increases in glucose absorption and total splanchnic output were observed for abomasal vs. ruminal infusion (Richards, 1999). Accompanying the observed increase in glucose supply, Richards (1999) found an increase in both glucose entry rate (i.e., rate of appearance and utilization under steady state conditions) and in peripheral utilization of glucose. Based on these findings, one would expect that an increase in the quantity of starch digested in the small intestine would be accompanied by an increase in glucose utilization.

Although glucose entry rate apparently is increased with small intestinal starch digestion, subsequent production responses have been mixed and dependent on productive state, reflecting a complex interaction between productive tissues, endocrine controls, and nutrient supply. When glucogenic precursors (ruminal propionate or duodenal glucose) each were infused at two different rates (1.72 or 3.45 Mcal NE_L/d), Lemonsquet et al. (2004) detected an increase in glucose appearance that exceeded the increase in lactose synthesis in early lactating dairy cattle. In contrast, Reynolds, (2001) reported that with late lactating dairy cattle, an abomasal infusion of 1200g/d wheat starch did not increase milk energy output when compared to water-infused controls. In that same report, Reynolds (2001) infused incrementally increasing amounts of corn starch (700, 1400 and 2100 g/d) in early lactating dairy cattle and observed that milk energy output increased only at the highest rate of starch infusion. Moreover, across these studies, the increase in milk energy output with increased postruminal supply of starch represented only a small portion of the increase in ME from the infusate. Thus, the balance of energy from glucose must either be oxidized or used for tissue gain. Supporting this observation, abomasal infusion of partially hydrolyzed starch (1.5 kg/d) relative to ruminal infusion (1.5 kg/d) increased glucose entry rate but did not affect lactose synthesis, thus resulting only in a tendency for milk yield of mid-lactation dairy cows to increase (Knowlton et al., 1998). Abomasal infusion of starch did increase the fraction of carbon dioxide that was derived from glucose. Taken together, this indicates that under normal physiologic conditions with adequate energy supply, the quantitative supply of glucose does not appear to limit milk production. However, at high levels of milk production, the fraction of glucose entry that appears in lactose increases, while the fraction

oxidized to carbon dioxide decreases (Baumann et al., 1988).

In growing beef steers, we demonstrated that both ruminal and abomasal infusion of partially hydrolyzed starch at a rate of 20 % of the ME supply increased retained tissue energy above that observed for the basal forage diet alone, with greater retention from abomasal rather than from ruminal starch delivery (McLeod et al., 2001). Partitioning of the increased retained tissue energy, using C-N balance techniques, revealed that retained energy deposited as protein and lipid comprised 30 and 70% for ruminally-infused energy compared to 16 and 84% for abomasally-infused energy. After accounting for protein accretion, the increase in tissue energy retention from abomasal as compared with ruminal infusion of starch was accounted for solely as adipose tissue. In a subsequent terminal experiment using the same infusion model, McLeod et al. (2007) further confirmed the stimulatory effect of abomasal starch delivery on adipose accretion in growing beef steers. Specifically, the absolute and relative amounts of alimentary fat mass were greater following infusion of starch abomasally as compared to ruminal infusion. Because an isoenergetic glucose infusion treatment was included in this experiment, it was apparent that the increase in abdominal adiposity was exacerbated by compared to starch infused abomasally. It is unclear whether this reflects a difference in energy supply to the tissues or in glucose entry rate.

In an effort to further examine the functional response of the mesenteric, omental, and subcutaneous adipose depots to intestinal carbohydrate infusion by growing beef steers, we collected adipose samples following the 35 d infusions from the aforementioned steers for ex-vivo analysis of lipogenic and lipolytic activity (Baldwin et al., 2007) as well as analysis of lipogenic enzyme and adipose regulatory protein gene expression (Baldwin, 2006). Lipolytic rates were largely unaffected by infusion treatment. However, incorporation rates for both acetate and glucose into fatty acids were greater for

adipose tissues harvested from steers abomasally-infused with either glucose or starch compared with those receiving ruminal infusion (Baldwin et al., 2007). Similar to the observed mass changes, incorporation of lipogenic substrate was greater with abomasal infusion of glucose than of starch (McLeod et al., 2007). However, given that the rate of glucose incorporation was only a fraction of that observed for acetate, it seems unlikely that direct incorporation of glucose carbon into adipose is responsible for the increased adiposity. Although insulin has been shown to increase the uptake of glucose and acetate by muscle and adipose tissue, these actions are permissive; the major role of insulin in adipose accretion in ruminants is mediated via antilipolytic actions rather than by stimulation of fatty acid synthesis (Brockman, 1986). In our experiment, circulating insulin concentrations were not changed by carbohydrate infusion treatment at the end of the 35 d treatment period (Baldwin et al., 2007). Therefore in the absence of a change in circulating insulin concentrations, it seems likely that an increase in the glucose supply stimulated lipogenesis independent of insulin, by either sparing acetate carbon for de novo lipogenesis and/or directly stimulating lipogenic gene expression. In support of the latter idea, glucose has been shown to stimulate expression of lipogenic enzyme mRNA (Fatty Acid Synthetase and Acyl-CoA Carboxylase) in rat adipose tissue via elevation of intracellular glucose-6-phosphate concentrations (Girard et al., 1997). Moreover, abomasal glucose infusion induced increases in the transcription of genes encoding for lipogenic regulatory nuclear proteins including: carbohydrate response element binding protein, sterol regulatory element-binding protein 1, and Spot 14, as well as their established targets - FAS and ACC (Baldwin et al., 2006). However, more research is necessary to ascertain the exact mechanism(s) responsible for stimulation of adipose accretion observed with abomasal carbohydrate infusion and to discern whether this increase in adiposity depends specifically to carbohydrate or to other energy sources and whether it applies to grain feeding programs.

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QUESTIONS AND ANSWERS

- Q:** Kyle, you mentioned that starch digested in the lower GI tract may increase the amount of omental fat. Would you elaborate on the mechanism?
- A:** We don't know the mechanism. Think about the kid drinking soda pop at school; he is likely to have a big waistline. In studies where we have increased the amount of circulating glucose, we have seen a similar response. Glucose may have a direct effect. We may be increasing the expression of nuclear regulatory proteins that have been shown to increase fatty acid synthesis; these are prominent in omental fat. Perhaps omental fat is less insulin dependent than other tissues or its anatomical location allows more direct use of absorbed glucose.
- Q:** Kyle, as you increase glucose supply to the small intestine, the additional energy appeared in fat. What depots were affected primarily?
- A:** In our slaughter experiments, we saw some increase in subcutaneous fat, but the fat depth measurement was not very quantitative. In the alimentary fat, where we have separated the adipose depot into omental and mesenteric fat, the increase is in the omental fraction and not the mesenteric. Whether this is based on our method of separating these fractions or if there is truly a difference in metabolism of omental and mesenteric fat is not known.

COMPARING COST VERSUS BENEFITS OF CORN PROCESSING FOR FEEDLOT CATTLE

Thomas M. Peters

Superior Attitude Livestock Technology, LLC

tpfdlot1@essex1.com



SUMMARY

Corn processing techniques differ in their effects on feedlot performance and carcass characteristics of finishing cattle. Capacity of a feedlot (critical mass) can dictate which processing method is most feasible economically due primarily to fixed costs for equipment. The local and regional corn pricing basis and availability of other ration ingredients also can influence which corn processing equipment/methodology is preferred at different feedlots. Energy cost also will have a major impact on choice of grain processing techniques. The preferred corn processing technique also may differ when ethanol by-products are included in the finishing diets of feedlot cattle. Processing costs were compared with cattle performance benefits based on published data summaries. Processing costs adjusted to a bushel of #2 corn (85% DM) were \$0.03, \$0.05, -\$0.11, and \$0.20 per bushel for dry-rolled corn (DRC), finely-ground corn (FGC), high-moisture corn (HMC), and steam flaked corn (SFC), respectively. Steam flaked corn was the only processing method economically feasible to apply to finishing feedlot cattle diets when using traditional feedlot diets, applying modern processing and energy costs. However, when processing techniques were applied to feedlot diets including corn ethanol by-products, HMC, a combination HMC/DRC, or DRC yielded superior economic returns when compared to SFC. With the rapid expansion of the ethanol industry, an examination of grain processing techniques and costs may be justified, especially with increasing energy costs/inputs.

INTRODUCTION

Corn processing techniques have been evaluated ardously for many years. In fact, most feedlot cattle expansion in the United States has occurred where grain is readily available; new and improved economically viable processing techniques have evolved and been adopted readily during this expansion. Basically, corn is processed to increase starch availability from the corn kernel; this improves energy availability and feed efficiency through benefits in terms of increased daily gain while realizing enhanced carcass value and thus impacting economic returns. Some of these parameters cannot be measured until the cattle have been harvested. Measurements that can be taken during the growth period of cattle (pre-harvest) include daily dry matter intake, fecal starch concentration, manure scores, and incidence of metabolic disorders. Roughage inclusion rate and particle size of the roughage may have a profound impact on the relative value of different grain processing techniques. Most researchers and nutritionists recognize that other ration components also can have a profound impact on the associative affects of feeds and can interact with grain processing techniques. Finally, selection of a processing technique also needs to consider environmental impacts, cattle in-weight, and total days on feed.

A plethora of excellent reviews have examined cattle performance responses to various corn processing techniques (Owens et al., 2005, Zinn et al., 2002, Owens et al., 1997, Huntington., 1997). These reviews generally recognize that other components of the diet, specifically roughage quantity and source, can alter the benefit from a specific grain processing technique. Less information is available that contrasts these benefits of corn processing against the costs of processing. Only by making such a comparison can the cost:benefit ratio of a grain processing method be properly evaluated. Costs associated with grain processing often are a major component that determines the economic viability of an individual feedlot. Once a grain processing technique is selected, investments in grain processing equipment can be huge and it becomes difficult and costly to make major changes. Only with a newly established feedyard or during feedlot expansion can processing procedures be freshly evaluated or altered. Factors that can predicate changes in grain processing method include some alteration in source and availability of grain or grain substitutes, in cost of the grain relative to cost of processing, and in cost of other inputs including energy, labor to operate equipment, and equipment maintenance costs.

Most finishing cattle on feed in the U.S. are fed steam-flaked corn, so steam flaking is the industry standard. The second most prevalent processing method is dry-rolling, and third would be high-moisture corn or some combination of high-moisture with dry-rolled corn. This paper will focus on corn as the grain source and its processing costs and resulting efficiencies.

The number of ethanol plants continues to expand, especially plants that use corn as a substrate. One by-product of the ethanol milling process is wet distillers grains plus solubles (WDGS). Because ethanol plants extract most of the available starch from the corn, the resulting WDGS has little starch. Many feedlots in the ethanol belt (also known as the corn-belt) include WDGS at approximately 30% of the dry matter of finishing cattle diets. It is not the objective of this paper to evaluate the optimal inclusion rate of WDGS, but rather to suggest that 30% (DM basis) WDGS is the current industry standard (Vander Pol et al., 2006). When feedlots substitute WDGS for 30% (DMB) of the dietary grain, starch content is decreased markedly. Many researchers have questioned if greater processing of corn (e.g., fine-grinding) is justified when WDGS can be included into finishing diets due to the low starch content of such diets. Obviously, processing can be increased, but greater processing increases the cost of processing.

With ethanol plants now competing for corn, cost of corn as a livestock feedstuff has increased. This competition has drastically increased the price of corn within the United States. With energy prices beginning to influence the price of corn, the concurrent costs associated with drying high-moisture corn versus ensiling becomes a pertinent questions. Historically, the grain industry had created a large negative price basis for corn within the ethanol belt. Drying costs are currently high enough (\$0.04-0.05 per point of drying to 85% dry matter; Peters-personal information, 2006) to encourage feedlots to offer corn producers a dockage of only \$0.02 per point of moisture. Thus, HMC often has been priced favorably for use by feedlots as the grain source in finishing cattle diets.

Macken et al. (2006) discussed the efficiencies of scale and operational differences in constructing and operating various corn processing facilities. These investigators discussed the initial costs and daily costs

to process corn using SFC, DRC or HMC. They recognized that critical mass (amortization of processing equipment assets related to size of feedyard) is an important consideration for determining the processing system preferable for each feedlot. Variable costs such as natural gas, electric rates and labor costs also will influence the choice of processing equipment and the degree of corn processing.

The objective of this paper is to combine current processing costs with previously published cattle performance responses from various processing techniques and compare economics. The paper is an attempt to consider parameters appropriate for a minimum size feedlot of 5-10,000 head capacity for DRC, FGC or HMC. Steam flaking is not considered because to justify the initial capital requirements for a steam flaked system, a feedlot would need to have at least 20,000 head to create positive economic returns. Economic efficiencies and comparisons for these differing corn processing systems will be compared based first for traditional finishing diets (devoid of by-products) and secondly for finishing diets containing 30% WDGS.

MATERIALS AND METHODS

High-Moisture Corn

Although numerous variables are involved with ensiling of HMC, modern equipment has markedly reduced the costs associated with harvesting, processing and storage. Owens et al. (2006) states that the preferred moisture content for corn for maximum feed efficiency and ruminal starch digestion, coupled with sufficient fermentation duration, is 26-31% moisture. For simplicity, HMC will be indexed at 30% moisture. Modern HMC management practices would include application of a fermentation inoculant and processing of kernels to about 1200 to 1550 micron geometric mean diameter (moderate rolled). Storage methods used across the feedlot industry for HMC vary substantially from upright silos, plastic storage bags, bunker silo's, to flat drive-over piles. The economic analysis for HMC storage will include plastic covered, bunker style storage using split tires holding down the plastic. Many feedlots have advanced to drive-over piles of HMC that are adequately packed but devoid of concrete sidewalls. These drive-over piles allow greater flexibility in the amount of corn and depth of

pile and reduced cost of the storage area. Labor requirements for ensiling HMC are intense during harvest times. HMC must be received, processed,

packed, and covered in a short time period to insure optimal fermentation and reduce DM loss.

Table 1. Pricing high-moisture corn vs. dry corn by the bushel and ton

Base price, \$/bushel	\$3.00	\$3.00	\$4.00	\$4.00
Moisture	15%	30%	15%	30%
With moisture discount, bu ¹	\$3.00	\$2.47	\$4.00	\$3.29
With elevator discount, bu ²	\$2.81	\$1.51	\$3.81	\$2.30
With feedyard discount, bu ³	\$3.00	\$2.00	\$4.00	\$2.79
With moisture discount, ton	\$107.14	\$88.24	\$142.86	\$117.65
With elevator discount, ton	\$100.36	\$53.75	\$136.07	\$81.96
With feedyard discount, ton	\$107.14	\$71.25	\$142.86	\$99.46

¹Moisture discount = 1.4% per point.

²Elevator discount = \$0.11/bu. Storage charge, \$0.08/bu. In/Out charge, and \$0.045/point drying charge.

³Feedyard discount = \$0.025/point drying charge, no In/Out or storage charge.

Pricing often is the most attractive attribute of high moisture corn. In the ethanol belt, many people grow and harvest large tracts of corn land, and the advantages from earlier harvesting corn (30% moisture HMC) are numerous. Harvesting of HMC can begin when drying the grain to #2 yellow corn (85% DM), would be cost prohibitive. As seen in Table 1, large shrink, drying costs and storage charges are associated with drying corn. In times of low corn prices (below loan rate economics), earlier harvest (30% moisture) usually allows crop farmers to take advantage of the USDA-Loan Deficiency Payment (LDP) because early harvest often is associated with lower cash corn prices. Earlier harvest of corn also expedites the entire harvest process and reduces losses of grain due to shattering, lodging of plants, and ear drop. Parameters 1 describes charges terminal elevators associate with grain delivery. Although it is difficult to set up a long term pricing strategy for feedlots to purchase HMC, the advantages usually out-weigh the disadvantages. Disadvantages associated with purchasing large quantities of HMC

include basis negotiations, carrying costs, additional moisture added to diets, and convenience factor for delivery and processing and pricing strategies (parameters 2) to name a few. However, the positive attributes associated with purchasing HMC often reaps huge economic benefits. Shown in Table 2, HMC provides an 11-cent per bushel advantage for the feedlot over processing costs when the parameters described in pricing are included. This economic advantage obviously is obtained most easily obtained when a feedlot is situated within a corn growing area.

Parameters 1. Corn pricing at terminal markets

Common elevator charges for 2006

1. Basis irregularities and variation!
2. Storage charges: 1 – 100 days is \$0.11/bu
3. In/out charges (handling) is \$0.08/bu
4. Adjusted to 84.5% dry matter
5. Shrink is 1.4 to 1.5%
6. Drying costs averaged \$0.045 per point
7. Delivery costs and time is expensive

Parameters 2. Negotiated basis & timing of pricing for high-moisture corn

1. At harvest: Large positive basis over locals
2. December 15 (or river freeze): Small positive basis over locals
3. On Dec. 15th for March board (and payment) is local basis (no storage cost)
 - ONE HAF DRYING COST CHARGE on 26 – 32% moisture, $\frac{3}{4}$ cost on 18 – 26, full drying costs on >32 moisture
 - 1.4% shrink, no storage or in/out charge

Table 2. Corn processing costs for a 10,000 head (DRC, FGC, HMC) or 20,000 head (SFC) feedlot¹

Item	DRC	FGC	HMC	SFC
Fixed Costs				
Dep. & Int.	0.63	0.84	1.08	0.62
Insurance	0.02	0.02		0.02
Taxes	0.01	0.02	0.03	0.02
Total fixed costs	0.66	0.88	1.11	0.66
Variable costs				
Labor	0.38	0.60	1.41	0.52
O&M	0.15	0.25	2.35	0.64
Natural gas				4.32
Electricity	0.05	0.06		1.06
Yearly storage			5.32	
Moisture discount			-16.99	
Carry costs			2.82	
Total variable costs	0.58	0.91	-5.09	6.55
Total cost per U.S. ton (as-fed basis)	1.24	1.79	-3.98	7.21
Total cost per U.S. ton (dry matter basis)	1.46	2.11	-4.68	8.48
Total cost per bushel, No. 2 yellow corn	0.03	0.05	-0.11	0.20

¹DRC, dry rolled corn; FGC, fine ground corn; HMC, high-moisture corn; SFC, steam flaked corn.

^aCorn dry matter percentage: DRC, 85; FGC, 85; HMC, 70; SFC, 80.

Adapted from Macken et al., 2006.

Dry-rolled Corn and Finely Ground Corn

Except for feeding corn whole, dry rolling is probably the easiest processing methodology to include in feedlot operations. Advantages for utilizing DRC include simplicity of the technique and management and low investments in equipment. Corn can be purchased and inventoried on a “just-in-time” basis. Equipment commonly includes either a single or double stack roller mill. Although feedlots will use different techniques to reduce shrink or temper corn prior and during the rolling process, transfer and processing loss (shrink) is estimated commonly to be about 1.5% of the corn weight. Processing corn through a roller mill requires an initial investment in bins, grain legs, reception pits and other grain handling equipment. Difficulties associated with

DRC include constant monitoring of rolls and of particle size to obtain a uniform or desired particle size, particularly if grain is finely ground (<800 microns). Many dairy operations that include high roughage content (more than 45%) into diets process corn as FGC. Feedlots that include by-products low in starch content, specifically wet gluten feed or WDGS, can safely feed FGC. However, Tables 3 and 4 both show that feedlot performance is poorer for FGC as compared with corn processed more coarsely when diets contain 30% WDGS. However, feedlots continue to investigate the potential for including FGC into diets containing WDGS and include roughage levels over 10% of diet dry matter. Limitations for FGC include the extra electricity inputs and slower processing throughput.

Table 3. Distillers grains & grain processing

Item ²	Processing ¹					
	FGC	SFC	HMC	DRC/HMC	DRC	WC
DMI, lb/d	20.4	20.4	21.0	21.5	22.6	23.1
ADG, lb	3.38	3.59	3.89	3.91	4.05	3.85
F:G	6.15	5.76	5.46	5.61	5.68	6.07
HCW, lb	801	821	852	854	870	849
% Choice	46.1	48.3	65.0	62.4	63.5	60.0
YG	3.06	3.22	3.37	3.30	3.62	3.49

¹FGC, fine-ground corn; SFC, steam-flaked corn; HMC, high-moisture corn; DRC, dry-rolled corn; WC, whole corn.

²DMI, dry matter intake; ADG, average daily gain; F:G, feed to gain ratio; HCW, hot carcass weight; YG, yield grade.

All diets contained 30% wet distillers grains (dry matter basis) and 61.4% corn.

Steers fed 168 days, initial weight = 701 lb.

Vander Pol et al., 2006 Nebraska Beef Report.

Table 4. Wet distillers grains & grain processing based on feed:gain¹

FGC	SFC	HMC	DRC/HMC	DRC	WC
% Improvement					
-1.3	+5.1	+10.1	+7.6	+6.4	--- ^a
-2.1	+8.3	+16.4	+12.4	+10.4	--- ^b

¹FGC, fine-ground corn; SFC, steam-flaked corn; HMC, high-moisture corn; DRC, dry-rolled corn; WC, whole corn.

^aExpressed as % above WC, calculated for entire diet.

^bExpressed as % above WC for the corn fraction only (61.4% of the diet).

Vander Pol et al., 2006 Nebraska Beef Report.

Steam-flaked Corn

Steam-flaked corn results in performance advantages when included in diets that do not contain WDGS. This advantage has been documented in numerous grain processing reviews; as compared with dry whole corn the improvement in feed efficiency is 11 to 12%. Zinn et al., (2002) examined various corn processing techniques and compared efficiency of feedlot cattle fed these diets. Compared to whole corn, SFC improved cattle performance efficiency by 12%. Efficiencies with dry rolled corn and FGC were 5% or 0.2% poorer than for whole corn in finishing cattle diets. As previously stated, most large commercial feedlots steam-flake their corn. Flake density (bushel weight) preference varies among feedlots and processing facilities. Owens et al. (1997) reported that medium flakes (24-29 pounds/bushel) offered improved feed efficiency despite lower DMI and ADG when compared to finer flakes (<23 pounds). For the sake of comparing economic advantages or disadvantages of processing corn, as in this paper, I assumed that SFC had a density of 26 to 28 pounds per bushel.

Vander Pol et al. (2006; tables 3 and 4) reported that SFC included into diets containing 30% WDGS improved finishing F/G when compared to whole dry corn (WC) by 5.1% but the efficiency was not improved as dramatically as with HMC, a DRC/HMC combination, or DRC (10.1%, 7.6% and 6.4%, respectively).

Steam-flaking corn is a very energy intensive process. Equipment for steam flaking includes a grain handling set-up similar to that for DRC plus a stainless steel steam chest to cook the corn (2 steam chests for a 20,000 feedlot). Flake density must be monitored, so processing is more intensive than other processing techniques. Natural gas requirements are substantial for steam flaking corn or other grains. Macken et al. (2006) described the economic inputs for operating a steam flaking unit and their values were adjusted to current (2006) energy costs. Each feedlot has a different critical mass, energy cost, and operational efficiencies for processing grain.

Parameters 3. What are current corn processing costs?

- Comparing 20,000 head feedlot using steam flaking equipment to 10,000 head feedlot using high-moisture corn or dry rolled corn
- Current electric costs of \$0.07 per kilowatt hour
- Current natural gas costs of \$10.15/1000 ft³ (November 2006)
- Dry rolled corn is > 1800 microns
- Finely rolled corn = 800 microns
- Labor at \$15.00/hour
- Rolling stock at \$40 per hour

Costs

The input costs associated with differing processing procedures are described in parameters 3 and incorporated into Table 5. Costs used were seven cents per kilowatt-hour for electricity and \$10.15/1000 cubic feet of natural gas (November, 2006 Wall Street Index). Many feedlots have negotiated “peak-shaving” electric rates or a kilowatt hour (kWh) rate that may be substantially less than \$0.07 cents per kWh. Likewise, natural gas rates currently are relatively high and some feedlots negotiate or contract for gas at a “quantity discount” use rate. When these inputs were incorporated into the model generated by Macken et al. (2006) and all processing types were equalized to 85%DM #2 Yellow corn basis, the costs for processing become transparent. Granted, each

individual feedlot will use a different depreciation schedule and this will alter the processing costs.

Prices for equipment also will vary depending on the initial investment cost, the depreciation schedule, and operation and maintenance costs (O&M). Relative costs for construction and upkeep must be benchmarked to realistically compare with animal efficiency differences. As observed in Table 6, the total cost for processing per bushel #2 yellow corn was \$0.03, \$0.05, -\$0.11, and \$0.20 for DRC, FGC, HMC and SFC, respectively. The negative price for the processing cost of HMC is derived from the purchase price advantages shown in parameters 1 and 2.

Table 5. Value of processing corn in rations without by-products (\$3.00 or \$4.00 per bushel)¹

	FGC	SFC	DRC	WC
\$3.00 Corn				
% Increase	(0.2)	12.0	(5.0)	0
Value (\$)/bushel	2.99	3.36	2.85	3.00
\$ Proc/bushel	0.05	0.20	0.03	0
Net \$/bushel	2.94	3.16	2.82	3.00
\$/1000 head	(3,942)	10,512	(11,826)	0
\$4.00 Corn				
Value (\$)/bushel	3.99	4.48	3.80	4.00
\$ Proc/bushel	0.05	0.20	0.03	0.00
Net \$/bushel	3.94	4.28	3.77	4.00
\$/1000 head	(3,942)	18,396	(15,111)	0

¹Based on 550# of gain & 65.7 bushels per head; FGC, fine ground corn; SFC, steam flaked corn; DRC, dry-rolled corn; WC, whole corn. Adapted from Zinn et al., 2002.

The value of processing corn is calculated (Table 5) for the various methods by comparing the efficiency improvements summarized by Zinn et al. (2002). These economic values greatly favor SFC when incorporated into feedlot diets without by-products. These economic benefits are compared at

various corn prices in the table. The economic advantage of SFC is magnified when the price of corn increases. In simple economic terms, the 12% improvement in cattle efficiencies far out-weighs the high cost of flaking when compared to DRC or FGC. The negative economic effects of converting whole

corn to DRC and FGC are magnified when the price of corn increases.

Table 6. Value of processing corn in rations with wet distillers grains (\$3.00 & \$4.00 per bushel)¹

	FGC	SFC	HMC	DRC:HMC	DRC	WC
\$3.00/bushel						
% Increase	-2.1	8.3	16.4	12.4	10.4	0
Value (\$)/bu	2.94	3.25	3.49	3.37	3.31	3.00
\$ Proc/bushel	0.05	0.20	(0.11)	(0.08)	0.03	0.00
Net \$/bushel	2.89	3.05	3.60	3.45	3.28	3.00
\$/1000 head	(5,243)	2,274	27,933	20,973	13,085	0
\$4.00/bushel						
Value (\$)/bu	3.92	4.33	4.66	4.50	4.42	4.00
\$Proc/bushel	0.05	0.20	(0.11)	(0.08)	0.03	0.00
Net \$/bushel	3.87	4.13	4.77	4.58	4.39	4.00
\$/1000 head	(6,218)	6,125	35,542	26,726	17,910	0

¹FGC, fine-ground corn; SFC, steam-flaked corn; HMC, high-moisture corn; DRC, dry-rolled corn; WC, whole corn. Based on 550# of gain & 46.4 bushels per head.

Adapted from Vander Pol et al., 2006 Nebraska Beef Report.

When processing costs are calculated for feedlot diets that include WDGS at 30% DM, the economic values change greatly based on the lower value of flaked corn when fed with WDGS (Table 6, adapted from Vander Pol et al., 2006). Compared with the large mass of research information available for diets without WDGS, value of processing methods with diets containing 30% WDGS is rather limited. Nevertheless, based on these data, feed efficiency was improved by 10.1%, 7.6%, 6.4%, 5.1%, and (-1.3%) for HMC, DRC/HMC, DRC, SFC and FGC, respectively. Table 6 compares the value of these processing methods with corn at various prices. These results differ markedly from the calculations with no WDGS in the diet. When WDGS is included in diets, HMC as the grain source provides an overwhelming economic advantage. All processing techniques appear justified when compared to whole corn (WC) with the exception of FGC and SFC. Processing to form HMC, DRC/HMC and DRC are viable and economically beneficial techniques regardless of the purchase price of corn. However, flaking appears justified when corn purchase price exceeds \$3.00 per bushel when diets contain 30%WDGS. Because efficiency advantages will differ depending on numerous factors, e.g., flake density, moisture content of HMC, further trials evaluating processing responses in diets containing WDGS are needed.

IMPLICATIONS

The cattle industry processes corn grain by various techniques primarily to improve starch utilization by feedlot cattle. When cattle are fed in areas where WDGS is not available or economically feasible to incorporate into diets, SFC is the method of choice. The improvements in efficiency for SFC far outweigh the cost associated with the processing technique and the economic benefit or detriment of processing grain is magnified when grain price increases. However, in studies where WDGS has been included in the diet, results indicate that HMC is the economically preferred processing technique. Numerous additional costs associated with these different processing techniques need to be carefully analyzed when constructing and operating or when expanding a feedlot. Operation and management costs may outweigh the cattle performance benefits realized with certain processing methods. As electric costs and natural gas costs fluctuate in price, feedlots should consider whether processing techniques should be altered. Although the quantified animal energy improvements differ among processing techniques, the economic return from certain processing methods may not validate long-term capital investment. As feedlots consider geographic regions for expansion or location, analysis of prices not only of grain but also for by-products and roughage becomes important.

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NEED FOR RUMINALLY DEGRADED NITROGEN BY FINISHING CATTLE FED PROCESSED GRAINS

Mike Brown

West Texas A&M University

Canyon, TX

msbrown@mail.wtamu.edu



ABSTRACT

Assuring an adequate supply of ruminally degraded N in diets for feedlot cattle is important to maximize ruminal organic matter fermentation and microbial CP production. Growth performance data predominantly from studies using urea as the sole supplemental N source were reviewed to assess the influence of grain processing method and the influence of inclusion of co-products on the need for ruminally degraded N to support optimum performance. Dietary ruminally degraded intake protein (DIP) needs are provided on a 'standardized' basis assuming that corn grain contains 9.5% CP and that barley grain contains 11.5% CP. Growth performance was optimum for cattle fed diets based on dry-rolled corn without co-product inclusion when DIP was approximately 6.5% of diet dry matter. Thus, the optimal percentage of urea in the diet would vary inversely with the ruminally degraded N content of other ingredients fed. Limited data suggest that optimum growth performance by cattle fed a high-moisture corn diet without a co-product occurs with DIP between 8.5 and 9.8% of dry matter. For diets based on steam-flaked corn without a co-product, optimum growth performance was evident when the diet contained approximately 8.25% of dry matter as DIP; the optimum for steam-flaked barley occurred at 9.5% of diet dry matter. Finishing diets containing 20 to 40% wet corn gluten feed supported optimum growth performance when DIP was approximately 9.5% of diet dry matter. Further research is needed to characterize the influence of fractions of DIP on growth performance and to explore the DIP need of cattle fed diets containing distiller's grains.

INTRODUCTION

The metabolizable protein needs of feedlot cattle are influenced by a variety of factors including growth potential, relative feed intake and body weight, and ration energy concentration. The protein profile presented to the small intestine for digestion and absorption directly reflects the undegraded feed protein and microbial CP produced. For a typical steer weighing 1025 lb (800 lb initial weight, 1250 lb shrunk final weight) and consuming 21.5 lb of a 90% concentrate diet based on steam-flaked corn (assuming 0.78 Mcal of NE_g/lb of steam-flaked corn; level 1 diet NE adjustment = 92%), predicted (NRC, 1996) microbial CP supply (13% of TDN with eNDF adjustment) alone would provide only 63% of the MP needed to achieve the rate of gain possible based on dietary ME. Thus, microbial protein alone is insufficient to meet protein requirement of this steer. The calculated diet TDN was 90% and diet eNDF was 8%. Thus, the 1142 g of MCP 'possible' ends up as 799 g with the eNDF adjustment or equal to 512 g of MP from bacteria. A deficiency in ruminally degraded N also will limit microbial CP production and in addition may limit ruminal organic matter fermentation and energy supply to the host. Moreover, providing ruminally

degraded N in excess of that required for maximum microbial CP production can improve growth performance.

Corn grain is the most common cereal fed in the feedlot industry in the U.S., although barley, wheat, and sorghum often are more cost-effective ingredients than corn in certain regions. Ruminal N needs can be altered by grain type and the processing method employed to improve starch utilization. Coproducts of the grain milling and ethanol industries such corn gluten feed (wet and dry) and distiller's grains (wet and dry) are being used widely, particularly in the Northern Plains and the Midwest. The objective of this paper is to review the influence of grain processing and level of coproduct inclusion on the need for ruminally degraded N, particularly NPN, for optimum growth performance. Data evaluated were derived from studies encompassing the entire feeding period to slaughter.

Ruminally degraded N in diets based on dry-rolled corn

Milton et al. (1997) conducted two performance studies with diets based on dry-rolled corn (44.7% DIP; NRC, 1996). In Exp. 1, yearling steers with an initial weight of 732 lb were fed diets containing 10% prairie

hay (60% DIP; NRC, 1996) and either 0, 0.5, 1.0, or 1.5% urea. Steers were given Revalor-S on day 1 and fed for 131 days (3 pens/treatment). Dry matter intake tended ($P < 0.15$) to be higher for steers that did not receive supplemental N (24.5, 23.1, 24.0, and 23.6 lb/day for 0, 0.5, 1.0, and 1.5% urea diets, respectively). Steer ADG was greatest for steers fed 1.0% urea (quadratic; 3.64 lb/day). Feed efficiency was improved 10% by including 0.5% urea in the diet, but feed efficiency was not improved when additional urea was included in the diet (7.31, 6.54, 6.59, and 6.78 lb of feed/lb of gain, respectively). Rib fat thickness and average yield grade increased linearly as dietary urea increased. In Exp. 2, yearling steers with an initial weight of 765 lb were fed diets containing 10% alfalfa hay (82% DIP; NRC, 1996) and either 0, 0.35, 0.70, 1.05, or 1.40% urea. These steers also were given Revalor-S on day 1 and were fed for 141 days (4 pens/treatment). Dry matter intake was greatest for steers fed 1.05% urea and lowest for steers fed 1.4% urea (quadratic; 20.1, 19.9, 20.5, 20.9, and 19.3 lb/day for 0, 0.35, 0.70, 1.05, and 1.40% urea, respectively). Steer ADG also responded quadratically, being greatest for steers fed either 0.35 or 0.70% urea (2.67, 2.80, 2.82, 2.69, and 2.36 lb/d, respectively). Feed efficiency was optimum when the diet contained 0.35% urea (quadratic). Regression analysis of performance data predicted an optimum dietary urea concentration of 0.5% for the diets containing alfalfa hay (second trial) and 0.9% for the diets containing prairie hay (first trial); these values are equal to a dietary DIP of 6.2 and 6.3% of DM, respectively, using tabular DIP values for ingredients (NRC, 1996).

Shain et al. (1998) pooled data from two finishing studies (8 pens/treatment) in which diets based on dry-rolled corn contained a blend of alfalfa hay (5% of DM; 82% DIP) and corn silage (5% of DM, 75% DIP; NRC, 1996). Diets were supplemented with 0, 0.88, 1.34, or 1.96% urea, resulting in dietary CP concentrations of 8.9, 11.1, 12.6, and 14.1% CP. Corresponding dietary DIP calculated from tabular values were 4.5, 7.1, 8.4, and 10.2% of DM. Steers weighed 791 lb initially and were fed an average of 87 days. Steers received either Compudose or Revalor-S on day 1 of the feeding period. Dry matter intake was not altered by treatment (25.5, 26.2, 25.7, and 26.0 lb/day, respectively). Steer ADG (3.15, 3.39, 3.31, and 3.42 lb/day, respectively) and feed efficiency (8.09, 7.73,

7.76, and 7.60 lb/lb, respectively) were improved by urea addition to the diet when one considers the average of all urea-supplemented diets to the unsupplemented control diet. Thus, the optimum dietary DIP presumably was between 4.5 and 7.1% of DM.

Ruminally degraded N in diets based on high-moisture corn

Surprisingly few data are available for high-moisture corn considering the changes in soluble N and the high extent of ruminal starch digestion with this processing method. Cooper et al. (2002) fed diets containing a blend of alfalfa hay (5% of DM) and cottonseed hulls (5% of DM, 50% DIP; NRC, 1996) and either 0, 0.4, 0.8, or 1.2% urea. Steers were given Synovex Plus on day 1 (initial weight = 835 lb) and were fed for 108 days. The high-moisture corn, harvested at 29% moisture, was rolled before ensiling. Diets were reported to contain 10.6, 11.8, 12.9, and 14.1% CP; corresponding DIP reported were 7.0, 8.2, 9.3, and 10.5% of DM. However, the high-moisture corn must have contained approximately 11.0% CP to match the dietary CP concentrations reported. To compare these data with that of other experiments compiled for this summary, dietary CP and degradable intake protein were calculated assuming that the high-moisture corn contained 9.5% CP (and 67.8% DIP; NRC, 1996). These adjusted values were 9.0, 10.2, 11.5, 12.5% dietary CP with 6.3, 7.4, 8.6, and 9.8% of dry matter as DIP. Dry matter intake was not altered by treatment (27.1, 26.7, 26.7, and 26.7 lb/day for 0, 0.4, 0.8, and 1.2% urea, respectively). However, steer ADG increased linearly as urea concentration increased (3.75, 3.79, 4.01, and 4.08 lb/d, respectively); the magnitude of the increase was much smaller beyond 0.8% urea. Feed efficiency data were evaluated only by regression against dietary urea; feed efficiency averaged 7.23, 7.04, 6.66, and 6.54 lb/lb, respectively. Carcass rib fat thickness increased linearly with dietary urea, but marbling score decreased linearly as dietary urea increased.

Ruminally degraded N in diets based on steam-flaked grains

Data describing the NPN needs for optimum performance by cattle fed steam-flaked sorghum or wheat are not available, but one experiment involving steam-flaked barley and several involving steam-flaked corn have been conducted. Zinn et al. (2003) fed calves with an initial weight of 556 lb for 84 days. Calves were fed diets based on steam-flaked barley (66.9% DIP;

NRC, 1996), 10% forage (alfalfa hay + sudan hay [69% DIP; NRC, 1996]), and either 0, 0.4, 0.8, or 1.2% urea as the sole source of supplemental CP (5 pens/treatment). Diets contained 10.5, 11.5, 12.5 or 13.5% CP; corresponding DIP calculated from tabular values were 7.1, 8.3, 9.5, and 10.6% of DM. The barley was reported to have contained 11.8% CP. Steer calves were given Synovex-S on day 1. Dry matter intake was not altered by treatment (14.9, 15.4, 16.1, and 16.2 lb/day, respectively). Although ADG increased linearly (3.02, 3.15, 3.37, and 3.26 lb/day, respectively), ADG was not numerically improved when the diet contained above 0.8% urea. Feed efficiency also increased linearly as urea increased (4.93, 4.89, 4.78, and 4.97 lb/lb, respectively), but feed efficiency was numerically optimum with 0.8% dietary urea.

Cooper et al. (2002) fed diets based on steam-flaked corn (29 lb/bu, 43% DIP; NRC, 1996) that contained 5% alfalfa hay and 5% cottonseed hulls. Supplemental N was provided by including 0, 0.4, 0.8, 1.2, 1.6, or 2.0% urea (4 pens/treatment). Dietary CP ranged from 9.5 to 15.3%, whereas DIP concentrations were 4.7, 5.8, 7.0, 8.2, 9.3, and 10.5% of DM, respectively. Steers were given Synovex-C on day 1 (initial weight = 782 lb) and Revalor-S on day 47 of the 129-day feeding period. Dry matter intake, ADG, and feed efficiency responded quadratically; performance was optimized between 0.8 and 1.2% urea.

Healy et al. (1995) fed yearling steers (785 lb) diets based on steam-flaked corn. Steers were provided either no supplemental N, or blends of urea and soybean meal (N basis; 0:100, 33:67, 67:33, and 100:0) to attain 13% CP in the diet. Corresponding urea inclusion rates were 0, 0.6, 1.2, and 1.7% of DM, whereas soybean meal (65% DIP; NRC, 1996) inclusions were 10.8, 7.0, 3.3, and 0%. Dietary DIP values were not calculated because complete diet composition was not available. Growth performance was improved markedly by providing supplemental N; performance was optimized with a blend of 33% soybean meal and 67% urea. Steers fed the 33:67 soybean meal:urea produced carcasses with the greatest fat thickness.

Gleghorn et al. (2004) pooled data across two experiments in which steers were fed diets based on steam-flaked corn contained 11.5, 13.0, or 14.5% CP

provided by blends of urea and cottonseed meal (N basis; 100:0, 50:50, and 0:100). Cottonseed meal was assumed to contain 57% DIP (NRC, 1996).

Corresponding DIP concentrations ranged from 6.1 to 9.7% of DM. Steers received Ralgro on day 1 and Revalor-S on day 56. Steers had an initial weight of 729 lb and were fed an average of 162 days (9 pens/treatment). No interaction of dietary CP and urea:cottonseed meal was detected for the performance data. Dry matter intake was not altered by either CP or urea:cottonseed meal. Adjusted ADG increased by 5% as dietary CP was increased from 11.5 to 13.0%. Adjusted ADG increased linearly and adjusted feed efficiency improved linearly as urea replaced cottonseed meal. Thus, the optimum performance occurred when the diet contained approximately 8.2% dietary DIP (1.0% urea).

Ruminally degraded N in diets containing milling and ethanol co-products

Block et al. (2005) compared performance of cattle fed a control diet based on steam-flaked corn formulated to contain 1.8% urea as the sole supplemental N source to provide 14% dietary CP (9.0% DIP of DM) with various diets containing wet corn gluten feed (Sweet Bran, 75% DIP; NRC, 1996). Diets containing 20% wet corn gluten feed were supplemented with 0.62, 0.87, or 1.13% urea (14.0, 14.7, and 15.4% dietary CP, respectively). Diets containing 30% wet corn gluten feed were supplemented with 0.15, 0.40, or 0.65% urea (14.3, 15.0, and 15.6% dietary CP, respectively), whereas diets containing 40% wet corn gluten feed were supplemented with 0 or 0.19% urea (15.4 or 16.0% dietary CP, respectively). The DIP of diets containing wet corn gluten feed ranged from 8.7 to 10.6% of DM. All diets contained 10% of DM as corn silage. Steer calves weighing 635 lb were implanted on day 1 with Synovex-S and received Revalor-S on day 70 of the 166-day feeding period (3 pens/treatment). Dry matter intake was highest with 30% wet corn gluten feed. Steer ADG and feed efficiency were optimized when the diet contained 20% wet corn gluten feed. Performance data indicated that optimum ADG and feed efficiency occurred when diets containing wet corn gluten feed contained a dietary CP concentration of 15.4% (20% wet corn gluten, 1.13% urea), 15.0% (30% wet corn gluten, 0.40% urea), and 15.4% CP (40% wet corn gluten, no added urea). The corresponding dietary DIP concentrations were 9.7 to 10.2% of DM, although the

authors reported that the regression-predicted optimum DIP was 9.6% of DM ($R^2 = 0.28$).

Macken et al. (2006) fed 679-lb steer calves diets containing 25% wet corn gluten feed (Sweet Bran) and 10% corn silage for 152 days. Treatments involved one of two dietary CP concentrations (14 or 15%) achieved by including 0.3 or 0.6% urea factored across five grain processing treatments that included dry-rolled corn, finely round corn, rolled high-moisture corn, ground high-moisture corn, and steam-flaked corn (4 pens/treatment). No interaction of dietary CP and grain processing was detected for growth performance data. Thus, the main effect of dietary CP was derived with 20 pens/treatment. Increasing dietary CP to 15% (9.8% of diet dry matter as DIP) did not influence growth performance or carcass characteristics beyond that achieved with 14% CP (8.8% of diet dry matter as degradable protein).

Richeson et al. (2006) implanted yearling steers (886 lb) on day 1 with Revalor-S and fed diets based on steam-flaked corn and 25% wet corn gluten feed (Sweet Bran) for 116 days. Treatments included diets formulated to contain 14% CP provided either by only urea (0.44% of DM; 9.4% of diet DM as DIP), 67:33 urea:cottonseed meal (N basis; 9.3% of diet DM as DIP), or 33:67 urea:cottonseed meal (9.2% of diet DM as DIP; 8 pens/treatment). The analyzed dietary CP concentrations were close to the expected values (13.5%), but the degradable protein content reported above was tabulated assuming that corn contained 9.5% CP. Dry matter intake was not influenced by source of supplemental N, but ADG increased linearly as the proportion of urea increased (4.19, 4.36, and 4.34 lb/day for 33, 66, and 100% urea, respectively). Feed efficiency tended to be

poorer when urea comprised only 33% of the supplemental N.

Grain protein and starch digestion characteristics

Tabular values for ingredient DIP for processed corn (NRC, 1996; Table 1) were applied to all studies reviewed. However, actual DIP of ingredients will indeed be influenced by factors other than grain processing that drive extent of ruminal OM digestion and microbial yield such as feed intake, rate of passage, and ruminal pH patterns. In vivo data summarized in previous reviews clearly indicate that steam flaking and high-moisture ensiling increase the extent of ruminal starch digestion (Table 1). Using the NRC (1996) level 1 model, estimates of the predicted DIP deficiency of a basal diet (no supplemental protein included) based on corn that was dry-rolled, steam flaked, or in high-moisture form were derived. Microbial efficiency was assumed to be 13% of TDN with the appropriate eNDF adjustment for each diet. Alfalfa hay was used as the forage source at 5, 10, and 10% of diet DM for diets containing dry-rolled, steam flaked, and high-moisture corn, respectively, to approximate diet composition of studies reviewed here. Feed intake was assumed to be equal for the steam flaked and high-moisture diets (21.5 lb/d), and feed intake of the dry-rolled diet was assumed to be 110% of the former (23.65 lb/d). Assuming in this example that the DIP deficit (Table 1) is equivalent to the added urea needed, the diets would need to include 0.79% (dry-rolled), 1.06% (steam flaked) and 0.02% urea (DM basis). Thus, the DIP need for each of these diets follows the extent of ruminal starch digestion much more closely than ruminal protein digestion. Indeed, Cooper et al. (2002) reported a very close relationship ($r^2 = 1.0$) between ruminal starch digestion (dry-rolled, steam flaked, and high-moisture corn) and regression-predicted DIP need (based on feed efficiency) derived from a growth performance study.

Table 1. Estimates of degraded intake protein (DIP), ruminal starch digestion and model-predicted DIP deficit in diets based on processed corn without supplemental N

Item	Tabular DIP, % of crude protein	Ruminal starch digestion, % of Dry matter		Predicted DIP deficit, g/d
Dry-rolled	44.7	76.2	63.8	- 244
Steam flaked	43.0	84.8	86.5	- 296
High-moisture	67.8	89.8	84.1	- 7
Source	NRC, 1996	Huntington, 1997	Owens, 2005	NRC, 1996

SUMMARY

Dietary need for ruminally degraded intake protein (DIP) was calculated for the experiments reported assuming that corn contains 9.5% CP and that barley contains 11.5% CP. Growth performance was optimum for cattle fed diets based on dry-rolled corn without co-product inclusion when degraded intake protein was approximately 6.5% of diet dry matter. Thus, the optimum percentage of urea to be included in the diet would vary inversely with the ruminally degraded N content of the other dietary ingredients. Limited data suggest that optimum growth performance by cattle fed a high-moisture

corn diet with no added co-products occurs with DIP near 9.5% of dry matter. For diets based on steam-flaked corn with no added co-product, optimum growth performance was evident when the diet contained approximately 8.25% of dry matter as DIP; the optimum DIP for steam-flaked barley occurred at 9.5% of diet dry matter. Finishing diets containing 20 to 40% wet corn gluten feed supported optimum growth performance when DIP was approximately 9.5% of diet dry matter. Further research is needed to characterize the influence of DIP fractions on growth performance and to describe the DIP requirement for diets containing distiller's grains.

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QUESTIONS AND ANSWERS

Q: Thirty years ago, we had papers about soluble protein content of high moisture corn. Today we heard about soluble protein in reconstituted milo. What's it mean? Can we use it?

A: Soluble protein is likely to be degraded in the rumen. High-moisture and reconstituted grains have higher amounts of soluble and ruminally degraded protein. This should be considered when you decide how much non-protein nitrogen should be added to the ration. Soluble N content is reflective of DIP.

Additional Comment by Soderlund: There is a high correlation between soluble N content and ruminal starch digestion; both increase during storage. Recent Nebraska work and some of our work from about 10 years ago show that correlation.

Q: Mike, you omitted values for the dietary DIP value for rations with wheat. What is your estimate of dietary DIP on steam-flaked wheat rations?

A: I would anticipate that DIP for steam-flaked wheat would be similar to the DIP value for high-moisture corn.

PROCESSING EFFECTS ON MANAGEMENT: TYPE, FORM, AND LEVEL OF ROUGHAGE

Robbi H. Pritchard, Ph.D.
South Dakota State University
robbi.pritchard@sdstate.edu



INTRODUCTION

This title has a very large scope. If one considers the predominant grain sources x predominant grain processing options x predominant roughages x practical roughage levels x roughage processing x roughage particle size, that factorial has literally hundreds of simple effect observations. Surely most of these have been tested at some level of experimentation. Many of the comparisons appear in publications, but this kind of work is probably not suited to a meta-analysis because of interactions and confounding factors that could lead to statistical outcomes that are not always predictive of biological outcomes.

The outcome-based criteria used to describe optimal roughage levels include optimized growth (ADG, F/G), digestive disorder rates, and cost of gain. The growth criteria are interesting in that roughage invariably is less energy dense than the grain it replaces in the diet. The role in managing digestive disorders also is obtuse considering the limited substitution for total starch load of the diet provided by small changes in finishing diet roughage levels.

The primary role of roughage in finishing diets probably is as a mechanical effector of rumen function. The varied aspects of this role include: slowing prehension and increasing mastication and rumination, which will serve to control rate of substrate availability to the rumen and to increase the amount of buffer provided (via increased salivation); provide tactile stimulation to evoke ruminal contractions to aid content mixing and gas release via eructation; increase liquid dilution rate, which improves YMP and fermentation endproduct removal. These functional roles intertwine as in stimulating saliva production leading to increased liquid dilution rate and higher pH, both of which promote increased YMP.

Intuitively, we should be able to envision complementarities between grain source and dietary roughage. The Beef NRC (1996) models this concept with eNDF estimates and predicted ruminal pH. Corn

fed whole (WSC), high moisture (HMC), dry rolled (DRC), finely ground (FGC) or steam flaked (SFC) results in different rates and levels of intake and of starch fermentation. Presumably, saliva production and tactile stimulation differ as well. Can we effectively match the roughage inclusion accordingly? Examples would be that less effective roughage would be necessary in WSC diets than HMC diets. For FGC, rate of starch fermentation is elevated, but DMI is lowered. The lower absolute starch load may cause the roughage optimum to differ compared to a DRC diet where DMI is higher and starch fermentation is only somewhat lower.

Roughage Levels

Vance et al (1971) provides an interesting example of the interaction between grain source and roughage level. Substituting corn silage for WSC did not affect (reduce) ADG until diets reached 40% CSil (Fig. 1). The ADG depicted in the graph are a recalculation based upon carcass weight and a constant dress to remove bias caused by potential differences in fill. In contrast to the WSC diets, when corn silage was substituted for DRC, ADG climbed as corn silage increased to 35% diet and then dropped at 50% corn silage. Corn silage caused an increase in DMI in both grain sources, peaking at 25% corn silage in WSC diets and 35% corn silage in DRC diets (Fig. 2). These would equate roughly to 11% and 15% roughage diets, respectively. It is interesting to note that these were peaks and that subsequent inclusions of corn silage caused DMI to decline. These data fit (probably were the source of) my bias that a more readily fermentable feed would respond favorably to higher dietary roughage.

The relationship between roughage level and DMI is quite strong within the lower range of roughages used in finishing diets. Defoor et al (2002) evaluated multiple roughage sources included at up to 15% of the diet and found that DMI expressed as NE_G intake increased linearly as the amount of NDF contributed by roughage increased ($r^2 = 0.68$). In those SFC diets, roughages provided from 2 to 13% points of NDF. In a subsequent study of pooled experiments analyses,

Galyean and Defoor (2003) found that the NDF contributed by the roughage was better than roughage

and comparable to eNDF for predicting DMI (Table 1).

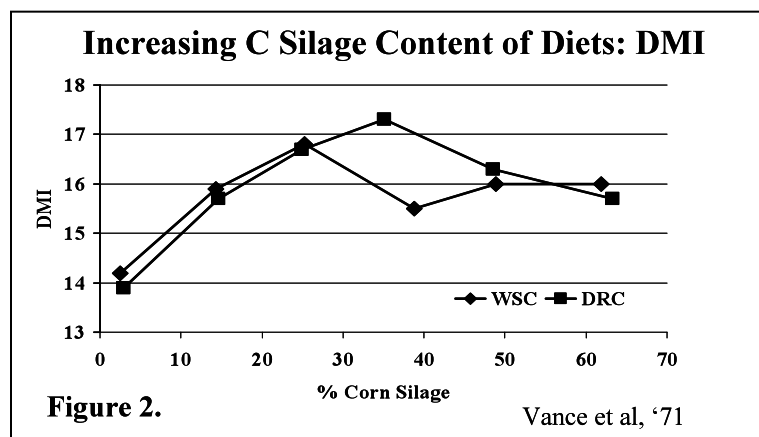
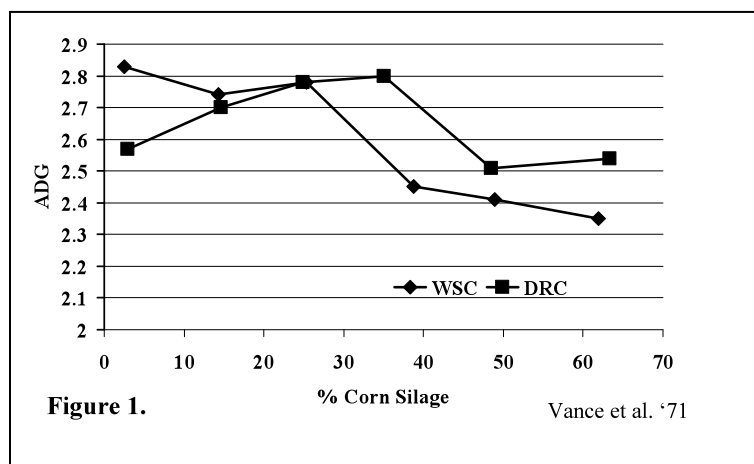


Table 1. Predicting Roughage Influence on dry matter intake^a

Component	R ²	Relationship
Dietary roughage, %	0.699	1.866 + 0.0169 (% Roughage)
Roughage NDF, % points	0.920	1.856 + 0.0275 (NDF _R) ^b
Roughage eNDF, % points	0.931	1.858 + 0.0290 (eNDF _R) ^c

^a From Galyean and Defoor (2003).

^b Dietary percentage points of neutral detergent fiber (NDF) contributed by roughage.

^c Dietary percentage points of effective NDF (eNDF) contributed by roughage.

It is important to keep in mind that this linearity is within a narrow, low range of dietary roughage. The data used also are from diets based upon relatively readily fermentable starch sources (SFC, HMC, Wheat, etc.). Given those constraints, the observations do not contradict the observations of Vance et al (1971) using less fermentable grain (WSC, DRC) across a much broader range of roughage

levels; they merely focus on the range that is most relevant to today's finishing diets.

Roughage level effects on DMI are only a partial perspective and will not necessarily predict gain response. Using a blend of 1/3 alfalfa hay 2/3 corn silage, Gill et al (1981) evaluated responses to roughage levels when feeding HMC or SFC. Consistent with the previous discussion, there was a

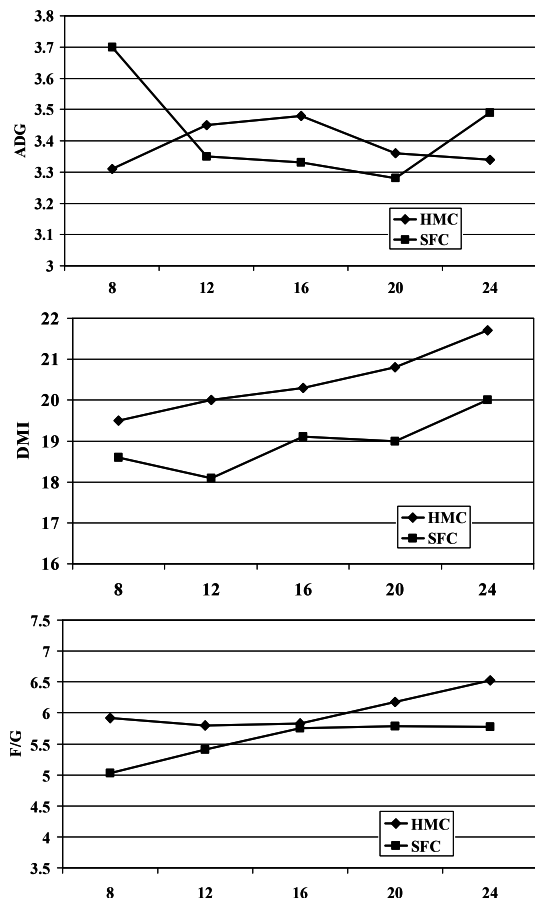


Figure 3.
Roughage, %
Gill et al., 1981

linear increase in DMI for either grain source in response to added roughage. However, the carcass adjusted ADG and F/G responses diverged. When fed SFC, growth was optimized at 8% roughage, but when HMC was fed, optimum roughage level was 16% (Fig. 3). Since both grain sources are very readily fermented in the rumen, other factors apparently became involved. One possibility is that HMC has a higher DIP value than does SFC. Higher roughage levels may have aided growth on the HMC diets by improving YMP. The additional YMP may have been needed to achieve equal MP to the SFC diet that would have had more UIP outflow.

ROUGHAGE SOURCES

Kreikemeier et al (1990) evaluated roughage (50% alfalfa – 50% corn silage) levels with steam rolled wheat diets. If the corn silage were assumed to be 50% grain, then the corrected roughage level (Rc) of the diets would be 0, 3.75, 7.5, and 11.25%. The wheat would have somewhat higher starch digestion

rates than SFC or HMC and very high (75%) DIP (NRC, 1996). In that experiment DMI peaked at 11.25% Rc, but ADG and F/G were optimized at 7.5% Rc. This would correspond to optimal responses at a Rc level of 5% for SFC and 11% for HMC in the Gill et al (1981) experiment.

The NDF profile alone is inadequate to classify roughages. Using F/G and ADG as the criteria for ranking of roughage sources in iso-NDF diets based on HMC, Loerch (1993) found that corn silage was superior to alfalfa and alfalfa was superior to wheat straw. In that study, the 5% wheat straw and 7.6% alfalfa diets improved DMI over 0% roughage controls, but yielded no benefit in ADG and actually inflated F/G over controls. In iso-NDF diets based on SFC, Defoor et al (2002) reported sorghum silage was superior to cottonseed hulls and cottonseed hulls were superior to alfalfa in ADG and gain efficiency. Some of this may be related to particle size differences. Other variables would include mix integrity, potential for sorting during prehension or ability to stimulate saliva production and rumen motility.

These iso-NDF studies yield different outcomes than the conventional thinking as iso-roughage. Guthrie et al (1996) fed either SFC or WSC with 10% roughage as alfalfa or sorghum grass hay. No roughage x grain interactions occurred. The SFC and WSC diets supported similar ADG, but when fed SFC, cattle had 11.5% lower DMI and 11.5% improved F/G ($P < 0.05$). Roughage source had no effect on ADG, but feeding alfalfa resulted in 7.6% lower DMI and 5% improved F/G ($P < 0.05$). In contrast to the iso-NDF data, alfalfa was superior to sorghum silage at iso-roughage levels.

A dry x wet/fermented feeds pattern was observed in the literature suggesting the potential for an interaction between the moisture content of the grain and the moisture content of the roughage. Results of two of these experiments as reported by Mader et al (1991) are shown in Table 2.

Within these experiments, interactions occurred between grain source and roughage source. In each case it was more favorable when the grain and roughage source were either both high or both low in moisture content. Combining a dry feedstuff with a high moisture feedstuff by either means (grain or roughage) resulted in poorer performance. That may

explain why Loerch (1993) saw that iso-NDF roughage feeding favored corn silage over alfalfa in HMC diets. It should be noted that in those

experiments, the high moisture feeds were all fermented feeds, and that characteristic may be more germane than the moisture content.

Table 2. Corn form by roughage source^a

Experiment 1	Dry-rolled corn		Ground high-moisture corn	
	11.5% corn silage	9.2% Alfalfa	11.5% corn silage	9.2% Alfalfa
Daily gain, lb	2.87	2.82	2.82	2.78
Daily dry matter intake, lb	20.37	19.62	19.86	21.61
Feed:Gain	7.14	6.94	7.02	7.81

Experiment 2	Dry whole corn			Whole high-moisture corn		
	Corn silage	Alfalfa hay	Alfalfa silage	Corn silage	Alfalfa hay	Alfalfa silage
Daily gain, lb	3.22	3.17	3.11	3.22 ^c	2.98 ^d	3.17 ^{cd}
Daily dry matter intake, lb	24.36	23.66	23.61	20.24	19.42	19.53
Feed:Gain	7.56	7.45	7.60	6.26 ^{ef}	6.50 ^e	6.14 ^f

^aMader et al., 1991.

^bCorn type × roughage source interaction ($P < 0.05$).

^{c,d}Means differ ($P < 0.10$).

^{e,f}Means differ ($P < 0.05$).

CONCLUSIONS

When considering responses to dietary roughage inclusions, we should think of lower roughage finishing diets (<15% roughage) as a distinct entity compared to diets with higher roughage levels. In the classic paper describing negative associative effects (Joanning et al, 1981) those effects were calculated for diets containing approximately 16 and 24% roughage. Fill, rates of particle size reduction, rumen retention time, and bacterial fermentation are very important at these higher levels of roughage. Goetsch et al (1986) point out that in finishing diets, criteria defining roughage value are factors that stimulate mastication, rumination, and outflow without interfering with starch digestion in the small intestine.

Interactions clearly exist between grain processing and roughage sources and levels. Slowly fermented WSC responds little to added roughage. Some rapidly fermented feeds like SFC responds optimally to low roughage (~5%), but others including HMC and steam rolled wheat respond optimally to somewhat higher roughage levels. This may be in part influenced by the dynamics of ruminal N metabolism. Roughage sources do influence ruminal pH (Goetsch et al 1986) and may interact with grain source. The examples I encountered in this review infer that using fermented

roughage with fermented grains or dry roughage with dry grains is superior to mixing combinations of fermented and dry feedstuffs.

There are simply too many potential combinations of grains, roughages, and roughage levels to provide all possible direct comparisons. That leaves us, good or bad, to rely on the intuitive insight of the nutritionist. The key points to consider are the roughage contribution to dietary NDF, the fermentability (rate and extent) of the feed ingredients, perhaps the DIP/UIP and consequently MP supply from the diet, and whether dry or fermented feeds are involved. One last consideration not previously addressed relates to DMI. Diets used in northern climates of the US have much higher DMI than cattle fed further south, more than would be anticipated from the greater percent roughage generally included in those diets. Perhaps a conventional wisdom has evolved that with high DMI and consequently higher daily total starch loads on the rumen, feeders have learned that proportionally more roughage is needed to maintain rumen function! Roughage level x total starch load should be evaluated further.

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GRAIN PROCESSING EFFECTS ON MANAGEMENT: ADAPTATION DIETS

C. R. Krehbiel*, B. P. Holland* and C. T. Milton[€]

*Department of Animal Science, Oklahoma State University, Stillwater, 74078

[€]Consulting Nutritionist, Grand Island, NE 68801

clint.krehbiel@okstate.edu



ABSTRACT

Methods for adapting cattle to high-concentrate diets are important to consider due to potential effects on animal health and performance throughout the finishing phase. In general, transition diets allow the rumen microorganisms to adapt from predominantly fibrolytic bacteria to predominantly amylolytic bacteria in a manner that minimizes ruminal acidosis. This traditionally has been accomplished by gradually increasing the grain (or concentrate) and decreasing the roughage level over a 3 to 4 week period using a series of “step-up” diets. More recently, some feedyards have begun using two diets (a starter and finisher) and increasing the finisher:starter ratio over an established period of time. The concept of limiting maximum intake based on multiples of maintenance was established to prevent intake reductions during transitions and ensure maximum intake of the final high-concentrate diet. Adaptation also has been achieved by limit feeding the final finishing diet with feed supply gradually increasing until cattle are full fed. This potentially could decrease costs associated with purchasing and processing roughage sources in the feedyard. We conducted an experiment to evaluate effects of different methods for adapting calves with a high-risk of morbidity to a high-concentrate, program-fed diet. Steer and bull calves (n = 534) were purchased from auction markets in Florida, Missouri, Oklahoma, and Texas during November and December 2006 and delivered to Stillwater, OK. Calves were adapted to an 88%-concentrate diet either 1) traditionally using 3 transition diets, 2) with intake of each transition diet limited to 2.1, 2.3, and 2.5 times their initial maintenance energy requirements, 3) fed a 64%-concentrate (receiving) diet for 28 days before being transitioned traditionally, or 4) were program fed the final 88%-concentrate diet from day 1 through the end of the experiment. Results suggested that feeding a high-roughage diet for an extended period (28 days) after arrival resulted in the greatest gain during the 60-day growing period. However, when those cattle were adapted to being fed a high-concentrate program-fed diet, they were less efficient than traditional or program-fed steers. Either free choice intake or limit feeding the high-concentrate diet initially resulted in increased morbidity due to bovine respiratory disease. Therefore, extending the period during which a high-roughage diet is fed or limiting the maximum intake during the adaptation period may reduce morbidity in high-risk calves.

INTRODUCTION

Managing nutrition during adaptation of beef cattle to a high-grain diet has carryover effects on performance and health (Brown et al., 2006). Different methods for adapting cattle to high-concentrate diets have been investigated (Bartle and Preston, 1992; Choat et al., 2002) and the results have been reviewed (Brown et al., 2006). Brown et al. (2006) summarized that adapting feedlot cattle to a high-energy diet too rapidly (14 d or less) with incremental increases in concentrate (approximately 55 to 90% of diet DM) can decrease performance over the entire feeding period. In addition, Bevans et al. (2005) suggested that because high-energy diet adaptation can affect the number of health-impaired or poor-performing animals in a pen of feedlot cattle, management of diet adaptation should be tailored for the most susceptible cattle within the pen.

Adapting cattle to a high-concentrate diet involves adapting the microorganisms in the rumen towards a greater number of amylolytic and a lesser proportion of fibrolytic bacteria (Goad et al., 1998; Tajima et al., 2001). This was traditionally accomplished by using transition or “step-up” diets with increasing grain (or concentrate) and decreasing roughage concentration during a 3 to 4 week period (Bevans et al., 2005). With a gradually increasing concentrate supply, populations of ruminal microorganisms can adjust to a ruminal environment with a lower pH so that subacute acidosis and intake variation is minimized. An abrupt change from a high-forage to a high-concentrate diet can result in acute or subacute acidosis (Goad et al., 1998; Coe et al., 1999; Bevans et al., 2005). Ruminal acidosis, as extensively reviewed by a number of researchers (Dunlop, 1972; Counette and Prins, 1981; Britton and Stock, 1987; Owens et al., 1998), has been characterized by a rapid decline in ruminal pH,

following starch ingestion, with an accompanying rise in ruminal concentrations of total volatile fatty acids (VFA) and lactate. The increased concentrations of ruminal VFA and lactate are the result of production of organic acids exceeding rates of utilization, absorption and/or ruminal dilution. The physiological effects of acidosis in feedlot cattle can range from a temporary loss in appetite to acute physiological alterations resulting in death (Koers et al., 1976; Owens et al., 1998; Brown et al., 2006). Much of what is known about the acidotic condition in ruminant animals is the result of extensive studies using models of acute acidosis; more information is needed under commercial feedlot settings (Titgemeyer and Nagaraja, 2006). This paper summarizes the importance of diet adaptation and current methods for adapting cattle to high-concentrate diets.

IMPORTANCE OF GRAIN ADAPTATION

Although our knowledge of the etiology of ruminal acidosis is fairly extensive (Owens et al., 1998), less is known about how the amounts and the number of increases in feed consumption during adaptation to a high-energy diet can impact cattle performance throughout the entire growing/finishing

period (Brown et al., 2006). For growing and finishing cattle, optimizing ruminal function is very important because VFA provide 65 to 75% of the metabolizable energy needs of the animal (Bergman, 1990). Disrupting VFA production by bacteria or impairing VFA absorption and/or metabolism by the ruminal epithelium most likely will have a negative impact on animal performance. Although care must be taken during the adaptation process to prevent acidosis, establishing DM and therefore caloric intake seems to be one of the most important aspects of the diet adaptation period. There is a strong positive correlation between DMI and ADG (Figure 1) and between DMI and saleable weight (Figure 2) in feedlot cattle. After accounting for total cost of gain, cattle value increased by \$13/animal for each 1 lb increase in DMI assuming an \$85 cash market (Figure 2). Whereas a portion of this intake response most likely is driven by initial BW, the data reflect the total value realized from additional DMI when corrected for cost of gain. Therefore, early in the finishing period, successful transitioning to the finishing diet presents an opportunity for establishing high feed consumption that ultimately can increase ADG and saleable weight.

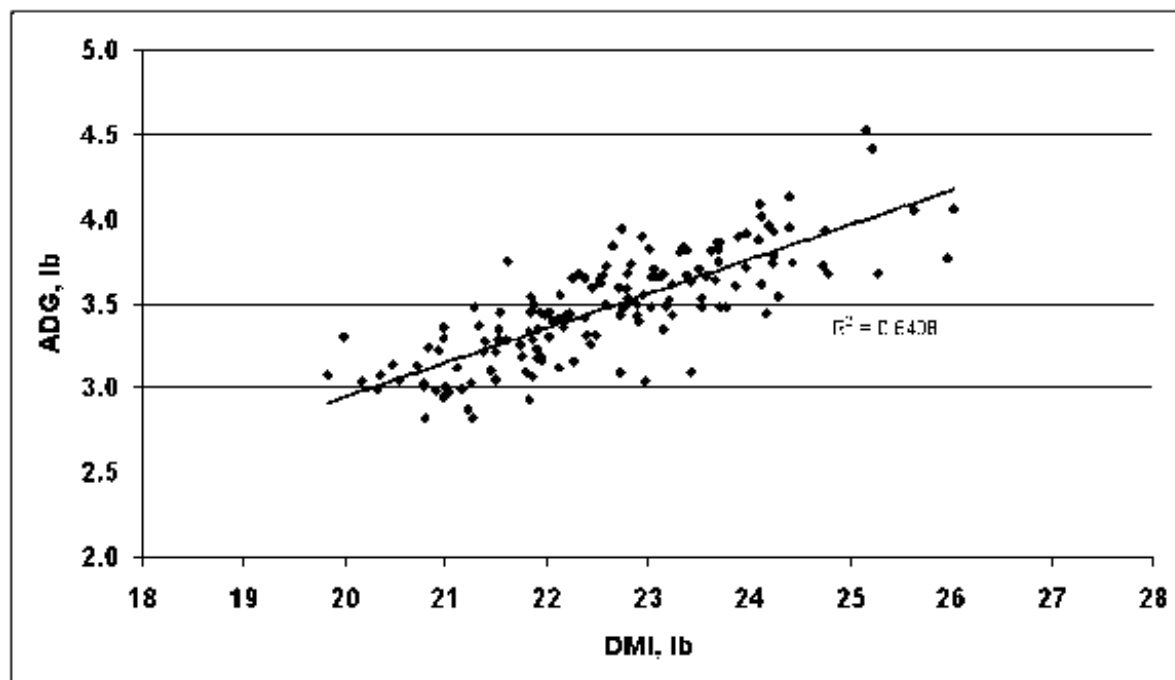


Figure 1. Relationship of DMI to ADG within feedyard in 700 to 800 lb steers (Milton, 2005; personal communication).

HOW DO FEEDYARDS PUT CATTLE ON FEED?

Many factors are involved with how cattle are placed on feed; these include animal factors, feed milling capabilities, economics and overall feedyard efficiency. Animal factors include cattle biological type, age and/or weight (calves vs. yearlings), previous management (forage amount and quality, days in a backgrounding yard, etc.), and expected days on feed. In North American feedlots, adapting cattle to high-concentrate diets commonly is characterized by a few days of feeding long-stemmed hay, followed

by a series of transition or “step-up” diets, where concentrate levels are gradually increased while roughage levels are decreased to promote ruminal adaptation to the high-concentrate finishing diet. This approach generally involves 3 to 6 transition diets and a total period of 21 to 28 days. In a recent survey, Vasconcelos and Galyean (2007) reported that of 29 feedlot consulting nutritionists questioned, 22 used a series of transition diets as the exclusive adaptation program, and 2 used transition diets in combination with other methods.

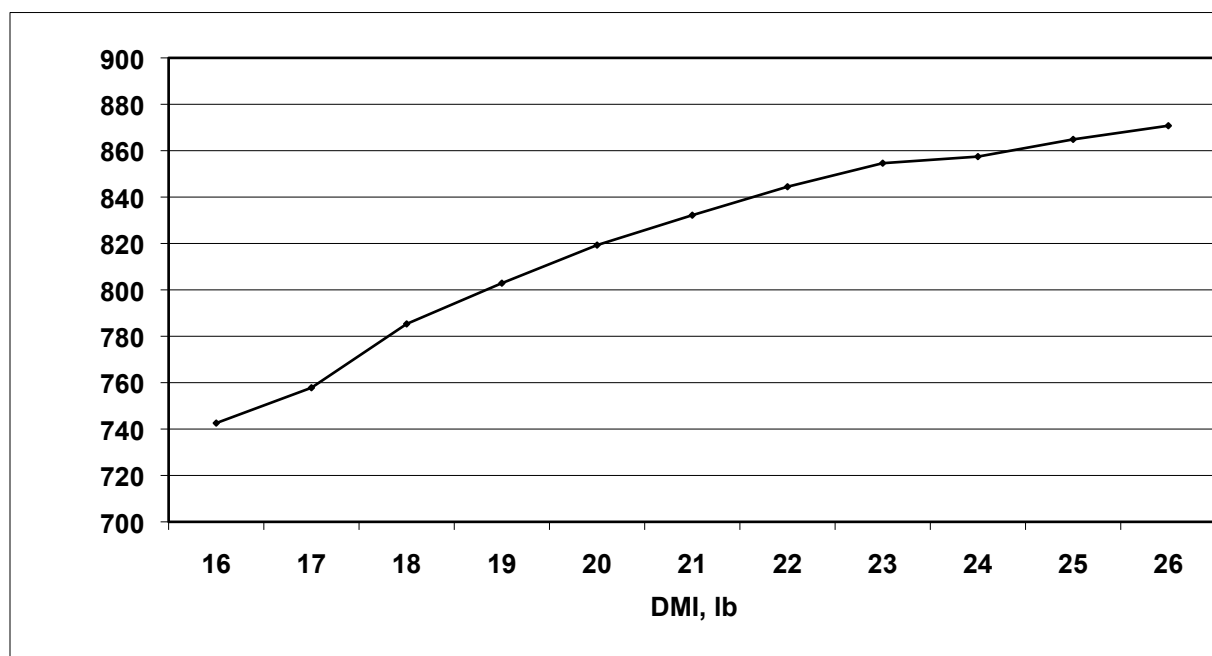


Figure 2. Relationship of DMI to saleable weight dollars minus total cost of gain in Central Plains 700 to 899 lb steers (VetLife Benchmark; Milton, 2005; personal communication).

As an alternative to this traditional approach, Xiong et al. (1991) and Bartle and Preston (1992) initiated the concept of feeding at multiples of maintenance by establishing an upper energy intake limit during adaptation based on the animal's calculated maintenance requirement. The stated purpose was to control peaks in DMI and decrease daily intake variation rather than to program energy intake. More recently, some feedyards have begun using two diets (a starter and finisher) gradually increasing the finisher:starter ratio over the same 21 to 28 d period of time as used for the traditional approach (Milton, 2005; personal communication). Alternatively, rumen microbial adaptation can be achieved by limit feeding the final finishing diet, with

gradual increases in feed supply until the cattle are full fed (Bierman and Pritchard, 1996; Weichenthal et al., 1999; Choat et al., 2002). If this can be achieved without causing ruminal disorders and days off feed, then the cost of feeding cattle could be decreased due to the reduced cost for purchasing and handling harvested roughages in the feedlot. These adaptation methods are discussed in more detail below.

“Traditional” Transition Diets

Theoretically, a greater the number of transition diets, the smaller the changes in forage and energy intake at each step and the greater the potential for smooth adaptation to the final finishing diet. This should result in greater DMI and improved animal

performance. However, problems associated with using a large number of transition diets include inefficiency of feedyard operations associated with an increased number of required feed loads (especially a greater number of small loads), an increased number of feeding times, and lack of storage capacity for

finished feed. Therefore, a compromise between feedlot management and nutrition has most commonly resulted in the use of 2 to 5 transition rations fed from 4 to 11 days each (Vasconcelos and Galyean, 2007). Figure 3 is an example of a pen of cattle started using 3 rations prior to the finisher being fed on d 22.

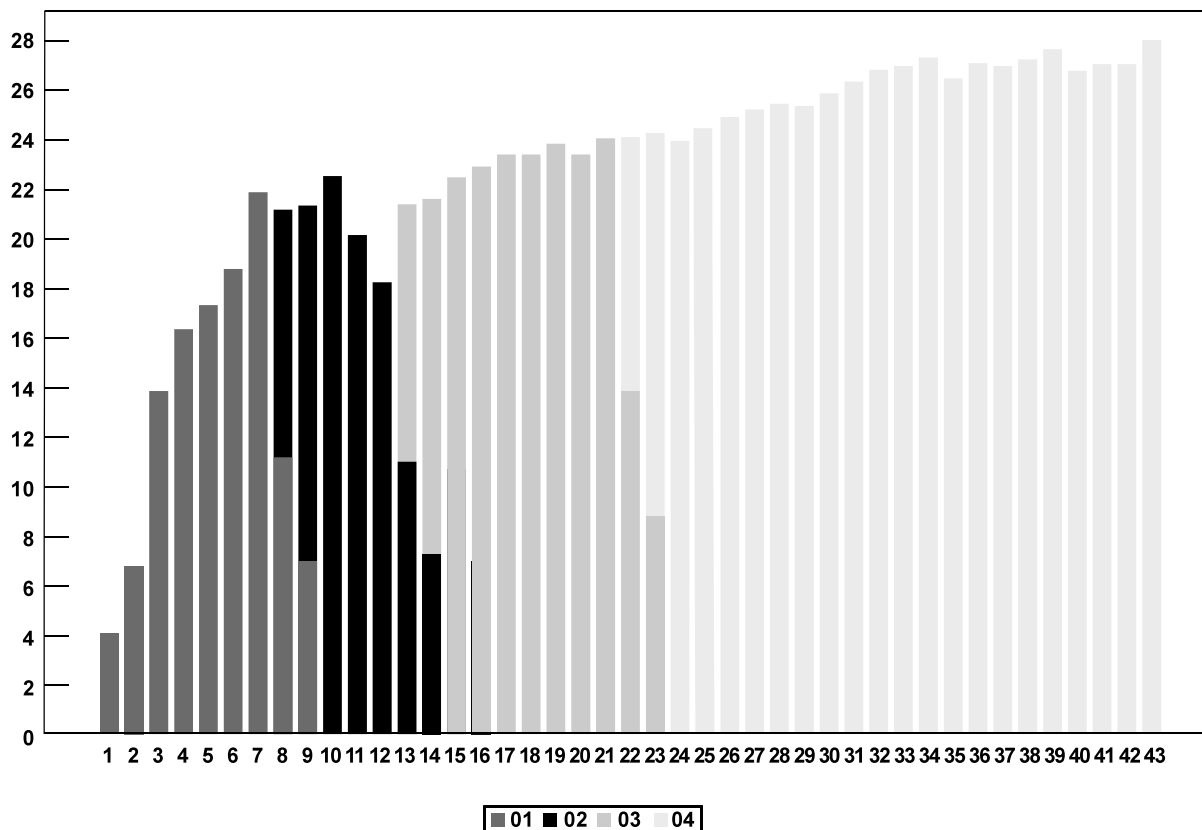


Figure 3. Example of a four-ration “step-up” approach to adapting cattle to a high-concentrate diet. 01, 02, 03, and 04 represent increasing levels of concentrate and decreasing levels of roughage. Note that on transition days 8 and 9, both 01 and 02 rations are fed, with an increased amount of 02 on day 9. Likewise, on transition days 15 and 16, and days 22 and 23, ration 02 and 03, and 03 and 04, respectively, are fed with an increased amount of 03 on day 16 and 04 on day 23 of the adaptation period.

Multiples of Maintenance

Limiting maximum intake based on multiples of maintenance energy requirements when feeding a series of diets that decrease in the fraction of roughage has resulted in comparable or improved performance relative to cattle offered the same diets free choice (Xiong et al., 1991; Bartle and Preston, 1992). Predicting consumption and setting targeted intakes is useful particularly when training feed bunk callers with little experience. Using an intake “guide” can help to prevent lost intake during transition, and ensure maximum intake on the highest energy diet. The ultimate goal is to achieve maximum DMI

following transition to the final diet. One potential downside is training feed callers to rely exclusively on numeric targets rather than evaluation of the feedbunks and behavior of the cattle when determining the amount of feed to be delivered.

Xiong et al. (1991) fed steers steam-flaked grain sorghum-based diets to appetite using either typical feedlot bunk management practices or feeding at multiples of maintenance (MM). Steers on the MM regimen were fed in a similar manner to free choice steers except that an upper intake limit was established for each pen based on their calculated

maintenance requirement. For the MM regimen, the upper limits for feed energy offered were set at 2.3, 2.5, and 2.7 times maintenance for wk 1, 2, and 3 of the diet adaptation period. At and beyond the 4th wk, the maximum feeding level was 2.9 times maintenance. Step-up diets fed during each of the four weeks contained 35, 25, 18, and 9% roughage for wk 1, 2, 3, and 4, respectively. Maintenance requirements were calculated from the initial BW for the first 4 wk; thereafter, the most recent BW was used. It was assumed that on days when the assigned upper limit was offered, MM steers were not fed to their maximal voluntary intake. However, the degree of restriction was not determined. The overall frequency of restricted feeding was 26, 80, 66, and 66% for wk 1, 2, 3, and 4, respectively. However, when the 9% roughage was fed, cattle adapted using the MM did not show improved ADG or feed efficiency. In a subsequent experiment, Bartle and Preston (1992) used a similar approach with two sets of MM limits that were 2.1, 2.3, 2.5, and 2.7 times maintenance (2.7MM) or 2.3, 2.5, 2.7, and 2.9 times maintenance (2.9MM) during wk 1, 2, 3, and 4, respectively. During the concentrate step-up period, limiting maximum intake to an assigned multiple of maintenance decreased feed intake by 4.7 (2.7MM) and 5.8% (2.9MM), respectively, when compared with the free choice treatment. The 2.7MM treatment also resulted in a numeric increase in ADG and tended to improve gain efficiency during the step-up period. After the step-up period, MM steers had numerically greater DMI and a slight advantage in ADG and gain efficiency, so that over the entire feeding period, the 2.7MM treatment tended to improve ADG (6%) and gain efficiency (4%) compared with steers given free choice access to feed. Performance of cattle fed at 2.9MM was intermediate. There were no differences among limiting maximum intake strategies for carcass characteristics. In conclusion, limiting maximum intake to a multiple of the estimated maintenance energy requirement (2.7MM) tended to improve ADG and efficiency. Although frequency of use of this strategy in commercial feedyards is unknown, the basic theory has potential as an easily implemented method to control fluctuating feed intake during the concentrate step-up period.

Two Ration Approach

Recently feedyards have begun using two diets (a starter and finisher) with an increase in the ratios of finisher:starter over a 21 to 28 d period of time to

adapt cattle to a high-concentrate diet. With this approach, various proportions of a starter (40 to 45% roughage) and a finisher diet are fed daily starting at approximately day 3 to 5 after feedlot arrival. Similar to a large number of transition or “step-up” diets, small increases in energy and small decreases in roughage daily theoretically should improve the potential for microbial adaptation in the rumen and result in greater DMI and improved animal performance. Rather than mixing the two feeds in the delivery truck or wagon, the two diets can be fed at separate times during the day. One example of this approach using a three times per day feeding schedule is shown in Table 1. The starter diet is fed for 3 days, followed by increasing proportions of the finishing diet every 4th day through day 12. On days 13 through 15, the finishing diet is fed at feedings 2 and 3. From days 16 through 21, the finisher diet is fed at the first and third feedings, and the starter is fed at the second feeding with increasing finisher:starter at 3 day intervals. By day 22, cattle are on the finishing diet only. An alternative method used involves feeding the starter diet for the initial 3 to 5 days, and then, beginning on day 4 to 6, feeding a proportion of each diet (starter and finisher) at each feeding time. The starter diet is fed first followed by the finishing diet within a set period of time. Advantages of using a two-ration approach with altered delivery times include improved feeding efficiencies resulting from reduced milling of multiple rations, trucks always carrying a maximum load, and a reduction in the number of total loads fed throughout the day. Feeding times should be consistent for a given pen of cattle. As previously indicated, small incremental changes in energy and forage content should promote smoother adaptation of the microbial populations in the rumen and of the host animal to the final diet. Disadvantages generally involve increased complexity in management of feed trucks and feed delivery within the feedyard because feed distribution and timing are critical. Coordination of feeding with the two rations being fed to various pens at various times throughout the day results in more intensive management. This approach also makes the assumption that all cattle in a pen consume equal proportions of each ration daily, an assumption that may not be correct. The risk associated with the increased management constraints and possibilities of mistakes may be why only 6 of 29 consultants used this method to any extent (Vasconcelos and Galyean, 2007).

Limit Feeding the Finishing Diet

Little information is available concerning the use of restricting intake of the final finishing diet as a means of adapting cattle to a finishing diet (Bierman and Pritchard, 1996; Weichenthal et al., 1999; Choat et al., 2002). Choat et al. (2002) hypothesized that restricting intake of the final finishing diet would reduce DMI and increase digestibility during adaptation and improve overall feed efficiency by cattle, compared with free choice feeding of adaptation diets. They reported results from two experiments where effects of restricting intake of the final finishing diet as a means of dietary adaptation were compared with diets increasing in grain over a period of 20 to 22 d. In their first experiment, restricting intake of yearling steers during adaptation had no effect on overall feed efficiency, but it decreased DMI compared with free choice access to adaptation diets. Overall ADG was not affected by treatment. In their second experiment, restricting intake of steer calves decreased overall ADG (3.33 vs 3.64 lb/d) and DMI (19.1 vs 20.2 lb/d) compared with steers given free access to feed; however, feed

efficiency was not influenced by this adaptation method. The results of the first experiment concurred with results of Bierman and Pritchard (1996) and Weichenthal et al. (1999). In their studies, limiting intake during diet adaptation did not influence ADG but decreased DMI, resulting in improved feed efficiency by those steers limit-fed the final diet compared with steers given free access to their adaptation diets. Therefore, limiting intake of the final diet as a method of adaptation appears to be effective for adapting cattle (at least yearlings) to high-concentrate diets. This method of adaptation may produce other benefits, such as simplified bunk management, decreased feed waste (Lake, 1987), and the potential for decreased manure and nutrient output. The results from Choat et al. (2002) indicate that limit-feeding of the final diet as a means of dietary adaptation can be used for finishing cattle with few problems from acidosis or related intake variation. However, for calf-fed steers, disruptions in intake during the adaptation period might result in restriction for an extended period and result in decreased hot carcass weight.

Table 1. Two ration method for adapting cattle to a high-concentrate diet

Feeding 1		Feeding 2		Feeding 3		Days
Ration	%	Ration	%	Ration	%	
1	33	1	33	1	34	3
1	45	4	15	1	40	3
1	35	4	30	1	35	3
1	30	4	45	1	25	3
1	40	4	30	4	30	3
4	33	1	33	4	34	3
4	45	1	15	4	40	3
4	33	4	33	4	34	3

ADAPTING HIGH-RISK CALVES

Until the recent increase in the price of corn, the prevalence of calves placed in feedlots was increasing in most feedyards; this increased the risk for morbidity and mortality. Debate has raged over the degree of impact that diet formulation and management can have on morbidity and mortality. Rivera et al. (2005) suggested that performance is lost equal to approximately \$20/head by feeding 40% compared with 100% roughage. In their review, morbidity of lightweight, highly stressed cattle due to bovine respiratory disease (BRD) was decreased when roughage concentration in the diet was increased. However, the change was small, and the authors

concluded that the disadvantage in ADG and DMI that occurs when cattle are fed greater roughage concentrations in receiving diets likely would be offset by favorable effects of increased roughage concentration on BRD morbidity. Anecdotal information indicates that higher morbidity in the starting period often results in a higher incidence of morbidity at later in the feedlot, and that feeding a higher roughage starting ration (40 to 45% roughage) may decrease the incidence of morbidity throughout the feeding period.

We recently conducted an experiment to evaluate receiving and adaptation programs on health and

performance of high-risk calves program-fed a high-concentrate diet during the receiving phase. The experiment was designed as a randomized complete block in which steers ($n = 536$ with an initial BW = 626 ± 46 lb) were allocated to pens assuring homogeneity among groups within and among pens. The design included 4 treatments and 6 replications/treatment for a total of 24 pens holding 20 to 25 calves/pen. Four diets with increasing concentrate levels (64, 72, 80, and 88% concentrate) were fed during the adaptation to the high-concentrate diet and the subsequent growing phase. During the growing phase of the experiment, calves were fed to a similar target BW (NRC, 1996). This target weight was calculated as initial BW plus 150 lb (ADG of 2.5 lb/d for 60 d). Calves originated from auction markets in Florida, Missouri, Oklahoma, and Texas. Individual BW was recorded approximately 1 h after arrival and steers were identified by an individual numbered ear tag. Based on this weight, calves were allocated into treatments and pens. Twenty-four to 48 h later, calves were processed; processing included a 5-way viral vaccine (revaccination on d 11), clostridial bacterium/toxoid, oral and topical dewormers, castration and dehorning, recording weight, and sorting into pens. Subsequently, individual BW were recorded on d 21, 42, and 60. The day prior to weighing, steers were fed one-half their previous day's allotment of feed and withheld from water for approximately 12 to 16 h to reduce differences in fill.

Experimental treatments included: 1) **TRAD**; the three adaptation diets were offered ad libitum for 7-d intervals until d 21. On d 1, 2.5% of initial BW of diet 1 was offered with feed supply increasing 1.5 lb/steer daily when no feed remained in the bunk. The final diet was offered on d 21 with intake restricted such that cattle would attain their final target weight on day 60; 2) **PF**; the 88% concentrate diet was offered d 1. The metabolizable energy delivery/steer was equivalent to TRAD calves initially. However, when no feed remained in the bunk, feed delivered was increased 0.5 lb/steer daily until the amount of feed delivered reached that required for the calves to gain to the target weight; 3) **REC**; the 64% concentrate diet was offered free choice during a 28-d receiving period followed by traditional adaptation using a series of diets with increasing concentrate levels fed for 7-d intervals (72 and 80% concentrate, respectively). The final diet (88% concentrate) was

initially offered on d 42. Bunk management during the 42-d adaptation period was the same as TRAD; and 4) **LMI**; the four adaptation diets were offered such that maximum metabolizable energy intake was restricted to 2.1, 2.3, and 2.5 times that required for maintenance during wk 1, 2, and 3, respectively (Bartle and Preston, 1992). The final diet was fed on d 21.

Based on BW of steers on d 21 (treatments 1, 2, and 4) and d 42 (treatment 3), steers were program fed so they reached their target weights on d 60. Steers were fed twice daily at approximately 0700 and 1000 in the morning throughout the trial. Bunks were evaluated twice daily and feed deliveries were called so that approximately 10%orts remained prior to feeding each morning during the ad libitum periods for TRAD and REC. Bunks were swept and remaining feed was weighed weekly, and if necessary, throughout the remainder of the experiment. Diet samples were collected twice each week and composited within diet and weigh period. Proximate analyses were conducted on composite diet samples. Trained personnel evaluated cattle for signs of BRD daily and treatments were administered based on standard protocol. Health and performance data were analyzed on a pen basis using the Mixed procedure of SAS.

Performance

Growth performance results for cattle in the study are shown in Table 2. Steers fed the four adaptation treatments had similar BW ($P = 0.55$) and ADG ($P = 0.41$) on d 21. However, from d 22 to 42, REC steers gained faster ($P > 0.001$) and therefore weighed more ($P < 0.001$). Even though steers given free choice access to feed had their feed removed on the day prior to weighing, a portion of the advantage of REC steers on d 42 most likely can be attributed to gastrointestinal fill because on d 60, after all steers had been program-fed a common diet for 18 d, the difference in BW between REC (BW=772 lb) and PF steers (BW=760 lb) was numerically less than on d 42. However, REC steers still had the greatest ($P = 0.06$) BW and PF the least BW with TRAD and LMI steers being intermediate. Over the entire growing period, ADG was greatest ($P = 0.02$) for REC steers, intermediate for TRAD and LMI, and least for PF steers. As intended, REC steers consumed the most feed ($P < 0.05$) and PF consumed the least amount of feed. However, no significant intake differences

existed between TRAD and LMI steers, even though LMI steers were restricted to some extent during the first 21 d while TRAD steers had free choice access to feed. Using yearling cattle, Bartle and Preston (1992) reported that steers fed limited maximum intake consumed less feed during the adaptation period than steers with free access to feed, but they detected no difference in BW or feed efficiency. With our steer calves, Choat et al. (2002) reported similar results to the present study with decreased DMI and ADG of calves limit-fed the finishing diet compared with traditional adaptation using multiple diets with intermediate levels of concentrate. This effect was consistent throughout the 173-d feeding period. In another experiment in the same report, yearling steers limit-fed consumed and gained less during the initial

28 d, but gains were similar when averaged over the entire 70 d finishing period. Calves and yearlings may differ in their response to limiting intake of high-concentrate adaptation diets.

Due to the design of the experiment with dietary restriction and free choice intake treatments occurring at the same time, we calculated the efficiency of converting metabolizable energy intake to gain (calculated as average daily ME intake/ADG) rather than calculating efficiency of conversion of DMI to ADG. Over the 60 d growing period, REC steers consumed the greatest ME/d ($P < 0.001$), but they tended to be least ($P = 0.06$) efficient in converting energy to gain.

Table 2. Performance of steers on four different programs for adaptation to a high-concentrate diet

Item	Treatment ¹				$P > F^{\dagger}$
	TRAD	REC	LMI	PF	
BW, lb					
Initial	624	622	626	624	0.55
d 21	675	674	670	666	0.58
d 42	730 ^a	761 ^b	728 ^a	721 ^a	0.001
d 60	772 ^{ab}	776 ^a	765 ^{bc}	761 ^c	0.055
ADG, lb/d					
d 0 – 21	2.34	2.38	1.98	1.92	0.41
d 22 – 42	2.54 ^a	4.06 ^b	2.78 ^a	2.60 ^a	0.001
d 43 – 60	2.54 ^b	0.90 ^a	2.18 ^b	2.29 ^b	0.001
d 0 – 60	2.49 ^{bc}	2.58 ^c	2.34 ^b	2.29 ^a	0.017
ME intake, Mcal/d					
d 0 – 21	16.18 ^a	16.02 ^a	16.77 ^a	13.26 ^b	0.003
d 22 – 42	18.41 ^b	23.99 ^a	18.47 ^b	18.73 ^b	0.001
d 43 – 60	19.01 ^b	19.54 ^a	18.09 ^b	18.97 ^b	0.002
d 0 – 60	17.67 ^{bc}	19.75 ^a	17.93 ^b	16.72 ^c	0.001
ME:Gain, Mcal/lb					
d 0 – 21	9.15	7.45	8.81	7.25	0.48
d 22 – 42	9.73	5.97	7.29	2.41	0.10
d 43 – 60	8.52 ^b	21.50 ^a	11.68 ^b	8.76 ^b	0.003
d 0 – 60	7.37	7.81	7.79	7.39	0.057

¹TRAD = three adaptation diets (64, 72, and 80% concentrate; DM basis) offered ad libitum for 7-d intervals; REC = 64% concentrate diet offered ad libitum during a 28-d receiving period followed by traditional adaptation fed for 7-d intervals (72 and 80% concentrate, respectively); LMI = four adaptation diets offered such that maximum intake was restricted to 2.1, 2.3, and 2.5 times that required for maintenance during wk 1, 2, and 3, respectively; and PF = final 88% concentrate diet offered d 1.

[†] Probability of overall F test.

^{a,b,c,d} Means within a row without a common superscript differ ($P < 0.05$).

Morbidity

In the reports mentioned previously, incidence of morbidity due to BRD was never reported. In the case of Bartle and Preston (1992) and Choat et al. (2002; Exp. 1), yearling cattle, that presumably are at low risk for BRD, were used. Therefore, one of our goals was to obtain cattle with a relatively high risk for BRD and use pens with adequate population numbers to provide a robust indication of the impact of various treatments on the incidence of BRD. Bovine Respiratory Disease morbidity was relatively high with 38.7% of calves being treated at least once for BRD. Total BRD morbidity was greater ($P = 0.02$) for TRAD and PF steers compared with REC and LMI steers (Table 3). The number of steers treated three times for BRD (chronics) was greatest ($P = 0.03$) for PF steers, intermediate for TRAD steers, and least for REC and LMI steers. These results are consistent with those reviewed by Rivera et al. (2005). The reasons for increased morbidity with an increased percent of dietary concentrate are not known. While the fecal pH results in the present study and metabolism data in the Choat et al. (2002) study did not detect an increased prevalence of digestive upsets, one postulate is that the higher concentrate diet results in more cases of sub-clinical ruminal acidosis that are diagnosed incorrectly as BRD. Also of interest, though not significant statistically, steers on the LMI and PF treatments initially were detected as being sick an average of 1 to 5 days earlier than TRAD and REC steers. Perhaps a decreased gastrointestinal fill of steers limited in intake altered the perception of personnel seeking visual signs of morbidity and allowed BRD events to be detected earlier.

In summary, feeding a higher roughage diet for an extended period (28 d) after arrival resulted in the greatest ADG. However, when those cattle subsequently were adapted to their high-concentrate program-fed diet, they were less efficient. A 21-d adaptation period with free access to feed or feeding the high-concentrate diet initially increased the incidence of morbidity from BRD. Therefore, extending the period during which a higher roughage diet is fed or limiting the maximum intake during the adaptation period can reduce morbidity in newly received feedlot steers.

GRAIN SOURCE AND PROCESSING DURING ADAPTATION

Few experiments have evaluated the effects of grain source or degree of processing during the adaptation period on animal performance. In the experiment of Bartle and Preston (1992), feeding whole-shelled corn resulted in 12% greater DMI, 4% greater ADG, and a 7% poorer gain efficiency compared with steers fed steam-flaked milo for the overall experiment. The observed differences in ADG and DMI occurred within the first 28 days of the experiment. Results indicate that grain source and processing may have a much greater effect on performance than the method of adaptation. Similarly, the relative ranking of performance variables remained similar across the adaptation and feeding period when grain sorghum was processed to various degrees in the experiment of Xiong et al. (1991). In their experiment, an increased degree of grain processing resulted in a decreased frequency of restricted feedings during the periods from d 0 to 7, d 8 to 14 and d 22 to 28 and during the periods from d 29 to 56 and d 57 to 84. The decrease in the frequency of restricted feeding with increased degree of grain processing was associated with a similar decrease in DMI, and suggested that net energy content was improved as flake density decreased (Xiong et al., 1991). In addition, flaking may make batches of grain more consistent and thereby decrease daily fluctuations in metabolizable energy content of the diet. These data indicate that degree of grain processing has a greater impact on feeding period performance than grain adaptation method and that more extensive grain processing may simplify diet adaptation.

Finding ways to ensure maximum feed intake while minimizing the risk of ruminal acidosis would be beneficial to the feedlot industry, due to increased performance with increased DMI. Lee et al. (1982) reported greater DMI and ADG with ratios of 75% whole-shelled corn:25% steam-flaked corn and 25% whole-shelled corn:75% steam-flaked corn compared with 100% steam-flaked corn. The authors concluded that up to 25% whole-shelled corn could substitute for steam-flaked corn without influencing animal performance. Based on the increased DMI with the addition of less processed grain, slowly adapting cattle to processed grains may help to maximize feed intake. However, more research is needed.

Table 3. Morbidity of steers on four different programs for adaptation to a high-concentrate diet.

Item	Treatment ¹				<i>P</i> > F†
	TRAD	REC	LMI	PF	
Total Morbidity	45.94 ^a	33.97 ^{bc}	29.64 ^c	43.56 ^{ab}	0.021
Second Treatments	22.95	15.18	18.52	28.38	0.107
Third Treatments	4.48 ^{ab}	1.45 ^a	2.24 ^a	7.98 ^{bc}	0.032
Total Mortality	4.48	0.72	1.48	0.69	0.138
Case fatality rate	7.66 ^d	1.52 ^c	0 ^a	1.39 ^b	0.034
DOF to 1 st Treatment	10.91	12.79	7.21	9.28	0.124

¹TRAD = three adaptation diets (64, 72, and 80% concentrate; DM basis) offered ad libitum for 7-d intervals; REC = 64% concentrate diet offered ad libitum during a 28-d receiving period followed by traditional adaptation fed for 7-d intervals (72 and 80% concentrate, respectively); LMI = four adaptation diets offered such that maximum intake was restricted to 2.1, 2.3, and 2.5 times that required for maintenance during wk 1, 2, and 3, respectively; and PF = final 88% concentrate diet offered d 1.

† Probability of overall F test.

^{a,b,c,d} Means within a row without a common superscript differ (*P* < 0.05).

SUMMARY

Multiple approaches can be used to adapt cattle to high-concentrate rations successfully. With challenges related to cost of production, feedyard size, and personnel all increasing, we likely will see more customization of feeding programs to specific individual operations. Basic nutritional knowledge, feedyard capabilities, management, and cost of doing business most likely will dictate the specifics of an individual's starting program. Establishing a high

DMI early in the finishing period is important to optimize overall finishing performance and profitability. The industry will continue to struggle with starting calves and other high-risk cattle. More data are needed to better define specific interaction of nutrition/management and animal health. In addition, although differences in performance due to grain source and/or degree of grain processing appear to be greater than for adaptation method, more data are needed to clarify these effects and their interactions.

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QUESTIONS AND ANSWERS

- Q:** Clint, today many of the cattle entering the feedyard are backgrounded. Can backgrounded cattle be brought onto feed more rapidly?
- A:** I did not address previous management of cattle in my talk. Yes, certainly. It helps to understand the history of the cattle and the type of substrate fed previously, whether it was low-quality forage, high-quality forage like wheat pasture, or a limit or program fed concentrate diet in a receiving or growing program. Certainly we can move backgrounded cattle to their final diet at a faster pace because the rumen already has been primed to utilize starch and can deal with a larger concentration of starch.
- Q:** Clint, will you comment about preconditioning and what role preconditioning can play in adaptation at the yard?
- A:** Todd addressed preconditioning recently at the Alpha Symposium. One of our greatest challenges is adapting higher risk calves to high-concentrate diets. Anything we can do in terms of a 45-day PreVac program, in which calves are trained to eat from a bunk so they know what a bunk is and will eat readily is going to be advantageous. Substrate fed during preconditioning has received little research attention. The types of feedstuffs fed during a preconditioning program are very diverse. We have defined the importance of vaccines clearly, but we have not defined how important energy supplementation and adequate protein may be during the preconditioning period and how preconditioning nutrition can influence performance not only during the first month on feed but during the entire feedlot period.
- Q:** Clint, for these different ration adaptation strategies that you described, is information available about the incidence of sick pulls and not just intake patterns and performance?
- A:** Some data are available, but effects on health have not been well characterized. In Bartle's work, the pull rate was too small for statistical analysis. Galyean wrote a review about the effect of energy level during the receiving period and how energy level can affect morbidity. As we increase concentrate level, we increase morbidity, but the cost of the increased morbidity does not outweigh the benefit from greater feed efficiency from a higher concentrate. Steve, you have as much data as anyone on animal health responses and have done a nice job of characterizing morbidity in various receiving systems.

ASSOCIATIVE EFFECTS AND MANAGEMENT – COMBINATIONS OF PROCESSED GRAINS

Rick A. Stock and Galen E. Erickson

Cargill Incorporated, Blair, NE 68008

Department of Animal Sciences, University of Nebraska, Lincoln 68583

rick_stock@cargill.com



INTRODUCTION

When feeding grains to feedlot cattle, the goal is to maximize starch digestion while managing acidosis in order to provide optimal economic utilization of the finishing diet. Starch, the main component of grains, is digested primarily in the rumen with some digestion occurring in the small intestine and cecum. The small intestine is the preferred location of starch digestion to occur because digestion in the small intestine is more efficient (20 to 25%; Waldo, 1973) than digestion by the rumen microbes. However the capacity of the small intestine to digest starch may be limited (Karr et al., 1966; White et al., 1971). Starch digestion and acidosis are closely intertwined. Acidosis usually occurs in feedlots with cattle fed high-energy diets. Therefore, the relationship between rate of starch digestion, acidosis, and intake is important in determining whether the level of performance attained equals the level predicted for the cattle and feedstuffs used. Acidosis is one of the most important nutritional disorders in feedlots. In general, acidosis is considered one disorder, but it needs to be separated into acute and subacute types. During acute acidosis, the animal's life may be threatened or at least some physiological function, usually absorption, may be impaired (Britton and Stock, 1987). In subacute acidosis, the major response observed is a reduction in feed intake with a concomitant reduction in performance (Fulton et al., 1979). Processed grains may differ in site of digestion, rumen versus post-rumen. Processed grains also may differ in their rate and extent of starch digestion in the rumen. In addition, the amount of starch fed (% grain in the diet) has an important effect on acidosis, and consequently, on cattle performance. Thus, it is important to consider rate, extent, site, and amount of starch digestion

when determining an appropriate combination of processed grains to be fed.

Combinations of Processed Grains

Grains can be categorized by rate of ruminal fermentation. In general, wheat and barley have the fastest rates of starch digestion whereas corn and grain sorghum generally are the slowest. Any grain processing method that reduces particle size and/or causes gelatinization of the starch granules increases the rate of ruminal breakdown of that starch and increases the possibility of acidosis. Grains harvested at high moisture (greater than 24%), ground and stored in a bunker silo have faster rates of ruminal starch fermentation than the same grains fed after being dry rolled. However, the rate of fermentation also may be affected by moisture level of the incoming grain, particle size, and length of storage. Steam flaking increases the rate of ruminal starch fermentation but the rate also can be affected by grain type, flake density, and flake thickness. With dry processing (rolling or grinding), rate of fermentation may be impacted by grain type, particle size, and the amount of fines. Figure 1 depicts the relative rate of starch digestion in the rumen for various grains and processing methods. This figure was constructed without absolute rates because values within grain processing methods vary and this alters rate of fermentation and the rank order. Processed grains with the fastest rates of starch digestion generally cause the most acidosis. Another factor to consider is that slower fermented grains also will shift the site of digestion from the rumen to the lower tract. Both changes in acidosis and site of digestion can affect efficiency of utilization of the grains fed. Thus, the concept of feeding a combination of processed grains is based on blending two processed grains, one with a rapid rate of starch fermentation with a second processed grain with a slower rate of starch fermentation.



Figure 1. Grains categorized by rate of starch breakdown in rumen. DR, dry rolled; HM, high moisture; SR, steam rolled; SF, steam flaked.

Nebraska Trials, High Moisture Corn – Dry Grain Blends

Nine trials were conducted at the University of Nebraska (Schindler et al., 1978; Stock et al., 1987ab; Stock et al., 1991) to evaluate the complementary effects of feeding a combination of early harvested high moisture corn (HMC) with either dry corn (whole or rolled) or dry-rolled grain sorghum (DRGS). High moisture corn was ground through a tub grinder and stored for a minimum of 90 d in an oxygen limiting structure. Among the trials, the screen size of the grinder varied from 0.75 to 2 in and grain moisture content varied from 23 to 30%. Dry corn and grain sorghum were harvested as dry grain and stored whole. Dry corn was fed either whole or coarsely rolled. Grain sorghum was finely rolled. Cattle were fed high-grain diets consisting of approximately 80% grain, 10% forage (a mixture of corn silage and alfalfa hay), and 10% supplement. Cattle were implanted and fed Rumensin and Tylan. The formulation of the 100% HMC diet was similar among all nine trials.

The complementary effects appeared different when cattle were fed a combination of HMC with dry corn (Figure 2) versus a combination of HMC with DRGS (Figure 3). Cattle fed 100% HMC or 100% dry corn gained and converted feed to gain similarly (Figure 2). However, cattle fed a

combination of 67-75% HMC and 33-25% dry corn gained 2.9% faster and 4.3% more efficiently than cattle fed either HMC or dry corn alone. The complementary effect of HMC and dry corn was reduced when the combination consisted of 50% HMC and 50% dry corn. When a combination of 25 to 33% HMC and 75 to 67% dry corn was fed, cattle consumed more feed resulting in faster gains, but the feed/gain ratio was similar to the expected values.

Cattle fed 100% DRGS (Figure 3) consumed 7.0% more feed, gained 5.6% slower, and were 13.7% less efficient than cattle fed 100% HMC. Cattle fed a combination of 67 to 75% HMC and 33 to 25% DRGS gained as fast and as efficiently as cattle fed 100% HMC; the complementary effect was 2.6% for gain and 4.8% for feed/gain. When cattle were fed a combination of 50% HMC and 50% DRGS, the complementary effect was 3.6% for gain and 4.8% for feed/gain. Cattle fed a combination of HMC and DRGS consistently consumed less feed than expected, although the magnitude of this depression (1.3 to 1.6%) was small.

The slope of the expected gain and feed/gain lines are quite different in Figures 2 and 3. However, the magnitude of the complementary effect of feeding 25 to 33% dry corn or DRGS together with HMC was quite similar.

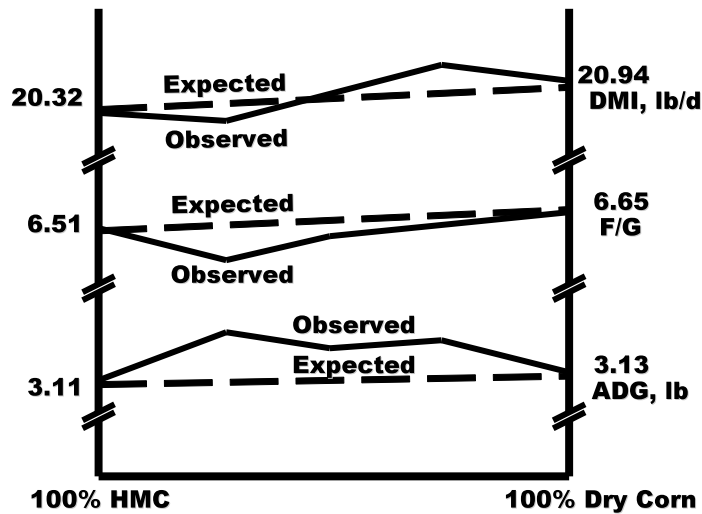


Figure 2. High moisture corn (HMC) – dry corn combinations (72 pens). DMI, dry matter intake; F/G, feed/gain; ADG, average daily gain.

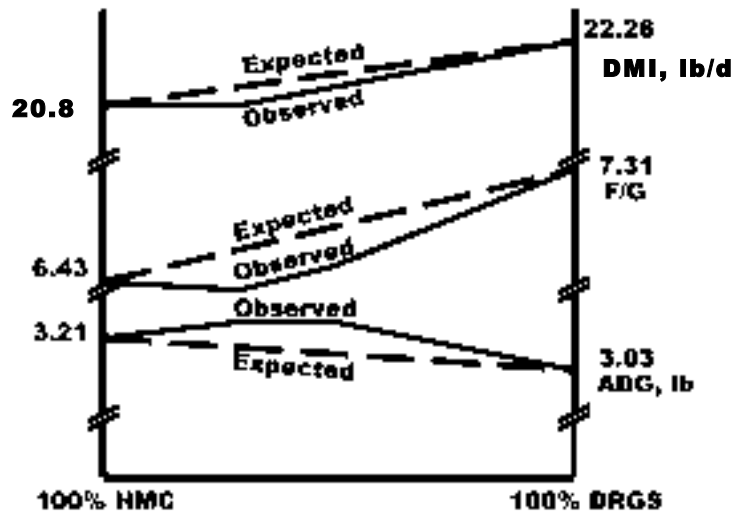


Figure 3. High moisture corn (HMC) – dry rolled grain sorghum (DRGS) combinations (69 pens). DMI, dry matter intake; F/G, feed/gain; ADG, average daily gain.

In a cattle metabolism trial (Stock et al., 1987b), 89% of the starch from a 100% HMC diet was digested in the rumen compared with only 46% for a 100% DRGS diet (Figure 4).

In vitro starch digestion rates were 10.8%/h for HMC and 5.8%/h for DRGS. Thus, both rate and extent of starch digestion were greater for HMC

compared with DRGS. Cattle fed a mixture of HMC and DRGS digested more starch in the rumen compared with expected values. The small intestine partially compensated by digesting more starch as the level of DRGS increased. Total tract starch digestion was similar for steers fed HMC alone or in combination with DRGS, but values were greater when DRGS was fed alone (Figure 5).

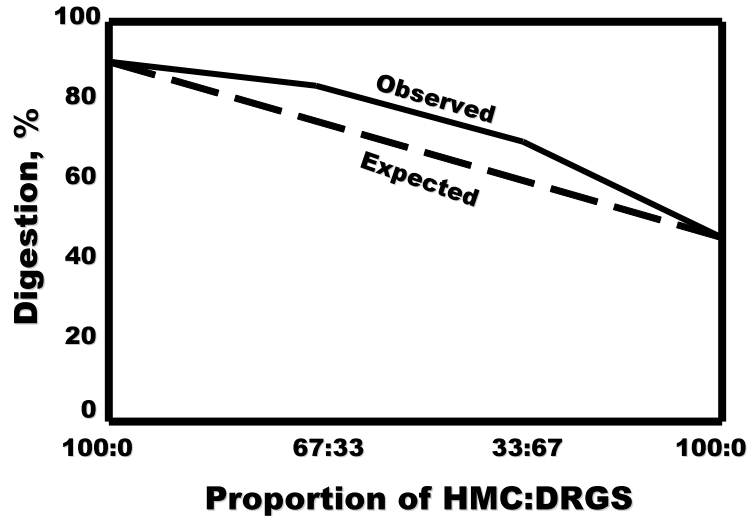


Figure 4. High moisture corn (HMC) – dry rolled grain sorghum (DRGS), ruminal starch digestion.

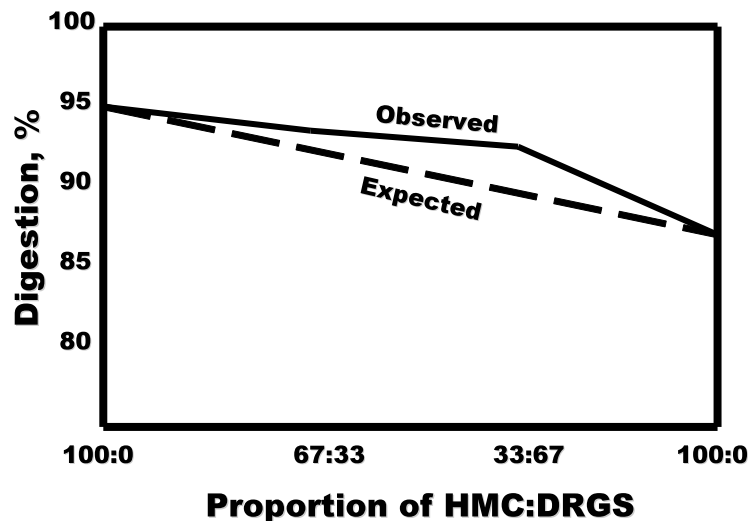


Figure 5. High Moisture corn (HMC) – dry rolled grain sorghum (DRGS), total tract starch digestion.

Observations With Feeding a Blend of HMC and Dry Grain

When HMC is the only grain source in the finishing diet, feed intake generally is reduced as compared with feeding dry grain; the magnitude of the reduction in feed intake appears related to the rate of ruminal starch digestion of the HMC. On the other hand, dry grain, particularly DRGS, is less digested in the rumen and total tract so feed intake increases significantly. Replacing some of the HMC with a slower fermenting grain source such as DRGS, slows the rate of starch digestion in the rumen (less subacute acidosis) compared with feeding HMC alone, but the amount of starch digested in the rumen and total tract is increased

when compared with feeding DRGS alone (improved starch utilization). In addition, the processed grain combination increases feed intake compared with feeding HMC alone, but feed intake is lower than for DRGS fed alone. The improvement in feed/gain from feeding a combination of processed grains is the result of reduced acidosis and increased ruminal starch digestion. Therefore, the benefit should be attributed to both grains and not just one single grain – positive associative effect.

Other Combinations of Processed Grains

Table 1 summarizes processed grain trials with different grain combinations. Feeding a combination of a rapidly fermented processed grain, such as dry-rolled

wheat, with a slower fermented processed grain, such as dry-rolled corn (Varner and Woods, 1971; Kreikemeier et al., 1987) or high moisture grain sorghum (Axe et al., 1987) resulted in a complementary effect in gain and feed/gain. Feeding a combination of steam-flaked corn and whole corn (Lee et al., 1982) or a combination of HMC and steam-flaked grain sorghum (Huck et al., 1998) also resulted in complementary effects on gain and

feed/gain. However, feeding a combination of two rapidly fermented grains (HMC and dry-rolled wheat or HMC and steam-rolled barley) had no complementary effect on gain or feed/gain (Bock et al., 1991; Duncan et al., 1991), and feeding a combination of two different dry grains (dry-rolled corn and dry-rolled or finely ground grain sorghum) had no complementary effect on gain or feed/gain (Sindt et al., 1989).

Table 1. Complementary effect (%) of processed grain combinations on average daily gain (ADG) and feed/gain

Processed Grain Types Reference	ADG	Feed/gain
Dry-rolled wheat and dry-rolled corn Varner and Woods, 1971	+4.1	+0.7
Steam-flaked corn and whole corn Lee et al., 1982	+5.3	+0.5
Steam-flaked corn and whole corn Lee et al., 1982	+2.5	+0.1
Dry-rolled or dry ground corn and whole corn Turgeon et al., 1983	+7.1	+5.5
Dry-rolled wheat and high moisture grain sorghum Axe et al., 1987	+5.4	+5.7
Dry-rolled wheat and dry-rolled corn Kreikemeier et al., 1987	+4.2	+3.9
Dry-rolled corn and dry-rolled or dry ground grain sorghum Sindt et al., 1989	-0.8	+2.0
High moisture corn and dry-rolled wheat Bock et al., 1991	-3.8	-3.3
High moisture corn and steam-rolled wheat Bock et al., 1991	+2.9	+3.1
Steam-rolled barley and dry-rolled corn Duncan et al., 1991	+2.6	+2.9
Steam-rolled barley and high moisture corn Duncan et al., 1991	-4.3	-5.8
Dry-rolled barley and whole corn Pritchard and Robbins, 1991	-0.03	-2.3
Steam-flaked grain sorghum and high moisture corn Huck et al., 1998	+6.2	+4.9
Steam-flaked grain sorghum and dry-rolled corn Huck et al., 1998	+6.4	+5.0
Steam-flaked grain sorghum and steam-flaked corn Huck et al., 1998	+4.3	+1.4
Steam-flaked corn and steam-flaked grain sorghum Duff et al., 2002	-1.0	-1.9

Interestingly, cattle fed a combination of whole and finely ground corn or whole and rolled corn gained faster and more efficiently than cattle fed either whole, ground, or rolled corn (Turgeon et al., 1983). These complementary responses are greater than one would predict based on differences in rate and extent of ruminal starch digestion.

In two trials, feeding a combination of steam-flaked corn and steam flaked grain sorghum was evaluated. A complementary effect with gain was observed in one trial (Huck et al., 1998), but no complementary effect with gain or feed/gain was observed in the second trial (Duff et al., 2002).

Several trials demonstrated a 2 to 3% complementary effect in gain and feed/gain when two grains were combined, but this small difference may be due to random variation. Comparing different trials is difficult because the formulation of diets, processing methods, and experimental protocols differ.

Future - Blends with other feed ingredients

With the increased availability of wet milling (corn gluten feed) and dry milling (distillers grains) feed byproducts, the benefit from feeding a combination of rapidly and slowly fermented grains may be altered. One of the advantages of feeding wet corn gluten feed is its effect to reduce subacute acidosis in the feedlot. Thereby, one might hypothesize that some of the benefit of feeding a slowly fermented processed grain with a rapidly fermented processed grain could be negated by including 20 to 30% (DM basis) wet corn gluten feed in the diet. In the review of Owens et al. (1997),

feeding HMC and steam-flaked corn improved efficiency 1.4% and 11.4% compared with feeding dry-rolled corn. However, when HMC, steam-flaked corn, and dry-rolled corn were fed in diets containing 25 to 30% (DM basis) wet corn gluten feed, HMC and steam-flaked corn improved feed efficiency 8.1% and 14.6%, respectively, compared with feeding dry-rolled corn (Erickson; elsewhere in this publication). Thus it appears that feeding wet corn gluten feed allows higher levels of highly processed grains to be fed without increasing the incidence or severity of acidosis.

With the abundance of the wet and dry milling feed byproducts, the need to feed high amounts of grain also can be reduced. The University of Nebraska has fed combinations of wet corn gluten feed and wet distillers grains at levels that replaced up to 75% of the grain in the diet. Feeding diets composed with different grain byproducts (gluten feed, distillers grains, midds, beet pulp) may be the combinations of the future.

CONCLUSIONS

Feeding combinations of rapidly digested grains (high moisture corn, dry-rolled wheat) with more slowly digested grains (whole corn, dry-rolled corn or dry-rolled grain sorghum) resulted in a positive complementary effect in gain and feed/gain in the feedlot. This improvement in performance can be explained partially by a reduction in subacute acidosis as compared with feeding the rapidly fermented grain alone and partially by an increase in ruminal and total tract digestion as compared with feeding the slowly fermented grain alone.

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EFFECT OF CORN PROCESSING IN FINISHING DIETS CONTAINING GRAIN MILLING BYPRODUCTS

M. E. Corrigan, G. E. Erickson, V. R. Bremer, and T.J. Klopfenstein
University of Nebraska-Lincoln
Lincoln, NE 68583-0908
geericks@unlnotes.unl.edu



ABSTRACT

Processing cereal grains generally increases starch digestion and improves feed efficiency and/or gain. However, the supply and cost effectiveness of using either wet corn gluten feed (WCGF) or wet distillers grains plus solubles (WDGS) is likely to increase in the future. Therefore, understanding how grain processing interacts with these byproducts will be critical for feedlots. Feeding wet byproducts improves performance compared to feeding dry byproducts, and the wet byproducts will likely be more commonly used and at greater inclusions compared to dry byproducts. When feeding WCGF, corn processing is more beneficial than in diets without WCGF. Cattle fed steam-flaked corn (SFC) were 14.6% more efficient than cattle fed dry-rolled corn (DRC) across three experiments. Cattle fed high-moisture corn (HMC) were 8.1% more efficient than cattle fed DRC in these experiments. These data suggest that processing corn as either HMC or SFC may be more beneficial in diets containing WCGF at 22 to 32% of diet DM. These data suggest that HMC and SFC are considerably better than DRC and even more so than in diets without WCGF. Interestingly, there does appear to be an interaction between corn processing and feeding WDGS. Unlike diets without WDGS, feeding DRC and HMC in combination with WDGS results in better performance than feeding SFC in combination with WDGS. However, performance differences are likely related to inclusion of WDGS. In one experiment evaluating 0, 15, 27.5, or 40% WDGS in diets based on either DRC, HMC, or SFC, the optimum inclusion was different between corn processing methods. We conclude that if diets are based on SFC, then the optimum inclusion of WDGS is likely 15 to 20% of diet DM. With diets comprised of DRC or HMC, the optimum inclusion of WDGS is 40% or 27.5 to 40%, respectively, for optimal gains and feed efficiency.

Key Words: Corn processing, Wet distillers grains plus solubles, Wet corn gluten feed

INTRODUCTION

Supply of grain milling byproducts is expected to increase greatly with the rapid expansion of ethanol production (Cassman et al., 2006). Currently, two primary types of milling processes are utilized. The wet-milling process produces corn gluten feed (CGF) and the dry-milling process produces distillers grains plus solubles (DGS; Stock et al., 2000). These feeds can be marketed as wet corn gluten feed (WCGF) and wet distillers grains with or without solubles (WDG and WDGS, respectively), or they can be dried and marketed as dry corn gluten feed (DCGF) and dry distillers grain's with or without solubles (DDG and DDGS, respectively). The majority of the discussion in this paper will be about WCGF and WDGS, as they are the byproducts most commonly utilized in finishing cattle diets in the U.S. Today, most plant expansions are dry milling plants that produce DGS; however, an increase in supply of CGF is also expected. With a greater amount of annual corn production going to the corn milling industry and an increasing supply of byproducts, these feeds will become increasingly important for beef producers.

This paper will briefly touch on the use of byproducts in feedlot diets, but the main focus will be on the effect of grain processing in diets that contain grain milling byproducts.

NUTRIENT PROFILE OF BYPRODUCTS

In feedlot diets with byproduct inclusion levels less than 20% of the diet dry matter (DM), generally they are used as a source of supplemental protein. At higher inclusion levels, byproducts are used primarily as an energy source. The crude protein (CP) content and rumen degradability of byproducts is variable due to the differences in byproduct composition and processing techniques and among milling plants. The CP content of WCGF can range from 14 to 24% (DM basis; Stock et al., 2000) but is generally 18 to 24%. In 1984, Firkins et al. estimated the undegradable intake protein (UIP, % of CP) of WCGF and DCGF to be 26 and 14%, respectively. However, because of differences in the UIP of corn bran, steep, and germ meal (13, 35, and 40% of CP, respectively; Herold et al., 1999), CGF composition will affect ruminal protein degradabilities. Generally, DGS are higher in

CP than CGF (29-33%, DM basis; unpublished data) because the gluten fraction is not removed in the dry-milling process. The gluten fraction also has greater UIP, and therefore the UIP of DGS is also greater compared to CGF. Firkens et al. (1984) estimated the UIP % of DDG and WDG to be 54 and 47%, respectively. More recently, we estimated the UIP of DDGS, WDGS, and condensed corn distillers solubles samples taken from a single plant to be approximately 65% for all three (Erickson et al., 2006).

Corn milling by-products also serve as a source of highly digestible NDF, and WDGS are relatively high in fat. The NDF content of WCGF typically ranges from 37 to 48% DM (Stock et al., 2000). Spiehs et al. (2002) analyzed DDGS from 11 plants and reported average NDF values ranging from 35.4 to 49.1% DM, with an average for more recently constructed plants being 42.1% NDF (DM basis). In the wet milling process the corn germ is separated and the oil is extracted; thus, CGF is relatively low in fat (3% or less). The oil is not extracted in most dry-milling processes, so DGS are higher in fat than CGF. The plant average fat content of samples of WDGS from six ethanol plants analyzed in our lab have ranged

from 10.7 to 13.1% fat (DM basis) with an overall average of 11.8%. The fat content of DGS is related to solubles level, as the fat content of DDGS increases with increasing solubles level (Corrigan, 2007b). The fat content may be a limiting factor for inclusion of DGS and/or sulfur content.

FEEDING VALUE OF BYPRODUCTS

The feeding value of CGF and DGS is dependent on whether the byproducts are fed wet or dry and the level of dietary inclusion. Both CGF and DGS have a higher feeding value when they are fed wet compared to feeding after they are dried. Although the feeding value of WCGF is better than corn (100 to 109% the feeding value of corn), the feeding value of DCGF is 88% of dry-rolled corn (DRC) when fed at 25 to 30% of diet DM respectively (Green et al., 1987). Ham et al. (1995) observed better performance by feeding WCGF compared to DCGF. Firkens et al. (1985) also observed better performance when feeding WCGF compared to DCGF as well as when feeding WDGS compared to DDGS. Similarly, Ham et al. (1994) observed better performance by feeding WDGS compared to DDGS (Table 1).

Table 1. Feeding value of wet versus dry distillers grains when included at 40% of diet dry matter (Ham et al., 1994)

	Control	WDGS	DDGS		
			Low ^a	Medium ^a	High ^a
Dry matter intake, lb/d	24.2 ^{bc}	23.54 ^b	25.3 ^c	25.0 ^c	25.9 ^c
Average daily gain, lb	3.23 ^b	3.71 ^c	3.66 ^c	3.71 ^c	3.76 ^c
Feed:Gain	7.69 ^b	6.33 ^c	6.94 ^d	6.76 ^d	6.90 ^d
Improvement					
Diet	---	21.511.9 (average).....		
Distillers vs. corn	---	29.8.....		

^aLevel of acid detergent insoluble nitrogen, 9.7, 17.5, and 28.8%.

^{b,c,d}Means in same row with different superscripts differ ($P < 0.05$).

Experiments evaluating the use of WCGF replacing DRC or high-moisture corn (HMC) in feedlot diets are available (Buckner et al., 2007a; Herold et al., 1998; Loza et al., 2007; Richards et al., 1995; Scott et al., 2003; Scott et al., 1997). In 2004, Macken et al. demonstrated the importance of WCGF composition on feedlot performance. In that study they fed WCGF, composed of different steep to bran ratios, at 25% of the diet DM. A linear improvement in efficiency was observed with increasing levels of steep in the WCGF. Therefore, higher feeding value (and protein) is associated with increases in steep

added in WCGF. Distinct differences exist in WCGF composition, even within companies, due to plant-to-plant variation. Stock et al. (2000) divided WCGF into 2 main categories, depending on the ratio of steep to bran. Based on differences in the amount of steep added, WCGF has 100 to 109% the feeding value of DRC when fed at levels of 20 to 60% of diet DM (Stock et al., 2000). In studies with finishing cattle, the replacement of corn grain with WCGF (Sweet Bran, Cargill Inc.) consistently improved feed efficiency (Figure 1). Replacing DRC with WCGF in feedlot diets also improved ADG linearly (Figure 2).

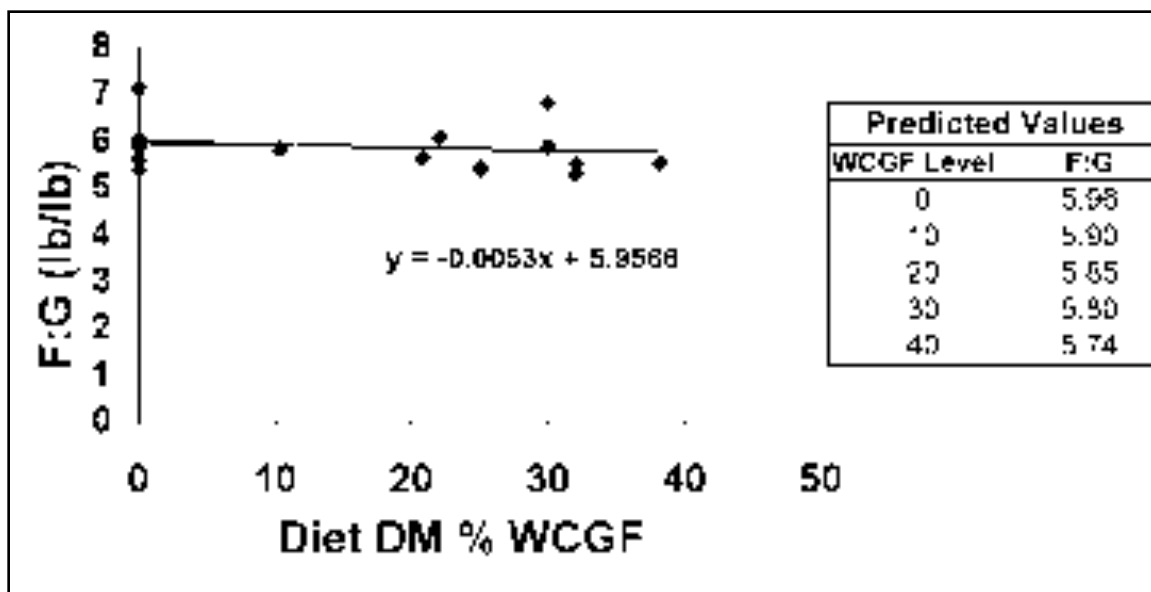


Figure 1. Feed conversion of feedlot cattle fed diets containing wet corn gluten feed when replacing corn at different inclusions.

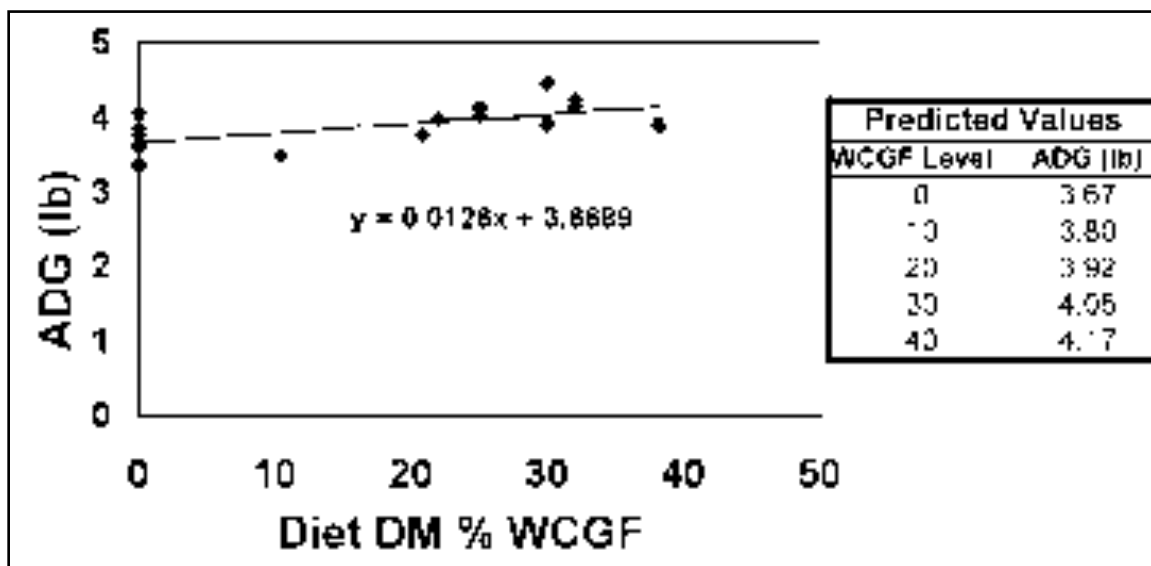


Figure 2. Average daily gain of feedlot cattle fed diets containing wet corn gluten feed when replacing corn at different inclusions.

The majority of the research on distillers grains as a feed source has been conducted on finishing cattle. Vander Pol et al. (2006b) evaluated 0, 10, 20, 30, 40, and 50% inclusion of WDGS (Table 2). They observed a quadratic improvement in ADG and G:F when WDGS replaced a blend of DRC:HMC. Buckner et al. (2007b) conducted a 145 day feedlot finishing study to evaluate 0, 10, 20, 30, and 40%

dietary DM inclusion of DDGS in corn-based diets on steer performance. There was a quadratic response in performance. The 20% DDGS diet had the most improved performance when compared to a traditional no-byproduct diet, with a feeding value of 126% the value of corn (Table 2). However, all DDGS levels had improved G:F and feeding value relative to the no-byproduct diet.

Table 2. Cattle performance when fed different levels of wet distillers grains plus soluble (WDGS; Vander Pol et al., 2006b) or levels of dry distillers grains plus soluble (DDGS; Buckner et al., 2007b) to finishing cattle in different experiments^a

WDGS (DM basis)	0%	10%	20%	30%	40%	50%	SEM ¹	Lin ²	Quad ³
DMI, lb/d	24.0	24.6	25.1	26.0	24.4	23.3	0.3	0.09	<0.01
ADG, lb	3.65	4.07	4.11	4.31	4.27	3.92	0.09	0.01	<0.01
G:F	0.153	0.165	0.164	0.173	0.176	0.169	0.002	<0.01	<0.01
DDGS (DM basis)	0%	10%	20%	30%	40%	SEM ¹	Lin ²	Quad ³	
DMI, lb/d	20.4	20.9	21.0	21.4	20.9	0.4	0.23	0.30	
ADG, lb	3.30	3.55	3.70	3.57	3.50	0.11	0.26	0.05	
G:F	0.162	0.177	0.177	0.168	0.168	0.005	0.61	0.14	

¹Standard error of the mean.

²Linear orthogonal contrast *P*-value.

³Quadratic orthogonal contrast *P*-value.

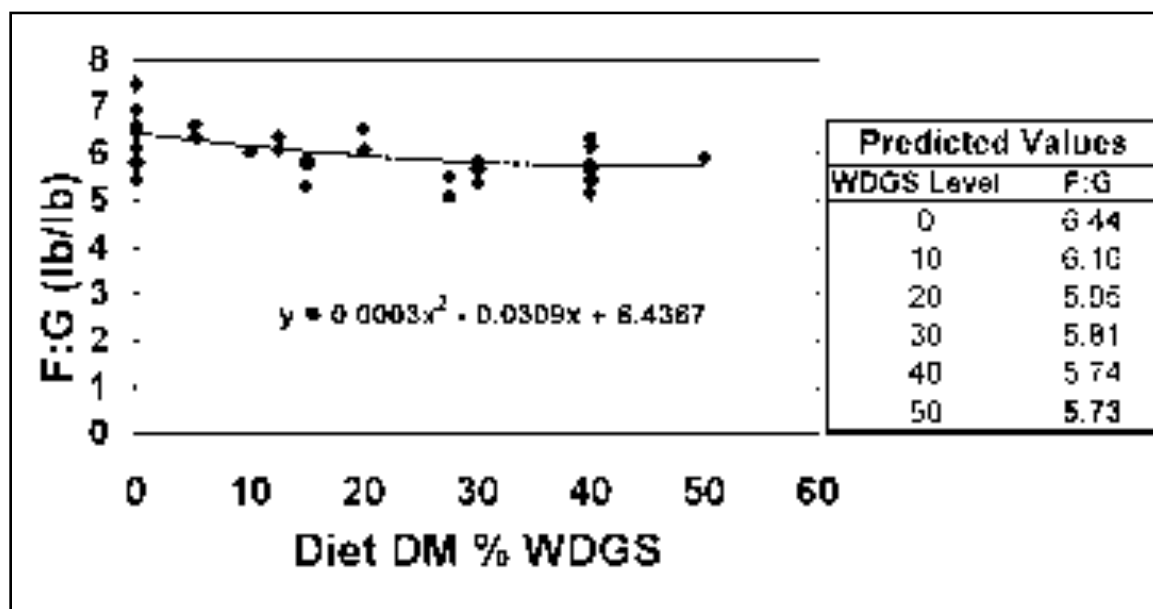


Figure 3. Feed conversion of feedlot cattle fed diets containing wet distillers grains plus solubles when replacing corn at different inclusions.

Numerous experiments evaluating the use of wet distillers byproducts in ruminant diets are available (Buckner et al., 2007a; Corrigan et al., 2007a; DeHaan et al., 1982; Fanning et al., 1999; Farlin, 1981; Firkins et al., 1985; Larson et al., 1993; Luebke et al., 2007; Trenkle, 1997a; Trenkle, 1997b; Vander Pol et al., 2004; Vander Pol et al., 2006b) and were summarized to determine the optimum amount of WDGS to include in DRC or DRC:HMC based diets. In studies with finishing cattle, the replacement of DRC or DRC:HMC blends with WDGS consistently improved feed efficiency (Figure 3). Figure 4 summarizes University of Nebraska studies conducted on WDGS

with feeding value expressed relative to corn. The feeding value of WDGS is consistently higher than corn. However, these studies suggest a linear decrease in the feeding value (measured as improvement in feed efficiency and inclusion level) when WDGS replaces DRC. The feeding value at low levels (10%) is approximately 145% the feeding value of corn. When higher levels of WDGS are used (40%), the feeding value was still greater than corn, but average 131% the feeding value of corn. Replacing DRC with WDGS results in a quadratic improvement in ADG (Figure 5). The optimal

biological response in ADG was at 30% WDGS inclusion.

The biological optimum level of DDGS to feed with DRC and HMC is less than with WDGS. The biological optimum level for DDGS is likely 20%

whereas optimum level of WDGS is 30-40% (DM basis). Because there is a linear improvement in performance with feeding Sweet Bran WCGF, the optimum level is likely 50% or more in DRC or HMC based diets.

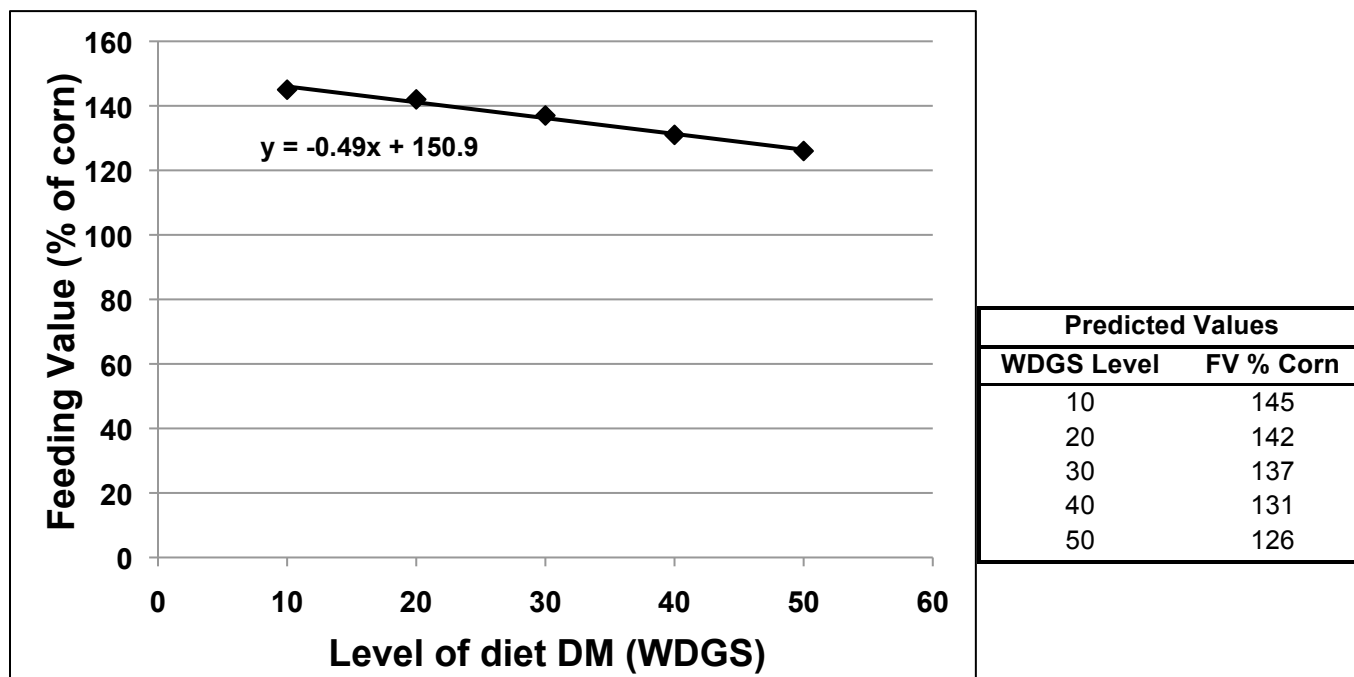


Figure 4. Feeding value of wet distillers grains plus solubles when replacing corn at different inclusions.

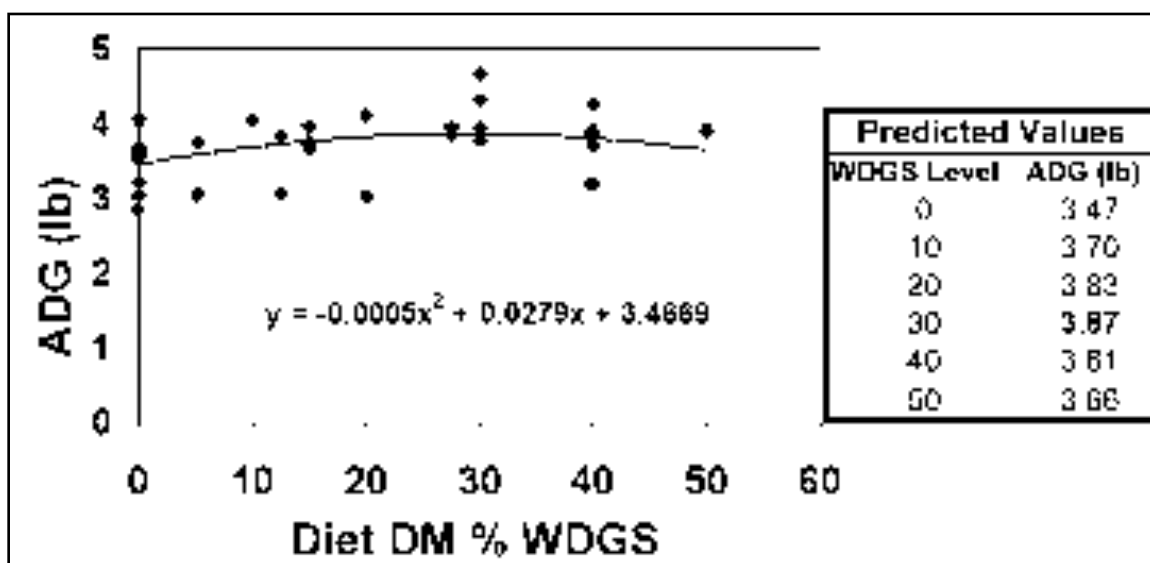


Figure 5. Average daily gain of feedlot cattle fed diets containing wet distillers grains plus solubles when replacing corn at different inclusions.

CORN PROCESSING INTERACTION WITH CORN BYPRODUCTS

Wet Corn Gluten Feed

Because processing corn increases rate of digestion by microbes, rumen acid production is increased and the risk of acidosis is increased (Stock and Britton, 1993). Feeding WCGF helps prevent risk of acidosis with high-grain diets (Krehbiel et al., 1995). Therefore, numerous studies have been conducted at the University of Nebraska to determine if energy values are markedly improved in diets containing WCGF when corn is more intensely processed. Scott et al., (2003) evaluated numerous corn processing techniques in diets containing 32 or 22% WCGF (Table 3). Feed conversions were improved as processing intensity increased with both calves and yearlings. Compared to whole corn,

relative improvements in G:F for DRC, fine-ground corn (FGC), HMC, and steam-flaked corn (SFC) were 6.8, 10.1, 11.1, and 12.5%, respectively, in calves fed 32% WCGF. When fed to yearlings, whole corn was not included, but response to processing was not as marked as with calves. Feeding fine rolled corn and HMC did not significantly improve feed conversion compared to DRC. Macken et al., (2006) fed DRC, FGC, SFC, and HMC processed as rolled (roller mill) and ground (tub grinder) to calves with all diets containing 25% WCGF (Table 3). Whole corn was not fed in this study, but processing corn more intensely significantly improved performance. When compared to a diet based on DRC, net energy (calculated from performance; Owens et al., 2002 and NRC, 1996) was increased by 4.8, 9.1, 11.0, and 14.9% for FGC, rolled HMC, ground HMC, and SFC, respectively.

Table 3. Effect of corn processing when fed with wet corn gluten feed (WCGF; Macken et al., 2006; Scott et al., 2003)

Macken et al., 2006; 25% WCGF					
Processing ¹	DRC	FGC	RHMC	GHMC	SFC
Dry matter intake, lb/d	23.2 ^a	23.0 ^a	21.6 ^b	21.4 ^b	21.3 ^b
Average daily gain, lb	4.23	4.35	4.21	4.24	4.33
Gain:Feed	0.182 ^a	0.189 ^b	0.195 ^c	0.198 ^c	0.204 ^d
Fecal starch, %	19.2 ^a	11.8 ^b	10.6 ^{bc}	8.4 ^c	4.1 ^d
Scott et al., 2003; 32% WCGF with calf-feds					
Processing ¹	Whole	DRC	FGC	RHMC	SFC
Dry matter intake, lb/d	24.8 ^a	23.4 ^b	22.2 ^c	21.8 ^c	22.0 ^c
Average daily gain, lb	4.18	4.24	4.17	4.15	4.25
Gain:Feed	0.168 ^a	0.180 ^b	0.187 ^c	0.189 ^{cd}	0.192 ^d
Scott et al., 2003; 22% WCGF with yearlings					
Processing ¹	DRC	FRC	RHMC	SFC	
Dry matter intake, lb/d	24.2	24.3	24.0	23.4	
Average daily gain, lb	3.98 ^a	3.95 ^a	4.02 ^a	4.22 ^b	
Gain:Feed	0.164 ^{ab}	0.162 ^a	0.167 ^b	0.181 ^c	

¹DRC, dry rolled corn; FGC, fine ground corn; FRC, fine rolled corn; RHMC, rolled high moisture corn; GHMC, ground high moisture corn; SFC, steam flaked corn; whole, whole corn.

^{a,b,c,d}Means with different superscripts differ ($P < 0.10$).

In previous reviews, feeding HMC in diets containing no byproducts improved efficiency by 2% compared to DRC. Interestingly, HMC appears to be much greater in value when diets contain WCGF. When WCGF is fed at 20 to 35% of diet DM, cattle fed diets based on HMC are 5 to 10% more efficient than cattle fed similar diets based on DRC. Because of higher ruminal starch digestibility for HMC

compared to DRC and SFC, perhaps this response is expected. For example, the energy value of HMC in diets comprised of HMC only is lower than when HMC is fed in combination with other grains with lower ruminal starch digestibilities (Stock et al., 1991). With SFC, gelatinization of the starch improves digestion in both the rumen and small intestine compared to DRC. In diets with no

byproducts, feeding HMC and SFC improves G:F by 1.4 & 11.4%, respectively, compared to DRC (Cooper et al, 2002). In diets containing WCGF however, feeding HMC and SFC improves G:F by 8.1 and 14.6% compared to DRC and HMC, respectively (Scott et al., 2003; Macken et al., 2006). Effects of corn processing method on ruminal starch digestion likely explain most of the differences in responses to WCGF inclusion. Ruminal starch digestion is greatest for HMC, lowest for DRC, with SFC being intermediate (Huntington, 1997). Therefore, replacing HMC with WCGF would cause a greater reduction in dietary ruminally degraded starch than replacing DRC or SFC with an equal amount of WCGF. Our conclusion is that intense processing has tremendous value in diets containing WCGF, by replacing high starch grains and therefore attenuating acidotic insults. Additionally, fine grinding may be possible in wet byproduct diets because “fines” settling in bunks is less of a concern. However, the response has been variable with fine-grinding and fine-rolling dry corn.

Wet Distillers Grains with Solubles

Vander Pol et al. (2006b) examined the effects of WDGS inclusion level in diets based on a 1:1 mixture of DRC and HMC (Table 2). In that study, G:F was optimized when WDGS was included in the diet at 40% (DM basis). In contrast, Daubert et al. (2006) observed that G:F was optimized in SFC based diets when WDGS was included in the diet at 16% (DM basis). Furthermore, Vander Pol et al. (2006a) observed that in diets containing 30% WDGS, G:F was improved in HMC based diets when compared to SFC based diets, and G:F was similar between DRC and SFC based diets. In that study, G:F values were 98.7, 105.4, 111.2, 108.2, and 106.9% of the whole corn value, for FGC, SFC, HMC, DRC, and a 1:1 blend of HMC and DRC, respectively (Table 4). However, ADG was dramatically decreased for cattle fed FGC and SFC compared to DRC, HMC, or a blend of DRC:HMC.

Table 4. Effect of corn processing when fed in diets containing wet distillers grains plus solubles (Vander Pol et al., 2006a)*

Treatment ¹	WC	DRC	FGC	DRC:HMC	HMC	SFC	SEM	F-test
DMI, lb/d	23.1 ^a	22.6 ^b	20.4 ^c	21.5 ^b	21.0 ^{bc}	20.4 ^c	0.2	<0.01
ADG, lb	3.85 ^b	4.05 ^a	3.37 ^d	3.92 ^{ab}	3.90 ^{ab}	3.59 ^c	0.07	<0.01
G:F	0.166 ^c	0.179 ^{ab}	0.166 ^c	0.182 ^{ab}	0.185 ^a	0.176 ^b	0.002	<0.01
Fecal starch, %	15.9 ^a	12.0 ^{ab}	13.4 ^a	12.0 ^{ab}	8.7 ^b	4.2 ^c	1.3	<0.01

*DMI, dry matter intake; ADG, average daily gain; G:F, gain to feed ratio.

¹WC, whole corn; DRC, dry-rolled corn; FGC, fine-ground corn; HMC, high-moisture corn; DRC:HMC, 1:1 blend of DRC and HMC; SFC, steam-flaked corn; SEM, standard error of the mean.

^{a,b,c,d}Means in same row with unlike superscripts differ ($P < 0.05$).

In 2007(a), Corrigan et al. examined the effects of WDGS inclusion level in diets based on DRC, HMC, or SFC (Table 5). In that study a corn processing method × WDGS inclusion level was observed for ADG and G:F. Optimal ADG, and feed conversion were seen with 40% WDGS in DRC based diets, 27.5% to 40% WDGS in HMC based diets, and 15% WDGS in SFC based diets.

It is interesting that a greater performance response to WDGS inclusion in diets based on less intensely processed grain was observed. The reason for the interaction is not clear, but it appears likely that it is the result of a number of interacting factors.

That discussion is beyond the scope of this paper and will be covered in a subsequent paper in these proceedings by Dr. Cole. It is important to note that in diets containing no WDGS, cattle fed SFC were 11.2% more efficient than cattle fed DRC. However, cattle fed DRC and 27.5 or 40% WDGS performed as well or better than cattle fed any of the SFC based diets. Also, steers fed HMC and 15, 27.5, or 40% WDGS were more efficient than cattle fed any of the DRC or SFC based diets. These data suggest that inclusion of WDGS in diets consisting of DRC or HMC may be an attractive alternative to SFC based diets.

Table 5. Effect of corn processing in diets containing increasing amounts of wet distillers grains plus solubles (Corrigan et al., 2007)¹

	0.0	15.0	27.5	40.0
Dry-rolled corn				
Dry matter intake, lb/d ³	22.3	22.2	21.4	21.3
Average daily gain, lb ²	3.64	3.77	3.87	3.92
Gain:Feed ²	0.163	0.170	0.181	0.185
High-moisture corn				
Dry matter intake, lb/d ³	20.1	21.0	20.2	20.0
Average daily gain, lb ³	3.68	3.96	3.97	3.86
Gain:Feed ²	0.183	0.189	0.197	0.194
Steam-flaked corn				
Dry matter intake, lb/d ³	20.2	20.2	19.8	18.8
Average daily gain, lb ³	3.67	3.74	3.60	3.44
Gain:Feed	0.182	0.186	0.182	0.183

¹For ADG: Effect of corn processing method, $P < 0.01$; effect of WDGS level, $P = 0.01$; effect of corn processing method \times WDGS level, $P < 0.01$. For G:F: Effect of corn processing method, $P < 0.01$; effect of WDGS level, $P < 0.01$; effect of corn processing method \times WDGS level, $P < 0.01$.

²Linear effect of WDGS level within corn processing method ($P < 0.05$).

³Quadratic effect of WDGS level within corn processing method ($P < 0.05$).

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QUESTIONS AND ANSWERS

Q: How does feeding byproducts to cattle alter dressing percentage?

A: In our studies, dressing percentage tends to be improved with feeding of distillers' grains or byproducts. Most of the Nebraska cattle are fed on a carcass weight basis. We can measure carcass weight more accurately than live weight due to the lack of gut fill. So in a lot of our studies, we do not measure dressing percentage. Others may have more experience about dressing percentage effects.

Q: Galen, would you recommend the same level of diet inclusion for wet as for dry distillers' grains?

A: A few experiments have been conducted comparing wet versus dry distillers' grains and corn gluten feed. Something happens when you dry the material, particularly if you start with the same material and feed some wet and some dry. The dry material does not look as energetically favorable. We recently completed a trial with Terry Mader in which we fed 0, 10, 20, 30, and 40% dry distillers' grains in dry rolled corn diets. Cattle fed the dry product performed well up to 20% but tailed off sooner than cattle fed the wet product. So the optimum inclusion level may be lower with the dry product. Management challenges also will differ. Wet feeds help with ration mixing and conditioning. The dry product is the opposite being a meal. Dry distillers' does not pellet well. I would recommend feeding the dry product as a protein supplement, but that is a whole different ball game.

GRAIN PROCESSING AND BYPRODUCT INTERACTIONS – AN INDUSTRY PERSPECTIVE

Robert J. Cooper
Cattlemen's Nutrition Services, LLC
Lincoln, NE
rcooper@cattleservices.com



INTRODUCTION

The availability of corn milling byproducts has increased dramatically in recent years and this is having a tremendous impact on cattle feeding and feeding programs. Others (Erickson and Klopfenstein, 2006; Forester, 2006) have described the differences between the wet milling and dry milling industries and their respective byproducts. In this discussion, the primary foci will be wet corn gluten feed (WCGF) and wet distillers grains (WDG).

The primary question that I was asked to address for this discussion is: Do the results of university studies regarding grain processing and corn milling byproducts agree with field observations of a consulting nutritionist? My immediate thought was "which trials?" because there seems to be disparity among trials. However, disparity may be less than it first appears once the apparent interaction between grain processing and byproduct feeding level are understood. I will not attempt a complete literature review of university trials studying the interaction of grains processing and corn milling products; this already has been done (Cole et al., 2006; Erickson and Klopfenstein, 2006). However, I will discuss several specific trials that predominately agree with my observations in the field, and that describe this apparent interaction quite well.

DISCUSSION

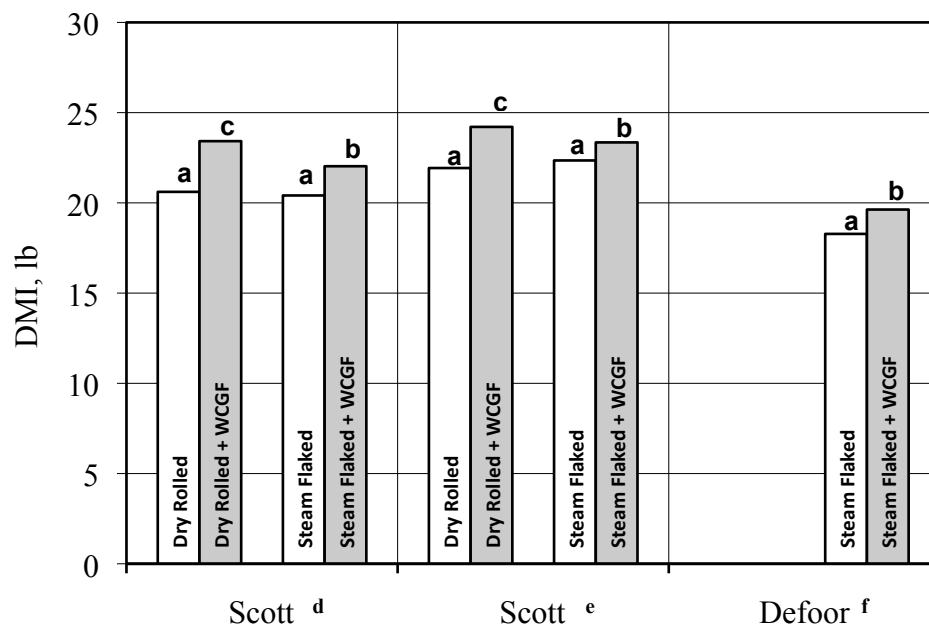
Two primary types of university studies have evaluated grain processing and byproduct interactions. The first typically feeds one or more level of byproduct within a corn processing method and estimates the value of that byproduct relative to the corn that it replaced. The second typically feeds one level of byproduct across two or more corn

processing methods and compares the value of the two processing methods. Both of these types of studies, as well as one which does both, will be discussed below.

Value of Byproducts across Corn Processing Methods

Wet Corn Gluten Feed. Wet corn gluten feed, a byproduct of the wet corn milling industry, basically is a combination of corn bran and steep water from the wet corn milling process. Wet corn gluten feed typically ranges from 40-60% DM depending on which milling facility it comes from, with a typical nutrient content of 18-22% crude protein, 2% fat, and 0.45% sulfur (DM basis). When WCGF is substituted for corn in finishing diets, we typically observe increased DM intake, higher ADG, and similar DM conversions compared to non-byproduct diets. These observations are in agreement with university trials conducted by Scott et al. (2001) and Defoor et al. (2003).

Scott et al. (2001) fed dry rolled corn (DRC) and steam flaked corn (SFC) diets with or without 32% (Trial 1) and 22% (Trial 2) WCGF (DM basis). Defoor et al. (2003) fed SFC diets with or without 25% WCGF (DM basis) and incremental levels of added fat. For this discussion, I will only use the Control diet that contained 3% added fat and the WCGF diet with 3% added fat in the trial of Defoor et al (2003). Performance data for all three trials are shown in Figures 1, 2, and 3. Dry matter intake and ADG were significantly higher ($P < 0.10$) in both trials of Scott et al. (2001) when WCGF was added to the diet. Similarly, DMI was significantly higher ($P < 0.10$) and ADG tended to be higher ($P = 0.11$) when WCGF was added to the diet in the trial of Defoor et al. (2003). Dry matter conversions, however, were similar or slightly inferior in all trials when WCGF was added to the diet.



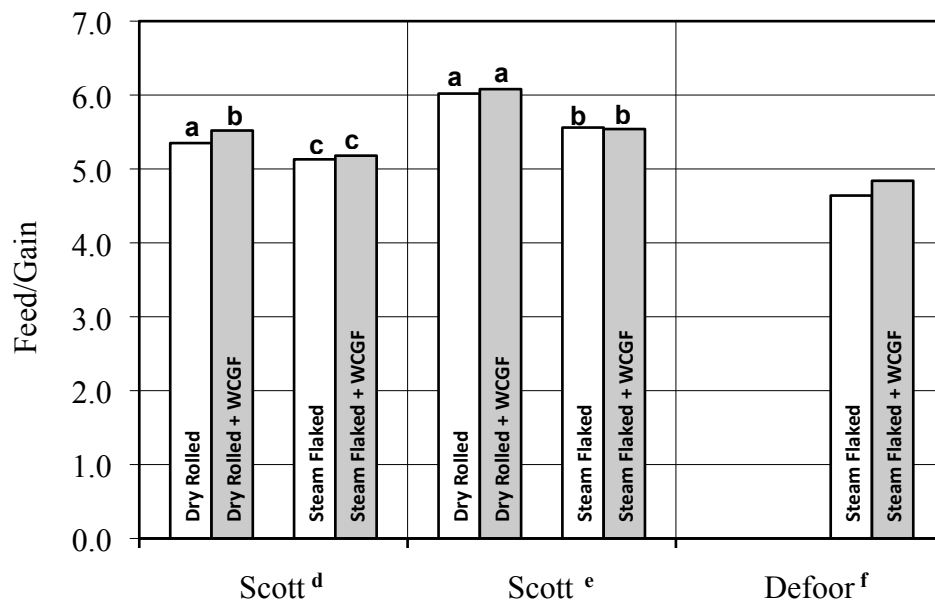
^{a,b,c}Means within trial with unlike superscripts differ (P < 0.10).

^dScott et al. (2001), 32% WCGF (Dry matter basis).

^eScott et al. (2001), 22% WCGF (Dry matter basis).

^fDefoor et al. (2003), 25% WCGF (Dry matter basis) with 3% added fat.

Figure 1. Effect of wet corn gluten feed (WCGF) on dry matter intake (DMI) of finishing cattle fed dry rolled corn or steam flaked corn based diets.



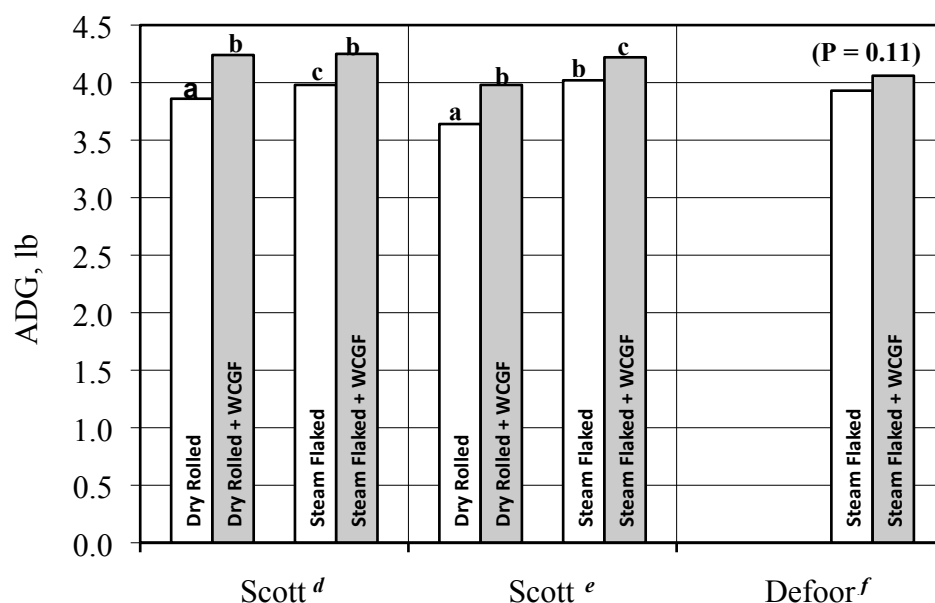
^{a,b,c}Means within trial with unlike superscripts differ (P < 0.10).

^dScott et al. (2001), 32% WCGF (Dry matter basis).

^eScott et al. (2001), 22% WCGF (Dry matter basis).

^fDefoor et al. (2003), 25% WCGF (Dry matter basis) with 3% added fat.

Figure 2. Effect of wet corn gluten feed (WCGF) on feed/gain of finishing cattle fed dry rolled corn or steam flaked corn based diets.



^{a,b,c}Means within trial with unlike superscripts differ ($P < 0.10$).

^dScott et al. (2001), 32% WCGF (DM basis).

^eScott et al. (2001), 22% WCGF (DM basis).

^fDefoor et al. (2003), 25% WCGF (DM basis) with 3% added fat.

Figure 3. Effect of wet corn gluten feed (WCGF) on average daily gain (ADG) of finishing cattle fed dry rolled corn or steam flaked corn based diets.

The results of these trials by Scott et al. (2001) and Defoor et al. (2003) agree very well with my feedyard observations that WCGF promotes greater DMI and ADG but with similar to slightly poorer DM conversions when substituted for corn. Based on the negligible change in DM conversion, WCGF typically is given an energy value similar to dry corn. However, energy value should not be confused with the overall feeding value of WCGF; feeding value includes many other factors such as the value of additional weight gain, reduced protein supplementation cost, improved ration palatability, and acidosis/bloat control. It is also important to note that all WCGF's are NOT the same, with the primary difference being the amount of steep liquor placed in the product; this affects the energy value of WCGF.

Wet Distillers Grains. Wet distillers grains, a byproduct of the dry milling industry, basically is the concentration of the nutrients in corn or milo once the starch is removed. Its DM content will

typically vary from 32 to 50% depending on the design of the dry milling plant, and this unfortunately can vary at times within a plant. The typical nutrient content (DM basis) is 28 to 32% crude protein, 10 to 12% fat, and 0.45 to 1.2% sulfur. A slight increase in DMI along with significant improvements in ADG and DM conversion typically are observed when WDG is substituted for corn in finishing diets. However, the response appears to depend on level of feeding and grain processing with the optimal level being much lower with SFC diets than with DRC or high moisture corn (HMC) diets.

The results of Vander Pol et al. (2006) and Daubert et al. (2005) agree closely with the response to WDG observed in the field. In diets based on a 50:50 ratio of DRC and HMC, Vander Pol et al. (2006) fed 0, 10, 20, 30, 40, and 50% WDG (DM basis); DMI and ADG responded quadratically ($P < 0.01$) to level of WDG with maximums occurring at the 30% inclusion level (Figure 4).

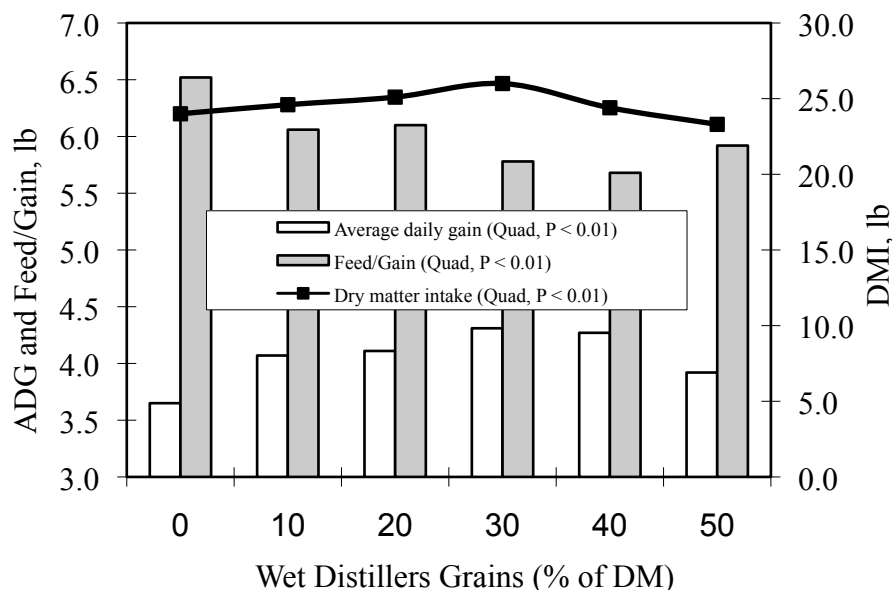


Figure 4. Effect of wet distillers grains added to dry rolled, high moisture corn based finishing diets on steer performance (Vander Pol et al., 2005). ADG, average daily gain; DMI, dry matter intake.

Dry matter conversion also responded quadratically ($P < 0.01$) with 40% being the optimum inclusion level. With SFC diets, Daubert et al. (2005) fed 0, 8, 16, 24, 32, and 40% WDG (DM basis) and observed maximum DMI at 8% WDG

with a linear ($P < 0.01$) decline in DMI as WDG was increased further (Figure 5). Both ADG and DM conversion responded quadratically ($P < 0.01$) to level of WDG with maximum ADG at 8% WDG and optimal DM conversion at 16% WDG.

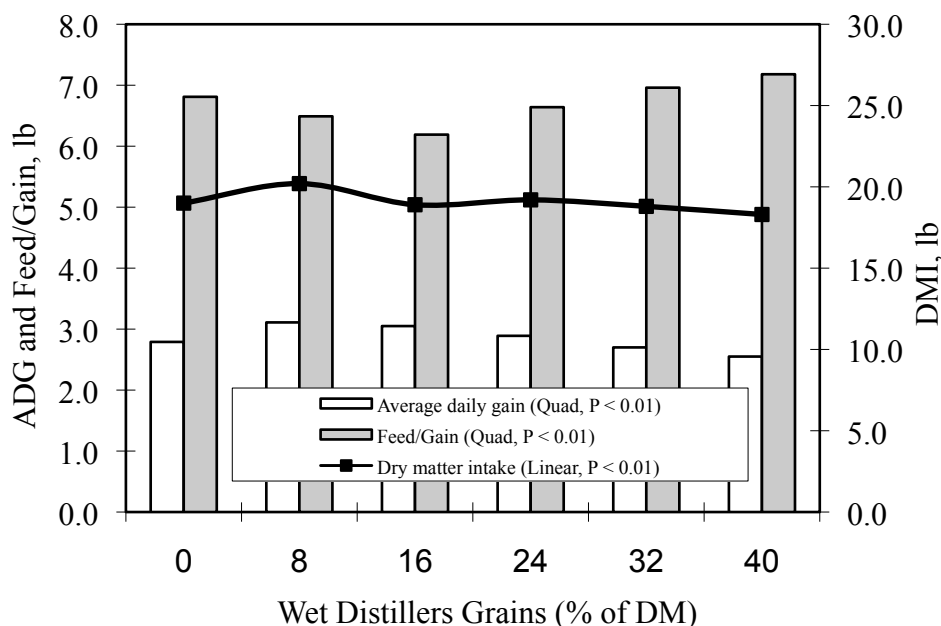
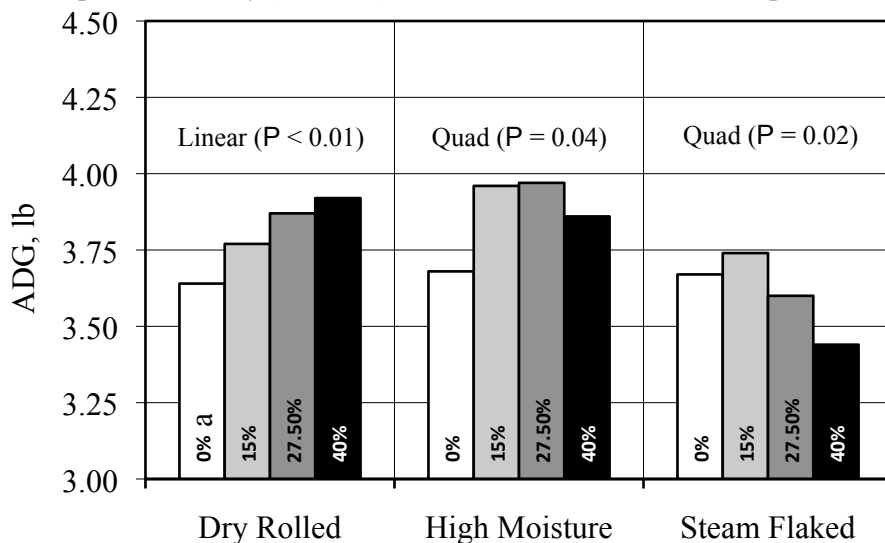


Figure 5. Effect of wet distillers grains added to steam flaked corn based finishing diets on heifer performance (Daubert et al., 2005). ADG, average daily gain; DMI, dry matter intake.

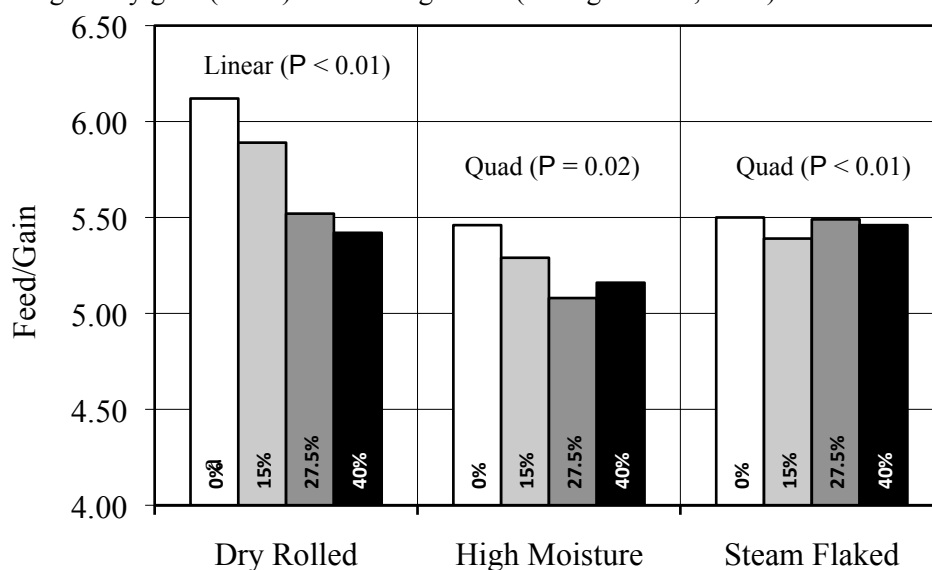
The data of Vander Pol et al. (2006) and Daubert et al. (2005) indicate that the optimum WDG grains inclusion level for performance is between 20% and 30% (DM basis) for DRC and HMC diets and between 10 to 15% of the dietary DM for SFC diets. These observations are supported further by results from a recent study by Corrigan et al. (2007) that evaluated 0, 15, 27.5, and 40% WDG (DM basis) in DRC, HMC and SFC diets. In this study, ADG and DM conversion responded linearly ($P < 0.01$) to

WDG level in DRC diets but quadratically ($P < 0.05$) in HMC and SFC diets (Figures 6 and 7). The optimum ADG and DM conversion was achieved at the 40, 27.5, and 15% WDG level for DRC, HMC and SFC diets, respectively; this clearly illustrates a level by grain processing interaction that is observed in feedyards. Note that these optimum levels are based solely on performance. Obviously the economically optimum inclusion level also depends on the price of the WDG relative to corn and protein supplement costs.



^aNumbers inside bars represent level of distillers grains (DM basis).

Figure 6. Effect of level of wet distillers grains in dry rolled corn, high moisture corn, and steam flaked corn diets on average daily gain (ADG) in finishing steers (Corrigan et al., 2007).



^aNumbers inside bars represent level of wet distillers grains (DM basis).

Figure 7. Effect of level of wet distillers grains in dry rolled corn, high moisture corn, and steam flaked corn diets on feed/gain in finishing steers (Corrigan et al., 2007).

Value of Corn Processing with Byproduct Diets

Wet Corn Gluten Feed. A portion of the performance response when WCGF is fed to finishing cattle has been attributed to a reduction in subacute acidosis (Krehbiel et al., 1995). This certainly agrees with the feedyard observations of increased DMI and a reduction in digestive disturbances when WCGF is included in finishing diets.

Scott et al. (2003) and Macken et al. (2006) each conducted trials with the hypothesis that if subacute acidosis is controlled by WCGF in the diet, then an

improvement in feed conversion should be observed when corn is processed more intensively to increase starch digestibility. In three trials, these authors fed 22 to 32% WCGF (DM basis) in DRC, HMC, and SFC-based diets. As hypothesized, DM conversion generally improved as the corn was more intensively processed (Figure 8). Processing intensity was ranked by fecal starch in these trials. Another interesting observation in the first trial of Scott et al. (2003) was the marked improvement in DM conversion between dry rolled corn as compared to whole corn in diets containing WCGF (Figure 8).

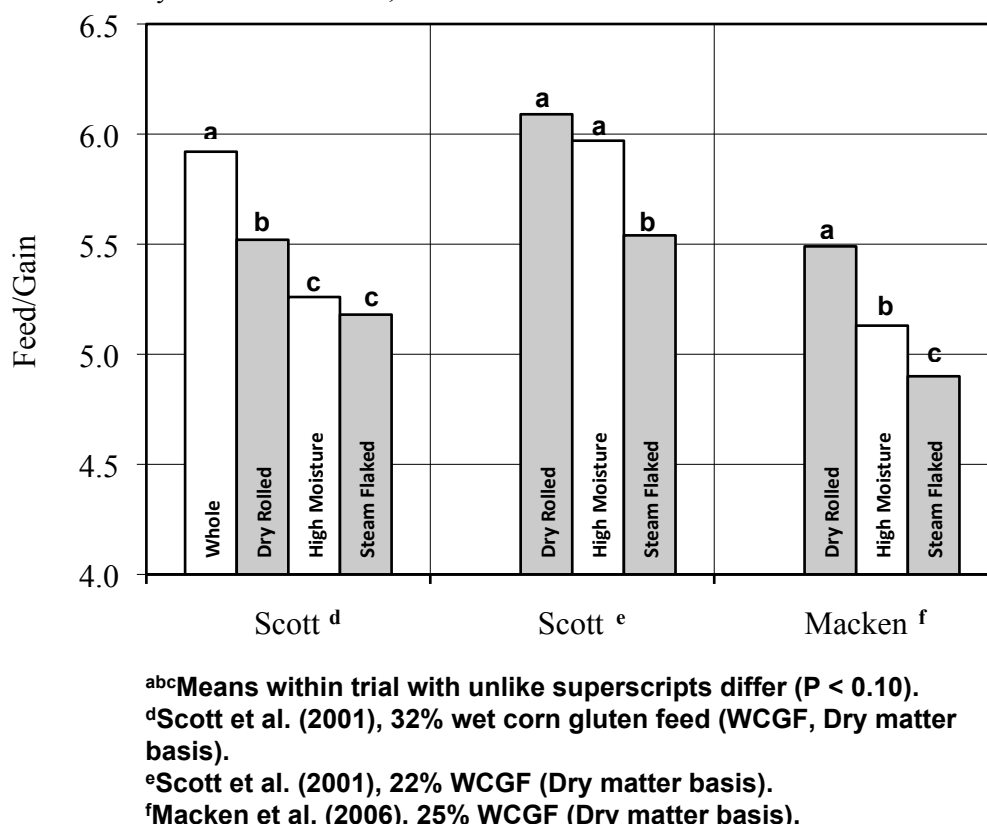


Figure 8. Effect of corn processing on feed/gain in diets containing wet corn gluten feed.

Wet Distillers Grains. We have noted that the corn processing response may be slightly different for WDG than for WCGF; this is supported by two recent feeding studies. Vander Pol et al. (2006) fed 30% WDG (DM basis) across various corn processing methods and observed no significant difference in DM conversion among the DRC, DRC/HMC, or SFC treatments (Figure 9).

The HMC treatment had a significantly improved ($P < 0.05$) DM conversion over the SFC

treatment, but DM conversion was not different for HMC than for the DRC or DRC/HMC treatments. Whole corn and fine ground corn had poorer ($P < 0.05$) DM conversions than all other processing methods. Note that only 30% WDG (DM basis) was fed in this trial and it was shown previously that there appears to be an interaction between WDG level and corn processing method. To illustrate this interaction more clearly, the data of Corrigan et al. (2007) are shown in Figure 10.

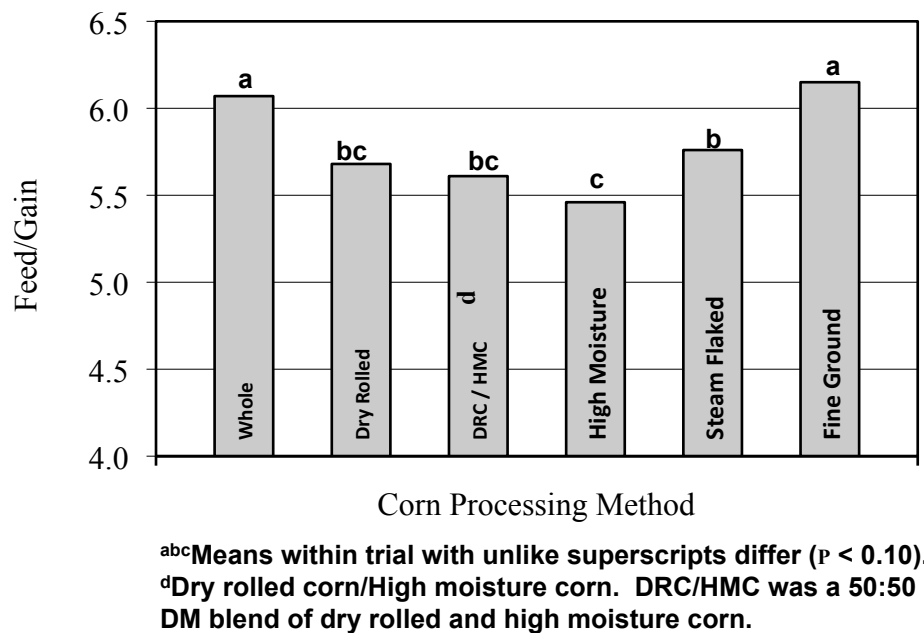


Figure 9. Effect of corn processing method on feed/gain of steers fed diets containing 30% (DM basis) wet distillers grains (Vander Pol et al., 2006).

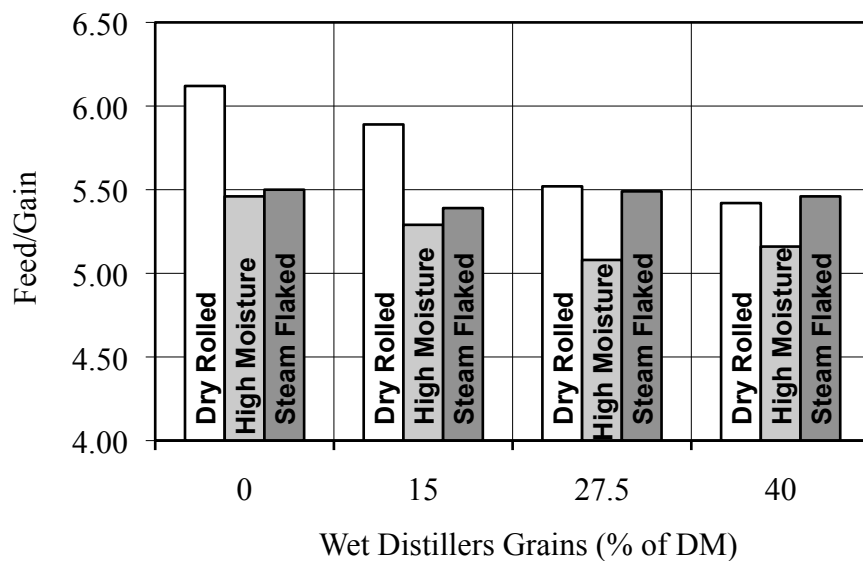


Figure 10. Effect of corn processing method on feed/gain in finishing steers fed various levels of wet distillers grains (Corrigan et al., 2007).

These are the same data as Figure 7, but the treatments have been rearranged and grouped by WDG level rather than by corn processing method. Statistics are not available for this figure because

treatments were not analyzed in this manner in the original report. However, this figure clearly illustrates the interaction between WDG level and corn processing method. Most interesting is the relative difference

between DRC and SFC as WDG level in the diet is increased. In the control diet, steam flaking produced a 10% improvement in DM conversion over dry rolling. With 15% WDG (DM basis) in the diet, the SFC advantage over dry rolled corn was reduced to 8.5%, and all treatments were essentially equal at 27.5% WDG. The treatment levels that most

accurately reflect our current feeding programs are the SFC diet with 15% WDG and the DRC diet with 27.5% WDG. Steam flaking still has an advantage in this comparison, but the advantage certainly is smaller than before WDG became a significant part of our feeding program.

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QUESTIONS AND ANSWERS

- Q:** For Rob or Andy, are the economics going to drive distillers' grains into the ration well above the level where performance is optimum? I was intrigued about the interaction between grain processing and distillers' grains. What will be the basis for deciding what level to feed if optimum performance is not the target?
- A:** Can we afford to give up performance and still get better cost of gain? We are at that point in several yards where distillers' grains are priced below the price of corn. We often think that we cannot afford to give up feed conversion but perhaps we should. As yet, we resist giving up efficiency, but if we owned the cattle, we would. The limitation for the custom cattle feeder is perception of their customers. Dry matter conversion, not the cost of gain, drives a customer's perception of the cattle and the feedlot. We currently are discussing how much efficiency we can give up to improve our cost of gain.
- Q:** Rob or Galen, is there any effect of high levels of co-products on carcass traits when cattle are harvested at a constant carcass weight or composition?
- A:** This is a popular question. You may have seen Certified Angus Beef white paper that shows a trend for less marbling of cattle fed distillers' grain. I think that Galen has data that shows that for cattle fed for a similar number of days on feed, marbling was not reduced. From a practical feeding standpoint, with rolled corn or high moisture corn diets where we had no fat in the diet without distillers' grains, we are increasing rate of

gain by half a pound per day by feeding distillers' grains, so we are feeding these cattle 20 fewer days. So is quality grade lower? Probably so. But with the same days on feed, we probably would not see that reduction in quality grade.

Erickson: The CAB paper forced us to look at quality grain effects on marbling. The meta-analysis we conducted was to look at quality grade effects. Our conclusion from that data was that feeding up to 40% of either corn distillers' grains or corn gluten feed did not negatively affect marbling score. Most of our studies feed cattle fed all diets for the same number of days; we are criticized if we don't. I would prefer to sell cattle at same end-point in all treatments if someone could show me how to predict that accurately across treatments. We feed the same number of days, so generally speaking, our cattle that are performing better, those that are fed by-products, are fatter at harvest. So with our cattle fed higher amounts of by-products tend to have equal or greater marbling. Alfredo Dicostanzo (Minnesota) with Dr. Reinhardt from Kansas State put together a summary of many additional experiments and concluded that feeding up to 35% does not negatively affect quality grade. If we were to feed higher levels, then what? We will be looking into that. Lots of interest. As an industry, we are seeing a depression in quality grades and marbling scores.

Additional Comment by Krehbiel: The correlation between the decrease in quality grade and the increase in distillers' probably is about the same as between quality grade and black hided cattle, isn't it?

INTERACTION OF GRAIN CO-PRODUCTS WITH GRAIN PROCESSING: ASSOCIATIVE EFFECTS AND MANAGEMENT

N. Andy Cole, M. L. Galyean, J. MacDonald, and M. S. Brown

USDA - Agricultural Research Service, Bushland, TX; Texas Tech Univ., Lubbock;
Texas Agricultural Experiment Station, Amarillo; and West Texas A&M Univ., Canyon
andy.cole@ars.usda.gov



INTRODUCTION

The vast majority of research with corn milling co-products such as distiller's grains (**DG**) and corn gluten feed (**CGF**) has been conducted in the Northern Great Plains and Corn Belt with the type of finishing diets commonly fed in that region. More recently these co-products have become available for feeding in the Southern Great Plains. Feedlot diets in the Northern Great Plains differ from those fed in the Southern Great Plains because 1) corn generally is dry rolled rather than steam flaked; 2) supplemental fat is not routinely fed in the Northern as compared with the Southern Great Plains and 3) feedyards tend to be larger in the Southern than the Northern Great Plains. Thus, management and storage of co-products, especially wet co-products, will differ. Moreover, environmental issues tend to differ between the two regions with the Northern Great Plains and Corn Belt being grain-exporting regions whereas, the Southern Great Plains imports grain.

With increased availability of these co-products in the Southern Great Plains, researchers have begun to evaluate their use in finishing diets typical of those fed in that area. Indeed, current research studies indicate that DG has a lower feeding value with steam-flaked corn (**SFC**)-based diets than with dry-rolled corn (**DRC**)-based diets (Cole et al., 2006; Erickson and Klopfenstein 2006a, b; Vasconcelos et al., 2007). With diets based on DRC, substituting wet DG for corn improved feed efficiency (Erickson and Klopfenstein, 2006a, b). Erickson and Klopfenstein (2006b) concluded that wet DGS had 110 (50% inclusion) to 150% (10 to 20% inclusion) the energy value of DRC. In contrast, studies in Kansas and Texas (Cole et al., 2006) indicated that DG had energy and feeding values considerably lower than SFC. In contrast to results with DG, with CGF no interaction with grain processing method has been detected.

Knowledge about possible reasons for the interaction between grain processing method and DG could lead to development of economically beneficial management regimens. For example, if the interaction favors DRC, less intensive processing of corn might be used to decrease energy costs; alternatively, cattle feeders may need to modify roughage or fat levels to decrease feed costs and/or digestive disturbances.

IS THERE AN INTERACTION BETWEEN CO-PRODUCTS AND GRAIN PROCESSING?

Our first objective was to examine the validity of the claim that a grain processing x co-product interaction exists. Therefore, data were obtained from 37 reports (published papers and unpublished research progress reports) in which wet DG or CGF was fed. The NEm and NEg values of the basal/control diets were determined using tabular (NRC, 2000) values, DMI, and animal performance data using the quadratic equation of Zinn (1990). The tabular NEm and NEg values of the ingredients in the diets then were adjusted *en masse* to equal the performance-based values. The modified NE values for the feed ingredients then were used to calculate the NE of DG and CGF by substitution. The NE values of co-products also were determined based on chemical composition using average chemical compositions presented by Holt and Pritchard (2004) for DG and by NRC (2000) for CGF using the equations of Zinn and Plascencia (1993) and NRC (2000).

On the average, the composition of the basal/control diets in the DRC-based trials and SFC-based trials did not differ greatly in composition. In general, SFC diets contained more added fat; however, the studies conducted in Texas contained added fat whereas those conducted in Kansas did not. Based on tabular composition of diet components, the DE, NE, CP, DIP, and ether extract values were greater for SFC-based diets than for DRC-based diets. Grain processing did not affect the calculated effective NDF (**eNDF**), dietary cation-anion balance (**DCAB**), or mineral composition of the control diets.

Table 1. Average performance by cattle fed the control diets in each trial*

Item**	Wet distiller's grains + solubles			Corn gluten feed		
	DRC	SFC	Std dev	DRC	SFC	Std dev
Initial BW, lb	759	816	69.1	752	693	63.58
Animal performance						
Days fed	130	111	30.1	132	150	19.1
ADG, lb	3.52	3.08	0.55	3.48	3.76	0.42
DMI, lb	23.6	18.4	3.41	22.5	19.6	2.48
DMI, % BW	2.39	1.86	0.32	2.28	2.02	0.23
F/G, lb/lb	6.70	6.00	0.55	6.42	5.18	0.40
MP required, lb/d	1.36	1.32	0.06	1.36	1.40	0.04
MP intake, lb/d	2.07	1.76	0.25	1.96	1.78	0.17
ADG, NE						
predicted/actual, %	109.6	107.9	14.8	107.2	103.0	14.1
Calculated from performance						
NE _g , Mcal/cwt	55.0	67.2	0.90	57.7	70.4	0.90
DMI, lb/d	20.5	16.6	3.08	20.0	17.9	2.13
Based on tabular values						
NE _g , Mcal/cwt	64.1	75.4	--	65.4	77.3	--

*DRC, dry rolled corn; SFC, steam flaked corn; Std dev, standard deviation.

**BW, bodyweight; ADG, average daily gain; DMI, dry matter intake, F/G, feed/gain; MP, metabolizable protein; NE, net energy; NE_g, NE for gain.

The average performance by cattle fed the control diets in each trial and the calculated NE values are presented in Table 1. In both DG- and CGF-studies, mean DMI was greater in trials where the diet was based on DRC rather than on SFC. The calculated MP intakes of the control diets in each of the 37 studies reviewed appeared adequate. This is significant because if the control diet was deficient in protein, the response to dietary DG additions would be inflated as a result of correcting a deficiency in DIP or MP. The NE values and DMI calculated from animal performance tended to be less than tabular values, but the relative difference between calculated and tabular values were similar for both grain processing methods.

The mean NE values for wet DG and CGF calculated from animal performance in the 37 trials and average chemical composition data are presented in Table 2. The mean NE values for CGF were similar whether the diet contained SFC or DRC. In addition, the performance-based values for CGF were similar to values in NRC (2000) tables and to values calculated from chemical composition. However, the mean NE values for DG were considerably greater when DG was fed in diets based on DRC than on SFC. In addition, the NE values for DG in DRC-based diets tended to be greater than NRC (2000) and chemical composition-based values; whereas, the NE values for DG in SFC-based diets tended to be less than NRC (2000) and chemical composition-based values.

Table 2. Net energy values of wet distiller's grains + solubles and corn gluten feed determined by substitution in dry rolled corn (DRC)-based or steam flaked corn (SFC)-based diets and from tabular (NRC, 2000) values and chemical composition (mean \pm standard deviation)

Item*	DRC	SFC	Tabular	Chem. Comp.
Distiller's grains				
NE _m , Mcal/cwt	114.5 \pm 15	92.3 \pm 29	99.1	107.7
NE _g , Mcal/cwt	80.9 \pm 14	61.8 \pm 25	68.2	75.9
Corn gluten feed				
NE _m , Mcal/cwt	94.1 \pm 10	90.4 \pm 14	88.2	89.0
NE _g , Mcal/cwt	63.6 \pm 9	61.4 \pm 14	59.1	59.5

*NE_m, net energy for maintenance; NE_g, NE for gain.

To ascertain the veracity of these results, performance data from cattle fed the experimental diets were compared to those of control cattle. In studies with DRC-based diets, ADG and G:F of cattle fed DG were 5.7 to 8.3% greater than for control cattle; in studies with SFC-based diets, ADG and G:F of cattle fed DG were approximately 1.2% less than for control cattle. Dry matter intakes of control and treated cattle were similar. With CGF trials, the relative responses of treated vs. control cattle were similar whether the diet was based on DRC or SFC.

In one recent direct comparison of processing methods, Macken et al. (2006) compared the feeding value of diets containing 35% wet CGF and either DR or SF corn. Cattle fed SFC had lower DMI, similar ADG, and greater G:F than cattle fed DRC. These results match what would be expected with diets containing no CGF. Vander Pol et al. (2006a) conducted a similar study with 30% wet DG (DM basis) diets. In contrast to the results of Macken et al. (2006) with CGF, when DG was added to the diet, ADG and DMI by cattle fed DRC was greater than performance of cattle fed SFC-based diets.

Based on these trials, an interaction between grain processing and co-products exists with DG but not with CGF. Several differences exist between DG and CGF; these include DM content (35 vs. 60% for WDG vs. CGF, respectively), CP concentration (31 vs. 24%), DIP concentration (33 vs. 75% of CP), fat concentration (12 vs. 3.9%), NDF concentration (42 vs. 36%), odor/aroma, ethanol content, microbial cell content (i.e., yeasts, etc.), as well as physical characteristics such as particle size and bulk density. The cause for the DG x grain processing interaction presumably lies in one or more of these characteristics. In addition, the benefits in performance which occur in DRC-based diets and/or the adverse effects on performance with SFC-based diets appear to occur at relatively low DG concentration (< 20%). Therefore, the substance within, or property of, DG that produces these effects is apparently provided at these lower concentrations. Thus, our next objective was to examine potential reasons for an interaction between grain processing and DG feeding value, limiting our discussion to factors that would meet these criteria.

POSSIBLE REASONS FOR A PROCESSING-CO-PRODUCT INTERACTION

Lodge et al. (1997) attempted to distinguish the component(s) of DG that accounted for its unexpectedly high calculated NE values with DRC-based diets by formulating a “simulated wet DG” composite comprised of wet CGF, corn gluten meal, tallow, and condensed distiller’s solubles. The NEg value for this composite was similar to that of DG and averaged 121% that of DRC. When tallow was removed from the composite, the NEg value decreased to 116% of DRC, and when germ meal was removed, the NEg value decreased to 110% of DRC. However, they were unable to clearly determine to what extent fat, fiber, protein, and undegraded protein affected the response to DG. Lodge et al. (1997) used NRC (1984) energy values for all feed ingredients to determine the NE values of the DG. When the NE values of DRC were calculated based on performance of the control diet cattle, the DRC had a NEg concentration of 0.74 Mcal/lb, a value 104.4% of the NRC (2000) tabular value for DRC.

Potential for improvement: Dry-rolled corn vs. steam-flaked corn

Using NRC (2000) values, Krehbiel et al. (2006) suggested the upper caloric limit for maximizing ADG is 1.44 Mcal ME/lb of DM and for G:F it is 1.56 Mcal of ME/lb. Obviously, if this hypothesis is correct, when energy intake of the control diet in a feeding experiment is near the “maximal,” the ability to improve animal performance via feed additives or specific ingredients is limited. In the reviewed trials with DRC-based diets, the mean dietary ME was 1.38 Mcal/lb (Std. dev. = 0.005); in the SFC-based trials the mean ME concentration was 1.55 Mcal/lb (Std. dev. = 0.006). These differences suggest the lack of a performance or efficiency response to DG in SFC-based diets may be the result of the simple fact of cattle already performing near their genetic potential so dietary changes have limited capacity to improve performance. In contrast, with DRC-based diets ME intake is less than optimal so an opportunity exists for improving performance. Similarly, the potential to have adverse associative effects on the utilization of SFC-based diets likely would be greater than for DRC-based diets.

Effects on diet digestibility

Few studies have measured the digestibility of diets containing DG. Wayne Greene and coworkers at the Texas A&M Research and Extension Center in Amarillo (preliminary unpublished data reported by

Cole et al., 2006) noted feeding 5 to 15% DG in SFC-based diets tended to decrease N digestion and urinary N excretion as a percentage of N intake. However, N retention did not differ among diets. Richardson et al. (2006) reported in vitro DM disappearance of 90% concentrate SFC-based diets tended to be less for diets containing 5 and 10% wet sorghum DG than for diets containing 0 or 15% wet sorghum DG. With SFC-based diets, Debenbusch et al. (2005) noted lower apparent total-tract DM (mean 81.5 vs. 83.8%, respectively) and OM (84.4 vs. 86.8%, respectively) digestibilities with diets containing 15% (DM basis) DG than with control diets. With DRC-based diets, Ham et al. (1994) reported diets containing 40% wet DG had apparent total-tract OM digestibilities similar to the control diet (82.8 vs. 81.3 %), but diets with 40% wet DG had greater digestibilities for starch (91.7 vs. 93.9), NDF (62.5 vs. 69.6%), and N (74.9 vs. 79.1%). However, it is not clear how OM digestibility was not improved when digestibility of N, starch, and NDF were increased. Somewhat in contrast to the results of Ham et al. (1994), with DRC-based diets Mateo et al. (2004) reported no effect of either wet or dry DG (20 and 40% of diet DM) on apparent digestibility of DM, OM, N or NDF.

Based on these results, differences in total-tract digestibility do not appear to contribute to the apparent DG x grain processing interaction. However, differences in the site of digestion still might be important. The highly digestible NDF in DG might affect fermentation within the rumen and large intestine, and this effect might be different in DRC- and SFC-based diets. With SFC-based diets little starch survives to be digested in the large intestine, and to inhibit post-ruminal NDF digestion. In contrast, with DRC-based diets digestion of residual starch flowing to the large intestine could depress pH and inhibit NDF digestion in the large intestine. Replacing some of the DRC starch with DG should decrease the quantity of starch reaching the large intestine and allow for greater post-ruminal NDF digestion.

Theoretical effects on starch digestion and utilization

Site of starch digestion may affect the efficiency of utilization of dietary energy from starch. Huntington et al. (2006) noted that the effect varied

depending on the extent of ruminal starch digestion and the quantity of starch entering the small intestine. They also proposed that starch digestion/absorption in the small intestine was limited to approximately 1.7 lb/d in growing beef cattle. Ruminal digestibility of starch from DRC is considerably less than from SFC (Owens et al., 1986). Thus, using the equations of Huntington et al. (2006) and Harmon and McLeod (2001) we calculated the theoretical effects of DG on starch utilization and energy obtained from starch intake. These calculations assume that associative effects are absent. Assuming either a constant DMI for all diets or using DMI values from our 18 reviewed studies, DG additions at 20 to 40% of diet DM would increase the efficiency of energy utilization from starch by 3.2 to 4.8% with DRC-based diets vs. 1.7 to 2.4% for SFC-based diets. Thus, based on these assumptions, feeding DG seemed to improve energy utilization of dietary starch with a greater response on DRC-based diets than SFC-based diets.

Variation in chemical composition

The nutrient composition of DG varies both within and across ethanol plants (Table 3; Holt and Pritchard, 2004; Knott et al., 2004a, b). In addition, the source of grain used to make DG (i.e., sorghum vs. corn) can affect the nutrient composition and apparent energy value of DG (Lemon, 2004; Vasconcelos et al., 2007) with the feeding value of DG from sorghum grain being slightly lower than DG from corn. Because sorghum-based DG were used in a number of the SFC-based studies, the NE value of DG when fed with SFC could be lower than when fed with DRC if the DG was from corn when fed with DRC but from sorghum grain when fed with SFC.

In general, the majority of protein from wet DG is not degraded in the rumen (65% UIP). The large variability in acid detergent insoluble nitrogen (ADIN) noted by Holt and Pritchard (2004) suggests the ruminal degradation of CP from DG may be highly variable. However, Nakamura et al. (1994) and Klopfenstein (1996) suggested that ADIN was not reliable as a predictor of total tract protein digestibility of DG or of performance of cattle fed DG.

Table 3. Nutrient composition of wet distiller's grains with solubles from three plants in South Dakota (Holt and Pritchard, 2004) and of dried distiller's grains from plants in the Midwest (Knott and Shurson, 2003a, b)

Item	Mean	Minimum	Maximum	SEM*	NRC, 2000
Holt and Pritchard, 2004					
Dry matter, %	31.4	29.52	36.48	0.28	25.0
Crude protein, %	35.5	34.39	36.58	0.25	29.7
Neutral detergent fiber, %	42.3	36.1	48.2	0.51	40.0
Acid detergent fiber, %	12.1	9.81	16.9	0.26	--
Ash, %	3.8	2.75	4.23	0.15	5.2
Fat, %	12.1	11.04	13.12	0.29	9.9
Acid detergent insoluble N, % of N	9.8	7.9	16.5	--	--
Knott and Shurson, 2003a,b					
Moisture, %	11.69	9.67	13.57	0.91	--
Crude protein, %	26.63	24.54	28.42	0.97	29.7
Ether extract, %	10.06	9.20	11.55	0.70	
Crude fiber, %	6.90	5.80	9.10	0.78	

*Standard error of the mean.

Differences in the chemical composition of DG are in a large part due to differences in the grain used in the fermentation. Removal of the starch fraction accentuates relative differences in the grains. Other factors can also affect the chemical composition of DG. Additions of acid (usually sulfuric acid) are sometimes required during the fermentation process to optimize ethanol production. This results in increased sulfur concentrations in the DG produced. The moisture content of DG leaving the plant can also vary from day-to-day depending upon the extent of drying and the quantity of solubles added back to the wet or partially dried grains. The type (in bag or silo, on concrete slab), length, and conditions (open to atmosphere, precipitation, solar drying, etc.) of storage at the feedyard can also affect the moisture content of the final product and the apparent nutritive value.

Effects of fat/caloric density

The fat content of DG can vary from less than 10% to more than 13% of DM (Holt and Pritchard, 2004; Knott and Shurson, 2004a, b). Thus, based solely on fat content, the NEm values of DG calculated from chemical composition (Zinn and Plascencia, 1993) can vary by 5 to 6% (1.04 to 1.10 Mcal/lb for 10 and 13% fat, respectively).

Zinn and Plascencia (1996) reported that animal performance was decreased when fat intake exceeded 0.72 g/lb of BW. Total fat intake did not

exceed this level in any of the studies reviewed. Thus, decreased performance caused by excessive fat intake with SFC-based diets probably is not causing the grain processing x DG interaction.

To evaluate the possibility of a fat x DG interaction, Mike Brown and coworkers (unpublished data) at West Texas A&M University currently are studying the effects of fat intake on utilization of wet DG in finishing diets based on SFC. Preliminary results indicate that the NEg of the wet sorghum DG is 0.59 Mcal/lb, a value somewhat lower than suggested by NRC (2000).

Obviously one reason for the high NE values for DG reported in many trials with DRC is the fat provided by DG. Larson et al. (1993) reported that wet DG contained 47% more energy than DRC when fed to yearlings; however, only 9% of the added energy could be attributed to the additional fat from DG added to the diet. With DRC-based diets, the effects of adding fat on animal performance have been variable (Krehbiel et al., 1995; Vander Pol et al., 2006b). In addition, the fat in corn is less saturated than fat from yellow grease or tallow typically supplemented in feedlot diets. Studies with whole cottonseed indicate that fats contained within feed ingredients may be more readily tolerated than supplemental fats. The comparative feeding value of corn oil within DG seems to be similar to that of yellow grease or tallow (Montgomery et al., 2005; Sulpizio et al., 2003).

Some ethanol plants are currently removing some or all of the fat from DG for use as bio-diesel or for other uses. This trend is expected to increase in the future. The effects of fat removal on the feeding value of DG will require additional research. Removal of the fat should produce a product with a chemical composition more similar to CGF; however, the physical properties (particle size, density, etc.) will differ from CGF.

Effects on methane production

Based on the theoretical ruminal fermentation balance of Wolin (1960), Barajas and Zinn (1998), and Corona et al. (2006) calculated that methane production was as much as 37.5% less with SFC-based diets than with DRC-based diets. Wainman et al. (1984) reported that methane production from the ruminal fermentation of distillery products was only half to one-third that of common feedstuffs of “comparable digestibility.” Whether those differences are the result of the high fat content of many distiller’s products, to the yeast content (McGinn et al., 2004), to effects on ruminal pH (Lana et al., 1998), to the fermentation pattern of the fiber, or to other factors is not clear. This finding suggests, however, that the feeding of DG potentially may decrease ruminal methane production. If ruminal methane production is 37% greater with DRC than SFC (Wolin, 1960; Barajas and Zinn, 1998; Corona et al., 2006), decreasing methane loss would have greater benefit with DRC-based than SFC-based diets. Vander Pol et al. (2006b) reported that the ruminal acetate:propionate ratio was lower when DG was added to DRC-based diets, which would support the concept that methane production is reduced when DG is included in the

diet. However, the acetate:propionate ratio may also have been decreased simply due to glycerol present in the DG; as glycerol can be as much as 5% of the DM in DG.

Yeast

Knott and Shurson (2004) noted that up to 3.9% of dried DG weight was yeast biomass and residual yeast metabolites. Although results have been variable, yeast additives contain compounds that potentially are beneficial biologically and immunologically (Yoon and Stern, 1995; Krehbiel et al., 2003; McGinn et al., 2004). To date, no studies have tested the feeding value of yeast or yeast cultures in DRC- and SFC-based diets; therefore, whether yeast might cause a DG x grains processing interaction is not known.

Dietary cation-anion balance

In the studies reviewed, the DCAB increased as the concentration of DG in the diet increased due to the relatively high Na and K concentrations in the DG (Table 4). Ross et al. (1994) reported that ADG increased in a quadratic fashion as DCAB ($\text{Na} + \text{K} - \text{Cl}$) increased from 0 to 45 mEq/100 g of DM, with optimal performance at 15 mEq/100 g. Higher DCAB can result in greater systemic buffering capacity and a possibility of less sub-clinical and clinical acidosis (Owens et al., 1998). Higher dietary DCAB could potentially explain some of the improvement in animal performance noted with supplemental DG; however, this effect should be more beneficial with diets based on SFC than on DRC because of the more rapid ruminal fermentation of starch from SFC. However, because of higher intake of DRC-based diets, the quantity of starch digested in the rumen may be similar in DRC- and SFC-based diets.

Table 4. Dietary cation-anion balance (mEq/100 g of dry matter) of diets containing varying concentrations of wet distiller’s grains (DG)*

% DG in diet (DM basis)	(Na+K)-Cl	Std dev.	(Na+K)-(Cl+S)	Std. dev.
0 (n = 14)	3.80	2.75	-7.58	3.94
5-14 (n = 2)	5.89	2.08	-5.51	3.53
15-25 (n = 12)	7.07	3.46	-6.23	3.71
26-40 (n = 16)	14.61	3.62	-0.66	2.48
> 40 (n = 3)	20.82	0.88	1.99	0.50

*DM, dry matter; Std. dev., standard deviation.

Effects of crude protein, ruminally degraded protein, and metabolizable protein

Results of several performance studies indicate cattle fed SFC have higher DIP requirements (as a %

of the diet) than cattle fed DRC (Cooper et al., 2002a; Galyean, 1996; Gleghorn et al., 2004). Barajas and Zinn (1998) noted for SFC but not DRC, the NE values were affected by the protein source (urea vs. cottonseed

meal) and/or concentration (11% for urea vs. 14% for CSM). In contrast, using cannulated steers, Cooper et al. (2002b) reported that the DIP requirement was similar for cattle fed diets composed of DRC and SFC but approximately 12% lower than for calves fed diets composed of high-moisture corn.

The post-ruminal amino acid supply of cattle fed DRC-based diets is potentially deficient when urea is the sole protein supplement because of limited ruminal microbial protein synthesis. In addition, DRC-based diets that contain corn silage, rather than alfalfa, as a roughage source could provide less metabolizable protein. To examine protein concentration effects on calculated grain energy

values, Fred Owens (personal communication) plotted the calculated ME value of DRC and SFC (based on animal performance) vs. dietary CP using the data set from the grain processing review of Owens et al. (1997). The results (Figure 1) indicate that calculated ME values of DRC are not affected by dietary CP concentrations above approximately 11.5%, whereas, calculated ME values of SFC decreased as CP values decrease from 13.5 to 11%. This suggests that the ME value of SFC, but not DRC, could be decreased if dietary DIP concentrations are decreased by the addition of DG. Although the calculated metabolizable protein intakes of the control diets were adequate in the 37 studies we reviewed, because these values are based solely on tabular values, they could be misleading.

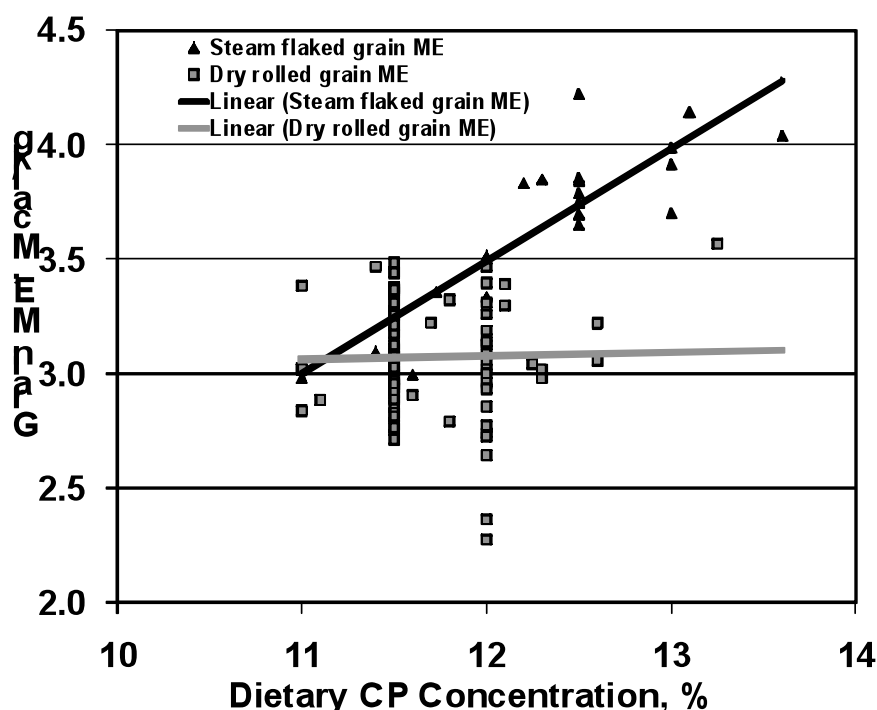


Figure 1. Plot of grain metabolizable energy (ME) concentration (calculated from animal performance) and dietary crude protein (CP) concentration (F. Owens, personal communication) using the data set of Owens et al. (1997).

With isonitrogenous, SFC-based diets Lemon (2004) reported that DG had adverse effects on animal performance when DG concentrations exceeded 10% of dietary DM. Analyzed dietary CP concentrations were less than the formulated value of 13.5% CP, ranging from 11.71 to 12.29%. Therefore, Galyean and coworkers hypothesized that the poor performance of DG cattle in the study of

Lemon (2004) was due to a DIP deficiency. However, adding urea to replace the DIP lost when DG was substituted for corn and urea failed to improve animal performance (Shaw, 2006; Vasconcelos et al., 2007: Table 5). These results suggest the DG x grain processing interaction is not the result of a DIP deficiency.

Although in vivo studies are less conclusive (Cole and Todd, 2007), results of some in vitro experiments indicate that for optimal utilization of dietary energy and nitrogen the rate of release of both components from feeds in the rumen need to be synchronized (Taniguchi et al., 1995). It is not known whether the rate of release of N from DG within the rumen is more advantageous with DRC-based diets than with SFC-based diets. Recycling of N to the rumen from the lower gut, as well as other physiological changes such as altered feeding

patterns and rate of passage, may be adequate to compensate for a deficiency in DIP and/or may adequately synchronize ruminal energy and N availabilities (Cole and Todd, 2008). If synchrony is important, increased synchrony might have a greater benefit with DRC-based than SFC-based diets because of less ruminal fermentation with DRC leaving more starch to reach the large intestine for fermentation. Ruminal synergy might also be affected by the rate of passage, but it is not known if, or how, DG and CGF may alter the rate of passage.

Table 5. Effect of degradable intake protein (DIP) replacement on performance of cattle fed steam-flaked corn-based diets containing 0 (control) or 10% wet distiller's grains + solubles with increasing crude protein (CP) and DIP concentrations (Shaw, 2006)

Item ^a	Control	0% of DIP	50% of DIP	100 % of DIP
Diet CP, % DM	12.95	13.25	14.01	14.68
Diet DIP, % DM	8.41	7.23	7.83	8.40
Diet UIP, % DM	5.09	6.27	6.27	6.30
ADG, lb	3.78	3.70	3.54	3.45
DMI, lb	20.3	20.4	19.8	19.2
F:G	5.38	5.52	5.59	5.56

^aAnalyzed values for CP and formulated values (NRC, 2000) for DIP and UIP. DM, dry matter; UIP, undegradable intake protein; ADG, average daily gain; DMI, dry matter intake; F:G, feed:gain.

In a number of studies with DRC-based diets, CP concentrations of diets containing DG reached 20% with no apparent adverse effect on animal performance. In contrast, Gleghorn et al. (2004) noted that feeding high concentrations (14.5%) of protein to cattle on SFC-based diets could adversely affect animal performance and decrease calculated dietary NE values. Thus, the increased dietary CP from adding DG might possibly decrease NE values in SFC- but not in DRC-based diets.

Effects on subclinical acidosis

Based on the studies with CGF by Krehbiel et al. (1995), several authors have proposed that a portion of the beneficial effects on performance when feeding corn co-products can be attributed to a decrease in the incidence of subclinical acidosis. In contrast, with DRC-based diets Ham et al. (1994) and Vander Pol et al. (2006a) reported that ruminal pH was lower in steers fed DG-containing diets than in steers fed the control diet. Thus, based on studies with small numbers of animals fed DRC-based diets, effects of DG on subclinical or clinical acidosis might be small or nonexistent.

Moreover, a decrease in subclinical acidosis is not likely to be the cause of the grain-processing x DG interaction because the benefit should be greater with a more rapidly fermented starch source like SFC than with less rapidly degraded starch from DRC. Contrarily, if DG reduces ruminal pH as noted previously, then DG should increase the incidence of subclinical acidosis more for cattle fed the more readily fermented SFC. Also, one might expect the added fat from DG to attenuate ruminal starch fermentation. If fat is already included in the diet, as it typically is in SFC diets, no further benefit would be expected from fat in the DG containing diets.

Effects on feed/energy intake

Averaged across the experiments summarized, DMI was not affected by including DG in the diet. Nonetheless, in some individual studies, including DG in diets based on DRC significantly increased DMI. In general, however, it seems that improvements in performance with the feeding of wet DG were not the result of increased feed intake. Also, although ADG and G:F might be improved by increased DMI, the calculated NE values for DG should correct for differences in DMI.

Effects of ethanol in the wet distiller's grains

Using DG produced in a small university-scale unit, Larson et al. (1993) reported that the ethanol concentration of wet DG was 10.7% (DM basis); private consultants (anonymous, personal communication) have reported that ethanol concentration was as high as 11% (DM basis) in commercially available wet DG.

Results of studies that have evaluated the feeding value of ethanol to ruminants have produced variable results. Burroughs et al. (1958) reported that ethanol supplementation improved animal performance. Kreul et al. (1993) reported that ADG was increased by 25% in steers limit-fed diets containing 0, 2, 4, or 6% ethanol. However, when steers were given free choice access to feed, ethanol (4% of dietary DM) failed to improve performance. Ham et al. (1994) reported that ADG and DMI by lambs fed DRC-based diets containing 0, 5, or 10% ethanol were not affected by ethanol although G:F decreased linearly as ethanol concentration in the diet increased. Larson et al. (1993) reported that when G:F of steers fed DG was adjusted for ethanol intake (method not described) improvements in G:F ranged from 5 to 20%. Thus, presence of ethanol in wet DG potentially could increase the energy value of DM by 10% or more if the ethanol has a feeding value equal to grain and the ethanol is lost when measuring the DM concentration. However, benefits should be similar whether the basal diet is based on DRC or SFC.

Mineral toxicities or interactions

Distiller's grains can contain high concentrations of certain minerals and mycotoxins that are concentrated during the fermentation process. The NRC (2000) maximum tolerable level for dietary S is 0.40% of DM; however, with SFC diets, Zinn et al. (1997) reported that performance was depressed for calves fed diets containing 0.25% S from ammonium sulfate. Feeding a high concentration of DG in the diet potentially would produce dietary S concentrations that meet or exceed the maximum tolerable level. Unfortunately, S concentrations in diets are rarely reported in the literature. Reduction of sulfate to the more toxic sulfide form of S in the rumen is increased at lower pH values with accumulation of hydrogen sulfide in the gas cap of the rumen (Gould, 1998). Thus, the potential for S toxicity might be greater in diets based on SFC than

in DRC-based diets. In addition, use of other co-products or supplements rich in S, such as molasses, or having high S concentrations in drinking water might exacerbate negative effects of S in co-products.

Effects on ration integrity and physical characteristics of the diet

Factors such as moisture, bulk density, particle size of diets, and digestible NDF concentration can affect mixing efficiency, ingredient segregation during handling, diet consistency, rumination/salivation, ruminal turnover rate, rate of passage, feed intake variation, and site of digestion (Pritchard and Stateler, 1997). Wet DG in diets could have either beneficial or detrimental effects on diet characteristics and the response might differ between DRC-based diets vs. SFC-based diets because particle size of DRC- and SFC-based diets will differ (Scott, et al., 2003; Corona et al., 2006). Knott and Shurson (2004b) noted that the mean particle size (mean 1,282 μm ; range 612 to 2,125 μm ; CV = 24%) and bulk density (mean 28.6 lb/ft³; range 24.7 to 31.6 lb/ft³; CV = 7.8%) of dried DG varied considerably from one ethanol plant to another. In addition, wet DG tends to have a smaller particle size than CGF (Lodge et al., 1997).

With addition of wet DG or GCF to dry diets, separation of fine particles in the mixer or feed bunk should be decreased: this could potentially help to reduce acidosis. If particle separation is a greater problem with DRC-based diets than with SFC-based diets, especially without added fat, then more benefit might be expected with DRC-based diets than SFC-based diets.

Potential effects of research methods

Differences in experimental methods (storage of DG and/or SFC, bunk management, weighing conditions, lab analyses, etc.) and/or experimental errors could potentially produce a grain processing x DG interaction. If so, it is not apparent whether the interaction is the result of an "overestimation" of DG feeding value in DRC-based diets, an "underestimation" of its value in SFC-based diets, or some combination of these two. However, this grain processing x DG interaction has been noted in trials from Nebraska, Kansas, and Texas and interactions between wet CGF and grain processing have been absent in trials both in the Northern and Southern Plains.

Storing wet co-products, even for a short time, can result in a change in the DM concentration. Because of the high moisture content of DG and CGF, even a small error in DM calculation results in an appreciable error in the calculated NE values (Table 6). Wet DG also can contain appreciable quantities of volatile compounds, such as ethanol. Thus, the method used to determine the DM content

of wet DG can affect the apparent DM content (Thiex and Richardson, 2003) and subsequent NE estimates. Storing DG in bags potentially should decrease variation in moisture content over time and(or) might allow some anaerobic fermentation to occur. However, Kalscheur and Garcia (2005) suggested fermentation of DG within silo bags was minimal because of the low pH of DG when added to the bag.

Table 6. Effects of errors in dry matter (DM) concentration of co-product on true diet formulation and calculated net energy values if diets are formulated assuming a 30% DM value for wet distillers grains (DG)

Formulated % corn, DM basis	True DM %	True % DG in diet	True % corn in diet	Calculated NE _m *, Mcal/cwt
If DG = 10% of diet DM				
80% corn	25	8.33	81.4	109
80% corn	30	10	80	91
80% corn	35	11.67	78.7	78
If DG = 30% of diet DM				
60% corn	25	26.32	63.2	109
60% corn	30	30	60	91
60% corn	35	33.33	57.1	78

*Net energy for maintenance.

CONCLUSIONS

An interaction / associative effects between grain processing and feeding of wet distiller's grains has been detected in several trials, but no interaction exists for wet corn gluten feed. Potential reasons for the interaction between grain processing method and distiller's grains in the diet would include effects of dietary fat/energy, ethanol contamination, yeast effects, reduced methane production, errors in dry matter concentrations, and numerous other

possibilities. Because of the inherent variability in nutrient composition of wet distiller's grains and its high moisture content, the true feeding value of DG probably is quite variable and may differ from one source or one load to another. Additional research is needed to determine how best to employ these co-products in beef cattle finishing diets and their potential to alter the need for grain processing and level of dietary roughage needed.

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QUESTIONS AND ANSWERS

Q: Andy, your cation-anion balance calculations were based on sodium, potassium and chloride. Bill Tucker's work would suggest that half the sulfur should be included in that calculation as an anion. How would including sulfur alter the calculations? Has anyone monitored urinary pH as an index of metabolic acidosis conditions with feeding of distillers' products?

A: Although the actual calculated DCAB values decreased when sulfur values from NRC were included in the calculation, the trends were similar because of the high Na and K concentrations in DG. I am not aware of anyone measuring urinary pH or fecal pH with feeding of distillers' grains.

Additional comment by Erickson: We are making some measurements on this now.

FORMULATION OF RUMINANT DIETS USING BY-PRODUCT INGREDIENTS ON THE BASIS OF FERMENTABLE NDF AND NONSTRUCTURAL CARBOHYDRATES

Michael L. Thonney and Douglas E. Hogue
Cornell University
Ithaca, NY
mlt2@cornell.edu



ABSTRACT

The carbohydrate portion of ruminant diets formulated with by-product ingredients should contain a minimum level of fermentable NDF (FNDF) and a maximum level of nonstructural carbohydrates (NSCHO). This concept is supported by data from six feeding trials designed to quantify the optimum levels of these fiber fractions for growing lambs. The pooled data from these trials show that the effect of NDF on feed intake depended upon the fermentability of the NDF. While NDF, alone, could explain only 30% of the variation in feed intake, a regression equation with NDF divided into two component parts: 1) FNDF; and 2) indigestible NDF (INDF), could account for 85% of the variation of the 31 diet means in the pooled data from the six experiments. Increasing dietary FNDF dramatically increased intake and prevented metabolic disturbances, likely because FNDF provided substrates for rumen microorganisms to produce fermentation products desirable to maintain health and absorptive function of the rumen papillae that, in turn, absorbed substrates useful for metabolism by animal tissues. Based upon these results, a plan and a computer tool to formulate diets based on FNDF and NSCHO was developed. Example formulations containing by-product ingredients using this plan are provided for self-feeding diets for lactating ewes, growing lambs, lactating dairy cows, and feedlot cattle.

INTRODUCTION

Diets for ruminants traditionally have been balanced for energy, protein, vitamins, and minerals. Because rumen function must be maintained for optimum animal production, minimum fiber levels also often are specified as a given percentage of forage or NDF, but digestibility of the fiber is seldom considered in diet formulation. Although Krehbiel et al. (2006) recently proposed that an upper limit on the ME concentration existed in diets for feedlot cattle to optimize growth and efficiency, this approach does not account for the different ruminal effects of the various carbohydrates that provide dietary energy. During the past 20 years at the Cornell sheep farm, experiments were conducted to define the minimum fiber requirements of growing lambs. Results from those experiments led to the conclusion that the fermentable portion of the NDF (FNDF) should be balanced against nonstructural carbohydrates (NSCHO).

Development and maintenance of the ruminal absorptive surface requires products of microbial digestion, the volatile fatty acids (VFA; Flatt et al., 1958; Warner et al., 1956) and it seems logical that the best balance of VFAs to maintain rumen function comes from fermentation of NDF. Alternatively, fermentation of diets high in NSCHO increases

ruminal lactic acid, which is about 10 times stronger than acetic, propionic, and butyric acids. This can lead to rumen parakeratosis and displaced abomasa (Van Soest, 1994). Metabolic acidosis can result, especially when fermentation of diets high in NSCHO results in high levels of the D-isomer of lactic acid because this isomer is metabolized very slowly by mammalian tissues (Krehbiel et al., 1995). Thus, a minimum level of FNDF and a maximum level of non-structural carbohydrates (NSCHO) should be specified for ruminant diets. In this review, we provide evidence that ruminant diets should be formulated for these carbohydrate components.

MATERIALS AND METHODS

Calculation of Carbohydrate Fractions

The indigestible NDF (INDF) was calculated based upon the amount of DM that was not digested from each feed ingredient. Metabolic fecal losses, assumed to be 10 to 15% of the dry matter (Van Soest, 1994), were subtracted from DM indigestibility (100 – digestibility) to determine the amount of DM, and thereby NDF, that was not digested (INDF). Fermentable NDF (FNDF) was NDF of the feed ingredient minus INDF. NSCHO was calculated as the difference between 100 and the total of NDF, CP, EE and Ash.

Combined Lamb Feeding Experiments

Six experiments, each lasting about 42 d with about 72 lambs of similar numbers of ewes and rams, were conducted to determine the minimum fiber requirements for optimum feed intake of growing lambs shortly after weaning (40 to 73 days of age) using the STAR management system (Lewis et al., 1996). Lambs had Dorset or Finnsheep or cross dams and were sired within each experiment either by Dorset or Finn x Dorset rams or by Suffolk rams. Diets were formulated based upon analysis of feed ingredients and calculated INDF values based upon the intake discount factors of Van Soest (1992) for digestibility. Various amounts of oat hulls, soy hulls, or other by-product ingredients that contained relatively high concentrations of NDF but differed in fermentability were included (Figure 1). In addition to fiber sources, soybean meal for protein, and appropriate mineral and vitamin supplements; corn or barley comprised the remainder of each diet with vegetable oil added to control dust.

Results were averaged over five to six pens of two lambs per diet; diet means were adjusted for the effect of experiment based upon the results of a statistical analysis that included the fixed effect of experiment and the continuous effects (covariates) of INDF and FNDF. After adjusting for experiment, the diet means were analyzed to determine the effect of INDF and FNDF on feed intake based upon two- and three-dimensional plots of the data and upon regression analysis. The complete regression model predicted dry matter intake from INDF, FNDF, $INDF \times FNDF$, $INDF^2$, $FNDF^2$, and $INDF^2 \times FNDF^2$. A step-down procedure removed nonsignificant effects until only effects with P -values < 0.05 remained.

Other trials

Results from feeding trials with diets balanced for FNDF and NSCHO also are described for lactating ewes, lactating dairy cows, lambs fed high-fiber diets, and feedlot cattle.

Implementation

The Dugway Nutritional Plan (DNP) conceptualizes this approach to balance diets for FNDF and NSCHO. The plan will be presented in the results and discussion section. To implement diet formulation based upon the DNP, a Microsoft Access-based feed formulation tool was developed. The architecture and availability of the software are presented in the results and discussion section.

RESULTS AND DISCUSSION

Combined Lamb Feeding Experiments

High feed intake is a reliable indicator of excellent rumen function and of overall animal health. Several models predict that feed intake will first increase and then decline as the concentration of dietary NDF increases from zero to a high concentration (Fisher, 1996; Mertens, 1987). As shown in Figure 1, intake declined as expected when poorly fermentable NDF from oat hulls was added to the diet. In contrast, intake increased as highly fermentable NDF from soy hulls or other ingredients was added to the diet. In fact, the NDF concentration of the diet for the lambs that had the highest intake was 54%, while the NDF concentration of the diet for the lambs that had the lowest intake was 36%. Thus, the relationship of feed intake to dietary fiber differed depending upon the fermentability of the fiber.

To account for the fermentability of the NDF, the effect of both FNDF and INDF on feed intake for the lambs in these experiments was examined (Figure 2). The data points on the left side of the figure where INDF increases at low FNDF confirm the traditional concept that feed intake first increases and then declines as INDF increases (Fisher, 1996; Mertens, 1987). The data points on the right side of the figure show that this reduction in feed intake that occurs with high INDF can be mitigated if the diet has a high FNDF.

The relationship between feed intake and the fermentable and indigestible components of NDF was quantified by regression (Figure 3). This equation contains cross product terms and quadratic terms for INDF and FNDF producing the curved surface shown in Figure 3. Thus, feed intake generally curves up and then down as INDF increases. But feed intake generally curves up as FNDF increases, particularly at high INDF levels. Note that only two factors (INDF and FNDF) can explain 85% of the variation in diet mean feed intakes over a wide range of experimental diets for lambs. From these results, we conclude that diets should contain minimum levels of FNDF for rumen microorganisms to produce fermentation products desirable to maintain health and absorptive function of the rumen papillae (Flatt et al., 1958; Warner et al., 1956) that, in turn, absorb substrates useful for metabolism by animal tissues.

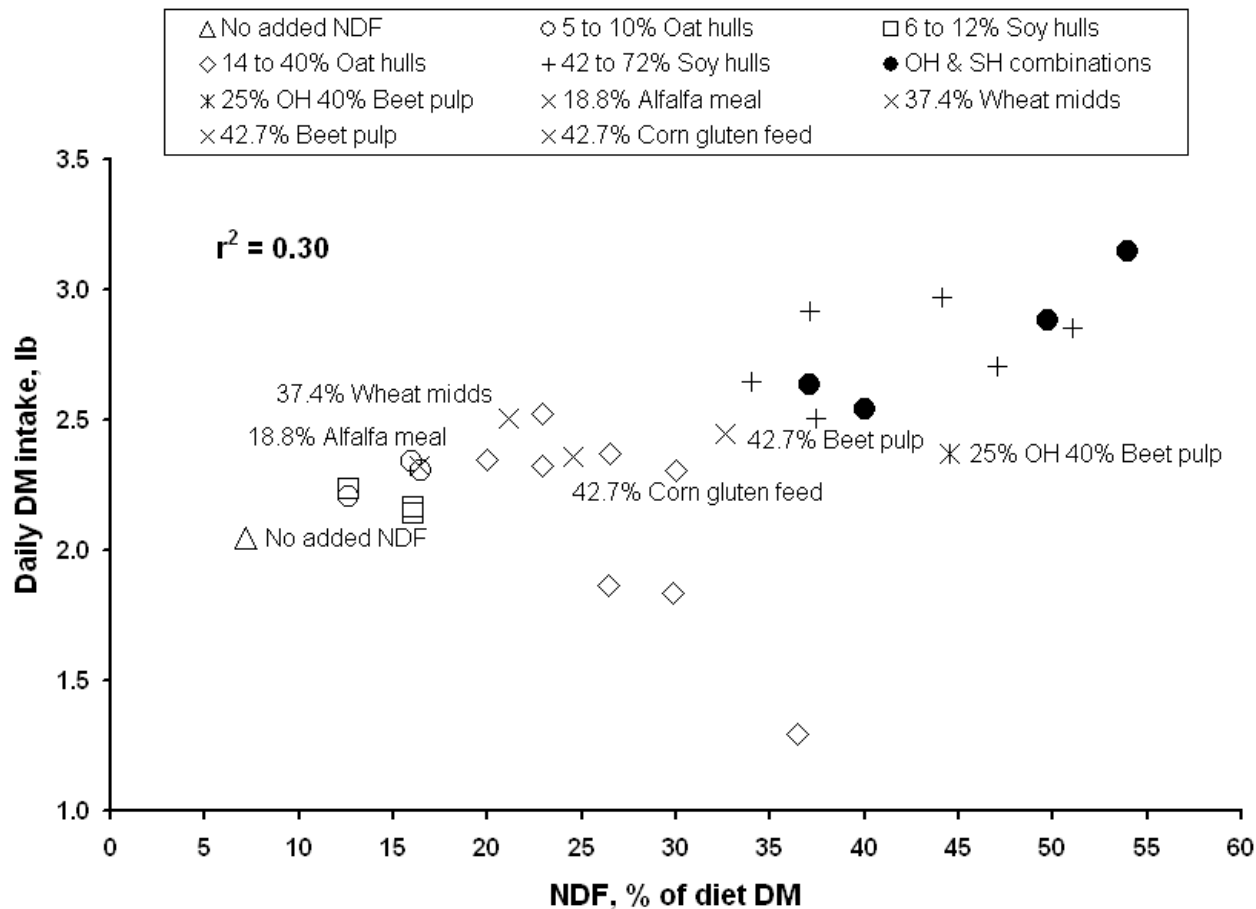


Figure 1. Relationship of feed intake to the concentration of neutral detergent fiber (NDF) in the diet of growing lambs.

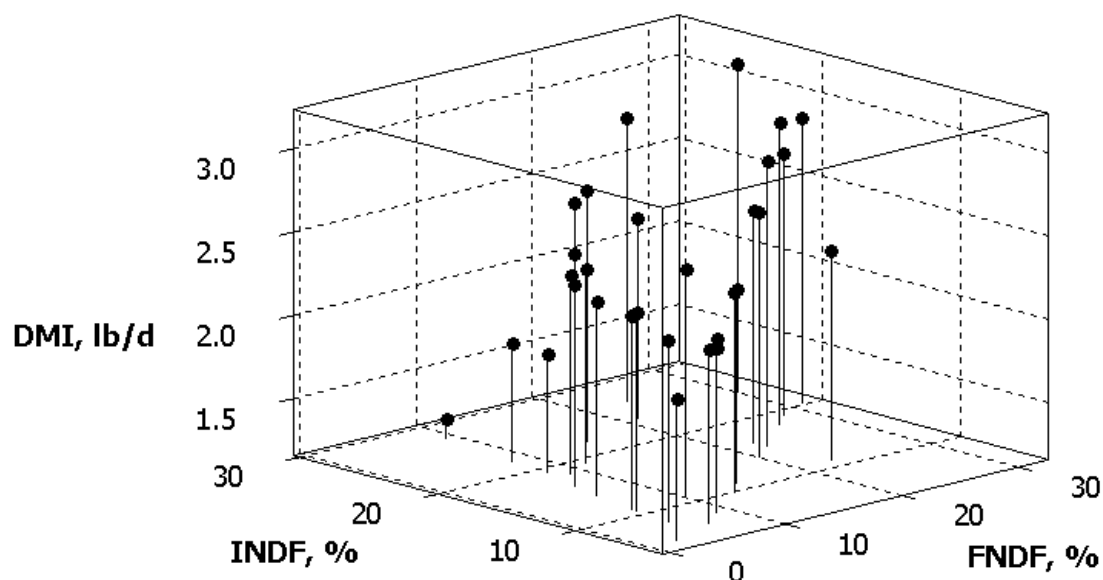


Figure 2. Relationship of feed intake to the dietary concentrations of indigestible neutral detergent fiber (INDF) and fermentable NDF (FNDF).

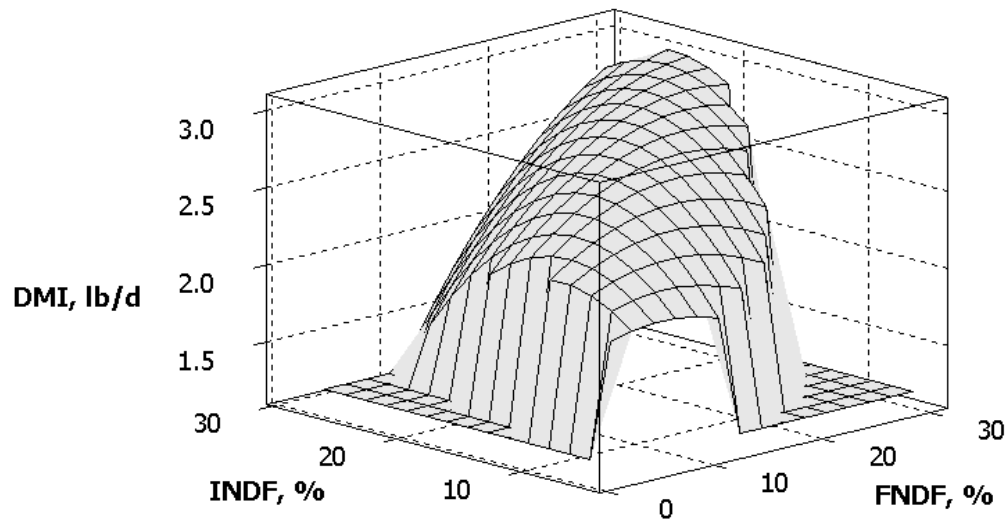


Figure 3. Surface plot showing the equation that describes the relationship of dry matter intake (DMI) to dietary indigestible neutral detergent fiber (INDF) and fermentable NDF (FNDF) concentrations. The equation was $DMI = 1.59 + 0.1014 \cdot INDF + 0.00610 \cdot INDF \cdot FNDF - 0.00228 \cdot FNDF^2 - 0.00584 \cdot INDF^2$ with $SE = 0.14$ and $r^2 = 0.85$.

Feeding Ewes with Triplet Lambs

These feeding trials (Hogue, 1994) were conducted to determine if a diet with sufficient FNDF would allow ewes nursing twins or triplets to consume enough feed to prevent weight loss in early lactation. Hay consumption was restricted to the amounts shown in Table 1.

Total feed intake was much higher than the NRC (1985) expected dry matter intake of 6 lb for ewes of this weight rearing twins during early lactation. In fact, total DMI of ewes in trial 2 was almost 7% of body weight. Furthermore, although digestibility data were not available, the available energy fed in this trial most probably exceeded that anticipated by the NRC (1985). Instead of losing weight, these ewes all gained weight while their triplet lambs gained rapidly and at an outstanding rate in trial 2. These results indicate that, if the diet is formulated properly so that intake is not limited, a negative energy balance for ewes with twins or triplets during early lactation is not obligatory.

Lactating Dairy Cows

After demonstrating in sheep that, by including sufficient FNDF in the diet, feed intake of animals in early lactation could be increased sufficiently to prevent body weight loss, this theory was tested with high producing dairy cows in the Cornell herd. A supplement of 70% soy hulls, 20% corn, and 10% Ren-plus was added to the feed already being consumed by high-producing lactating dairy cows. These cows consumed all of their original feed in addition to the 6 to 8 pounds of this supplement daily. This increased milk production in the Cornell herd by about 20% or 16 pounds per day. These findings further confirm that ruminant diets need to include a minimum concentration of FNDF in order to optimize feed intake.

Effect of High-Fiber Diets on Lamb Growth

Based upon the experiments outlined above from Hogue (1987; 1991) we formulated a diet with corn, corn gluten feed, and soy hulls that could be self-fed

Table 1. Observed feed intake and body weight gains of triplet-rearing ewes and their lambs

Item	Trial 1 (30 days)	Trial 2 (41 days)
Ewe feed intake	lb/d	lb/d
Hay	2.0	3.3
Pellets ¹	6.9	7.6
Total	8.9	10.9
Daily gain	lb/day (n)	lb/day (n)
Ewes	0.29 (8)	0.55 (14)
Lambs	0.49 (23)	0.71 (42)
3 lambs	1.47	2.13

¹High Energy Lamb Pellets, Agway Inc., Syracuse, NY. A key ingredient to improve intake was 20% soy hulls.

to lambing and lactating ewes to substitute for the more expensive hay. Because the lambs also had access to the high-fiber ewe feed, the effect of that diet on efficiency and growth of lambs also was quantified in a feeding experiment comparing 1) a soy hull diet (64% corn, 20% soy hulls, 10% soybean meal); 2) a high fiber diet (35% corn, 34% corn gluten feed, 23% soy hulls); and 3) a corn gluten feed diet (54% corn, 37% corn gluten feed) with the remainder of the diets being 2.2% vegetable oil, 2.2% vitamin-mineral premix, and 2 to 4.1% limestone (to maintain Ca:P at 2:1); all on a DM basis.

No metabolic disturbances among lambs fed any of the diets were detected, indicating that proper rumen function. Growth and feed intake results sufficient FNDF was provided by each diet for are shown in Table 2. As expected by the random assignment of lambs to diets, initial weights were similar across diets. Although lambs fed the soy hull diet gained faster and had heavier weights, the effect of diet on growth rate was not significant. Lambs fed the high fiber diet consumed more dry matter either per day ($P = 0.01$) or as a proportion of body weight

($P < 0.001$) but grew less efficiently ($P < 0.001$) than lambs fed the other diets. There was no significant difference in growth, feed intake or feed efficiency between lambs fed the soy hull diet and those fed the corn gluten feed diet.

Our results do not fit models that have used NDF (Mertens, 1987) and DDM or functions of DDM such as NE_m (Fox et al., 1992) to predict feed intake. The dry matter intake of the high fiber diet in our experiment was much higher than that of the soy hull or corn gluten feed diets even though the three diets had similar predicted DDM. Furthermore, traditional models of feed intake would have predicted lower – not higher – dry matter intake for the higher fiber diet. In contrast and in support of the necessity to balance for FNDF, increased NDF fermentability resulted in higher feed intakes in dairy cows consuming diets with the same level of NDF (Oba and Allen, 1999). The dramatic intake-enhancing effect of diets high in FNDF also indicates that ruminant diets cannot be balanced properly by assuming a given intake level independent of the feed ingredients included in the diet.

Table 2. Effect of fiber level and protein source on growing lambs

Item	Diet			SEM*	P-value for orthogonal contrast	
	Soy hull	High fiber	Corn gluten feed		High fiber vs others	Soy hull vs corn gluten feed
Initial weight, lb	45.4	45.9	45.4	1.12	ns	ns
Final weight, lb	73.6	71.6	72.1	1.50	ns	ns
Gain, lb/day	0.67	0.62	0.64	0.024	ns	ns
DMI**, lb/day	2.19	2.36	2.10	0.065	0.010	ns
Gain/DMI	0.307	0.263	0.303	0.0074	<0.001	ns
DMI, % BW	3.69	4.09	3.63	0.083	<0.001	ns

*Standard error of the mean.

**Dry matter intake.

Feedlot Cattle

The principle of balancing for minimum FNDF and maximum NSCHO has been applied at a custom feedlot in the Finger Lakes Region of New York since 2001. This paved, covered lot has a one-time capacity of 1,000 in pens of 75 to 250 head. Initial success with a diet based upon whole shelled corn, corn gluten feed, and a premix was followed by adding soy hulls to the mix.

Currently, the diet contains 70% corn and 30% custom pellet. This pellet contains 65% wheat midds, 30% soy hulls, 4% mineral-vitamin package

(including Rumensin), and 1% urea. A pen of cattle starts with two big round hay bales and is fed 50% corn and 50% pellets for a few days before switching to the 70% corn and 30% pellet diet.

No cases of metabolic upsets, acidosis, or cattle going off feed have been detected since the diets first included sufficient FNDF. Excellent rates of gain, feed efficiency, and carcass grades have resulted from these diets. An example of performance based on a pen of heifers marketed in November 2006 is given in Table 3.

Table 3. Performance indicators of 70 heifers

Item	Value
Initial weight, lb	707
Final weight, lb	1192
Days fed	158
Average daily gain, lb/d	3.07
Feed/lb gain	8.54
Dry matter intake/lb gain	7.64
Feed cost/lb gain	\$0.45
Yardage/lb gain	\$0.11
Total cost/lb gain	\$0.57
Death loss	1.4%
Net sale value per animal	\$1,047
Net return	\$30.60

The Dugway Nutritional Plan

The Dugway Nutritional Plan (DNP) was developed to provide an effective method of feeding ruminants and to overcome some limitations of traditional systems. Specifically, the DNP recognizes that diet formulation can have a significant effect on feed intake and also that the proper balance of dietary components can effectively prevent most metabolic disturbances such as acidosis and animals going off-feed.

Pooled energy values such as TDN, DE, ME, NE, NE_m, NE_g, NE_l, and NEL are ignored in the DNP. Instead, diets are balanced on the carbohydrate components that generally make up these pooled values. The other dietary components are Ash, EE and Protein fractions (that is, CP or soluble, degradable, escape, and indigestible N), which are comparable to generally accepted systems. Because both EE and ash in ruminant diets are generally about 5%, it is suggested both are to be included at about this level and not discussed further. For simplicity, the protein fraction(s) are only considered as the total or crude protein. The carbohydrates are divided into INDF, FNDF, and NSCHO and are the variable fractions that receive the most emphasis in the DNP. Decreasing the INDF in the diet and/or increasing the feed intake are the most effective ways of increasing the supply of

nutrients available for animal production. However, at high feed intakes, the proper balance between FNDF and NSCHO becomes important, especially for preventing metabolic disturbances.

The Ash, EE, Protein fractions, INDF, FNDF and NSCHO components can be summed together or properly pooled and adjusted to estimate a pooled energy value such as TDN or DE or ME or NE, but that pooling is unnecessary and redundant. Furthermore, the effects of the individual components are lost when pooled.

Minimum levels of FNDF and maximum NSCHO are suggested. Animals fed diets high in good quality forage such as the beef cow herd and sheep either at maintenance or pregnant or suckling a single lamb usually will have diets that exceed the minimum FNDF in the diet and not approach the maximum suggested level of NSCHO. Higher producing lactating dairy cows, ewes suckling 2, 3, or 4 lambs, feedlot lambs, and feedlot cattle fed high grain diets often will not meet the suggested minimum FNDF and maximum NSCHO levels unless the diets are balanced carefully.

The growth and production of beef cattle up to 3 years of age and the suggested dietary components for them are depicted in Figure 4. These are presented for the growth and production of heifers up to 36 months and for steers up to harvest at about 1100 pounds. A mature cow weight of 1200 lb was assumed.

The suggested feed components for the steers are not as detailed as that given for the heifers. Primarily the suggestion is that the DDM of the diet is as high as appropriate (and the INDF as low) but that sufficient FNDF is included to balance the high levels of NSCHO. The FNDF level is suggested to be at least 15%. The CP level is reduced from 14 to 12% from early to later growth periods and the DMI depends upon the stage of growth and weight of the steers. This level of 15% FNDF will allow the animals to maintain adequate rumen function and prevent metabolic disturbances.

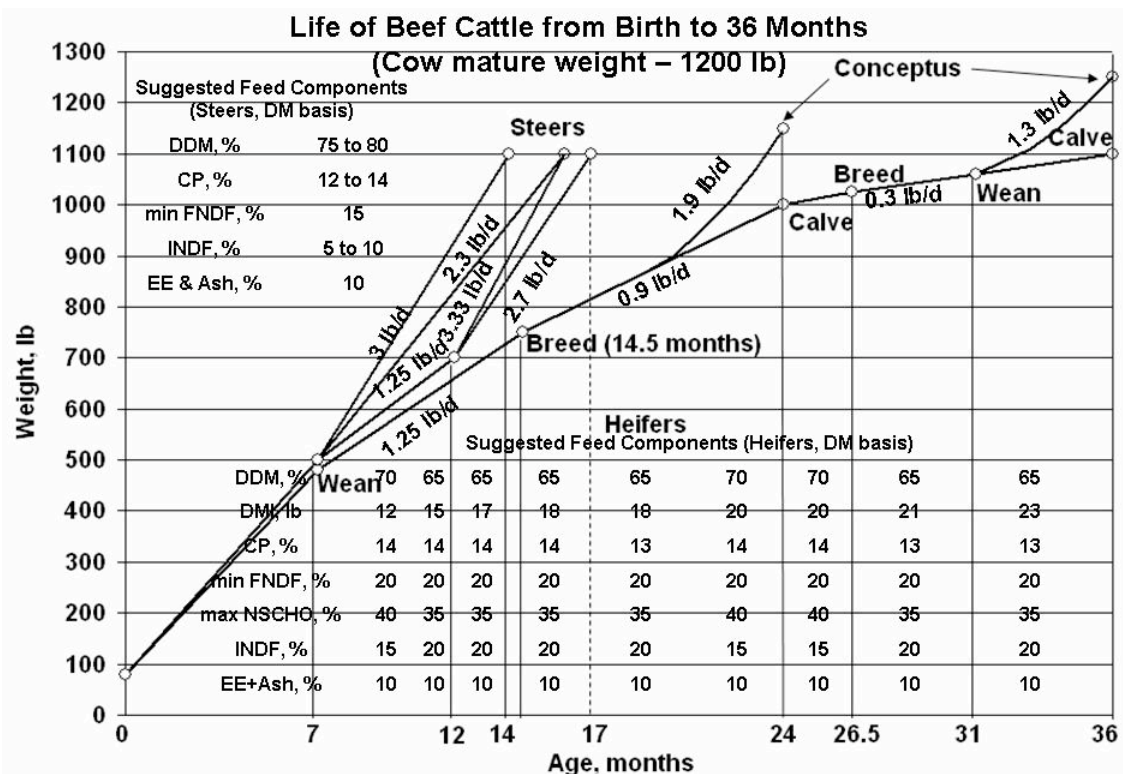


Figure 5. Life of beef cattle and suggested feed component levels from birth to 36 months. Suggested component levels are based upon feed composition tables that include fermentable neutral detergent fiber (FNDF) levels computed assuming intakes at one times maintenance.

Feed Component Values

Some approximate feed component values are given in Table 4. Included are several forages at different maturity levels, the major grains and a variety of by-products that now are widely available for feeding. Values are listed for nonstructural carbohydrates (sugars and starches), neutral detergent fiber (NDF) divided into fermentable (FNDF) and indigestible (INDF), crude protein (CP), ether extract (EE), and ash. These components sum to 100% of the dry matter.

The DDM, CP, EE and Ash values were taken from existing tables, primarily those of Van Soest (1992). Digestible dry matter (DDM) generally was considered to be equivalent to TDN except for feeds rich in EE or Ash. Furthermore, INDF is highly negatively correlated with DDM so that one or the other could be omitted. However, digestible dry matter at one times maintenance was included so that INDF could be calculated as the difference between indigestibility and endogenous fecal losses. Highly digestible feeds like corn yield about 10% endogenous losses while forages yield about 15% (Van Soest,

1994). Intake levels higher than maintenance result in a depression in digestibility (Van Soest et al., 1992; Wagner and Loosli, 1967). Because it is primarily fiber digestibility that is depressed as intake increases, the ingredient FNDF levels would be lower for producing animals with consumptions above maintenance. To compensate for this digestibility depression, correspondingly higher FNDF levels were suggested in Figure 4 for growing, pregnant, and lactating cattle. Most feed components will have considerable variation and therefore the numbers in Table 4 should be considered as being approximate.

Feedform Diet Formulation Software

A simple Microsoft Access-based program was developed to balance diets based upon the Dugway Nutrient Plan. Included are modifiable tables of feed components and suggested levels of components for sheep and cattle. Formulation is based upon the substitution method. Premixes can be formulated and added directly to the table of feed components. After balancing a complete diet, the ingredients that are not the substitution ingredient can be specified as a supplement. Details are available at

[<http://www.sheep.cornell.edu/sheep/management/economics/cspsoftware/feedform/>], from where the program can be downloaded.

IMPLICATIONS

Grain by-products that contain high concentrations of FNDF are available to balance diets of high-producing ruminants. Providing adequate

FNDF prevents rumen metabolic disturbances that limit feed intake and production. FNDF, INDF, and NSCHO values have been estimated for common feed ingredients, suggested dietary levels for these carbohydrate fractions have been estimated and a formulation tool has been developed and is available to use these estimates to balance diets for cattle and sheep.

Table 4. Some approximate feed component values for intake at maintenance*

Ingredient	NSCHO	FNDF	INDF	CP	EE	Ash	DDM
Forages	----- % of dry matter -----						
Alfalfa							
Early bloom	27	19	23	19	3	9	62
Mid bloom	25	21	25	17	3	9	60
Late bloom	23	23	32	12	2	8	53
Orchard grass							
Early bloom	20	37	20	10	3	10	65
Late bloom	13	36	31	8	3	9	54
Timothy							
Late veg.	20	40	15	14	3	8	70
Early bloom	18	40	21	11	3	7	64
Late bloom	14	39	29	8	3	7	56
Seed stage	14	34	38	6	2	6	47
Corn silage, 45% grain	42	28	13	9	3	5	72
Wheat straw	2	40	45	3	2	8	40
Grains							
Barley							
Heavy	63	14	5	13	2	3	84
Light	52	17	11	14	2	4	77
Corn	75	6	3	10	4	2	87
Oats, 32 lb/bushel	37	27	15	13	3	5	73
Wheat	69	10	6	11	2	2	84
By-products							
Beet pulp	32	40	14	8	1	5	74
Citrus pulp (15 pls ^a in FNDF)	44	32	6	7	4	7	82
Corn germ meal	6	50	12	26	3	3	76
Corn gluten feed	18	40	5	25	7	5	83
Cottonseed hulls	0	50	40	4	2	4	45
Dried brewers grains	17	28	18	26	7	4	67
Dried distillers grains	10	42	8	26	10	4	80
Hominy	25	50	5	12	7	1	85
Oat hulls	9	28	50	4	2	7	35
Soy hulls	11	62	8	12	2	5	80
Wheat midds	40	32	5	18	3	2	83
Protein supplement							
Soybean meal, 44% CP	28	9	5	49	2	7	80

*NSCHO, nonstructural carbohydrate; FNDF, fermentable neutral detergent fiber; INDF, indigestible NDF; CP, crude protein; DDM, digestible dry matter.

^aPectin-like-substances.

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FACTORS LIMITING FEED OR ENERGY INTAKE OF PROCESSED GRAINS

Jock G. Buchanan-Smith
BeefInfo Technologies
Cambridge, ON, Canada
beeftech@buchanan-smith.com



ABSTRACT

Processing method used for cereal grains for feedlot cattle can alter dry matter intake. Analysis of data from a review in the literature and from two individual studies revealed that processing of corn or sorghum grain has less effect on energy intake than on dry matter intake; differences in energy intake among processing methods were small to insignificant. In contrast, with barley, either steam rolling or feeding the grain whole depressed energy intake relative to feeding barley in the dry rolled form. Potential reasons why energy intake of diets containing high moisture ensiled corn might be lower than for dry corn were explored. Based on results of studies with ensiled forages, non-protein nitrogenous constituents such as amines can inhibit feed intake. However, more detailed analysis detected no causative explanation for this role of amines. Even though systematic effects of processing on energy intake may be small with corn and sorghum grains sub-clinical acidosis can cause significant and economically important depressions of intake under some circumstances.

INTRODUCTION

This paper is designed to study two questions. First, does the method of processing of cereal grains have systematic effects on intake of feed or energy by feedlot cattle? Secondly, might nitrogenous constituents of high moisture ensiled grains depress intake of such diets?

Systematic Effects of Processing Grain on Energy Intake

Studies generally show that certain processing methods, notably steam flaking, will decrease dry matter intake but increase energy value of the grain (Owens et al., 1997). Most nutritionists agree that energy concentration is the predominant feed related factor that affects dry matter intake of cattle fed high concentrate diets (e.g., NRC, 2000), but few if any research studies have addressed the specific question concerning whether processing method alters energy intake. Two approaches were used to assess this issue. First, data from the review of Owens et al. (1997) were used to calculate the effect of processing corn, sorghum grain, and barley on metabolizable energy (ME) intake. Second, two studies were published in 1998 where high grain diets containing processed corn were fed to feedlot cattle in which net energy (NE) values of the diets were estimated from the performance data; these were analysed to compare actual and predicted dry matter intake (Barajas and Zinn, 1998; Zinn et al., 1998). If actual dry matter intake agrees with that predicted from NE, then differences in energy concentration of the diet must be accounting for the

observed differences in feed intake. Because the prediction equations in NRC (2000) were first published in 1996 and results from these two studies were published after the Owens et al. (1997) paper, analyses of these 1998 feedlot studies should give independent data to assess whether processing has a systematic effect on intake.

Owens et al. (1997) summarized processing effects from data published in 164 individual references, involving 22,834 cattle and 605 contrasts, from 1974 to the mid-nineties. The studies were accepted for analyses if the roughage, as a percentage of the diet, was less than 15% (or 30% for corn silage) of dry matter, the grain of interest comprised more than 55% of dietary dry matter, cattle had ad libitum access to feed, a single grain and processing method was employed, and cattle had been fed for more than 99 days. Least square means for dry matter intake by grain and processing method were calculated. They also estimated ME concentration of the diets from weights of cattle at the start and end of the feeding period and calculated diet ME from observed dry matter intake and daily NE_m and NE_g requirements based cattle performance. The ME content of the grain alone for each diet was determined by subtracting ME from other components of the diet and ME values were adjusted to account for an effect of weight of the cattle on ME of the diet. In the present evaluation, diet ME concentrations were back-calculated using information on the composition of the diets.

Table 1. Processing effects on dry matter and metabolizable energy (ME) intakes of high grain diets by beef cattle (from Owens et al., 1997^a)

Item	Dry matter intake, lb/d	ME, Mcal/lb	ME Intake, Mcal/d
Corn			
Dry rolled	20.8 ^b	1.35	28.2
High moisture	19.2 ^c	1.43	27.6
Steam rolled	18.4 ^d	1.54	28.3
Whole	18.9 ^{cd}	1.46	27.5
Sorghum grain			
Dry rolled	23.1 ^b	1.23	28.5
High moisture	20.2 ^c	1.34	27.1
Steam rolled	19.1 ^d	1.46	28.0
Reconstituted	19.4 ^{cd}	1.38	26.7
Barley			
Dry rolled	19.8	1.48	29.3
Steam rolled	18.2	1.47	26.8
Whole	20.5	1.23	25.2

^aDry matter intakes from Owens et al. (1997), diet ME adapted from text.

^{b,c,d}Dry matter intakes within grain with different superscripts differ, $P < 0.05$.

Effects of processing the three grains - corn, sorghum grain and barley, on daily ME intakes are shown in Table 1.

For corn, daily dry matter intake was significantly reduced for the steam rolling and high moisture treatments relative to the dry rolled product. However, the impact of these processing methods on daily ME intake, with no more than a 3% difference overall, was negligible. For sorghum grain, differences in daily dry matter intake were detected, but the difference in daily ME intake from the lowest (reconstituted) to the highest (dry rolled) was only slightly greater (7%) than for corn. For barley, an effect of processing on ME intake was larger. Daily dry matter intake of dry rolled barley was comparable to that of whole barley, but the daily intake of ME from whole barley was almost 10% below that for dry rolled barley. Unfortunately, only one contrast involving whole barley was found in the entire dataset compiled by Owens et al. (1997). From these results, we can conclude that for corn and sorghum grain, any systematic effect of processing on energy intake appears very minimal. This does not preclude the likely possibility within individual studies, that processing could have had a significant effect on the energy intake of feedlot cattle.

Effects of density of steam flaking grains on daily intake of dry matter and ME are shown in Table 2. No significant effects of flake density from steam rolling or flaking on daily dry matter intake of corn, sorghum grain or barley diets were detected (Owens et al., 1997). For both corn and barley, the numerical differences in daily ME intake among flake densities were smaller than on daily dry matter intake; this can be interpreted to suggest that daily ME intake was not altered by flake density.

Zinn et al. (2002) reviewed the more recent literature and reported that flaking to a density below 24lb/bushel reduced daily dry matter intake of steam flaked corn diets. Interestingly, daily ME intake from steam flaked sorghum grain at between 21.8 and 28.8 lb/bushel was numerically greater than the ME intake values calculated for sorghum grain diets with heavier or lighter flakes. For diets containing high moisture grain, analysis by Owens et al. (1997) revealed that daily dry matter intake of diets containing ground or rolled corn was less when the high moisture corn contained over 27% as opposed to less than 27% moisture. In contrast with daily dry matter intake, daily ME intake of diets containing rolled corn over 27% moisture was numerically greater than for drier high moisture corn. The corresponding comparison for ground corn shows that daily ME intake of diets with the wettest corn was intermediate to diets with drier corn.

Table 2. Effects of flake density of steam rolled grains on dry matter and metabolizable energy (ME) intakes by beef cattle (from Owens et al., 1997^a)

Item	Bushel wt., lb.	Dry matter intake,		ME Intake, Mcal/d
		lb/d	ME, Mcal/lb	
Corn	< 21.8	17.3	1.65	28.5
	21.8 – 28.8	16.1	1.71	27.5
	> 28.8	16.3	1.68	27.5
Sorghum grain	< 21.8	18.4	1.49	27.4
	21.8 – 28.8	19.4	1.49	28.9
	> 28.8	19.3	1.41	27.2
Barley	< 21.8	16.1	1.58	25.4
	21.8 – 28.8	18.5	1.44	26.7
	> 28.8	17.0	1.53	26.0

^aDry matter intakes from Owens et al. (1997), diet ME adapted from text.

Analyses of data published from the studies of Barajas and Zinn (1998) and Zinn et al. (1998) are shown in Tables 3 and 4. Barajas and Zinn (1998) fed either dry rolled or steam flaked corn to 80 medium-framed yearling crossbred heifers with a starting weight of 787 lb. Diets contained either 74% corn with 1% urea as the primary source of

supplementary protein or 64% corn with 1% urea and 10% cottonseed meal. Diets were fed for 110 days. Daily dry matter intake was lower for heifers fed steam flaked than for heifers fed dry rolled corn, but feed efficiency and calculated net energy values were greater for diets that contained steam flaked corn (Table 3).

Table 3. Effects of moisture content of high moisture corn in high grain diets for beef cattle on intake of dry matter and metabolizable energy (ME) (from Owens et al., 1997)

Item	Moisture, %	Dry matter intake,		ME Intake, Mcal/d
		lb	ME, Mcal/lb	
Ground	18 – 22	19.4 ^b	1.30	25.2
	23 – 26	19.9 ^b	1.35	26.8
	> 27	18.1 ^c	1.45	26.2
Rolled	18 – 22	19.9 ^b	1.24	24.7
	23 – 26	19.1 ^{bc}	1.27	24.2
	> 27	18.3 ^c	1.38	25.2
Whole	23 – 26	20.0	1.39	27.8

^aDry matter intakes from Owens et al. (1997), diet ME adapted from text.

^{b,c}Dry matter intakes within grain process with different superscripts differ, $P < 0.05$.

Dry matter intake was predicted using the equation of NRC (2000) for yearlings, based on cattle body weight and NE_m values without any weight adjustment factors. Although daily dry matter intakes of the various diets all were between 80 and 90% of the amounts predicted, the average for both dry rolled corn diets (85.2%) was close to that for diets that contained steam flaked corn (83.8%). Thus, most of the effect of corn processing

on daily dry matter intake in this trial could be attributed to differences in cattle weight and feed energy availability (NE_m).

Zinn et al. (1998) published results of a second trial where dry rolled, steam flaked or tempered corn was fed in high (65%) grain diets to 125 crossbred yearling steers with an average initial weight of 820 lb. The feeding period lasted 109 days. Tempered grain was

fed in 3 different treatments that differed in the amount of surfactant applied with water to the grain before the grain was processed through a roller mill. Average daily gain in this trial was greater for cattle fed tempered grain than for cattle fed dry rolled with daily gain for cattle fed steamed rolled grain being

intermediate. Dry matter intake was greater for cattle fed tempered grain than for cattle fed steam rolled grain. Feed efficiency and diet NE values were greatest for cattle on steam flaked corn, followed by cattle fed tempered corn diets with cattle fed dry rolled corn having the lowest values.

Table 4. Dry or steam flaked corn with either urea or cottonseed meal and effects on actual and predicted^a dry matter intake (DMI) in feedlot cattle (from Barajas and Zinn, 1998)

Item	Dry rolled		Steam flaked	
	Urea	Urea + Cottonseed meal	Urea	Urea + Cottonseed meal
NE _m [*] , Mcal/lb	0.94	0.93	1.09	1.03
DMI – actual, lb/d	18.5	17.7	16.7	16.5
DMI – predicted, lb/d	21.3	21.3	19.4	20.2
DMI, actual/predicted, %	87.2	83.2	85.8	81.8

^aPredicted from NRC (2000), equation for yearlings.

^{*}Net energy for maintenance.

Using the NRC (2000) equation for yearlings to predict dry matter intake, results showed that measured gains fell to between 83 and 91% of the predicted gains across all treatments (Table 5). As in the analysis of the Barajas and Zinn (1998) data, daily dry matter intake calculated using the NRC (2000) equation compensated for the effect of grain

processing on daily feed intake. However, measured daily dry matter intake of steam flaked corn, expressed as a ratio over the predicted intake, was 7% units less than the corresponding ratio for the diet containing tempered corn with 430 mg surfactant applied per kg. The corresponding difference between dry rolled and steam flaked corn was 3% units.

Table 5. Dry rolled, tempered and steam flaked corn in feedlot diets and effects on actual and predicted^a dry matter intake (DMI) in feedlot cattle (from Zinn et al., 1998)

Item	Dry rolled	Tempered (surfactant applied, mg/kg corn)			Steam flaked
		43	172	430	
NE _m [*] , Mcal/lb	0.96	0.98	0.98	1.01	1.05
DMI – actual (A), lb/d	19.3	19.7	19.8	20.2	17.9
DMI – predicted, lb/d	22.4	22.4	22.4	22.3	21.4
DMI, actual/predicted, %	86.2	87.9	88.4	90.6	83.6

^aPredicted from NRC (2000), equation for yearlings.

^{*}Net energy for maintenance.

From the results summarized above, effects of processing grain on intake of corn or sorghum grain based diets appear substantially less for daily ME intake than for daily dry matter intake. Although the number of observations in the Owens et al. (1997) review were much fewer for barley than for corn and sorghum grain, steam rolling appeared to have greater impact on reducing daily energy intake of diets containing barley than for either corn or sorghum grain. Intake depressions with steam flaking or rolling might be attributed to the greater

dietary bulk of flakes or, more commonly, to the increased potential of flaked grain to cause sub-clinical acidosis. Moisture content of fermented corn affected daily dry matter intake (Owens et al., 1997) with no apparent effect on daily ME intake. However, some of the earliest studies with high moisture corn (e.g., Tonroy et al., 1974), where the grain contained more than 30% moisture, indicate that very high moisture content can reduce both daily dry matter intake and daily ME intake. Feedlot operators and researchers probably have taken precautions after the mid 1970's to

insure that high moisture grain without the ear was not harvested when moisture content exceeded 32%. This probably limits the number of observations from very wet (>32% moisture) corn that were included in the analysis by Owens et al. (1997). Cattle fed a very high moisture fermented corn grain may have a high incidence of sub-clinical acidosis. Subclinical acidosis often is not evident from gross observations of individual cattle or overall a pen of cattle. Avoiding sub-clinical acidosis should improve health, feed efficiency, and intake of feed and energy (see Beauchemin, 2007 *these proceedings*).

Fermentation Factors that Affect Intake of High Moisture Feedstuffs by Cattle

Voluntary intake of feedstuffs by ruminants is an extremely complex process involving many animal and feed factors (Ketelaars and Tolkamp, 1992). Years ago, fermentation products were recognized as depressing intake of forage-based silages (e.g. Demarquilly, 1973). Silage moisture, pH, organic acids, and nitrogenous constituents have been incriminated and studied most extensively (Soderlund, 1995). Steen et al. (1995) analysed results of feeding 136 forage silages fed individually to 192 beef cattle. They found that silage pH and lactic or acetic acid used as single factors in either linear or quadratic relationships to dry matter intake explained less than 10% of the total variation in dry matter intake. In contrast, soluble nitrogen or amino acid nitrogen could explain from 10 to 30% of variation; the best predictors of intake were soluble or total nitrogen minus ammonia nitrogen (>30% of variation explained). Soluble nitrogen is comprised mostly of non-protein nitrogen although peptide nitrogen may be included in either the soluble nitrogen or the NPN fraction. NPN would contain all of the ammonia and free amino acid nitrogen, as well as substantial amounts of amines and a small quantity of amides. Amines in silage, formed by decarboxylation of free amino acids, consist primarily of gamma amino butyric acid, cadaverine, putrescine, tyramine and histamine.

NPN in fermented high moisture corn can comprise as much as 50% of total nitrogen (Baron et al., 1986). By comparison, the amount of NPN in fresh unfermented corn is less than 10% of total N. As fermentation proceeds, proteolysis continues and

NPN concentrations increase curvilinearly although rate of formation does decline after several months of storage. One distinguishing feature between the fermentation of forages and grains is that proteolysis and NPN formation in forages usually is very rapid with NPN formation being nearly complete by the end of the first week of ensiling. NPN formation in corn also is correlated with moisture content; corn with 22% moisture was found to contain only about 10% NPN after 90 days whereas corn at 36% moisture contained approximately 40% NPN (Baron et al., 1986). Few detailed studies have examined whether the composition of the NPN in high moisture corn is altered by moisture content and length of fermentation. Phillip et al. (1985) performed a detailed free amino acid analysis of ear corn containing 36.5% moisture. For untreated material, 49.7, 11.0 and 6.4% of the total N, respectively, was classified as NPN, free amino-N, and ammonia-N. No values are available from the literature about amine content of high moisture corn. Phillip and Buchanan-Smith (1981) reported that corn silage extracts contained a ratio of 1:5.5 of amine to amino acid N. Assuming the ratio is similar for high moisture corn, NPN from high moisture corn should have about 22.2, 12.8, 4, and 0.5% free amino, ammonia, amine and amide N, respectively. This leaves a substantial portion, 60.5% of NPN undefined, but this probably is peptide N, that is not precipitable by TCA.

To test the hypothesis that organic acids with or without amines might be a cause for reduced feed intake by ruminants, Buchanan-Smith and Phillip (1986) measured intake of high dry matter alfalfa silage by sheep following intraruminal infusion of solutions of equal tonicity that contained saline or extracts of alfalfa silage with or without added lactic, acetic and butyric acids and with or without amines both individually and in combination. Although some of these preparations depressed intake over periods lasting up to 8 hours following feeding, effects were not significant over 20 hours after feeding. To determine the potential applicability of these results to feedlot cattle fed high moisture corn, the amounts of the fermentation constituents that could be consumed when cattle eat a diet based on high moisture grain were estimated. After adjusting for differences in body weight, the amounts of these constituents that would be consumed by feedlot cattle fed high moisture corn are at the very lowest extreme of the levels tested by Buchanan-Smith and Phillip (1986). Thus, organic acids with or without

amines likely do not appear to be causing feedlot cattle to consume less dry matter from high moisture ensiled corn than dry corn.

Dawson and Mayne (1995; 1996) reported results of two similar studies with forage silages with steers. Their studies focused on silage extracts and amines only, and they compared effects of adding the constituents to the feed versus administration by intraruminal infusion. Further, they monitored intake over several days. In the first study, an extensively fermented grass silage was used as the basal feedstuff while a less fermented and higher dry matter silage was used in the second study. No significant effects on dry matter intake during 24 hours were detected with any of the amines tested at levels up to 6 g per kg dry matter in either study. A level of about 2 g per kg dry matter should be comparable to the amount found in wet high moisture corn. In a subsequent study, Dawson and Mayne (1998) compared intraruminal infusion with the addition of free amino acids to a silage diet that was fed to sheep and cattle. Although addition of the amino acid mixture to the diet depressed intake by cattle relative to the same amino acids given by intraruminal infusion, no significant difference between intake by animals given either of these treatments and the control animals that received no amino acids was detected. Yet, the level

of free amino acids tested by these researchers was several fold greater than the level present in high moisture corn.

Although analyses such as that performed by Steen et al. (1995) have found a negative association between the level of NPN in forage silage and feed intake, subsequent research has not located any consistent causative explanation for this relationship. Furthermore, as levels of the NPN constituents in fermented grain are generally less than the levels found in forages, NPN constituents seem unlikely candidates as being responsible for reduced dry matter intake of wet high moisture grain by feedlot cattle. However, recognizing the complexity of feed intake control by ruminants, interactions between these constituents and with other characteristics such as moisture content of the feedstuff, tonicity or even the rate of degradation of the feed in the rumen might be involved in intake inhibition. Another candidate compound found in greater concentration in high moisture grains than in forages and that might be responsible for reducing intake is ethanol. Fermentation of feedstuffs with excess carbohydrate and deficient nitrogen in the rumen can cause compounds that inhibit fermentation in the rumen to be produced (Russell et al., 1998). This is another intriguing possibility that might explain depression of intake that sometimes occurs with high moisture grain or other high grain diets.

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DIGESTIVE DISTURBANCES: ACIDOSIS, LAMINITIS, AND BLOAT

Karen A. Beauchemin and Tim A. McAllister
Agriculture and Agri-Food Canada, Research Centre
Lethbridge, AB T1J 4B1
beauchemink@agr.gc.ca



INTRODUCTION

In modern North American beef and dairy production systems, cattle typically are fed relatively high concentrate diets to achieve maximum production. Usually grains are processed to increase their digestibility in the rumen and in the total digestive tract; this increases feed conversion efficiency and helps reduce feed costs. However, the potential benefits of increased ruminal starch digestibility must be balanced against the increased risk of digestive disorders in cattle. While it is critical to meet the energy requirements of high producing ruminants, digestive disturbances must be avoided to ensure that meat and milk are produced from healthy animals in an efficient and cost-effective manner.

ACIDOSIS

Acute Acidosis

Acute ruminal acidosis is characterized by an extended period of time that pH in the rumen remains very low (usually less than 5.2; Figure 1). The depression in ruminal pH usually is due to an abrupt increase in the intake of rapidly fermentable carbohydrates; this results in an accumulation of volatile fatty acids (VFA) and lactic acid in the rumen. The excessive build-up of short chained fatty acids in ruminal fluid increases the osmolality of rumen contents which in turn inhibits feed intake, salivation, and the onset of rumination following meals (Carter and Grovum, 1990). A prolonged period of acute ruminal acidosis leads to systemic or metabolic acidosis (Owens et al., 1998). High osmotic pressure in the rumen pulls water from the blood into the gastrointestinal tract causing diarrhea. Loss of water from the blood increases blood osmolality and packed cell volume leading to dehydration of the animal. Furthermore, rate of absorption of VFA from the rumen is enhanced at low pH. When acid absorption exceeds metabolism, these compounds can accumulate in blood and increase blood osmolality further.

Clinical signs of acute acidosis include complete anorexia, abdominal pain, rapid beating of the heart, abnormally fast breathing, diarrhea, lethargy, staggering, recumbency and death (Krause and Oetzel, 2006). Cattle that survive the systemic effects of acute acidosis often become “poor doers” or “realizers” due in part to damage of the gastrointestinal tract. Prolonged periods of low ruminal pH reduce the absorptive capacity of the ruminal epithelium by causing abnormalities of ruminal papillae and ruminitis (McGavin and Morrill, 1976; McManus et al., 1977). The absorptive capability of the ruminal epithelium can be limited for up to six months after a bout of acidosis (Krehbiel et al., 1995). Lesions of the ruminal epithelium also have been implicated in systemic bacterial infiltration that can lead to liver abscesses (Nagaraja and Chengappa, 1998).

Fortunately, the prevalence of acute acidosis usually is low in commercial feedlots and dairies. For feedlot cattle, Smith (1998) reported that 3 to 7% of sick cattle (those placed in sick pens) were treated for digestive disorders and that about one-third of feedlot mortalities (which usually total < 2%) were due to digestive disorders. The prevalence of acute acidosis usually is even lower in commercial dairies. Gröhn and Bruss (1990) reported the incidence of acute ruminal acidosis was only 0.3% throughout lactation among 61,000 dairy cows; incidence was greatest during the three months after calving. The risk of acute acidosis is low in adapted animals; gradual changes in diet composition and quantity of diet delivered allow the rumen environment added time to cope with rapidly fermented diets. Experimentally, acute acidosis can be induced by withholding feed for a period of time (usually 12 to 24 h) followed by over-feeding additional concentrates (Krause et al., 2005) or by delaying feeding followed by overfeeding (Erickson et al., 2003). Hence, the risk of acute acidosis appears greatest during the period of transition from high forage to high grain diets and when feed delivery is inconsistent, conditions that promote the excess consumption of rapidly fermented diets.

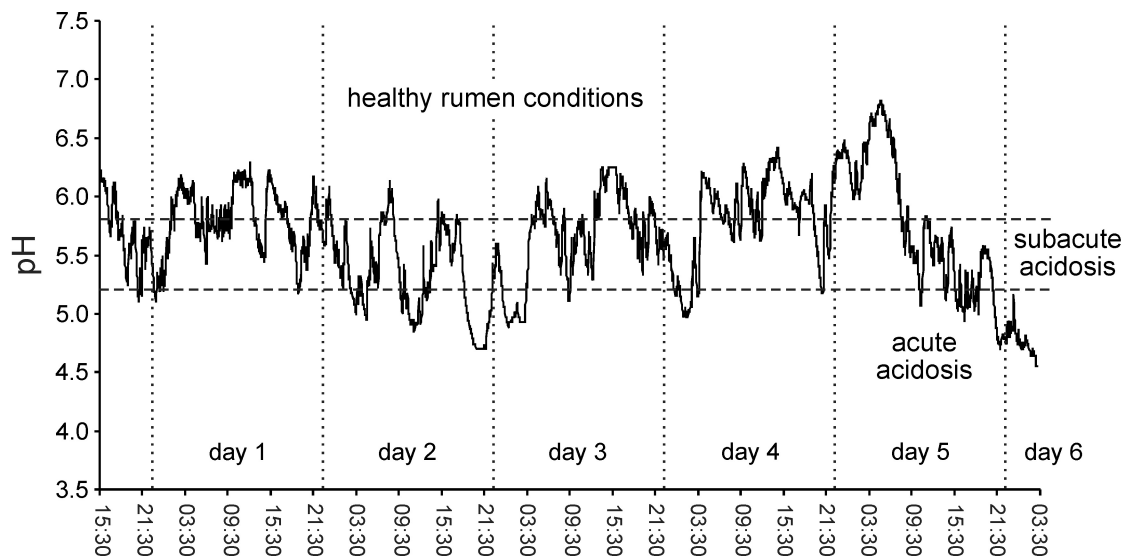


Figure 1. Ruminal pH profile in a dairy cow. Subacute acidosis was defined as pH < 5.8 and acute acidosis as pH < 5.2. The prolonged period of subacute acidosis that occurred on day 5 developed into acute acidosis on day 6 (Beauchemin, unpublished data).

Subacute Acidosis

Unlike acute acidosis, subacute ruminal acidosis (SARA) is prevalent in modern commercial feedlot and dairy production systems in North America. Its high prevalence has been correlated with the use of diets that contain substantial quantities of processed grains. It is difficult to identify animals suffering from subacute acidosis because clinical signs are not unique to acidosis. Cattle with subacute acidosis can experience diarrhea, weight loss, reduced milk production, and increased susceptibility to other metabolic disorders. Krause and Oetzel (2006) used rumenocentesis (i.e., percutaneous needle aspiration of fluid from the caudal ventral rumen) 6 to 10 h after feeding total mixed rations and 2 to 4 h after feeding component diets in 55 dairy herds to determine the prevalence of subacute acidosis in commercial dairies. They reported that during the first 140 days of lactation, 12 to 40% of the cows had a ruminal pH below 5.5. Prevalence of acidosis in the feedlot industry is not known, but considering that feedlot cattle diets contain even more grain, its prevalence is likely even higher than for the dairy industry.

An episode or bout of subacute ruminal acidosis occurs when pH of the rumen drops into a suboptimal zone for a period of time. Hence, the definition of subacute ruminal acidosis incorporates both a pH threshold and a duration. To characterize

bouts of subacute ruminal acidosis, the pH threshold value typically used is 5.6 to 5.8 (Figure 1). In our laboratory, we use a ruminal pH < 5.8 to denote acidosis in dairy cows because the reduced fiber digestion below a pH of 5.8 has negative effects on milk production. The threshold pH of 5.6 typically is used to denote subacute acidosis of feedlot cattle because negative impacts of acidosis on feedlot cattle are related more to its effects on intake, nutrient metabolism, and animal health than on fiber digestion.

Automated systems have been developed recently to continuously monitor ruminal pH over an extended period of time (Dado and Allen, 1993; Penner et al., 2006); this makes it possible to characterize subacute ruminal acidosis in terms of bout duration. We use 4 h as the minimum duration (continuous time period when pH remains below the threshold value) to define a single bout of acidosis (Paton et al., 2006); shorter durations with a low pH are less detrimental to bacterial growth. The total duration of time that pH remains below the acidosis threshold value in a 24 h time period is an additional method for characterizing subacute ruminal acidosis (Penner et al., 2007).

RUMEN MICROBIAL DYNAMICS DURING ACIDOSIS

Ingestion of carbohydrates provides substrate for microbial growth in the rumen; this increases the total number of bacteria and VFA production. When

production rate of VFA exceeds the capacity of the system to neutralize or absorb these acids, ruminal pH declines (Allen, 1997). Ruminal pH of feedlot cattle and dairy cows varies considerably during a day; the drop in pH following meals is substantial when the diet contains a high proportion of rapidly fermented carbohydrates (Figure 1). With subacute

acidosis, ruminal pH usually recovers to pre-feeding levels as the acids are absorbed from the rumen and as the buffering capacity of the rumen increases due to salivation. However, subacute ruminal acidosis can develop into acute ruminal acidosis in some cases as shown in Figure 1. For acute ruminal acidosis, immediate intervention is critical.

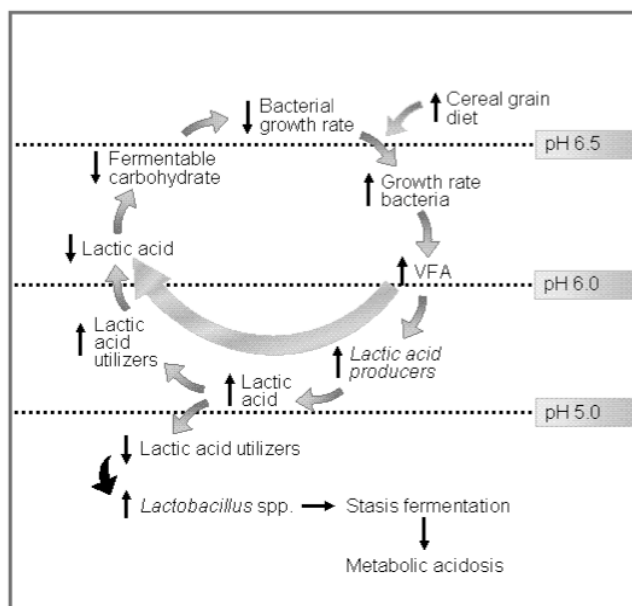


Figure 2. Sequence of events leading to subacute and acute acidosis (adapted from McAllister et al., 1996).

In the absence of acidosis, ruminal glucose concentrations remain low because glucose is transformed rapidly into VFA by rumen microorganisms. Lactic acid concentrations also are low because competition for substrate normally moderates the growth of lactic-acid producing bacteria, such as *Streptococcus bovis* and *Lactobacillus* spp. (Figure 2). Furthermore, growth of bacteria that use lactic acid, e.g., *Selenomonas* spp., *Megasphaera elsdenii*, and *Propionibacterium* spp., ensures that any lactic acid produced is rapidly metabolized; this prevents lactic acid from accumulating in the rumen. However, with high grain diets or a sudden change in diet composition or supply, the microbial populations become unstable and this allows rapid growth of lactic acid producers such as *S. bovis*. Because most lactate-utilizing bacteria are not acid tolerant, the balance between lactate-producing bacteria and lactate-utilizing bacteria is disrupted. During subacute acidosis transient spikes in lactic acid concentration in

ruminal fluid appear, but eventually the balance between lactic acid production and utilization is achieved. In contrast, during acute acidosis, lactate often accumulates in ruminal fluid (> 40 mM), although acute acidosis can occur without lactic acid being present. Low ruminal pH also activates lactate dehydrogenase, the enzyme involved in converting pyruvate to lactate; this exacerbates the accumulation of lactic acid in the rumen. Furthermore, feeding a large amount of starch also can increase ruminal concentrations of free glucose; this increases the competitiveness of lactate-producing bacteria such as *S. bovis* in the rumen (Owens et al. 1998). Lactic acid is a very potent acid (10-times stronger than VFA), and this property contributes further to the decline in ruminal pH.

Excess carbohydrates in the rumen can lead to the production of toxins by some ruminal bacteria. For example, an excess of glucose causes *Prevotella ruminicola* to produce methylglyoxal, a substance that

is toxic to rumen bacteria (Russell 1998). As a result, rumen fluid of acidotic animals can appear stagnant. Furthermore, cellulolytic bacteria and protozoa are inhibited by a pH below 6.0; instead, acid tolerant bacterial species such as *S. bovis* and lactobacilli become dominant when pH is maintained below 6.0 for a prolonged time. If the

pH drops further, *S. bovis* is inhibited; when pH drops below 4.7, only acid tolerant species such as lactobacilli are maintained. The many interconnected factors that cause ruminal pH to decline also make it very difficult to reverse a severe drop in ruminal pH that occurs during acute acidosis.

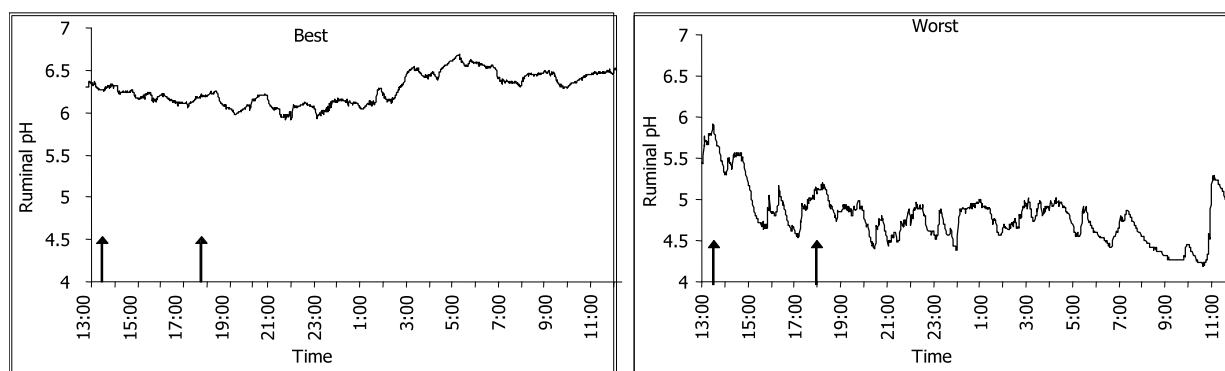


Figure 3. Ruminal pH measured 5 days after calving in two dairy cows (best and worst-case acidosis cows) fed the same lactation diet (Penner, Beauchemin and Mutsvangwa, unpublished data). Arrows indicating feeding of the total mixed ration.

VARIABILITY IN ACIDOSIS AMONG ANIMALS

The risk for acidosis is not equal for all animals. Individual dairy cows exhibit a tremendous amount of variation in the degree of acidosis. Figure 3 shows ruminal pH profiles on day 5 post-partum for two dairy cows fed the same diet. For the cow with the “best” profile, ruminal pH remained above 6, whereas for the cow with the “worst” profile, acute acidosis continued for the entire day.

Similar variability exists for beef cattle during the feedlot finishing phase (Figure 4). Factors accounting for this variation among animals are not well documented, but presumably they are related to differences in feed intake, eating rate, sorting of feed, salivation rate, rate of passage of feed from the rumen, and other aspects of physiology and behavior. The goals in beef and dairy production are to minimize the number of cattle that experience ruminal acidosis, and to reduce the duration and intensity of each episode of acidosis that an individual animal experiences.

IMPACT OF SUBACUTE ACIDOSIS

Fiber Digestibility

Subacute ruminal acidosis decreases the digestibility of fiber in the rumen; this decreases feed conversion efficiency and increases feed costs. Numerous in vitro studies using pure cultures of rumen microorganisms have shown that growth rate and ability of the major cellulolytic bacteria (*Ruminococcus albus*, *R. flavefaciens*, and *Fibrobacter succinogenes*) to degrade cellulose is negatively affected at pH below 6 (e.g., Russell and Wilson, 1996). Furthermore, ruminal cellulolytic protozoa and fungi also are sensitive to low pH. The effects of low pH on mixed cultures of rumen microorganisms have been studied using continuous culture in vitro systems. Decreasing ruminal pH to within the subacute acidosis range causes a 2 to 3 percentage unit decrease in NDF digestibility per 0.1 unit decrease in pH (Calsamiglia et al., 2002; Yang et al. 2002). In dairy cows, total tract acid detergent fiber digestibility decreased by 3.6 percentage units per 0.1 unit decrease in mean daily ruminal pH (Erdman 1998), while in dairy cows and feedlot cattle a decrease in mean ruminal pH from 6.4 to 5.7 lowered total tract NDF digestibility by 1.3 percentage units per 0.1 unit decrease in ruminal pH (Beauchemin, unpublished data).

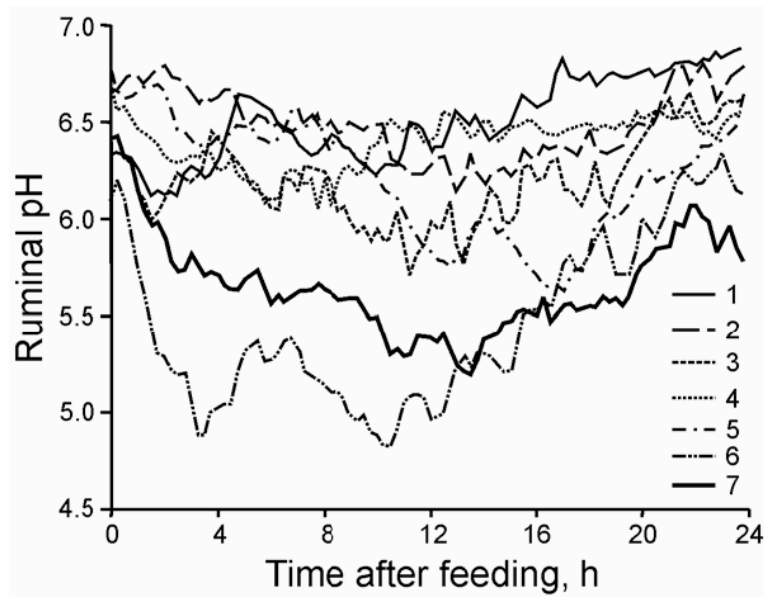


Figure 4. Changes in ruminal pH following ad libitum feeding of a high-grain finishing diet fed to feedlot steers (Schwartzkopf-Genswein et al. 2003). Each line represents an individual steer.

A constant low pH obviously has a negative effect on ruminal fiber digestion, but the effect of pH fluctuations on fiber digestion is less clear. Short (30 min), infrequent drops in pH failed to reduce NDF digestibility, unlike repeated 4-h periods of acidosis (Calsamiglia et al. 2002). Although subacute acidosis reduces fiber digestion in cattle, microbial populations apparently recover between bouts of acidosis when pH rises. In the case of dairy cows, the depression in fiber digestion associated with subacute acidosis is sufficient to reduce productivity. Oba and Allen (1999) proposed that a one percentage unit decrease in NDF digestibility was associated with a 0.25 kg/d decrease in 4% FCM yield and 0.17 kg/d decrease in dry matter intake. The significance of intermittent acidosis on fiber digestion by feedlot cattle in terms of production efficiency is less drastic because feedlot diets are typically low in fiber.

Feed Intake Variability

Subacute ruminal acidosis can lead to reduced feed intake and erratic eating patterns. For feedlot cattle, Brown et al. (2000) observed a high correlation coefficient ($r = 0.84$) between the lowest daily ruminal pH and feed intake on the subsequent day. When ruminal pH is low, the animal's feed intake drops; this limits further production of fermentation acids and restores pH to more optimum conditions. Once the pH is restored, the animal then resumes consuming feed that again may lead to excessive production of acids and this cycle can be repeated. Such an effect is illustrated in Figure 5, which shows the pH profile for an adapted feedlot steer fed a 92% concentrate diet containing barley. Variation in day-to-day intake is undesirable in terms of maximizing mean feed intake and providing a constant supply of nutrients for growth or lactation.

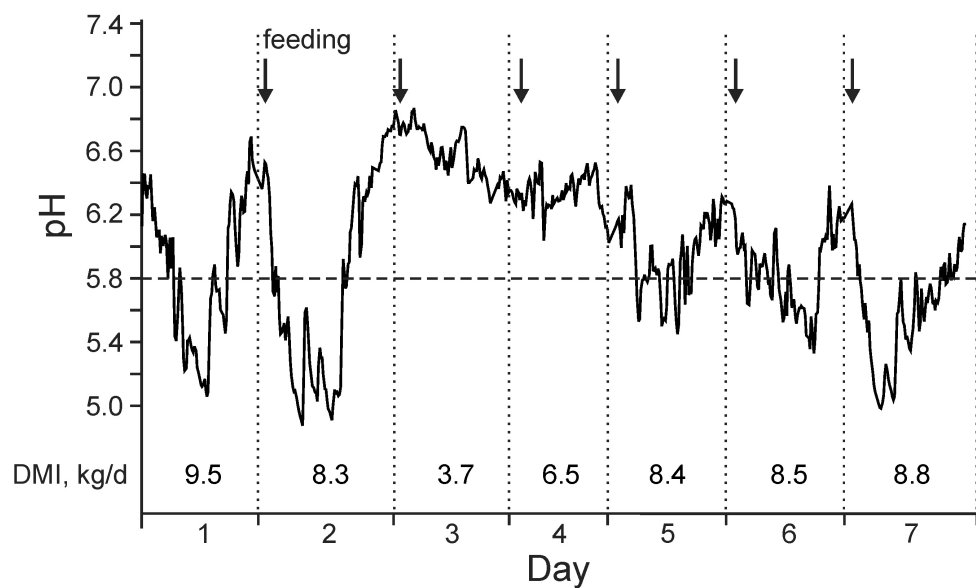


Figure 5. Ruminal pH and dry matter intake (DMI) for an adapted feedlot steer fed once daily (feeding indicated by arrows) measured for 7 days (Schwartzkopf-Genswein et al. 2003).

LAMENESS

Lameness is a major health and welfare concern for the North American cattle industry, particularly for the dairy industry (Hendry et al., 1997). Ruminal acidosis can cause lameness in cattle due to laminitis and associated hoof lesions (Cook et al., 2004; Nordlund et al., 2004). Laminitis is a generic term that refers to inflammation of the connective tissue located in the hoof. Severe cases of laminitis are characterized by deformed claws such as concave hoof walls, irregular hoof shape, and hoof overgrowth (Blowey, 1993). Laminitis can lead to white line hemorrhages, sole ulcers, and the formation of ridges on the hoof wall.

Several theories have been proposed to explain the link between acidosis and laminitis. According to one theory, a reduction in systemic pH during acidosis activates a vasoactive mechanism that increases total blood flow to the hoof (Nocek, 1997). Alternatively, histamine may be absorbed through rumen epithelium damaged during acidosis. Histamine is an inflammatory agent and vasoactive substance, and as such, may increase blood pressure

and damage blood vessel walls causing inflammation and haemorrhaging within the hoof. It is well established that grain feeding increases the formation of histamine in the rumen (Garner et al. 2002).

Recent studies have produced compelling evidence for a different link between acidosis and laminitis based on the effects of bacterial toxins rather than vasoactive substances. Acute acidosis and repeated bouts of subacute acidosis damage the surface of the rumen wall and possibly the intestine; this allows bacteria and bacterial toxins to enter the portal circulation, causing liver abscesses and an inflammatory response (Gozho et al., 2005). The exterior surface of the hoof (the horn) is joined to the major bone in the hoof (the pedal bone) by highly vascularized connective tissue (corium) that acts as a shock absorber when the hoof contacts the ground (Figure 6). The corium is attached to the horn through folds of tissue, called laminae (within the wall) or papillae (within the sole; Hendry et al., 1997). The impact of acidosis on laminitis may be mediated by matrix metalloproteinases in a manner similar to the effects of parturition.

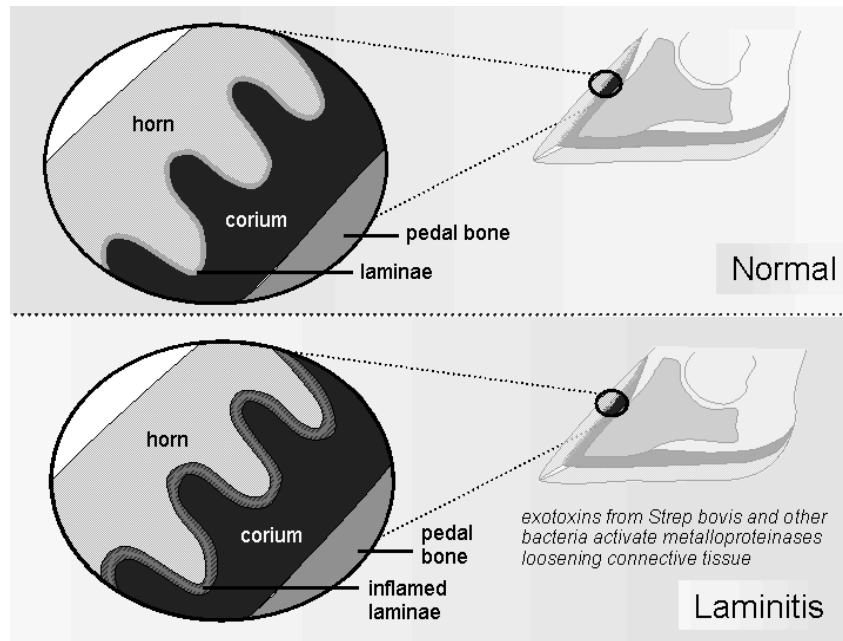


Figure 6. Schematic diagram of the hoof and the inflammation that occurs during laminitis.

At parturition, hormonal changes affect connective tissue metabolism within the hoof by elongating collagen fibers and loosening the connective tissues (Tarlton et al., 2002). In the case of laminitis, metalloproteinases are thought to be activated by exotoxins (proteases) released by bacteria. Once activated, these metalloproteinases degrade key components of the corium (Mungall et al., 2001). Studies in horses have shown that several gram-positive (*S. bovis*) and gram-negative bacteria produce exotoxins capable of activating the resident metalloproteinases within the lamellar structure of the hoof.

Dairy heifers subjected to an acute acidosis challenge developed signs of lameness within 24 h (Thoenes et al., 2005). Examination of the hoofs post-mortem detected weakening at the dermo-epidermal junction caused by stretching of the laminae and detachment of the basement membrane. However, acidosis in cattle does not always result in laminitis (Momcilovic et al., 2000; Donovan et al., 2004); thus, other factors appear to alter the susceptibility of cattle to acidosis induced laminitis. For example, an animal's environment may exacerbate or temper the effects of acidosis on laminitis (Cook et al., 2004).

GRAIN BLOAT

Grain-related bloat, or frothy-bloat, occurs primarily in feedlot cattle and often is associated with acidosis. However, prevalence of bloat in commercial feedyards usually is low due to the widespread use of ionophores combined with careful feeding management (Smith, 1998). The risk of feedlot bloat increases when rapid changes occur in diet composition or in feed delivery that increases the supply of rapidly fermented carbohydrate (Schwartzkopf-Genswein et al., 2004). A sudden increase in fermented carbohydrates in the rumen leads to rapid microbial growth rates and subsequent cell lysis. Extracellular bacterial mucopolysaccharides (slime) and stored carbohydrates released during microbial cell lysis increase the viscosity of ruminal fluid trapping gas and forming the stable foam that leads to bloat (Cheng et al., 1998).

Bloat results from the accumulation of gas in the rumen. Normally, gas produced during fermentation of feed rises through the rumen contents and forms a gas pocket in the dorsal sac. During frothy bloat, the gas, trapped within the liquid and particulate contents of the rumen, continues to accumulate. Continued accumulation of gas within the rumen increases the pressure within the rumen, eventually causing death by asphyxiation as the rumen exerts pressure on the diaphragm and lungs (Dougherty, 1956).

PREVENTING DIGESTIVE DISTURBANCES

Adaptation of the Rumen Environment

In general, the risk factors for digestive disorders include extensive grain processing, a low concentration of forage in the diet, and abrupt changes in diet supply or composition. The key to minimizing acidosis, bloat and laminitis is to provide ample time for the rumen environment to adapt to dietary changes (Schwartzkopf-Genswein et al., 2003). This adaptation phase allows the ruminal epithelium and the rumen microbial populations to adapt to changes in substrate supply.

Absorption of VFA from the rumen occurs passively through papillae (finger-like projections) located on the rumen wall. The rumen papillae gradually lengthen when cattle are exposed to a grain-based diet (Dirksen et al., 1985). This effect appears to be mediated by a stimulatory effect of VFA, especially butyrate (Sakata and Tamate, 1978), on papillae growth. This increased surface area and absorptive capacity of the rumen helps protect the cow from accumulating VFA in the rumen, the main driver of ruminal pH depression.

Gradual transitions of animals from a high forage to a concentrate diet helps to avoid the

instability of microbial populations observed in cases of acute acidosis. Similarly, chemical buffers like bicarbonate may be added to the diet as a means of stabilizing ruminal pH and preventing subacute acidosis. Other dietary additives that have positive effects upon ruminal pH include ionophores, lactic acid fermenting bacteria, and yeast. Ionophores also help to prevent bloat because they reduce the variation in feed intake and inhibit the growth of gram-positive bacteria (Bergen and Bates, 1984), including *S. bovis* and *Lactobacillus*, two of the major lactic-acid and mucopolysaccharide-producing species found in the rumen.

Balancing Starch Availability with Physically Effective Fiber Content

Maintaining a balance between physically effective fiber content of the diet and starch availability is a key factor for stabilizing ruminal pH. Starch availability in the rumen depends on the source of grain and its processing. As the amount of starch digested in the rumen increases, ruminal pH decreases and the risk of ruminal acidosis increases. For example, cattle fed steam-rolled barley have a lower ruminal pH than cattle fed steam-rolled corn because ruminal starch digestion is greater for barley than corn (Yang et al., 1997). Similarly, ruminal pH is lower for cattle fed high moisture corn than for those fed dry cracked corn diets (Figure 7; Krause et al., 2002).

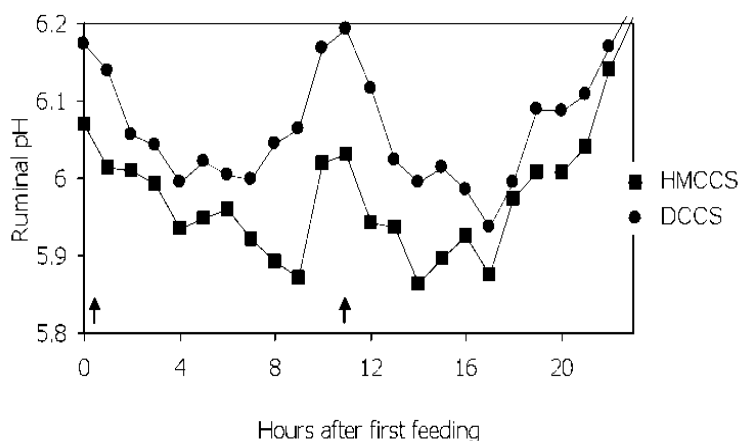


Figure 7. Ruminal pH of dairy cows fed high moisture corn (HMC) versus cracked shelled corn (DC). The forage was coarsely chopped (CS) corn silage (Krause et al., 2002).

Preventing ruminal acidosis requires a balance between the production of VFA and the neutralization/removal of VFA (which also reduces rumen osmolality). When the rate of ruminal

fermentation of starch is high, diets need to be formulated to supply sufficient forage and forage needs to be of an adequate particle length. Longer forage particles promote chewing and saliva secretion that help

to buffer the acids resulting from feed digestion. In addition, long forage particles create a floating mat in the rumen that stimulates reticuloruminal contractions. Without such mixing motions, the rumen can become a stagnant pool and removal of VFA via absorption and fluid passage from the rumen declines. This condition increases the risk of acidosis and bloat. Similarly, anecdotal evidence indicates that acidosis occurs in feedlots when water supply is interrupted, a condition that would decrease ruminal dilution and outflow. Fiber is more slowly digested than starch and sugar, so including fiber in the diet slows the rate of carbohydrate digestion in the rumen. Decreasing the rate of carbohydrate digestion reduces the rate of VFA production, thereby preventing abrupt drops in ruminal pH. Feeding long particle fiber also can shift the site of starch digestion from the rumen to the intestine and this can reduce the potential for ruminal acidosis (Yang and Beauchemin, 2006). The multitude of mechanisms whereby optimizing physically effective fiber in the diet helps to

modulate ruminal pH makes this approach a very effective method of acidosis prevention.

IMPLICATIONS

Processing grains to enhance ruminal digestion increases the risk of digestive disorders in cattle fed such grains. The key to attaining production responses from diets with high rates of ruminal starch digestion is through formulating diets and employing cattle management practices that avoid acidosis. Diet formulation typically is based on the average cow and often does not include a safety factor that considers the high variability among individual animals. Diets containing processed grains that are formulated to provide a minimum level of physically effective fiber will result in some degree of acidosis, and can have negative effects on production efficiency and animal health. The overall goal is to minimize the number of cattle that experience acidosis and, for individual animals that experience acidosis, to reduce the duration and intensity of the condition.

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QUESTIONS AND ANSWERS

- Q:** Karen, is there a learned behavior regarding feed aversion of cattle that experience acidosis similar to the feed aversions that Fred Provenza has studied for years?
- A:** I don't know, but Provenza's work is intriguing. He has clearly shown learning behavior for calves with their mothers. Perhaps there is some learned behavior associated with acidosis. If an animal is exposed to a bout of acidosis, that animal may become more reluctant in the future to eat as rapidly or fall into the acidosis "trap." We have a study on-going at the moment to look at this very issue. The graph I showed was from 8 dairy cows that were subjected to an acidosis challenge where we monitored how long it took for rumen pH to recover after a challenge. We repeated the acidosis challenge three consecutive times using the same cows and are in the process of looking at the data. A learned behavior could work to our favor. If animals can be trained to be less susceptible to acidosis, we could employ that as part of a management strategy. By using a very controlled exposure to acidosis, perhaps we could make animals more acidosis "fool-proof" in the future.

Update from Karen: Analysis of the data from that study is now complete. When cattle were subjected to repeated acidosis challenges (two weeks apart), the severity of each acidosis bout actually worsened even though the cows became increasingly reluctant to consume the grain offered each challenge. Thus, avoidance of grain intake did not minimize the severity of acidosis. These results lend support to the theory that animals will alter their feed consumption to correct ruminal imbalances, but our study also shows that this change in behavior does not necessarily reduce the incidence of acidosis. In fact, the study shows that once cows experience a bout of acidosis, cows are more prone to subsequent bouts of acidosis and each subsequent bout of acidosis is increasingly severe.

SUMMARY OF PRACTICAL CONSIDERATIONS IN GRAIN PROCESSING

Ken Eng
Eng, Inc.
San Antonio, TX
engcaroline@yahoo.com



When I was asked to participate in this conference, the first thing that occurred to me was is a symposium on grain processing necessary. Since that time, a number of events have occurred that have made this an important and timely topic. It has been said that in life, love and business, “timing is everything” and certainly, the timing of this conference is almost perfect. Recent events including an escalation in energy costs, an escalation in grain prices and an abundance of feed by-products all impact grain processing decisions.

Grain price is important when evaluating grain processing procedures because obviously, the higher the grain price the greater the value of improved feed efficiency. In my career, we have seen three bull markets in grains which were 1974, 1995, and 2006-2007. Table 1 summarizes the corn production, use,

yield and prices for these three years. By the way, since this symposium, corn prices have continued to escalate and the July 07 contract reached a high \$4.58/bu. The 2006 bull market differs from the 1974 and 1995 bull markets because the earlier markets were essentially “supply bulls” caused by low corn production. The 2006-7 market is a “demand bull” because it has occurred when corn production was high and is due to a tremendous increase in demand. Much of this increased demand is due to corn ethanol production, but feed and export demand has also been strong. The demand for ethanol production will continue to increase which means we will continue to need record grain production. Many believe that we have seen the last of cheap corn, but history tells us that if we give US Agriculture a profit incentive, we tend to find a way to over produce almost everything.

Table 1. Corn Production, Use and Price

	1974	1995	2006
Production	4.7	7.4	10.9
Bushels used (billions)	4.6	8.8	11.9
Yield/acre (bu)	71.9	113.5	153.3
Corn Future High (\$/Bu)	4.00	5.54	3.34

Almost all of the papers presented at this conference focused on grain processing as it applies to corn. Because corn breeders and farmers have done an outstanding job of increasing corn yield/acre, it has become not only the grain of choice, but in many areas the only feed grain available. However, it is well to remember other grains in including grain sorghum, barley and wheat have played an important role in feedlot rations. The importance of alternative grains may increase in the future because one way we can increase US grain production is by taking part of the 40 million acres currently in CRP Programs and putting them back into crop production. Much of this land is better suited for grain sorghum, barley or wheat than for corn production. Remember in the not too distant past grains other than corn made up the majority of feedlot finishing rations in much of the United States. Looking back on my personal career I

suspect that until approximately 1985 I used more grain sorghum, barley and wheat in client finishing diets than I did corn.

When discussing grain processing it is important to remember the response of various grains to steam flaking differ. Table 2 is the estimated improvement in feed efficiency of various grains as a result of steam flaking. These averages are based on the opinion of several feedlot consultants active in various parts of the United States. Most agreed that the improvement in corn feed efficiency due to steam flaking was approximately 9 to 10% while the improvement in grain sorghum was 15% with a lesser improvement in barley (6%) and wheat (4%). Some consultants including myself have often said if you can’t afford to steam flake grain sorghum, you can’t afford to feed it. On the other hand, if the rations are properly

formulated, dry processed barley and wheat work just fine and of course we know that either cracked or

whole corn can give respectable performance.

Table 2. Estimated response to steam flaking the four major feed grains

Grain	% Improvement
Corn	9
Grain sorghum	15
Barley	6
Wheat	4

For those of you relatively new to the feedlot nutrition business, I would point out that even though corn is an excellent feed grain, don't underestimate the value of heavy barley and certain types of wheat. If cost was no factor, I would probably prefer a finishing diet containing a combination of heavy barley and Durum wheat to any other grain.

As mentioned before, the cost of grain determines the relative value of various grain processing

techniques. Table 3 illustrates the estimated net return to steam flaking from a 10% improvement in feed efficiency using corn prices ranging from \$75 to \$175/ton. Again based on the survey of several feedlot consultants I estimated total flaking cost of \$7.50/ton. Thus, at any corn price less than \$75/ton steam flaking would be a losing proposition. On the other hand, at \$175/ton which is the current corn price in several areas, the net return to steam flaking is \$10/ton.

Table 3. Net return to steam flaked corn

Corn Price (\$/ton)	75	100	125	150	175
Value of 10% improve (\$)	7.50	10.00	12.50	15.00	17.50
Flaking cost (\$/ton)	7.50	7.50	7.50	7.50	7.50
Net return from flaking (\$)	0	2.50	5.00	7.50	10.00

Another factor determining the choice of grain processing is what equipment is currently present at the feedlot. For example if the feedlot currently has steam flaking capabilities as part of the total feed mill, most likely they will continue to use it. On the other hand, if the feedlot does not have steam flaking capabilities they may be reluctant to spend approximately \$300,000 or more for a 24 X 48 inch steam flaker which may flake 12 to 15 tons/hour.

The availability of feed by-products also has a significant impact on the processing method of choice. The tremendous increase corn ethanol production has resulted in an increase in both wet and dried distillers grains which are excellent feed by-product for ruminants. Ethanol plants continue to be constructed as this talk is presented and a lot of corn will go for ethanol production. On a dry matter basis, 30% of this corn comes back as feed by-products and if they are relatively inexpensive, they can be fed at levels up to 40% of the total ration. This impacts the choice of grain processing in two ways. First, if you are feeding approximately 40 to 50% by-products in your diet, the

amount of grain used is reduced to the point that an expensive grain processing may not be justified. Second, there is an inter action between grain processing techniques and the response to distiller's grains. It appears that higher levels of distiller's grains can be used to greater advantage in high moisture or ground corn rations as compared to flake corn rations. Some suggests that the maximum distiller's grain level which can be efficiently used with steam flaked grain may be 15%. There are several possible reasons for this, but at this time, the exact mechanism is not fully understood. Regardless, "the bottom line" is if a cheap and abundant source of distiller's grains is available in your area you are less likely to spend the money on steam flaking facilities.

The choice of grain processing facilities will differ depending upon the grains and by-products available in a particular area. There may also be a geographical difference in the benefits from steam flaking. It seems the greatest response to steam flaking grain is in the Southwest which also has the most consistent weather. In the High Plains and Midwest

when climate conditions are severe and variable, it's possible a highly processed flake might cause more problems than it solves.

SUMMARY

For the foreseeable future, it is probable that corn ethanol production and therefore distiller's grains production will continue to increase. This will change how and where cattle are fed. If the government's goal of 35 billion gallons of renewable fuel production in ten years is met there will be an abundance of by-products. Glycerin from bio-diesel production may become an important by-product and will also impact grain processing decisions. Long term, cattle tend to "follow the feed" and there are several examples of

this in the history of the cattle feeding industry. Bottom line, there are an incredible number of changes taking place in animal agriculture and cattle are better able to take advantage of these changes than other species. You can efficiently feed cattle without corn in the diet while this would be difficult with either swine or chickens.

Changes will continue to occur at a rapid pace in the feedlot industry and some of these will no doubt impact grain processing decisions. By the end of the decade we may not recognize our rations and these changes represent a unique opportunity for cattlemen and ruminant nutritionists who can "think outside the box." Once again, "timing is everything."

RESEARCH NEEDS

M. L. Galyean and J. T. Vasconcelos
Department of Animal and Food Sciences
Texas Tech University, Lubbock 79409-2141
michael.galyean@ttu.edu



The Animal Science Department at Oklahoma State University hosted yet another outstanding conference where practicing nutritionists and scientists could meet together and discuss issues of vital importance to the cattle feeding industry. The 2006 Cattle Grain Processing Symposium will provide important contributions through the various scientific papers published in the proceedings, and the discussion that was stimulated will no doubt have effects on research agendas for several years to come. In that regard, we have prepared the following summary of research needs extracted from comments made by various speakers and generated as a result of listening to the various presentations and attempting to identify gaps in research knowledge. The main divisions of the conference were used as the basic structure for this summary.

I. Grain Composition Basics and Quality Control

- Compositional changes that occur when grains are processed need to be clarified. Considerable discussion revolved around the changes in starch, protein, fat, and fiber that occur with steam flaking. Perhaps a mass balance approach would be useful to avoid sampling errors. Potential changes in availability of phosphorus with processing also were mentioned, which might deserve further attention.
- NRC feed composition data need to be updated, particularly with respect to effects of processing on nutrient composition.
- “Pre-processing” treatments should be investigated relative to removal of barriers to digestion (e.g., effects of enzymatic treatments on the pericarp and/or proteolytic enzyme treatments to affect the protein matrix and remove barriers to starch digestion).
- The effects of moisture, endosperm type, etc. on particle size distribution with grinding or rolling of various grains need to be evaluated.
- The extent to which attention to quality control in the steam flaking process at feedyards affects performance responses needs to be evaluated (i.e., are process limits defined adequately to allow for results to be correlated with cattle performance?).
- Optimal processing conditions for steam-flaked wheat need to be defined.
- Relationships between “fines” in high-moisture corn and soluble N concentration, endosperm type, cattle performance, etc. should be determined.
- Animal-to-animal variation in % fecal starch or pen-to-pen variation is probably well established, but this information should be summarized to allow for determination of the number of samples needed to reliably predict effects of fecal starch on dietary energy concentrations or other performance measurements.
- Components of differences among hybrids that are most important need to be determined (e.g., vitreousness, protein differences, fiber differences).

II. Processing Comparisons

- The “roughage value” of whole-shelled corn needs to be determined, along with the optimal roughage level and source to use with whole-shelled corn. Potential interactions with grain milling coproducts in whole-shelled corn diets should be determined.
- Effects of starch retrogradation (or perhaps changes in protein and/or carbohydrate fractions in the endosperm that occur with processing) on cattle performance should be determined. The extent to which retrogradation can be altered by changes in grain moisture and/or processing/handling conditions needs to be more clearly defined.

- Relationships between refractive index, flake color index, enzymatic starch availability and cattle performance are not well defined. Are these measurements merely quality control tools for the flaking process, or do they have predictive ability in terms of cattle performance and dietary energy concentrations?
- The relationship between corn moisture at harvest and grain endosperm type should be evaluated, as well as the response of different endosperm types to reconstitution. The effects on high-moisture/reconstituted corn of grinding vs. rolling or storage in the whole form with processing at the time of feeding might need further study.

III. Fermentation and Analysis

- The value (effects on product quality, fermentation losses, and cattle performance) of fermentation aids (e.g., microbial cultures) for high-moisture/reconstituted grains needs to be determined.
- Ensuring accuracy and precision of methods used for determination of moisture is critical for evaluating nutrient and performance responses. Standardization of methods used in research studies with high-moisture feeds would be beneficial.
- The relationship between dry matter intake and starch digestibility for feedlot beef cattle needs further review and experimentation. Current assumptions are likely based on intakes that are low relative to practical conditions.
- The validity of in situ data for predicting ruminal starch digestion needs further investigation.
- More direct measurements of methane production and overall energetics are needed in comparisons among processing methods.
- Direct estimates of the role of small intestinal digestion of starch on performance are needed.
- The role of site of digestion and of absorbed glucose on fat deposition and overall metabolism needs further research.

IV. Processing Effects on Management

- The degraded intake protein requirements with high-moisture corn vs. steam-flaked corn deserve further study. Current estimates are based on a limited number of observations.
- More research is needed to characterize the roughage value (e.g., NDF or effective NDF) of different roughage sources and relationships to site and extent of starch digestion.
- Optimal combinations of dry vs. high-moisture roughages (e.g., is dry grain better with high-moisture roughage and vice versa?) and grains seem yet to be determined. This area might become increasingly important with the addition of high-moisture grain milling coproducts to feedlot diets.
- The role of adaptation to increasing starch, increasing energy, or both as cattle are transitioned to finishing diets needs to be defined. The metabolic, energetic, and microbiological (ruminal and intestinal) changes with adaptation to high-concentrate diets are not adequately defined and could be a fruitful area for research.
- Direct comparisons of various adaptation strategies in terms of cattle performance and/or metabolism are needed.
- The role of the small and large intestine in adaptation to high-concentrate diets deserves study.

V. Associative Effects and Management

- The extent to which adding wet distillers grain to dry-rolled vs. steam-flaked corn alters the rates of passage and digestion of dietary fractions should be determined.
- Effects of adding wet distillers grains to diets with grains processed by different methods need continued study.
- As noted in Section III, frequent and accurate dry matter analyses are critical in studies involving high-moisture feeds. Standard protocols for dry

matter determinations should be established for such experiments.

- The role of storage (e.g., supplies delivered regularly vs. supplies being bagged and fed over time) of wet distillers grains should be determined.
- Continued studies on the role of fermentable/indigestible NDF relative to dry matter and energy intake are needed, particularly as it relates to grain milling coproduct additions to diets.
- The role of NDF (or NDF fractions) in wet distillers grains vs. wet corn gluten feed in explaining differential effects of these products on

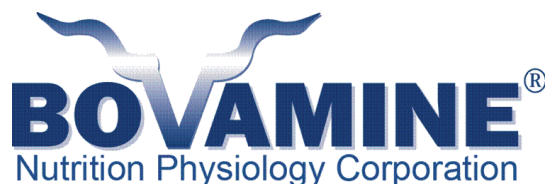
digestibility and cattle performance needs to be evaluated.

VI. Intake and Performance Limitations

- Mechanisms for potential interactions of grain processing methods and addition of grain milling coproduct diets on energy intake by feedlot cattle need to be determined.
- Methods to identify animals with greater susceptibility to metabolic disorders need to be developed, with the aim of applying different management schemes to susceptible cattle.
- The role of various grain milling coproducts in acidosis or other metabolic disorders needs further study.

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