Optimizing the Feeding Value of Steam-Flaked Corn for Feedlot Cattle

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Effects of steam flaking on performance of finishing beef steers (Ward et al., 2000, 75% corn)

	Grain processing method		
Item	DR	SF	
Body weight, kg			
Initial	366.5	366.2	
Final	562.2	577.2	
Daily gain, kg	1.56	1.68	
Daily DMI, kg/steer	9.21	8.57	
Feed:gain	5.96	5.11	
NEm, Mcal/kg	2.11	2.37	
Corn NEm, Mcal/kg	2.24	2.59	+15.5%

Assuming the NEm and NEg values of dry rolled corn as 2.24 and 1.55 Mcal/kg respectively

Reference	NEm	NEg
Matsushima and Montgomery (1967)	2.51	1.79
Lee et al, (1982)	2.60	1.87
Ramirez et al, (1985)	2.60	1.87
Zinn, (1987)	2.54	1.82
Barrajas and Zinn, (1998)	2.62	1.89
Ward et al, (2000)	2.59	1.86
Average	2.58	1.85
NRC (1984)	2.38	1.67
NRC (1996)	2.33	1.62

Observed vs expected NE values for dry roll and steam-flaked corn (242-trial summary)

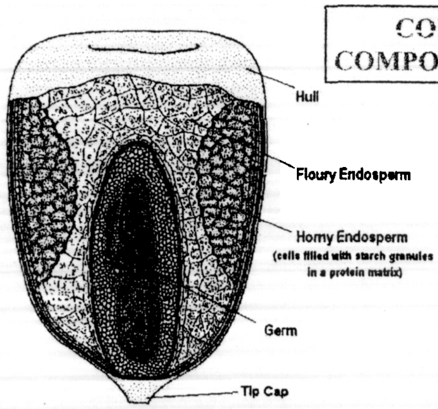
	Observed	NRC, 1996	
Trials	185	57	
Corn NEg, Mcal/kg			
Dry rolled	1.43	1.50	+5%
Steam flaked	1.65	1.62	-2%
% improvement	15.4	8.0	

How does steam flaking bring about this dramatic improvement in the feeding value of corn?

The influence of region on corn composition

	Region	
Item	Midwest	South East
Sample	45	45
Protein	8.93 (.54)	8.92(.65)
Oil	4.02 (.28)	4.02(.26)
Starch	71.38 (.79)	71.35(.97)

CORN COMPOSITION



Composition of "typical" corn starch

- **27% amylose**
  - **alpha 1-4 glucosidic linkages**
- **73% amylopectin**
  - **Less compact**
  - **alpha1-4 glucosidic linked chains connected by □1-6 glucosidic linkages (bush-like molecule)**

Gelatinization

- Irreversible swelling of the starch granule
- In "practice", it is defined by how its measured
  - Loss of birefringence
  - Swelling power
  - Solubility
  - Enzymatic reactivity

Raw starch

- Exhibits a maltese cross birefringence when observed microscopically with plain polarized light
- Absorbs water and swells within gelatinization temperature range (GTR)
  - At beginning of GTR some loss of birefringence
  - At the birefringence endpoint temperature (BEPT) there is 98% loss of birefringence

Gelatinization temperature range (GTR)

- Characteristic of:
  - Starch species
  - Crop production environment
- GTR of regular corn starch 62 – 72° C
- Moisture uptake (Leach, 1965)
  - !:2 at <62° C
  - 10:1 at 72° C (BEPT)
  - 24:1 at 95° C

Starch species affects gelatinization

(Leach, 1965)

		At 95° C for 30 min	
	GTR	Swelling power, g/g	Solubility %
Corn Species			
Regular	62-72	24	25
Waxy	63-72	64	23
High amylose		6	12

Environmental effects on BEPT of waxy corn (Freeman et al., 1968)

	BEPT. ° C
Waxy corn	
Texas	78
Illinois	75

BEPT 4% higher for corn grown in Coastal Texas than in the High Plains

The objective of steam flaking is to optimize feeding value

- The primary factor limiting digestion is the availability of starch to the enzymatic process.
- This limitation is not solely a function of starch solubility
  - Raw corn starch has very low solubility (3%) but very high ruminal digestibility (>90%)
- Disruption of the protein matrix capsulating the starch granule is a key limiting factor

Disruption of the protein matrix surrounding the starch granule

- **A function of:**
  - **moisture uptake by the starch granule**
  - **degree of shear (flake thickness)**
- **Disruption of the matrix will also increase starch solubility**

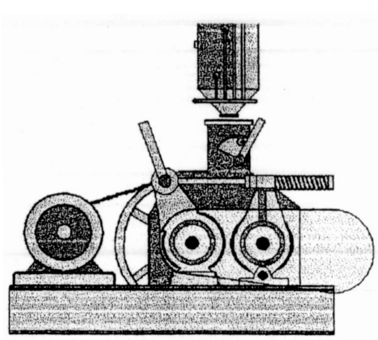
Hence, the process of steam flaking is intended to:

1. Induce moisture uptake or swelling of starch granules
2. Application of shear to swollen granules to disrupt the protein matrix

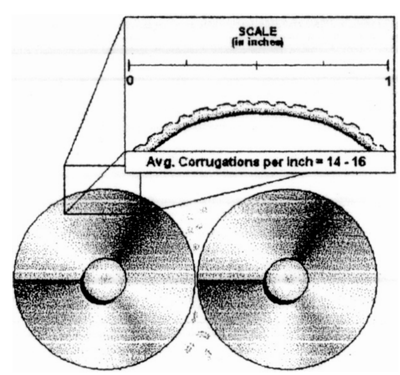
Influence of steaming vs steaming and flaking on enzymatic starch reactivity (Osman et al., 1970)

Sorghum grain	Starch reactivity, %
Untreated	16
Steam, not flaked	12
Steam-flaked	
Course	14
Medium	31
Thin	41

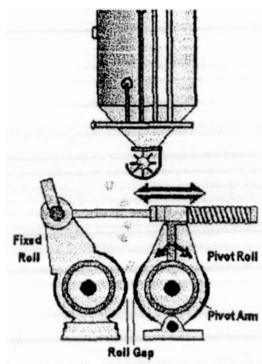
FLAKING MILL



ROLL CORRUGATION



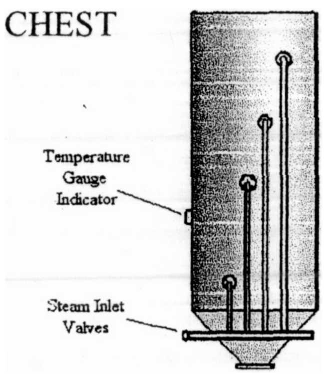
FACTORS IN FLAKE QUALITY



Influence of the distance between rolls and flake density on percentage of fecal starch.

	Flake density, Lb/bushel			
Distance between rolls.	20	24	28	32
0	1.4	3.5	5.1	11.6
.1	1.36	3.35	4.82	8.73
Difference, %	-2.9	-4.3	-5.5	-24.7

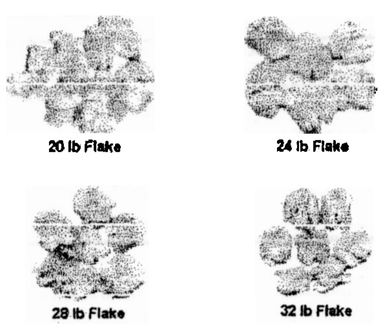
STEAM CHEST



What constitutes quality?

- **Common measures include:**
  - **Flake density**
  - **Flake thickness**
  - **Enzymatic starch reactivity**

FLAKE DENSITY COMPARISON



Relationship between density of steam flaked corn and measurements of flake thickness and in vitro enzymatic digestibility of starch (Zinn, 1990)

	Flake density, lb/bu		
Item	**28**	**24**	**20**
Replicates	5	5	5
Dry matter, %	84	84	85
Flake thickness, mm	2.23	1.83	1.68
In vitro enzymatic digestibility, % total starch			
Amyloglucosidase	6.8	9.1	12.1
Porcine pancreatin	14.2	23.0	33.0

Influence of density of steam flaked corn on characteristics of digestion of a finishing diet by feedlot steers (Zinn, 1990)

Item	Flake density, kg/l		
	28	24	20
Starch digestion, % intake			
Ruminal	79.8	82.6	86.9
Total tract	98.5	99.1	99.6

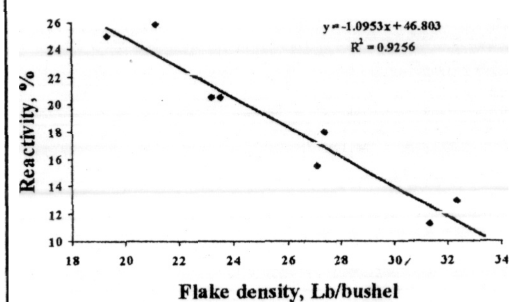
Influence of density of steam flaked corn on feedlot performance and estimated net energy value of diets fed to steers (Zinn, 1990)

Item	Flake density, lb/bu		
	28	24	20
ADG, kg/d	1.40	1.39	1.32
DMI, kg/d	7.49	7.31	7.16
Feed/Gain	5.37	5.24	5.48
Diet Energy, Mcal/kg			
Maintenance	2.25	2.31	2.27
Gain	1.56	1.62	1.58
Observed/expected diet net energy			
Maintenance	.99	1.02	1.00
Gain	.98	1.02	.99

Influence of flake density on starch reactivity

Equation	R^2
Amyloglucosidase reactivity = .253 - .442 (FD kg/l)	.87
Porcine pancreatin reactivity = .796 – 1.561(FD kg/l)	.79

Influence of flake density on amyloglucosidase reactivity



How much moisture should be added?

What is the optimum steaming time?

Influence of steaming time on characteristics of steam-flaked corn (Zinn, 1990)

Item	Dry rolled corn	Steam flaked corn Steaming time, min		
		34	47	67
Dry matter, %	88	83	83	80
Bulk density, kg/liter	.54	.35	.35	.32
In vitro starch reactivity,				
% total starch	3.3	5.2	6.4	11.7

Influence of steaming time on characteristics of ruminal, intestinal and total tract starch digestion (Zinn, 1990)

Item	Dry rolled corn	Steam flaked corn: Corn steaming time, min		
		34	47	67
Starch digestion, %				
Ruminal	68.3	84.9	79.1	85.8
Small intestinal digestion	54.3	93.6	96.1	95.6
Total tract	91.1	99.4	99.4	99.7

Retrogradation

- Re-association of dispersed starch molecules
- Stability of the gel affected by:
  - proportion of amylose
  - degree of dispersion
- Results in a decrease in porosity of the internal granular matrix

Enzymatic starch availability and in vitro dry matter disappearance (IVDMD) of steam flaked corn obtained directly off the rolls (Roll) Or after being conveyed to a storage bin (BIN) (Ward and Galyean, 1999)

Item	Roll samples [a]	Bin samples [b]
Starch availability, %	55.3	33.3
IVDMD, %		
4-h	21.79	20.32
8-h	27.66	34.51
12-h	43.16	45.98
18-h	67.58	68.47
24-h	84.01	84.35
48-h	93.09	96.81

[a]Composite of three samples.
[b]Composite of six samples

Treatment effects on characteristics of digestion of a finishing diet by feedlot steers (Zinn and Barajas, 1997)

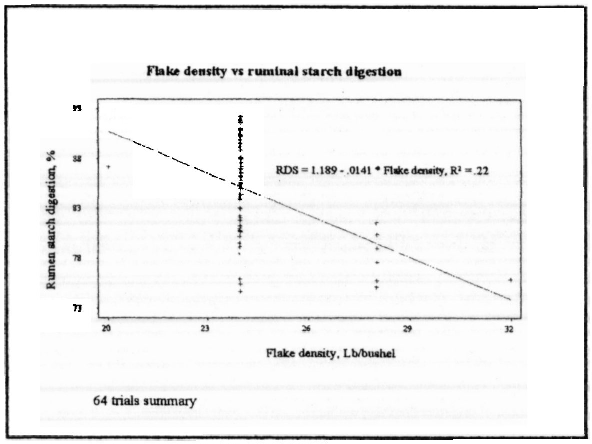
Item	Steam flaked corn: Air –dry	Fresh
Starch Intake, g/d	4,232	4,180
Starch leaving abomasum, g/d	361	375
Starch digestion, %		
Ruminal	91.5	90.2
Post-ruminal	94.9	95.0
Total tract	99.6	99.5

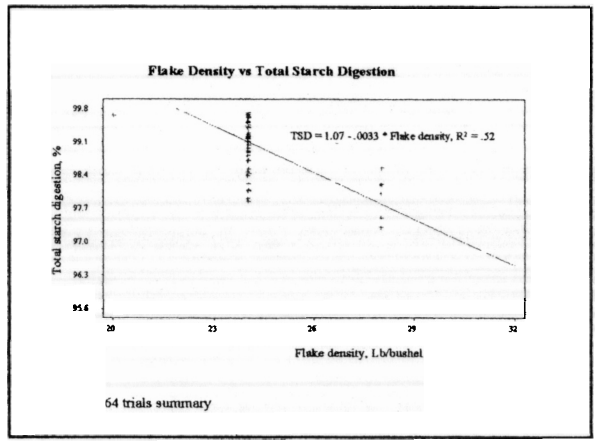
Fecal starch, a more reliable tool for assessing adequacy of corn processing.

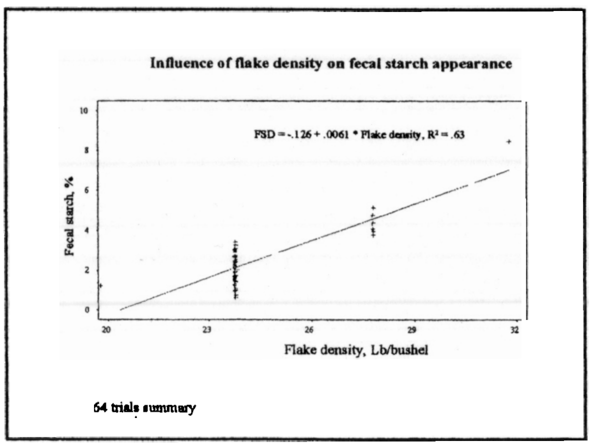
Relationship between fecal starch and starch digestion in cattle[a].

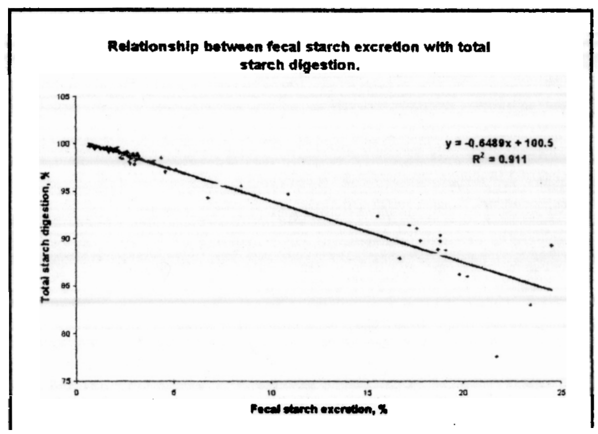
	Steam flaked	Dry rolled	Whole shell
Fecal Starch,%	2.4 (1.2)[b]	16.6 (5.1)	22.6 (1.3)
Starch digestion, %			
Ruminal	84.5 (4.8)	66.9 (8.8)	65.9 (3.0)
Total	99.0 (0.7)	90.5(3.0)	80.3 (3.9)

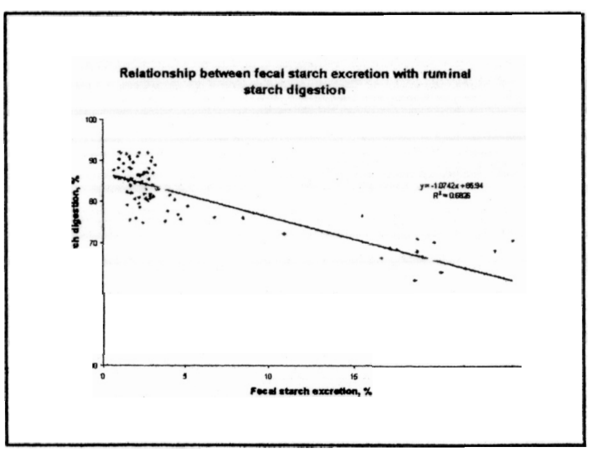
[a]64 trials summary
[b]Values in parenthesis are standard deviations

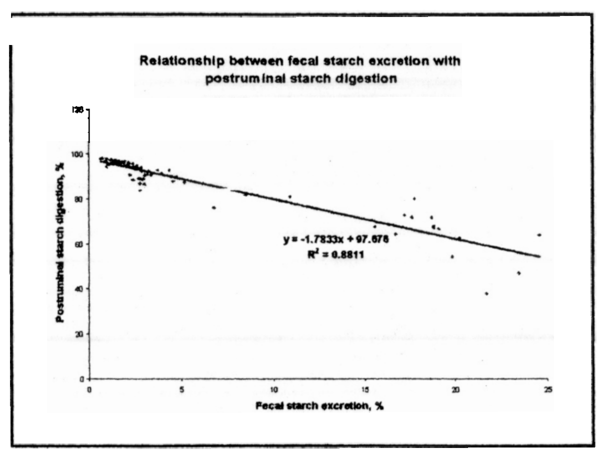

Flake density vs ruminal starch digestion
RDS = 1.189 - .0141 * Flake density, R² = .22
Rumen starch digestion, %
Flake density, Lb/bushel
64 trials summary


Flake Density vs Total Starch Digestion
TSD = 1.07 - .0033 * Flake density, R² = .52
Total starch digestion, %
Flake density, Lb/bushel
64 trials summary


Influence of flake density on fecal starch appearance
FSD = -.126 + .0061 * Flake density, R² = .63
Fecal starch, %
Flake density, Lb/bushel
64 trials summary


Relationship between fecal starch excretion with total starch digestion.
y = -0.6489x + 100.5
R² = 0.911
Total starch digestion, %
Fecal starch excretion, %


Relationship between fecal starch excretion with ruminal starch digestion
Fecal starch excretion, %


Relationship between fecal starch excretion with postruminal starch digestion
y = -1.7833x + 97.676
R² = 0.8811
Postruminal starch digestion, %
Fecal starch excretion, %

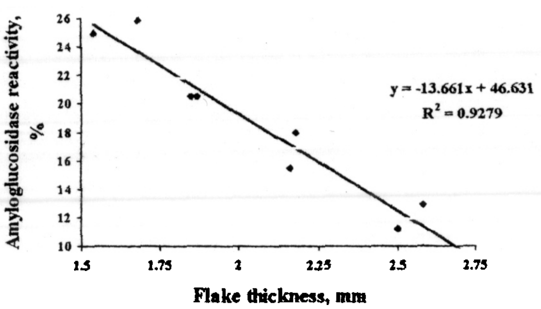
The NE value of corn can be explained as a function of starch digestion

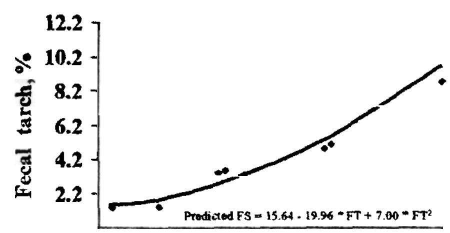
NEm, Mcal/kg = .032DS - .70 $R^2 = .88$

DS, % = total tract starch digestion

Testing measures of flake quality

Influence of flake thickness on Amyloglucosidase reactivity.





Influence of corn variety on response to steam flaking

- **Regular**
- **high amylose**
- **Waxy**
- **High oil**

A comparison of whole shell regular vs waxy corn varieties (Brahman et al., 1973)

	Whole shell corn (90%)		
	Regular	Waxy	
Steers	24	24	
Initial wt., kg	329	321	
Final wt., kg	501	505	
ADG, kg	1.54	1.64	**+6.5%**
Feed intake, kg	7.57	7.81	
Feed:gain	4.91	4.77	**-2.9%**
NEm corn, Mcal/kg	2.24*	2.26	**+1.0%**

*NRC (1984)

A comparison of cracked regular vs waxy corn varieties (Brahman et al., 1973)

	Cracked corn (90%)		
	Regular	Waxy	
Steers	30	30	
Initial wt., kg	314	326	
Final wt., kg	454	474	
ADG, kg	1.48	1.55	+4.7%
Feed intake, kg	8.2	8.3	
Feed:gain	5.57	5.37	-3.6%
NEm corn, Mcal/kg	2.24*	2.33	+4.0%

*NRC (1984)

Regular vs waxy corn varieties, 7-trial summary (Henderson, 1974)

	Corn (>70%)		
	Regular	Waxy	
ADG, kg	1.44	1.52	+5.6%
Feed intake, kg	8.91	9.07	+1.8%
Feed:gain	6.17	5.93	-3.9%

Note: growth performance suggests that the NEm of dry processed waxy corn is roughly 2.5% greater than that of regular corn.

Commercial feedlot comparison of steam-flaked regular vs waxy corn varieties (Snyder et al., 1974)

	Steam-flaked corn (85%)	
	Regular	Waxy
Steers	2408	2389
Initial wt., kg	320	319
Final wt., kg	474	474
ADG, kg	1.57	1.57
Feed intake, kg	12.8	12.9
Feed:gain	8.12	8.21

Regular vs high oil corn

Item	Normal	High oil
Oil, %	4.0	7.5
Protein, %	9.0	9.6
NFE, %	82.4	78.3
TDN, %	90.2	93.3
NEm, Mcal/kg	2.24	2.35

A comparison of steam-flaked regular vs high-oil corn varieties (Derington et al., 2000, carcass adjusted)

	Steam-flaked corn (77%)		
	Regular + 3.9% fat	High-oil	
Initial wt., kg	287	290	
Final wt., kg	588	582	
ADG, kg	1.82	1.77	-2.7%
Feed intake, kg	8.46	8.68	+2.6%
Feed:gain	4.65	4.90	+5.4%
NEm corn, Mcal/kg	2.38*	2.45	+2.9%

*NRC (1984) **Expected NEm = 2.51 Mcal/kg**

Ruminal vs small intestinal starch digestion

- Digestibility of starch in the small intestine is 25 to 35% lower for DR than for SF corn
- However, energy recovery from starch digested in the small intestine is 25 to 30% greater than for starch digested in the rumen
- Additional metabolizable protein recovery from increased ruminal starch digestion may be critical - particularly in light-weight cattle

Interaction of corn processing and level of feed intake on characteristics of digestion of a diet by Holstein steers

(Zinn *et al.* 1995)

	Low Intake		High Intake	
Item	**DR**	**SF**	**DR**	**SF**
Starch Intake, g/d	1,679	1,658	2,435	2,405
Starch digestion, %				
Ruminal	70.9	88.8	70.4	82.0
Post-ruminal	65.7	85.9	61.5	95.9
Total tract	90.4	99.0	89.3	99.1

Interaction of corn processing and level of feed intake on characteristics of starch digestion (Zinn *et al.* 1995)

	Low Intake		High Intake	
Item	DR	SF	DR	SF
Starch Intake, g/d	1,679	1,658	2,435	2,405
Starch leaving abomasum, g/d	489	184	721	433
Post-ruminal Starch Digestion				
g	321	158	443	415
%	65.7	85.9	61.5	95.9

Conclusions

- **Steam flaking increases the NEm and NEg values of corn by 15 and 19%, respectively.**
- **NRC(1996) underestimates the NEg value of steam-flaked corn by 2%**
  - NEm = 2.40 Mcal/kg
  - NEg = 1.69 Mcal/kg
- **NRC(1996) overestimates the NEg value of dry rolled corn by 5%.**
  - NEm = 2.09 Mcal/kg
  - NEg = 1.43 Mcal/kg

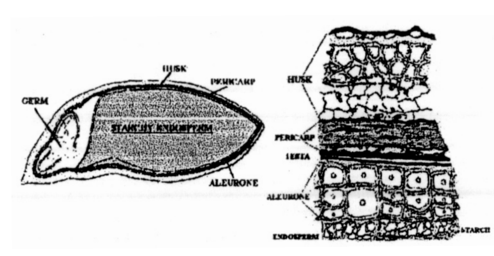
Conclusions

- **The primary objective of steam flaking is to optimize feeding value**
  - This may be more a function of disruption of the protective protein matrix than increasing starch solubility
- **Retrogradation of flaked corn that occurs during drying does not necessarily decrease the feeding value of flaked corn**
- **The NE value of corn is a predictable function of starch digestion** NEm, Mcal/kg = .032DS - .70 R^2 = .88

Conclusions

- **Starch digestion is a highly predictable function of fecal starch** SD, % = 100 - .65FS R^2 = .91
- **Flake thickness and flake density are closely associated**
- **Measures of starch reactivity may not be more reliable than flake thickness as indicators of adequacy in grain processing**
- **Decisions regarding the adequacy of steam flaking should be based on fecal starch analysis**
- **Reliable estimates of fecal starch can be obtain from a composite of 10 fresh fecal samples**

Barley



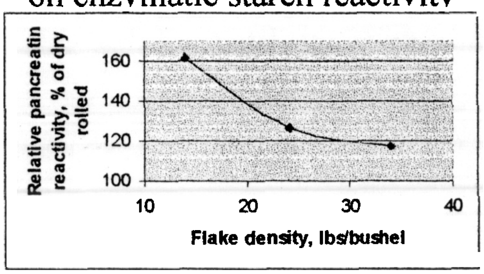
Energy value of barley (NRC, 1984)

	Whole	Ground	Flaked
TDN, %	84	84	84
NEm, Mcal/kg	2.06	2.06	2.06
** NEm = .0305 TDN - .5058 **			
IMPROVEMENT		0%	0%

Barley grain composition

	Starch (%)	% CP (%)	ADF (%)	Volume Kg/hL
Average	57	12	6.8	60
Range	55-74	10-19.5	5.2-7.0	55-67

Influence of barley flake density on enzymatic starch reactivity



Influence of steam processing on starch digestion of rolled barley in feedlot cattle (Summary: Huntington, 1997)

Item	Dry Rolled	Steam rolled	
Starch digestion, %			
Ruminal	79.3	84.6	+7%
Total tract	93.4	98.2	+5%

Site and extent of digestion of barley starch

	Starch digestion, % intake			
	Dry Rolled		Steam Rolled	
	Rumen	Total tract	Rumen	Total tract
Krause *et al.*, 1998		92.0		
Zinn *et al.*, 1996	82.8	95.8	90.0	98.1
Zinn, 1993	75.8	95.0	89.0	99.0
Huntington, 1997	81.0	94.0		
Spicer *et al.*, 1986			88	99
Zinn, 1987			86	98
Zinn, 1988			91	99
Zinn 1989			89	99
Rodriguez *et al.*, 2000			92	99
Average	79.86	94.2	89.3	99

Influence of flake density on barley DM digestibility in feedlot steers

	Dry Rolled	Steam Rolled	
Mc Ilory *et al.*, 1967		39 lb/bu	24 lb/bu
DMD, %	80.5	82.8	86.1
Parrott *et al.*, 1969		24 lb/bu	16 lb/bu
DMD, %	83.6	83.4	82.6

Influence of barley flake density on growth-performance and characteristics of digestion in feedlot cattle (Hironaka et al., 1992)

Item	Thin	Medium	Coarse	Whole
Thickness, mm	1.61	1.74	2.00	2.70
DMI/gain	0.188	0.194	0.17	0.15
NE of Barley				
Maintenance	2.165	2.215	2.063	1.82
Gain	1.489	1.533	1.40	1.187
Starch digestion, %	94.9	94.1	91.4	86.9

Influence of grain processing on characteristics of corn and barley (Zinn 1993)

Item	Steam Flaked Corn	Dry Rolled Barley	Steam-rolled barley: Coarse Flake	Steam-rolled barley: Thin Flake
DM, %	80.9	89.0	84.2	85.5
Density, kg/liter	.31	.39	.39	.19
Thickness, mm	1.67		1.35	.90
Starch, %	66.2	55.0	55.0	55.0
Starch reactivity, % total starch	17.3	8.4	15.0	36.4

Influence of grain processing on characteristics of digestion in feedlot steers (Zinn, 1993)

Item	Steam Flaked Corn	Dry Rolled Barley	Steam-rolled barley: Coarse Flake	Steam-rolled barley: Thin Flake
Starch digestion, %				
Ruminal	83.9	75.8	88.2	90.1
Post ruminal	90.0	78.6	81.3	86.6
Total tract	98.3	95.0	97.9	98.8
DE, Mcal/kg	3.47	3.24	3.36	3.40
ME, Mcal/	3.04	2.71	2.77	2.96

Diets contained 74% of respective grain, DM basis

Influence of grain processing on ruminal pH, VFA molar proportions and estimated methane production (Zinn 1993)

Item	Steam Flaked Corn	Dry Rolled Barley	Steam-rolled barley: Coarse Flake	Steam-rolled barley: Thin Flake
pH	5.56	5.70	5.63	5.35
Ruminal VFA, mol/dL				
Acetate	39.3	49.3	49.4	40.1
Propionate	51.6	36.6	33.9	50.6
Butyrate	9.1	14.1	16.7	9.4
	21	.39	.42	.22

Diets contained 74% of respective grain, DM basis

Influence of grain processing on growth-performance of feedlot steers (Zinn, 1993)

Item	Steam Flaked Corn	Dry Rolled Barley	Steam-rolled barley: Coarse Flake	Steam-rolled barley: Thin Flake
Days on test	172	172	172	172
Pen replicates	4	4	4	4
Live weight, kg				
Initial	259.9	260.4	260.0	260.7
Final	468.0	484.9	481.5	481.0
Weight gain, kg/d	1.21	1.31	1.29	1.28
DM intake	6.44	7.53	7.25	7.00
DMI/gain	5.33	5.77	5.63	5.45

Diets contained 74% of respective grain, DM basis

Influence of grain processing on NE value of the diet (Zinn, 1993)

Item	Steam Flaked Corn	Dry Rolled Barley	Steam-rolled barley: Coarse Flake	Steam-rolled barley: Thin Flake
Diet net energy, Mcal/kg				
Maintenance	2.28	2.10	2.15	2.21
Gain	1.5	1.43	1.47	1.53
Obs/exp diet net energy				
Maintenance	1.00	1.01	1.03	1.06
Gain	1.00	1.00	1.03	1.07
NE of Barley				
Maintenance		2.14	2.20	2.29
Gain		1.47	1.52	1.60

Diets contained 74% of respective grain, DM basis

Influence of grain processing on carcass characteristics (Zinn, 1993)

Item	Steam Flaked Corn	Dry Rolled Barley	Steam-rolled barley Coarse Flake	Thin Flake
Carcass weight, kg	303.7	314.7	312.5	312.2
Dressing percentage	65.5	64.6	65.2	64.3
Rib aye area, cm²	80.2	80.2	81.6	82.3
Fat thickness, cm	1.67	1.71	1.81	1.72
KPH, %	2.79	2.98	3.00	2.94
Marbling score, degrees	3.85	3.77	3.67	3.87
Retail yield, %	49.2	48.8	48.8	49.1
Preliminary yield grade	3.5	3.6	3.7	3.7

Influence of grain processing on average daily gain (kg/d) in feedlot steers

	Dry Rolled	Steam Flaked	Change %
Average daily gain, (kg/d)			
Thomas Meyer (1961)	1.40	1.40	0
Hale et al. (1966)			
Trial 1	1.32	1.41	6.38
Trial 2	1.30	1.41	7.80
Mc Ilroy et al. (1967)	1.21	1.41	14.18
Zinn et al. (1996)			
Covered barley	1.33	1.38	3.62
Hulless barley	1.25	1.33	6.01
Zinn (1993)	1.31	1.29	-1.5
Average	1.30	1.37	6.19

Influence of grain processing on NEm in feedlot steers

	Dry Rolled	Steam Flaked	Change %
NEm, (Mcal/kg)			
Thomas Meyer (1961)	2.06	2.12	+3.0
Hale et al. (1966)			
Trial 1	2.06	2.05	-0.5
Trial 2	2.06	2.00	-3.0
Mc Iroy et al. (1967)	2.06	2.29	+8.5
Zinn et al. (1996)			
Covered barley	2.06	2.17	+5.3
Hulless barley	2.18	2.30	+5.2
Zinn (1993)	2.06	2.21	+7.3
Average	2.08	2.16	3.69

Influence of processing on the feeding value of barley

	Whole	Ground	Flaked
Starch digestion, %	87	94	99
TDN, %	80	84	87
NEm, Mcal/kg	1.93	2.06	2.15
** NEm = .0305 TDN - .5058 **			
IMPROVEMENT		7%	11%

Conclusions

- Steam flaking barley may increase:
  - Ruminal and total tract starch digestion
  - NE value
  - Energy intake
  - ADG
- Relative improvement in feeding value of barley due to flaking is dependent on susceptibility to dry rolling
- Feeding value of flaked barley is optimized at flake densities of less than .39 kg/L (30 lbs/bushel)