Optimizing Feed Particle Size for Health and Performance

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Ration physical form continues to raise questions as corn silage processors, steam flaked corn, TMR mixing times, and fine ground corn choices are available. The challenge is to control fiber length to maintain rumen pH and health, optimize microbial growth, maintain dry matter intake, and dictate rate of passage through the digestive tract. Physical form of concentrate and forage must complement each other to achieve ideal nutrient intake, performance, and cow health. While forage particle size is critical in meeting rumen needs, this paper will focus on grain particle size. Review guidelines for the Penn State Forage Particle box to insure adequate function fiber levels are achieved.

Impact of Grain Particle Size

High producing cows receive grain as a major source of energy and starch in their diets. Cereal grains contain 45 to 80 percent starch. Optimizing starch utilization is critical to efficient milk production for several reasons.

1. Starch can be fermented in the rumen to volatile fatty acids (VFA) as a major source of energy for lactating cows.
2. If starch ferments too fast or excessively in the rumen, acidosis can lead to metabolic disorders and health problems.
3. Intestinal starch digestion results in a direct source of glucose needed for milk lactose production and source of alternative energy needs.
4. The amount of organic dry matter fermented in the rumen (especially starch) drives microbial protein synthesis.
5. Fecal losses of starch should be less than five percent of the total consumed (can exceed 15 percent due to improper processing or digestion.

Processing of grain will depending the source of starch, impact on feed intake, forage type, and level of non-fiber carbohydrate in the ration. Wheat, barley, and oats have faster rates of fermentation in the rumen while corn and sorghum are slower.

Goals of Grain Processing

The dairy manager and nutritionists are attempting to get the best of all worlds by maximizing total starch digestion in the animal, optimizing starch fermentation in the rumen to maximize VFA yield while avoid acidosis, and optimizing starch availability in the small intestine. If excess starch reaches the large intestine and is available, it can be fermented

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resulting in a less efficient energy resource. Fecal pH can drop below 6.0 which can used as diagnostic tool in the field. If corn is not process (fed as whole seed), 15 to 30 percent can appear in manure as whole grain. Because the starch and protein matrix is a tight complex, processing disrupts the matrix and exposes the nutrients to rumen fermentation and lower gut digestion. Reducing the particle size or increasing starch solubility (such as in gelatinized or high moisture grain) increases the rate and level rumen fermentation and digestion. A fine line exists between maximum rumen yield and an unhealthy rumen environment. The nutritionist must adjust ration levels of grain based on the extent of processing, feed system, forage resource, and rate of passage (dry matter intake).

Research in Grain Processing

Method and degree of grain processing affects the site and extent of digestion of starch. Optimal starch utilization is important to improving efficiency of production. Under processing grains increases feed costs and limits milk production, conversely, over processing reduces dry matter intake (DMI) and milk production. There is a limited amount of scientific research available to draw particle size recommendations from and few methods available to measure particle size and distribution accurately.

Studies have been conducted by cooperatives illustrating the importance of grinding particle size (Table 1). Farmland Coop compared cracked corn (2500 micron), ground corn (1100 micron), and a mix of the two corn forms (50 percent of each). Milk yield, milk components, and body weight change was optimal for the ground corn.

Table 1. Effect of corn processing on milk performance, dry matter intake, and weight change (Hutjens, 1999).

	Corn Source		
Item	Cracked	Blend (50/50)	Ground
Milk (lb/day)	69.2	72.2	75.3
Milk fat (%)	3.59	3.64	3.73
Milk protein (%)	3.19	3.26	3.29
D.M.I. (lb/day)	49.1	50.6	50.7
BW change (lb/day)	+0.34	+0.60	+0.67

A second study by the CRF research farm compared a complete pelleted concentrate (complete), protein supplement plus fine ground corn (ground), protein supplement plus cracked corn (cracked), protein supplement plus steam flaked corn (steam), and blend of fine ground (45%) and steam flaked (55%) plus protein (Table 2). All protein supplements were pelleted. Rations were fed as a TMR with 46 percent forage (half haylage and half corn silage on a dry matter basis).

Table 2. Effects of corn processing on milk yield, dry matter intake, milk components, and MUN (Luhman and LaCount, 1998).

	Pellet	Ground	Cracked	Steam	Blend
DMI (lb/day)	57.9	56.3	55.0	53.3	52.4
Milk (lb/day)	96.4	94.9	90.5	98.2	96.1
Milk fat (%)	3.33	3.50	3.44	3.21	3.35
Milk protein (%)	3.00	3.00	2.95	3.02	2.97
MUN (mg/dl)	15.4	16.3	17.6	15.0	16.6

Dry matter intake was greatest for the complete grain mix. Milk production was significantly lower for cracked compared to other treatments. Milk fat test was statistically highest for ground and lowest for steam flaked while other rations were intermediate. Milk urea nitrogen levels were higher for cows fed cracked corn and lower for cows fed complete and steam fed cows. From an economic basis (including milk production, milk components, and cost of processing), complete, ground, and steam flake were $0.84, $0.83, and $0.81 improvement over cracked processed corn. The particle size of the ground and cracked corn are summarized in Table 3.

Table 3. Grain particle size of cracked and fine ground corn in CRF study (Luhman and LaCount, 1998).

	Cracked corn	Fine ground corn
Over 3350 micron (#6)	55.2	0.5
2000 to 3350 micron (#9)	29.5	5.6
1200 to 2000 micron (#14)	8.0	16.2
800 to 1200 micron (#20)	2.2	14.4
Less than 800 micron (pan)	5.1	63.3

Researchers at the Pennsylvania State University have used in situ incubations and sieves to address issues concerning degradability and particle size distributions of corn and soybeans. They demonstrated that a reduction in particle size of dry shelled corn increased ruminal degradability of dry matter (DM), crude protein (CP) and total nonstructural carbohydrate TNC Table 4. Heat treatment of the shelled corn by steam flaking increased ruminal DM and TNC degradability but lowered CP degradability.

Table 4. Particle size distribution and effective ruminal degradability of dry shelled corn processed differently (Lykos and Varga, 1995).

Grain[1]	Mean particle size (µm)	Sieve pore size µm, expressed as a percent of total particles per screen							Ruminal degradability (%)		
		5000	3000	2000	850	500	250	<250	DM	CP	TNC
CC	4309	28.5	50.2	6.4	5.7	3.8	2.7	2.7	41.5^{c2}	37.1^{bc}	44.6^{d}
CCC	2577		41.5	45.6	12.9	0.03	0.01		50.1^{b}	45.0^{ab}	53.3^{c}
FGC	686			3.7	21.0	32.7	23.0	19.6	62.7^{a}	53.3^{a}	64.5^{b}
SFC36	2896	13.6	38.1	15.3	14.7	8.5	5.3	4.5	65.9^{a}	29.4^{c}	75.4^{a}
SEM									1.7	2.4	2.0

[1]CC = cracked corn, CCC = chick cracked corn, FGC = fine ground corn, and SFC36 = steam flaked corn with a density of 0.36 kg/L.
[2]Means in the same column with different superscripts differ ($P<0.05$).

Grinding soybeans, either raw or roasted, compared to cracking increased ruminal degradability of DM, CP and TNC (Table 5). Heat treatment by roasting improved CP and TNC ruminal degradability but had little effect on DM degradability.

Table 5. Particle size distribution and effective ruminal degradability of soybeans processed differently (Lykos and Varga, 1995).

Grain[1]	Mean particle size (µm)	Sieve pore size µm, expressed as a percent of total particles per screen							Ruminal degradability (%)		
		5000	3000	2000	850	500	250	<250	DM	CP	TNC
RSB-C	2266	5.1	33.1	17.8	18.2	11.8	7.6	6.4	53.2^{b2}	47.7^{bc}	75.3^{c}
RSB-G	1046		1.1	11.0	37.6	26.2	16.2	7.9	67.6^{a}	63.4^{a}	84.6^{a}
SB-C	4642	32.4	49.1	11.1	5.8	1.1	0.5		53.3^{b}	38.8^{c}	80.9^{b}
SB-G	1792		6.1	35.0	38.2	11.8	4.8	4.1	62.5^{a}	51.9^{b}	85.8^{a}
SEM									1.8	2.5	0.8

[1]SB = soybean, RSB-C = roasted SB cracked, RSB-G = roasted SB ground, SB-C = raw SB cracked, and SB-G = raw SB ground.
[2]Means in the same column with different superscripts differ ($P<0.05$).

A study by Aldrich (Akey Inc.) compared corn samples (n=21) of various particle size and distribution for in situ digestibility . Dry matter disappearance (DMD) is correlated with starch disappearance/digestibility. Particle size was negatively correlated with DMD at 16 h of ruminal incubation. A particle size of 400 µ resulted in a DMD of >90%. One sample >3300 µ had a DMD of 14%. Researchers suggests that the goal should be >70% DMD at 16 h which corresponds to approximately 80% starch digestibility. An average particle size of 500 µ resulted in about 80% DMD.

The relationship between ruminal starch degradation and the physical characteristics of corn grain was examined by French researchers. Two corn types, dent and flint, varied in the proportion of coarse particles, measure on sieves ranging in size from 90 to 500 μm, when ground at the same speed and length of time. Particles greater than 250 μm were considered course, while particles less than 125 μm were considered fine. The dent corn samples on average compared to flint corn samples had a smaller proportion of coarse particles (61.9 vs. 69.6%), a larger proportion of fine particles (15.6 vs. 9.0%) and a lower vitreousness (51.4 vs. 71.8%). Ruminal starch degradability averaged 61.9% and 46.2% in dent and flint corn types respectively. The researchers concluded that ruminal starch degradability could be predicted by vitreousness (R^2=0.89) or by a combination of apparent density and 1,000-grain weight (R^2=0.91).

Processing corn as fermented grain remains an attractive alternative in the Midwest as growing conditions result in immature grain, ear dropping is reduced, land preparation for the next spring can be completed earlier, and energy value per unit of dry matter is higher compared to dry corn. Fermenting corn increases the solubility of starch and protein in the rumen. Coworkers at the University of Maryland and USDA studied the performance, ruminal fermenation and site of starch digestion in early lactation cow (n=34) fed corn grain harvested and processed differently (Table 6). Diets were 42.4% corn, 45.3% alfalfa silage, 10.6% Soypass™ and 1.7% minerals and vitamins. Corn was fed as dry ground corn, dry rolled corn, high moisture ground corn and high moisture rolled corn, with a mean particle size of 618, 1725, 489, 1789 μm, respectively. Both grinding and moisture increased starch digestibility in the rumen. Grinding increased DMI and tended to increase yields of milk, protein, lactose, and solids non-fat. Moisture content of the corn did not affect intake or milk production.). Digestible, metabolizable, and heat energy as a percent of gross energy intake were higher for high moisture corn compared to dry corn. The net energy values for the four types of corn (substitution calculation base using NRC for dry ground corn) were 2.00, 1.96, 2.16, and 2.42 Mcal/kg for DR, DG, HR, and HG, respectively.

Table 6. Comparison of rolled and ground dry and high moisture corn (Knowlton, 1998).

	Dry corn		High Moisture Corn	
	Rolled	Ground	Rolled	Ground
Dry matter intake (lb/day)	45.5	50.4	47.9	53.7
Milk yield (lb/day)	74.8	77.4	77.4	77.4
Starch dig—rumen (%)	69.2	60.9	81.2	86.8
Starch dig—total (%)	76.4	88.9	95.7	98.2
NE-l (Mcal/lb DM)	0.75	0.74	0.78	0.83

Canadian researchers summarized studies with processing barley grain. It is suggested that the processing index (PI) is a practical means for measuring degree of processing in steam processed barley describe the extent to which starch will be available to degradation by ruminal microbes. By definition, the PI is a "measure of weight of a given volume of barley after rolling as a percent of the weight of the whole barley." A course rolled grain has a higher PI than fine rolled grain. In a study where cows were fed 31% barley silage, 8% alfalfa hay and 42.5% steam rolled barley, decreasing the PI from 81 to 72.5% resulted in a 14% increase in milk production because of the increased DMI and dry matter digestibility (Table 7). Decreasing the PI from 72.5 to 64% resulted in an additional 9.6% increase in milk production. However, further processing of the barley from 64 to 55.5% decreased DMI and milk production by 6.2%. The researchers suggested that the optimum PI for steam rolled barley is 64 to 68% in order to maximize DMI, digestibility and milk production. It was noted that PI would not be applicable to ground grains or dry rolled grains because the spaces between the larger grain particles would be filled with fines and not be a reliable indicator of particle size distribution.

Table 7. Milk production, dry matter intake, and digestibility in lactating cows fed steam rolled barley at different densities (Corbett, 2000).

Item	Coarse	Medium	Medium-flat	Flat
Processing index	81	73	64	56
Milk (lb/day)	56.3^{a}	61.8^{b}	67.8^{c}	63.8^{b}
Milk fat (%)	3.93	3.89	3.78	3.9
Milk protein (%)	3.15^{a}	3.30^{b}	3.29^{b}	3.34^{b}
D.M.I. (lb/day)	41.1	46.3	47.7	44.2
D.M. dig (%)	62.4^{a}	63.9^{ab}	70.3^{b}	69.8^{b}
Starch dig-rumen (%)	61	70	70	71
Starch dig-total tract (%)	78.0^{a}	84.1^{b}	93.6^{c}	92.9^{c}
NDF dig-total tract (%)	56.6	53.2	58.4	56.3

Means with difference superscripts differ (P < .05)

Most studies that have examined grain processing have used lactating cows. Little work has evaluated how grain processing can be incorporated effectively into the transition cow-feeding program. Allen and coworkers at Michigan State University fed 8 ruminally and duodenally cannulated Holstein heifers a diet containing 62% alfalfa silage and 36% corn grain before calving and 49% alfalfa silage and 38% corn grain after calving. Corn treatments were dry fine ground corn, dry course ground corn, high moisture fine ground corn and high moisture course ground corn with mean particle sizes of 810, 4442, 1996, and 5633 µm respectively. There was no treatment effect on dry matter and starch intake. Rate and extent of ruminal starch digestibility was higher for the high moisture corn compared to dry corn and higher for fine ground corn compared to course ground corn (Table 8). Fine grinding compared high moisture conservation had a larger impact on starch digestibility. The fine grinding increased fat corrected milk (FCM) and milk protein percentage. The high moisture corn tended to decrease FCM.

Table 8. The extent and rate of starch degradation and fat corrected milk (FCM) from cows fed corn processed differently (Ying and Allen, 1998).

	Treatment[1]			
	DF	DC	MF	MC
Before calving				
Ruminal starch degradation (%)	56.7	41.7	81.4	52.7
Rate of starch degradation, h^{-1}	21.6	9.8	27.5	22.8
After calving				
Ruminal starch degradation (%)	63.2	36.8	76.3	47.8
Rate of starch degradation, h^{-1}	22.8	7.6	33.7	16.1
FCM (lb/d)	65.8	61.4	61.4	59.8

[1]DF = dry fine ground corn, DC = dry course ground corn, MF = high moisture fine ground corn, and MC = high moisture course ground corn.

In a study conducted at the Pennsylvania State University, 65 cow were fed either cracked corn (34% of particles > 5000 μm, 99% of particles > 3000 μm) or steam flaked corn (0.36 kg/L) before calving and half the cows from each treatment group before calving received either cracked corn or steam flaked corn after calving. Although this trial did not address the particle size issue of corn, it did evaluate the cow's need for ruminally available starch. Heat treatment of corn increases the ruminally available starch. The prepartum diet was 38% corn silage, 14% alfalfa silage, 12% alfalfa hay, 15% concentrate pellet, and 21% corn. The postpartum diet was 25% corn silage, 14% alfalfa silage, 12% alfalfa hay, 25% concentrate pellet, and 24% corn. There was no difference in prepartum or postpartum DMI. Cows fed steam flaked corn either before calving or after calving had reduced (42 and 16% respectively) plasma non-esterified fatty acids than cows fed cracked corn. This indicates that the cows fed steam flaked corn were in better energy balance. Milk production was 2.3 kg/d higher for cows fed steam flaked corn postpartum during the first 63 DIM. There was a trend for cows fed steam flaked corn during the prepartum period to have higher milk production also. This research suggests that there is a potential benefit to processing grains, especially corn, for transition cows. More work is needed in this area to more clearly define requirements and make particle size recommendations.

Steam flaking of corn and sorghum grain is extensively used in finishing beef cattle. The grain is steamed for 30 to 60 minutes to increase grain moisture to 18 to 20 percent moisture. Large rollers flake the corn to a desired density (28 pounds per bushel for dairy cows). The equipment is expensive to purchase and the cost per ton to process higher than conventional methods such as grinding or rolling. Four trials with 92 lactating cows are summarized in Table 9. Milk production, milk protein, and starch digestibility are increased while milk fat percentage was significantly reduced. Net energy for lactation appears to 20 percent greater compared to traditional processed corn grain (dry ground or steam rolled). Stream flaked corn also increase microbial protein yield, glucose output from the liver, and use of recycled urea.

Table 9. Comparison of steam flaked to steam rolled corn (Theurer, 1997).

Item	Steam rolled	Steam flaked
Dry matter intake (lb/day)	58.3	58.3
Milk yield (lb 3.5% FCM)	73.9	76.1
FCM/DMI (lb/lb)	1.28	1.31
Milk (lb/day)	78.8	83.6
Milk protein (%)	2.99	3.06
Milk fat (%)	3.11	2.98
Milk value ($/day)	8.71	9.19
Total starch digestion (%)	85.1	94.1

Measuring Grain Particle Size

Swine nutritionists have been measuring corn particle size because it directly impacts feed conversion (pounds of gain per pound of feed) and digestibility. Illinois workers used a set of sieves to measure corn particle size.

- Top screen (number 4 and 4750 micron) captures whole and large particles
- Second screen (number 8 and 2360 microns) represents cracked corn
- Third screen (number 16 or 1180 micron) represents "cow" feed particles
- Fourth screen (number 30 or 600 micron) represents "pig" feed particles
- The pan which represents powder or feed grade starch

In a typical mid west ration containing hay, haylage, corn silage, and typical concentrate level, target less than 5 percent on the number 4 screen (passes through undigested), 25 percent on the number 8 screen (slow released starch in the rumen and small intestine digestion), 50 percent on the number 16 screen (finely ground feed), and less than 25 percent in the pan (rapid available starch for the rumen microbes). If higher levels of corn silage or grain were fed, corn particle size should be increased. If the ration contains higher levels of wet haylage, less corn, and more by-product feeds, the corn particle size could be reduced. Reducing corn particle size will increase the risk of rumen acidosis. Brass U.S. Standard sieves can be purchased from Fisher Scientific (800-766-7000) or Seedboro Equipment Company (312-738-3700). Prices will vary from $200 to $260 per set of five.

Another approach to measure finely ground corn is to use a flour sifter to estimate micron size. Swine guidelines are to weigh 10 ounces of ground corn, sieve it, and weight the amount of corn that does not pass through the screen. Increase the micron size by 100 for each one ounce of corn that does pass through the screen. If all the corn passes through, the corn particle size is 600 micron. If one ounce remains on the screen, add 100 microns to 700 resulting in a size of 800. If three ounces remain on the screen, the grain particle size is 900 microns (600 + 300). The IFA particle size testing kit for swine can be purchased from IFA at 800-426-0261 or 319-634-3849. Commercial labs can also measure corn particle size.

Another on farm method to evaluate if corn particle size is too large is wash manure in the second screen (number 8) listed above. If corn particles are found with remaining starch, significant losses of energy and rumen fermentable carbohydrate is occurring. For dairy cows, particle distribution may be more important than the mean particle size. On farm corn processing may not be able to achieve the fineness of grind needed for optimal performance. Purchasing 3 to 5 pounds of commercially processed corn may be an economically viable alternative even if corn grain is raised on the farm. One experimental approach to evaluating corn particle size is to calculate a relative corn index (RCI). Multiply the percent of corn grain on each screen by a constant (1 to 5 starting with the coarsest screen). The finer the corn is processed, the larger the RCI. In Table 10 illustrates an example of cracked or coarse and finely ground corn.

Table 10. An example calculation of RCI using a coarse (270 RCI) and fine (350 RCI) processed corn.

		Coarse corn		Fine corn	
Screen size	Factor	Percent	Score	Percent	Score
# 4 screen	1	10	10	0	0
# 8 screen	2	30	60	10	20
# 16 screen	3	45	135	40	120
#30 screen	4	10	40	40	160
Pan	5	5	25	10	50
RCI Score			270		350

If the RCI is over 350, the starch would be more readily available to be fermented in the rumen and could lead to acidosis if the forage was too fine, ration was not fed as a TMR, or diet contained higher levels of starch. A ration with a RCI below 300 could minimize the risk of rumen acidosis, but limit dry matter intake, rumen fermentation, milk yield, and milk components. No research has been conducted to determine the optimal RCI based on feed intake, forage particle length, or starch level.

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