Preparation and Evaluation of Popped Grains for Feed Use[1]

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ABSTRACT

Dry-heat expansion or "popping" of grains has been investigated as a method for increasing the digestibility of cereal grains for feedlot use. In-vitro data for different processing conditions show greatest starch digestibility associated with high initial moisture level and greatest degree of expansion. Comparison of in-vitro digestibility of popped milo with atmospheric-steamed and flaked or pressure-cooked and flaked milo indicates that the popped product is digested more slowly. Popping does not increase the amount of water-soluble material appreciably nor decrease the apparent availability of lysine, but does lower the amount of extractable protein. In-vivo ruminant feeding tests showed that popped grains performed as well as steamed and rolled or pressure-cooked and rolled grains.

Today most grains in cattle feedlots are processed in some manner to increase feed efficiency and rate of gain. The chief benefit of processing is thought to be enhanced utilization of starch in the grain. Although the subject is reviewed constantly by the feed industry (1–4), no processing method is clearly superior for all grains in all areas. Methods currently in favor include atmospheric steaming and flaking (5–7), pressure cooking and flaking (8,9), moist-heat expansion or extrusion (10,11), and dry-heat expansion or popping (12–16). Believing that popping offered certain advantages over other methods, we have investigated the production and evaluation of various popped grains. When the study was initiated, only a few cattle-feeding results had been reported for popped milo (13), and no in-vivo or in-vitro data were available for other grains. Since then other reports on popped milo have appeared (14,15), as has a recent general trade announcement (16). Since no in-vitro comparison of popped milo with milo processed by other methods has been published and information on other popped grains is completely lacking, we are reporting data covering these areas.

MATERIALS AND METHODS

Preliminary experiments to determine the effect of time, heat, moisture levels, etc., on grain popping were carried out in a Pilot Toaster manufactured by Surface Combustion, Toledo, Ohio. For the most part, grains were purchased locally and were of unknown origin. The grains used to compare the popping process with other grain-processing methods were supplied by E. S. Erwin & Associates, Tolleson, Ariz. They consisted of 11 varieties of milo grown on the same soil type under comparable fertilization methods. On an oven-dry basis, crude protein ranged from 10.7 to 12.7% and phosphorus varied from 0.32 to 0.53%.

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For production of larger quantities of material to use in feeding trials, grains were popped in a special popper designed and developed in this laboratory (17). Capacity of this prototype machine was 1,500 to 2,000 lb. per hr.

In-vitro analyses were carried out with diastase, pharmaceutical grade (*Aspergillus oryzae*) purchased from Mann Research Laboratories, New York. Starch digestion methodology was adapted from that of Erwin (8). Starch digestion was measured as increase in reducing sugar by Hassid's method as described by Joslyn (18). Increase in reducing value was calculated as mg. per g. dry matter on a glucose standard, although maltose could have been used as well. Grain samples were ground through a small Wiley mill with a 20-mesh screen. Two 200-mg. portions of each sample to be assayed were placed in 25 by 96-mm. screw-cap vials. To one vial was added 20 ml. 0.0167% diastase, and to the other, 20 ml. water. The vial containing sample and enzyme was placed on a shaker at 21°C., and 1 ml. of solution was removed for analysis after 1, 4, and 24 hr. of shaking. The 1 ml. of solution (or an aliquot containing less than 3.5 mg. of reducing sugar) was pipetted into a test tube containing 5 ml. $K_3Fe(CN)_6$, and 4 ml. of water was added. The tube was placed in a boiling-water bath for 15 min. and cooled rapidly to room temperature in cold running water; 5 ml. of 5N H_2SO_4 was mixed into the tube. Eight drops of Setopaline C was added and the contents were titrated with 0.01N $Ce(SO_4)_2$. Blanks to determine original reducing sugar present were run on the control sample. A blank was also run on the 0.0167% diastase. Starch (as mg. glucose per g. dry matter) was calculated from the titration value of the enzyme-hydrolyzed sample after we corrected for enzyme blank and original reducing sugar.

Preliminary experiments showed that errors caused from reducing sugars generated from nonstarch carbohydrates by action of invertase in the fungal amylase were small and fairly constant from sample to sample. When six simultaneous replicates were run on a popped milo sample at three digestion times, the largest standard deviation was 4.7 mg. on a mean value of 365.0 mg. glucose per g. dry matter for the 24-hr. group. Replicate runs made on 4 different days over a period of several weeks showed a standard deviation of 7.9 mg. on a mean value of 310.0 mg. glucose per g. dry matter.

Measurement of soluble amylose was adapted from the literature (19), and a water-absorption measurement was made at the same time. A 2-g. sample of ground grain was placed in a 40-ml. graduated centrifuge tube to which 20 ml. water was added. The top of the tube was covered with a piece of polyethylene, tied with a rubber band. The tube was placed on the shaker at 21°C. for 45 min. and the contents were then allowed to settle for 15 min. The settled volume of the residue was recorded as a measure of water absorption. About 1 teaspoon of analytical-grade Celite was mixed with the contents, which were centrifuged for 10 min. and then filtered through a Millipore 0.45-μ filter. One milliliter of clear filtrate was used for the iodine blue value amylose determination described by Gilbert and Spragg (19). The iodine blue value can give useful information about effects of processing on a particular variety of grain, but because of varietal differences in amylose-amylopectin ratios, the usefulness of the test is limited for intervarietal comparisons. For example, in a series of tests of eight milo varieties, the enzymatically determined total starch values of processed samples ranged only

±6% from a mean figure. In contrast, the iodine blue values (of the same samples) ranged from 55% lower to 93% higher than the mean.

The water-absorption measurements correlate very well with the more precise determinations of starch digestibility by amylase assay. Although correlation was not significant for the 1-hr. digestion values in a series of 30 determinations, the results were strongly correlated ($r = 0.92-0.95$) for the 4- and 24-hr. values. If the accuracy (±10%) of the water-absorption method were improved slightly, we believe starch digestibility could be estimated quite accurately from a regression curve relating amylase digestion values with water-absorption measurements.

Available lysine was determined by the procedure of Rao et al. (20). Nitrogen was determined by the standard AOAC Kjeldahl procedure (21). Soluble nitrogen was determined by the chemical extraction method of Lyman et al. (22).

The beta-amylase assay with crystalline sweet potato beta-amylase (Sigma Chemical Co., St. Louis, Mo.) was that described by Bernfield (23).

RESULTS AND DISCUSSION

The primary reason for processing grain for feed use is to disrupt the highly organized starch granules in the endosperm so that they may be more easily and rapidly digested. In dry-heat expansion, or popping, natural moisture in the seed (usually 10 to 15%) is vaporized to steam, gelatinizing and expanding starch granules within cells, usually without breaking the cell walls (24). As we will point out later, the extent of gelatinization can be partially regulated by controlling the moisture level of the grain.

Preliminary experiments to determine suitable conditions for grain popping showed that temperatures higher than 230°C. gave satisfactory results. At 246°C. grain was expanded in 30 sec.; longer holding times only increased the color and charring of the product. Wheat, barley, and ordinary dent corn expanded to about one and one-half to two times their original volume, but red and white milo popped like popcorn, some of the individual seeds increasing nine times in size. All the seeds of wheat, barley, and dent corn swell fairly uniformly and to about the same extent. However, at normal moisture levels only about 35 to 40% of the milo is completely expanded; the remainder ranges from partially expanded to not visibly changed. Rate of digestion and over-all digestibility depend on the degree of

TABLE I. DIGESTIBILITY DIFFERENCES DUE TO DEGREE OF EXPANSON OF MILO[a]

Size[b]	Reducing Values[c] 1-hr. Digest	4-hr. Digest	24-hr. Digest	Soluble Amylose	H_2O Absorption,
	mg. glucose/g. dry wt.			mg./g. dry wt.	ml.
Fully expanded	182 (61)	240 (81)	297	49	12.4
Partly expanded	64 (41)	110 (71)	156	8	7.5
Not expanded	35 (37)	67 (70)	96	1	6.3
Control, raw	11 (20)	29 (55)	55	2	...

[a]Average values derived from four different varieties.

[b]See text for exact definition of terms.

[c]Values in parentheses show percent of 24-hr. total.

TABLE II. IN-VITRO DIGESTIBILITY OF POPPED GRAINS

	Moisture %	1-Hour Digestion		4-Hour Digestion		24-Hour Digestion	
		Raw	Popped	Raw	Popped	Raw	Popped
		mg. glucose/g. dry wt.					
Barley	10.5	14	168	38	247	95	381
Red wheat	14	11	154	33	241	72	376
White wheat	11	11	54	29	100	80	168
Yellow corn	14	44	89	87	163	175	252

expansion of the milo. Typical differences in digestibility due to degree of expansion are shown in Table I. Four varieties of milo were popped and each was screened into three fractions: a fully expanded fraction, L, which was retained on a 12/64-in. round-hole screen; a medium-sized fraction, M, which was retained on a 7/64-in. by 3/4-in. screen; and a small-sized fraction, S, which passed through the slotted screen. Fraction S was not pure unpopped material, because some expanded fragments from the intermediate fraction dropped through the M screen into the S fraction. All the processed samples were digested more rapidly and thoroughly than the control raw material. Fully expanded material, L, gave final reducing values one and one-half to two times as great as any of the partially expanded products, M, and from two to four times that of the least-expanded fraction,S. The initial rate of starch degradation was also more rapid with the fully expanded product, since 60% of the material was digested in only 1 hr. The soluble amylose figure for fully expanded product is strikingly higher than that of the less-expanded materials. Water-absorption figures parallel digestion results.

Typical digestion values for wheat, barley, and yellow corn popped at ambient moisture levels are given in Table II.

Expansion of yellow corn gave less improvement in digestibility than did the other grains. Although rate and extent of digestion are improved over the control values, they are not as high as those obtained when moisture levels prior to popping are near or above those for safe storage of grain.

TABLE III. IN-VITRO DIGESTIBILITY OF GRAINS POPPED AT ELEVATED MOISTURE LEVELS

		Moisture Level %	Digestion Period		
			1 Hour	4 Hours	24 Hours
			mg. glucose/g. dry wt.		
Red wheat	raw	14	13	33	72
	popped	14	154	241	376
	popped	17.5	137	231	368
	popped	20	190	306	465
	popped	25	222	350	504
White wheat	raw	11	11	29	80
	popped	11	54	100	168
	popped	15	90	152	259
	popped	17.5	155	249	360
	popped	20	174	272	389
	popped	25	201	313	437

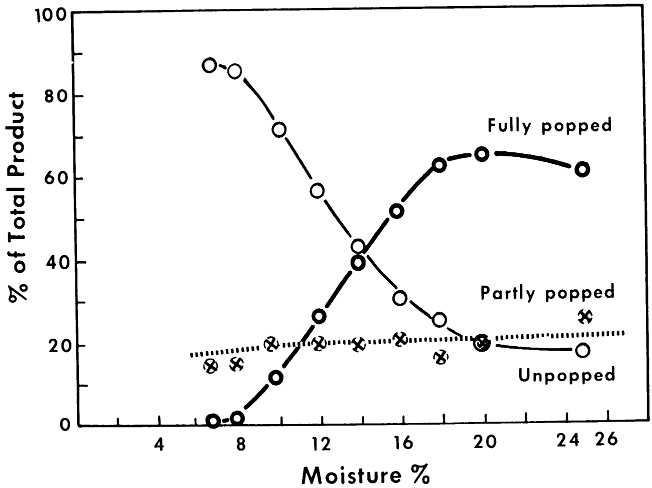

Fig. 1. Relation between moisture level of milo and extent of popping. Solid circles, fully popped; open circles, partly popped; cross in circle, unpopped.

Table III shows results with two different wheat samples. Moisture levels around 15% gave fairly satisfactory digestibilities, but to maximize in-vitro values, moisture should be increased to 25%. Results were similar with barley and yellow corn. It seems likely that a highly digestible product could be obtained if high-moisture grains were harvested (or normal grain reconstituted to higher moisture levels) and processed immediately.

When the moisture level of milo was adjusted to slightly above normal levels and the grain was popped, a different phenomenon was encountered. The percentage of fully popped material increased and the amount of unpopped material decreased, as summarized in Fig. 1. The partly popped fraction remained reasonably constant. Maximum yield of fully expanded material appeared to be about 65% by weight and was obtained only at moisture levels of 18% and above. Even though all individual grains of fully expanded milo have the same digestibility, the net result of popping high-moisture milo was that over-all digestibility was improved because of a high percentage of fully expanded grains.

An attempt was made to compare the digestibility of popped cereals with that of grains processed by other methods. Eleven varieties of milo were received from E. S. Erwin & Associates. Samples of each variety were processed by popping and flaking, pressure cooking and flaking, pressure cooking and not flaking, and atmospheric steaming and flaking. Popping was done at this laboratory; other process treatments were carried out at the Arizona facility. The results of diastase digestions on each processed sample are summarized in Table IV. It is apparent in this series of samples that pressure cooking and rolling increased the enzymatic digestibility of starch more than any other treatment. Grain popped at normal moisture levels or pressure-cooked whole grain gave almost identical enzymatic digestibility values, whereas atmospheric-steamed and rolled grain was intermediate between these treatments and pressure-cooked and rolled. The optimum degree of

TABLE IV. IN-VITRO DIGESTIBILITY OF ELEVEN MILO VARIETIES PROCESSED BY DIFFERENT METHODS

	24-Hour Digestion mg. glucose/g. solids		Soluble Starch	Water Absorption
	Average	Range	mg./g.	ml.
Raw	50	(37–70)	2.3	4.5
Popped	199	(166–238)	11.3	6.5
Pressure-cooked and rolled	508	(416–563)	27.6	10.0
Pressure-cooked and whole	202	(144–293)	4.9	6.5
Steamed and rolled	377	(317–452)	7.9	8.5

starch disruption to achieve maximum digestibility in the feedlot is not known. Complete gelatinization does not seem to be the answer (25). By regulating the moisture level in grains prior to popping, considerable control over the gelatinization can be achieved, once the optimum extent of gelatinization has been established.

Although the importance of the rolling step in increasing digestibility of pressure-cooked material shows up clearly in this experiment, we have been unable to demonstrate that rolling popped grain has any significant effect on in-vitro digestibility.

Disappearance of birefringence of starch granules has been used as a measure of starch disruption in processed feeds (26). We were unsuccessful in making good microscopic counts on popped barley and popped milo; average figures for popped wheat starch granules showed 28% intact starch granules and 72% gelatinized. These results are difficult to reconcile with results obtained with beta-amylase to estimate extent of gelatinization. Since this enzyme is unable to effectively attack intact starch granules, using it on a processed sample to compare with the same material completely gelatinized should give a measure of gelatinization and starch damage (27,28). Typical results on some processed feeds are shown in Table V. They suggest that even though popping may disrupt starch granules extensively, the disorganization is not complete enough to permit much digestion with beta-amylase. Only when milo was pressure-cooked and rolled were real gelatinization conditions approached. It is possible that in a number of processed samples, the gelatinized starch retrograded to such an extent that beta-amylase could no longer attack it.

Other in-vitro tests showed that popping grain did not increase significantly the total amount of water-soluble materials, but that it decreased the amount of water-extractable nitrogen by 60%. A similar or greater reduction in soluble

TABLE V. BETA-AMYLASE DIGESTION OF PROCESSED GRAINS

	Apparent Gelatinization %		Apparent Gelatinization %
Wheat, popped	12	Milo, pressure-cooked and whole	13
Barley, popped	37	Milo, steamed and rolled	14
Milo, popped	24	Milo, raw	2
Milo, pressure-cooked and rolled	50		

TABLE VI. AVAILABLE LYSINE IN POPPED GRAIN SAMPLES

Sample	Available Lysine g./16 g. N	Total Lysine g./16 g. N	Recovery %
Barley	2.71	2.85	95
Milo	2.12	1.80	117
Red wheat	2.47	2.40	103

nitrogen was found for other processing treatments. Apparent available lysine, although difficult to measure on high-starch cereal products (29,30), was determined on ball-milled, popped samples of rolled grain. Results in Table VI show high recovery of available lysine and indicate that short-term exposure to high temperature associated with popping does not tie up or destroy the free amino groups of lysine.

As in the case of many other in-vitro tests, the correlation between laboratory findings and the nutritional performance of animals is difficult to assess. The optimal degree of starch disruption to obtain maximal gains for a particular grain has not been ascertained. Results of this study show that popping produces feed grains with an intermediate starch digestibility, considerably higher than unprocessed material but considerably lower than that achieved by more drastic treatments. They also indicate that starch digestibility can be varied by controlling the initial moisture levels of grain for popping.

A digestion trial with sheep (six per dietary treatment) to compare atmospheric-steamed and flaked, and popped and flaked barley and milo was carried out by E. S. Erwin & Associates. Samples of feed and fecal matter were analyzed for dry matter, organic matter, and crude protein. Digestibility of each of these nutrients was calculated from the difference between intake and excretion. Volatile fatty acids were measured on rumen samples at the end of the test. Mean results of treatment effects are shown in Table VII. Analysis of variance of the data showed, however, that no significant difference in digestion of crude protein could be attributed to the type of grain or the over-all effect of processing. However, a

TABLE VII. EFFECT OF POPPING GRAINS ON DIGESTIBILITY OF VOLATILE FATTY ACIDS IN FEED AND RUMEN

	Barley		Milo	
	Steamed	Popped	Steamed	Popped
Digestibility coefficients (%):				
Dry matter	73.1	74.4	76.8	83.6
Organic matter	77.4	77.4	82.7	85.5
Crude protein	70.3	68.7	64.4	70.8
Volatile fatty acids				
Total acids[a]	460	566	382	558
Weight (%):				
Acetate	44	46	40	43
Propionate	32	34	35	31
Butyrate	18	14	18	18
Valerate	6	6	7	8

[a]Expressed as mg./100 ml. rumen fluid.

significant ($P < 0.01$) interaction of processing and type of grain was observed. Compared to the steam process, popping barley reduced digestion of crude protein, whereas popping milo increased the digestibility of the crude protein. The only statistically significant difference in digestibility of organic matter could be attributed to the type of grain. Compared to the steam process, the total quantity of rumen volatile fatty acids was significantly increased by popping both barley and milo.

In 1967, a commercial sheep-feeding trial was conducted by the Range Engineering Development Corporation of San Angelo, Texas. Results of this test indicated that animals fed popped milo made better gains than those fed ground milo. Part of the difference seemed to be that animals had less difficulty starting to eat the popped milo ration because of its greater palatability. The study has been extended to commercial beef-growing and -fattening operations, and it offers considerable promise of success in this area.

A carefully designed cattle fattening-feeding test (31) compared feedlot performance of popped and rolled, steamed and rolled, and pressure-cooked and rolled wheat and milo. No significant differences were found for any of the treatments or grains. Popped grains were as useful as the other processed materials, but there was no clear indication that they were a superior product. Further animal tests with popped grains will be required to determine whether this simple process should be exploited further.

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