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Nutrient Concentrations and Proportions in Particle Size Fractions of Corn Steam Flaked to Different Bulk Densities[1,2]

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DRAFT

ABSTRACT

The particle size distribution that results from steam flaking corn could be responsible for the difference in the chemical composition noted between steam-flaked corn and unprocessed grain. Steam-flaked corn processed to bulk densities of 283, 335, and 386 g/L (22, 26, and 30 lb/bu, respectively) was dry-sieved to determine the proportions in particle size fractions ranging from >8,000 to <600 μm, and total starch, CP, NDF, P, ether extract (EE), and ash concentrations were determined in the individual fractions. Data were analyzed as a completely randomized design using the 4 to 6 batches of corn that were flaked as experimental units. Concentrations of CP, NDF, P, EE, and ash of the intact flakes were generally not affected ($P \geq 0.09$) by flake bulk density. The greatest dry weight proportion of particles in grab samples was in the >8,000-μm fraction, with the smallest proportion associated with the 600-μm sieve fraction. The proportions of NDF, P, EE, and ash present in particles >8,000 μm decreased ($P < 0.05$) as flake bulk density decreased. In addition, the proportions of total starch within particle sizes of 4,760 to 8,000 μm and 1,180 to 2,360 μm were greater ($P \leq 0.02$) for 283 g/L flakes than for 335 and 386 g/L flakes. Within the range of bulk density of steam-flaked corn evaluated, certain nutrients were more concentrated in the finer particles created during the steam-flaking process. If smaller particles are disproportionately undersampled, flaked corn will appear to differ chemically from the grain being flaked.

Key words: bulk density, grain processing, particle size, steam-flaked corn

INTRODUCTION

Cereal grains commonly are flaked for use in the feedlot industry. The objective of mechanically processing cereal grain is to increase energy availability (Owens et al., 1997) and digestibility of starch by ruminants (Hale, 1973). Decreasing grain particle size is an important mechanical process that generally will improve the nutrient availability of grains and other feedstuffs. Sindt et al. (2006) mixed steam-flaked corn (**SFC**) for 15 or 30 min before adding other dietary ingredients to decrease its particle size; however, they found that the decreasing particle size of flakes did not appreciably affect cattle performance. Compared with dry-rolled corn grain, flaked grain consistently has greater starch digestibility and net energy content (Zinn et al., 2002) although bulk density of the flaked grain (257, 309, or 360 g/L) may have a limited impact on cattle performance or carcass characteristics (Zinn, 1990).

Nutrient content of grain has been reported to be altered by degree of processing. Preston (1998) observed that the P concentration of corn decreased markedly with steam flaking. Similarly, Drager et al. (2002) reported that the CP, NDF, and P concentrations of SFC decreased as the degree of processing increased (bulk density decreased). Logical reasons for

[1] Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the USDA.
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these changes in nutrient concentrations from steam flaking are not clear. It is possible that nutrients segregate during flaking, and these nutrients concentrate in smaller or larger particles. Corona et al. (2006) suggested that physical destruction of certain nutrients during steam flaking was not likely and proposed that accumulation of fine particles during flaking, coupled with a failure to representatively sample all particles in flaked grain resulted in under- or overrepresentation of specific nutrients. If particles of different sizes are sampled disproportionately after grains are processed, the analyzed nutrient content certainly could differ from that of the intact grain. To date, the nutrient profiles of particle size fractions that result from the flaking process have not been evaluated. Thus, our objective was to describe the distribution of nutrients among particles of various sizes in SFC processed to 3 different bulk densities.

MATERIALS AND METHODS

Steam-Flaking Process

Whole, shelled corn from a single load delivered to the Texas Tech University Burnett Center near New Deal, Texas, was used in this experiment. This load was randomly divided into 6 batches to provide replication. For each batch, the corn was weighed into 125-L plastic buckets (n = 12; 34 kg each), and 4.42 kg of water was added to each bucket. The corn was allowed to temper for approximately 18 h, after which it was steam-conditioned at 93°C for 20 min in a steam chamber at atmospheric pressure. After steam conditioning, corn in each batch was flaked to 283, 335, or 386 g/L (22, 26, or 30 lb/bu) by adjusting the roll pressure using 30 × 46 cm corrugated rollers. Each bulk density was not achieved in every batch because of mechanical problems with the steam flaker; therefore, the number of batches (4 to 6) per treatment was unequal. Corn bulk density was monitored by weight every 3 min, and roll pressure was adjusted as needed to ensure that the target densities were achieved. Samples of each bulk density, including all fines, were collected beneath the rolls for DM and nutrient analyses. To ensure the target moisture level of the processed grain was reached, DM analysis was conducted using a forced-air oven at 100°C for 15 to 16 h (AOAC, 2005; method 934.01). The remaining processed corn and fines for each bulk density were spread onto plastic tarps and air-dried in an open-air barn for 24 h. A subsample of the air-dried SFC and fines was collected and stored as intact flakes (flakes that were not mechanically sieved) for later nutrient analysis. Samples from each batch at each flake weight were sorted into various particle sizes by shaking 400 g of each air-dried sample through a series of metal sieves for 5 min using a Tyler Ro-Tap mechanical siever (W. S. Tyler Co., Salisbury, NC). Particle size categories for each bulk density were >8,000 μm; 4,760 to 8,000 μm; 2,360 to 4,760 μm; 1,180 to 2,360 μm; 600 to 1,180 μm; **[AU1: Are there overlaps in these particle sizes (same question throughout)?]**and <600 μm (Table 1). The quantity of corn collected on each sieve was weighed on a top-loading analytical balance (0.01-g readability; Sartorius L2200, Data Weighing Systems Inc., Elk Grove, IL) to determine the proportion of corn in the fraction. A sample of each particle size fraction was ground in a Wiley mill (Thomas-Wiley Laboratory Mill Model 4, Arthur H. Thomas Co., Swedesboro, NJ) through a 1-mm screen before further laboratory analyses.

Table 1. Particle size distribution of steam-flaked corn processed to different bulk densities[1] (DM basis)

	Distribution,[2] %			
Sieve size, μm	283 g/L	335 g/L	386 g/L	SE[3]
>8,000	41.60[a]	58.12[b]	64.40[c]	1.12
4,760 to 8,000	27.07[a]	21.18[b]	18.72[c]	0.41
2,360 to 4,760	10.08[a]	7.11[b]	5.98[c]	0.24
1,180 to 2,360	13.27[a]	7.49[b]	5.85[c]	0.43
600 to 1,180	3.68[a]	2.38[b]	1.93[c]	0.18
<600	4.26[a]	3.68[b]	3.08[c]	0.26

[a–c]Means within a row with different superscripts differ, $P < 0.05$.

[1]Steam-flaked corn was processed to a bulk density of 283, 335, or 386 g/L (22, 26, or 30 lb/bu).

[2]Proportion of sample remaining on the screen.

[3]Largest SE of the least squares means.

Laboratory Procedures

A sample of each particle size fraction along with intact flakes and whole, shelled corn were sent to a commercial laboratory (Servi-Tech Laboratories, Amarillo, TX) for determination of CP, NDF, and total P content (AOAC, 2005; methods 988.05, 2002.04, and 965.17, respectively). Analyses for DM and ash were performed at the USDA-ARS-Conservation and Production Research Laboratory near Bushland, Texas. These samples were dried at 100°C in a forced-air oven for approximately 16 h to determine DM (weight loss during drying) using the methods described previously and were subsequently placed in a muffle furnace at 550°C for 24 h to determine ash content (AOAC, 2005; method 924.05). The ether extract (**EE**), and total starch were determined at the Texas Tech University Ruminant Nutrition Laboratory in Lubbock. The EE was determined by refluxing petro-

leum ether over samples in Soxhlet tubes for at least 18 h (AOAC, 2005; method 920.39).

The analysis for total starch was adapted from McRae and Armstrong (196[AU2: Date changed to 1968 as in Lit Cited and on journal Web site.]8), in which duplicate samples (approximately 0.2 g) were placed in 125-mL Erlenmeyer flasks. The flasks and its contents were weighed on a top-loading balance (Mettler PC 8000, Mettler-Toledo Inc., Columbus, OH), and 50 mL of deionized water was added. Flasks were covered with aluminum foil and placed in a boiling water bath for 90 min to gelatinize the starch. The flasks were cooled to room temperature, and 50 mL of an acetate buffer solution (0.2 *M*; pH 4.5 ± 0.05) and 1 mL of glucoamylase enzyme (5 glucose activity units/mL; Valley Research, South Bend, IN) were added. The flask and its contents were reweighed to determine volume (assuming unit density), covered with aluminum foil, and incubated in a water bath at 60°C for 24 h. After removal from the water bath, the contents of the flask were mixed and allowed to settle while the flasks cooled to room temperature. A stock glucose solution (100 mg of glucose/mL) was prepared, to which benzoic acid (0.1 g/100 mL) was added as a preservative. A standard curve was prepared from the stock solution to provide concentrations of 0, 50, 100, 200, and 300 mg of glucose/100 mL. Glucose concentration in standards and samples was determined by combining 0.1-mL aliquots with 4 mL of a glucose reagent (Webster et al., 1971) in a disposable glass test tube. The glucose reagent included 1.5 g of thiourea, 9.5 g of sodium borate, and 80 mL of *o*-toluidine diluted to 1 L with glacial acetic acid. After addition of the reagent, tubes were vortexed and placed in a boiling water bath for 15 min, and the tubes were then placed in cool tap water for 15 min. Contents of the tubes were mixed and the absorbance was determined (Beckman DU-50 spectrophotometer, Beckman Instruments Inc., Irvine, CA) at 630 nm and compared with the glucose standards and a reagent blank.

The P composition of each sample was determined by NaOH-EDTA extraction and solution ^{31}P nuclear magnetic resonance (**NMR**) spectroscopy as described by Turner (2004). Phosphorus was extracted in triplicate by shaking 2.00 ± 0.01 g of dried sample with 40 mL of a solution containing 0.5 *M* NaOH and 0.05 *M* EDTA for 20 h at 20°C. Extracts were centrifuged at 10,000 × *g* for 30 min, and aliquots were analyzed for total P by inductively coupled plasma optical-emission spectrometry (Optima 4300 DV, Perkin-Elmer, Wellesly, MA). The remaining solutions from the triplicate extracts were combined, frozen rapidly at −80°C, lyophilized, and ground to a fine powder. Freeze-dried extracts were redissolved in 0.1 mL of D_2O (for signal lock) and 0.9 mL of a solution containing 1 *M* NaOH and 0.1 *M* EDTA, and then transferred to a 5-mm NMR tube. Solution ^{31}P NMR spectra were obtained using a Bruker Avance DRX 500 MHz spectrometer (Bruker, Rhinestetten, Germany) operating at 202.456 MHz for P. Samples were analyzed using a 5-μs pulse (45°), a delay time of 5.0 s, an acquisition time of 0.8 s, and broadband proton decoupling. Chemical shifts of signals were determined in parts per million relative to 85% (vol/vol) H_3PO_4 and assigned to individual P compounds or functional groups based on literature values (Turner et al., 2003). Signal areas were calculated by integration, and P concentrations were calculated by multiplying the proportion of the total spectral area assigned to a specific signal by the total P concentration (g of P/kg of dry sample) in the original extract. Only a limited number of samples (2 batches within 2 bulk densities) were analyzed using this procedure because of cost and labor limitations.

Statistical Analyses and Calculations

The nutrient concentration within each sieve size was multiplied by the proportion of sample remaining on the screen, and the nutrient distributions were reported as a proportion of the total nutrient content within each bulk density. The actual nutrient concentrations as a percentage of the DM within each sieve size fraction and bulk density treatment also were tabulated and are shown in parentheses in Tables 2 through 8. Data were analyzed as a completely randomized design using the mixed-methods procedure of SAS (PROC MIXED, SAS Institute Inc., Cary, NC) with a model that included the fixed effect of the 3 bulk density treatments. Batch of corn was the experimental unit, with 4 to 6 batches per treatment. Main-effect least squares means of bulk density within sieve size were evaluated by single-degree-of-freedom *F*-tests. In the case of a significant *F*-test, main-effect means were separated using the PDIFF option of SAS. Effects were considered significant at a *P*-value of ≤0.05, with tendencies declared at *P*-values between 0.05 and 0.10.

RESULTS AND DISCUSSION

The particle size distributions of the corn steam flaked to 3 bulk densities are presented in Table 1. The proportion of particles collected on the >8,000-μm sieve screen increased ($P < 0.05$) as bulk density of SFC increased from 283 to 386 g/L. Conversely, on all other sieves, the proportion of particles collected decreased ($P < 0.05$) as the bulk density increased, likely representing an increased amount of fine particles produced as the degree of processing increased.

The nutrient concentrations of whole corn sampled before steam flaking are shown in Tables 2 through 8. The whole-corn data are presented as a point of reference; thus, no statistical comparisons were made. The proportion of total starch (Table 2) was greater ($P = 0.01$) in SFC processed to 335 and 386 g/L in particles >8,000 μm. Furthermore, for particles of 1,180 to 4,760 μm, the proportion of total starch decreased ($P < 0.01$) when SFC was less extensively pro-

Table 2. Least squares means for starch content as a proportion of total starch across all sieve size fractions within each bulk density of steam-flaked corn[1]

Starch, %	283 g/L	335 g/L	386 g/L	SE[2]	*P*-value
In fraction, % of total starch					
Sieve size, μm					
>8,000	42.50[x] (79.88)[3]	58.45[y] (77.79)	62.85[y] (76.59)	3.57 (1.97)	0.01 (0.48)
4,760 to 8,000	30.07[x] (86.09)	22.31[y] (80.86)	19.33[y] (78.50)	1.52 (3.51)	<0.01 (0.30)
2,360 to 4,760	10.07[x] (76.82)	6.46[y] (69.72)	6.14[y] (76.06)	0.82 (2.64)	<0.01 (0.09)
1,180 to 2,360	10.06[x] (57.66[a])	6.40[y] (65.93[b])	5.77[y] (71.60[b])	1.04 (2.88)	0.02 (0.01)
600 to 1,180	2.83[x] (61.41[a])	2.43[x] (77.80[b])	2.03[y] (78.10[b])	0.22 (4.82)	0.05 (0.04)
<600	4.48 (81.60)	3.96 (82.64)	3.88 (91.30)	0.45 (3.98)	0.58 (0.16)
In intact sample,[4] % of DM	82.17[a]	76.61[b]	74.23[b]	1.43	0.01
In whole corn,[5] % of DM	75.56	—	—	—	—

[a,b]Means within a row with different superscripts differ, $P < 0.05$.

[x–z]Means within a row with different superscripts differ, $P < 0.05$.

[1]Steam-flaked corn was processed to a bulk density of 283, 335, or 386 g/L (22, 26, or 30 lb/bu).

[2]Largest SE of the least squares means.

[3]Values in parentheses reflect the total starch concentration in the corresponding particle size fraction (%, DM basis).

[4]Samples of steam-flaked corn remained intact and were not separated into various particle size fractions.

[5]A subsample of whole corn was collected and remained intact for laboratory analyses.

cessed to 335 or 386 g/L. There was no difference in total starch proportion or concentration across bulk densities for particles <600 μm. Particles 600 to 1,180 μm in size, however, had a greater ($P = 0.05$) proportion of total starch when SFC was processed to 283 g/L than when processed to 335 or 386 g/L. These differences in particle size separation might indicate that decreasing bulk density decreases flake durability; however, direct measures of flake durability were not obtained in our study. The concentration of total starch was greater ($P \leq 0.04$) for SFC processed to 386 g/L than to 283 or 335 g/L in particle sizes from 600 to 2,360 μm.

Table 3. Least squares means of the CP content as a proportion of total CP across all sieve size fractions within each bulk density of steam-flaked corn[1]

CP, %	283 g/L	335 g/L	386 g/L	SE[2]	*P*-value
In fraction, % of total CP					
Sieve size, μm					
>8,000	37.47[x] (7.65[a])[3]	56.58[y] (8.25[b])	63.91[y] (8.56[b])	3.25 (0.16)	<0.01 (<0.01)
4,760 to 8,000	24.58[x] (7.68[a])	20.91[y] (8.25[b])	19.02[y] (8.50[b])	1.26 (0.16)	0.02 (<0.01)
2,360 to 4,760	10.54[x] (8.83)	7.71[y] (9.10)	6.45[y] (8.84)	0.74 (0.21)	<0.01 (0.51)
1,180 to 2,360	18.29[x] (11.65[a])	9.52[y] (10.68[b])	6.57[y] (9.02[c])	1.23 (0.35)	<0.01 (<0.01)
600 to 1,180	5.09[x] (11.53[a])	2.50[y] (8.83[b])	1.81[y] (7.54[c])	0.42 (0.37)	<0.01 (<0.01)
<600	4.03[x] (7.90[a])	2.79[y] (6.42[b])	2.23[y] (5.83[b])	0.31 (0.25)	<0.01(<0.01)
In intact sample,[4] % of DM	8.27	8.10	8.40	0.21	0.53
In whole corn,[5] % of DM	8.83	—	—	—	—

[a–c]Means within a row with different superscripts differ, $P < 0.05$.

[x,y]Means within a row with different superscripts differ, $P < 0.05$.

[1]Steam-flaked corn was processed to a bulk density of 283, 335, or 386 g/L (22, 26, or 30 pounds/bushel).

[2]Largest SE of the least squares means.

[3]Values in parentheses reflect the CP content in the corresponding particle size fraction (%, DM basis).

[4]Samples remained intact and were not separated into various particle size fractions.

[5]A subsample of whole corn was collected and remained intact for laboratory analyses.

Table 4. Least squares means of the NDF content as a proportion of total NDF across all sieve size fractions within each bulk density of steam-flaked corn[1]

NDF, %	283 g/L	335 g/L	386 g/L	SE[2]	*P*-value
In fraction, % of total NDF					
Sieve size, µm					
>8,000	32.71[x] (8.15[a])[3]	54.48[y] (10.55[b])	64.08[z] (11.74[b])	3.70 (0.48)	<0.01 (<0.01)
4,760 to 8,000	21.54 (8.28[a])	20.67 (10.83[b])	19.34 (11.82[b])	1.39 (0.42)	0.51 (<0.01)
2,360 to 4,760	11.96[x] (12.30[a])	9.04[y] (14.12[b])	6.61[z] (12.32[a])	0.87 (0.33)	<0.01 (<0.01)
1,180 to 2,360	24.58[x] (19.03[a])	11.92[y] (17.70[a])	7.31[y] (13.74[b])	1.92 (0.63)	<0.01 (<0.01)
600 to 1,180	6.14[x] (16.80[a])	2.41[y] (11.23[b])	1.60[y] (8.98[b])	0.69 (1.33)	<0.01 (<0.01)
<600	3.08[x] (7.30[a])	1.48[y] (4.53[b])	1.06[y] (3.76[b])	0.33 (0.53)	<0.01 (<0.01)
In intact sample,[4] % of DM	10.30	10.74	10.98	0.20	0.14
In whole corn,[5] % of DM	12.67	—	—	—	—

[a,b]Means within a row with different superscripts differ, $P < 0.05$.

[x–z]Means within a row with different superscripts differ, $P < 0.05$.

[1]Steam-flaked corn was processed to a bulk density of 283, 335, or 386 g/L (22, 26 or 30 lb/bu).

[2]Largest SE of the least squares means.

[3]Values in parentheses reflect the NDF content in the corresponding particle size fraction (%, DM basis).

[4]Samples remained intact and were not separated into various particle size fractions.

[5]A subsample of whole corn was collected and remained intact for laboratory analyses.

Interestingly, the measurable total starch concentration in the intact flake samples was greater for 283 g/L than 335 and 386 g/L SFC, which implies that total starch concentration increased with extent of grain processing. These data are consistent with results reported by Preston (1996), in which the total starch concentration increased linearly as bulk density of steam-flaked sorghum decreased from 560 to 353 g/L. Similarly, when corn was processed by dry rolling to a bulk density of 592 g/L or by steam flaking to 360 and 283 g/L, the total starch concentration increased from 67.6 to 69.8 to 74.4%, respectively (Drager et al., 2002).

Table 5. Least squares means of the total P content as a proportion of total P across all sieve size fractions within each bulk density of steam-flaked corn[1]

P, %	283 g/L	335 g/L	386 g/L	SE[2]	*P*-value
In fraction, % of total P					
Sieve size, µm					
>8,000	22.40[x] (0.15[a])[3]	49.38[y] (0.24[b])	61.48[z] (0.27[c])	3.54 (0.01)	<0.01 (<0.01)
4,760 to 8,000	14.35[x] (0.15[a])	17.92[x,y] (0.23[b])	20.07[y] (0.29[c])	1.46 (0.01)	0.04 (<0.01)
2,360 to 4,760	10.67[x] (0.29[a])	9.26[x] (0.36[b])	6.33[y] (0.28[a])	1.01 (0.02)	0.02 (0.03)
1,180 to 2,360	33.72[x] (0.71[a])	15.60[y] (0.57[b])	7.61[z] (0.34[c])	2.02 (0.05)	<0.01 (<0.01)
600 to 1,180	11.37[x] (0.83[a])	4.24[y] (0.49[b])	2.29[y] (0.30[c])	1.11 (0.05)	<0.01 (<0.01)
<600	7.49[x] (0.47[a])	3.61[y] (0.27[b])	2.23[y] (0.19[c])	0.69 (0.04)	<0.01 (<0.01)
In intact sample,[4] % of DM	0.27	0.29	0.29	0.01	0.09
In whole corn,[5] % of DM	0.28	—	—	—	—

[a–c]Means within a row with different superscripts differ, $P < 0.05$.

[x–z]Means within a row with different superscripts differ, $P < 0.05$.

[1]Steam-flaked corn was processed to a bulk density of 283, 335, or 386 g/L (22, 26, or 30 lb/bu).

[2]Largest SE of the least squares means.

[3]Values in parentheses reflect the P content in the corresponding particle size fractions (%, DM basis).

[4]Samples remained intact and were not separated into various particle size fractions.

[5]A subsample of whole corn was collected and remained intact for laboratory analyses.

Table 6. Least squares means of the inorganic P content as a proportion of total P across all sieve size fractions within 2 bulk densities of steam-flaked corn[1]

Inorganic P,[2] % of total P	283 g/L	386 g/L	SE[3]	*P*-value
Sieve size, µm				
>8,000	51.52 (12.94[a])[4]	59.34 (8.15[b])	9.01 (0.61)	0.60 (0.03)
4,760 to 8,000	27.55 (13.10)	18.55 (9.10)	3.10 (0.83)	0.18 (0.08)
2,360 to 4,760	9.14 (11.07)	7.79 (11.13)	2.50 (0.89)	0.74 (0.96)
1,180 to 2,360	7.21 (6.30[a])	7.23 (10.28[b])	2.86 (0.49)	0.99 (0.03)
600 to 1,180	1.88 (5.85[a])	2.35 (9.93[b])	0.74 (0.64)	0.70 (0.05)
<600	2.70 (6.94[a])	4.75 (13.18[b])	0.89 (0.47)	0.25 (0.01)

[a,b]Means within a row with different superscripts differ, $P < 0.05$.

[1]Steam-flaked corn was processed to a bulk density of 283, 335, or 386 g/L (22, 26, or 30 lb/bu).

[2]Inorganic P represents the proportion of P in the form of inorganic orthophosphate.

[3]Pooled SE of main-effect means; n = 2 replications/least squares mean.

[4]Values in parentheses reflect the concentration of inorganic P as a proportion of the total P content in the corresponding particle size fraction (%, DM basis).

This decrease in starch concentration with increasing bulk density may be a result of the analytical method used to determine starch content. As noted previously, the analytical procedure involves boiling the samples to gelatinize the starch before adding glucoamylase. Starch should be more extensively gelatinized for flakes with a low bulk density than with a high bulk density. This greater inherent gelatinization of lighter bulk density samples might allow the glucoamylase enzyme to be more effective in liberating glucose, thereby resulting in an increased starch concentration. Alternatively, samples with lighter bulk density may have fewer barriers (e.g., modified protein solubility or structural integrity) to the action of glucoamylase. This could increase the amount of glucose liberated by the enzyme. Whatever the reason, an increase in starch availability for enzymatic attack would be expected to increase the rate, if not the extent, of ruminal digestion of starch.

The proportion of CP (Table 3) in the 1,180- to 8,000-µm particles was greater ($P \leq 0.02$) for the 283 g/L

Table 7. Least squares means of the ether extract (EE) content as a proportion of total EE across all sieve size fractions within each bulk density of steam-flaked corn[1]

EE, %	283 g/L	335 g/L	386 g/L	SE[2]	*P*-value
In fraction, % of total EE					
Sieve size, µm					
>8,000	26.66[x] (2.14)[3]	54.64[y] (2.92)	68.37[z] (3.46)	5.10 (0.38)	<0.01 (0.07)
4,760 to 8,000	10.83 (1.40[a])	16.77 (2.40[b])	16.57 (2.74[b])	16.77 (0.38)	0.13 (0.05)
2,360 to 4,760	10.31 (3.46)	6.61 (2.91)	5.90 (3.10)	1.30 (0.62)	0.06 (0.79)
1,180 to 2,360	39.09[x] (10.21[a])	16.31[y] (6.32[b])	5.72[z] (2.95[c])	3.25 (0.92)	<0.01 (<0.01)
600 to 1,180	9.47[x] (8.40[a])	3.33[y] (4.28[b])	1.33[y] (2.12[b])	1.34 (1.06)	<0.01 (<0.01)
<600	3.65 (2.83)	2.33 (1.82)	2.11 (2.09)	0.68 (0.49)	0.23 (0.31)
In intact sample,[4] % of DM	3.00	4.09	3.39	0.59	0.44
In whole corn,[5] % of DM	3.56	—	—	—	—

[a–c]Means in a row with different superscripts differ, $P < 0.05$.

[x–z]Means in a row with different superscripts differ, $P < 0.05$.

[1]Steam-flaked corn was processed to a bulk density of 283, 335, or 386 g/L (22, 26, or 30 lb/bu).

[2]Largest SE of the least squares means.

[3]Values in parentheses reflect the EE content in the corresponding particle size fraction (%, DM basis).

[4]Samples remained intact and were not separated into various particle size fractions.

[5]A subsample of whole corn was collected and remained intact for the laboratory analyses.

Table 8. Least squares means of the ash content as a proportion of total ash across all sieve size fractions within each bulk density of steam-flaked corn

Ash, %	283 g/L	335 g/L	386 g/L	SE[2]	*P*-value
In fraction, % of total ash					
Sieve size, µm					
>8,000	24.28[x] (0.89[a])[3]	48.92[y] (1.26[b])	61.16[z] (1.46[c])	3.68 (0.06)	<0.01 (<0.01)
4,760 to 8,000	15.72 (0.89[a])	18.60 (1.30[b])	18.77 (1.49[c])	1.38 (0.05)	0.22 (<0.01)
2,360 to 4,760	10.87[x] (1.66)	8.83[x] (1.85)	6.30[y] (1.55)	0.89 (0.12)	<0.01 (0.13)
1,180 to 2,360	31.38[x] (3.67[a])	15.15[y] (3.01[b])	8.54[z] (2.09[c])	1.85 (0.23)	<0.01 (<0.01)
600 to 1,180	10.36[x] (4.23[a])	4.44[y] (2.80[b])	2.45[y] (1.80[c])	0.99 (0.24)	<0.01 (<0.01)
<600	7.40[x] (2.61[a])	4.06[y] (1.67[b])	2.78[y] (1.30[b])	0.67 (0.17)	<0.01 (<0.01)
Intact sample,[4] % of DM	1.47	1.49	1.43	0.05	0.66
Whole corn,[5] % of DM	1.55	—	—	—	—

[a–c]Means within a row with different superscripts differ, $P < 0.05$.

[x–z]Means within a row with different superscripts differ, $P < 0.05$.

[1]Steam-flaked corn was processed to a bulk density of 283, 335, or 386 g/L (22, 26, or 30 lb/bu).

[2]Largest SE of the least squares means.

[3]Values in parentheses reflect the ash content in the corresponding particle size fractions.

[4]Samples remained intact and were not separated into various particle size fractions.

[5]A subsample of whole corn was collected and remained intact for laboratory analyses.

SFC than SFC processed to 335 and 386 g/L. Similarly, the proportion of CP in the finest particles (<600 µm) was greater ($P < 0.01$) for the most extensively processed SFC (283 g/L bulk density) than for the heavier flakes. Particle sizes with a greater proportion of CP presumably contained more horny or hard endosperm and germ, which inherently are richer in CP than floury endosperm or bran (Galyean et al., 1981). The concentration of CP in particle sizes >8,000 µm was greater ($P < 0.01$) in less extensively processed SFC of 335 and 386 g/L. The CP concentration was greater ($P \leq 0.02$) in SFC flaked to 335 or 386 g/L in larger particle sizes >4,760 µm. In contrast, concentration of CP was less ($P < 0.01$) in SFC processed to 386 g/L in particle sizes <2,360 µm. Despite differences among the particle size fractions, intact samples did not differ ($P = 0.53$) in CP concentration across the 3 bulk density treatments.

Preston and Matulka (1994) noted that when bulk density of steam-flaked sorghum was decreased from 528 to 193 g/L, the CP concentration decreased. Likewise, CP concentration was lower when sorghum was steam flaked than when it was dry rolled (Defoor et al., 2000), indicating that CP might be lost during the steam-flaking process. Drager et al. (2002) concluded that changing the bulk density of corn grain from 592 g/L (dry rolling) to 360 and 283 g/L (steam flaking) decreased the CP content from 9.1 to 8.5 to 8.1%. Galyean et al. (1981) also reported that CP concentrations of dry-rolled, steam-flaked, and ground corn separated by particle size differed (11.7, 9.5, and 8.6%, respectively), and they attributed this difference in CP to an endosperm separation within the grain kernel, consistent with our hypothesis of disproportionate sampling. Reasons for the apparent loss of CP with steam flaking are not clear, but Defoor et al. (2000) suggested that removal and loss of portions of the grain germ and seed coat during steam flaking might reduce the CP concentration. Preston (1998) hypothesized that the protein structure in sorghum was altered by steaming, and consequently, protein solubility was lower in more extensively processed sorghum. Our intact sample data suggest that CP was not lost during the steam-flaking process. Perhaps the apparent loss of nutrients reported in previous studies (Preston and Matulka, 1994; Defoor et al., 2000; Drager et al., 2002) may represent undersampling of the smaller sized particles that, in turn, constitute a greater proportion of the particles as the bulk density of flakes decreases.

In the largest sieve screen (>8,000 µm), the proportion of NDF increased ($P < 0.01$) as bulk density increased (Table 4). Likewise, Drager et al. (2002) reported that NDF concentration decreased linearly from 10.9 to 8.4% as corn was more extensively processed. The proportion of NDF decreased ($P < 0.01$) as bulk density increased in the 2,360- to 4,760-µm sieve size. In addition, the proportion of NDF was greater ($P < 0.01$) for SFC processed to 283 g/L flakes than to 335 or 386 g/L flakes in particle sizes <2,360 µm. Concentration of NDF increased ($P < 0.01$) with increasing bulk density in particle sizes >4,760 µm, whereas in particle sizes of 2,360 to 4,760 µm, NDF concentration was greater ($P < 0.01$) for SFC flaked to 335 g/L than to 283 or 386 g/L. In the smallest particle sizes (<1,180 µm), concentration of NDF was greater in SFC processed to 283 g/L than to 335 or 386 g/L. Reasons

for the differences in proportion of NDF observed in the present study are not readily evident, but could potentially relate to the presence of the seed coat in less processed SFC. Because most of the NDF of the corn kernel is located in the pericarp and tip cap, these fractions presumably are overrepresented in the coarse particles of flaked corn. Nonetheless, the lack of differences in the NDF concentrations of intact samples ($P = 0.14$) once again highlights the need to adequately sample all particle size fractions representatively to ensure that analytical values are correct. Despite the difference in the NDF concentration of intact samples, whole corn was numerically greater in NDF than corn steam flaked to 283, 335, or 386 g/L. Reasons for a possible loss of NDF because of processing are unclear.

The proportion and concentration of total P (Table 5) in the largest particle size (>8,000 μm) increased ($P < 0.01$) as the bulk density of the SFC increased. In particles ranging from 600 to 2,360 μm and <600 μm, the proportion and concentration of total P were greater ($P < 0.01$) in SFC processed to 283 g/L than to 335 or 386 g/L. The total P proportion in intermediate sizes (2,360 to 4,370 μm) was greater ($P < 0.02$) when SFC was processed to 283 and 335 g/L, whereas the concentration was greater ($P < 0.03$) for SFC flaked to 335 g/L than to 283 or 386 g/L. Preston and Matulka (1994) reported that total P concentration in sorghum grain decreased as the extent of processing increased from 528 to 193 g/L of bulk density. Similarly, in processed corn, Drager et al. (2002) reported a decrease in total P as the extent of processing increased from dry rolling to steam flaking corn to a bulk density of 283 g/L. Given the small and nonsignificant ($P = 0.09$) differences in proportion of total P of the intact flake samples, the effects of grain processing on P concentration reported in earlier studies are likely related to sampling errors after processing.

As noted previously, only 2 bulk densities were evaluated for P composition of the fractions. The proportion of total P that was inorganic P (orthophosphate; Table 6) was greater ($P \leq 0.05$) in SFC processed to 386 g/L than to 283 g/L in particle sizes of 600 to 2,360 μm and <600 μm, unlike the total P proportion and concentration, which were greater in SFC processed to 283 g/L than to 386 g/L. In particles >8,000 μm, however, the proportion of total P that was inorganic P was greater in the 283 g/L SFC, in contrast to the proportion and concentration of total P that was greater in SFC processed to 386 g/L. It seems that total P concentration and proportion are inversely related to inorganic P concentration. To our knowledge, changes in inorganic P content as a result of steam flaking have not been reported previously; however, Chitra et al. (1996) reported that heat treatment of legume seeds apparently resulted in phytate degradation. Whether air drying of samples, as used in the present study, might affect the proportion of inorganic P is not known, but this seems unlikely. As noted for CP and NDF concentrations, failure to collect all fines produced during the flaking process would be expected to result in an apparent decrease in the concentration of P when grain is more extensively processed.

As the bulk density of SFC decreased, the proportion of EE decreased ($P < 0.01$) in particles of >8,000 μm (Table 7). In addition, the EE concentration was greater ($P < 0.05$) for 335 and 386 g/L SFC than for 283 g/L SFC in particles from 4,760 to 8,000 μm. Conversely, EE proportion and concentration in the 1,180- to 2,360-μm particle sizes increased ($P \leq 0.01$) as bulk density decreased. Moreover, the proportion and concentration of EE was greater for 283 g/L SFC than for corn processed to 335 or 386 g/L in particles of 600 to 1,180 μm. The proportion of EE within the intact samples, however, did not differ ($P = 0.44$) among the 3 bulk densities. Changes in the proportion of EE content as a result of steam flaking have not been reported previously in the published literature. One possible explanation for an increased EE proportion in finer particle sizes of more extensively processed SFC (as observed in the present study for particles from 600 to 2,360 μm) is that a higher proportion of germ, which is higher in EE than other kernel fractions, is found with the smaller particle sizes.

The proportion of ash within the various particle size fractions is shown in Table 8. As bulk density increased, the proportion of ash increased ($P < 0.01$) in the largest particle size (>8,000 μm); however, as bulk density increased, ash proportion decreased ($P < 0.01$) in particles from 1,180 to 2,360 μm. The proportion of ash was greater for 283 and 335 g/L SFC than flakes processed to 386 g/L in particles of 2,360 to 4,760 μm. In addition, the proportion of ash was greater for SFC processed to 283 and 335 g/L flakes than for the 386 g/L SFC in finer particle sizes from <600 to 1,180 μm. Ash concentration increased ($P < 0.01$) as bulk density increased in particle sizes >4,760 μm, whereas it decreased ($P < 0.01$) in particles <1,180 μm. Ash concentration of the intact samples did not differ ($P = 0.66$) among the 3 bulk density treatments.

Previous reports have indicated that the concentration of ash decreased ($P < 0.05$) as bulk density of steam-flaked sorghum decreased and extent of grain processing increased (Preston and Matulka, 1994; Preston, 1996, 1998). Similarly, Drager et al. (2002) reported a linear decrease in ash content from 2.12 to 1.76 to 1.59% as a consequence of more extensive grain processing from dry rolling corn to 592 g/L versus steam flaking to bulk densities of 360 and 283 g/L. The lack of changes in ash concentration of the intact samples in the current study once again suggests that these previously reported differences might be the result of sampling errors associated with the failure to adequately sample finer particles.

IMPLICATIONS

The results of this experiment are interpreted to suggest that nutrient concentrations, other than starch, are not likely to change greatly as the bulk density changes in SFC grain. Nonetheless, some nutrients accumulate in the fine particles created during the steam-flaking process, and the proportion of finer particles increases with decreasing bulk density of SFC. Therefore, as the degree of processing increases, there is an increased likelihood of observing changes in nutrient concentrations if smaller particles are not representatively sampled. In the case of starch, which increased in concentration as bulk density decreased, laboratory procedures associated with its analysis need further study. Research is needed to investigate how such changes in particle size distribution and nutrient concentration within particle sizes might affect the performance of cattle fed steam-flaked grains.

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