Effects of Corn Sample, Mill Type, and Particle Size on Corn Curl and Pet Food Extrudates[1]

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ABSTRACT

The effects of corn sample, grinder type, and particle size of ground corn on the extrusion of corn curls and pet food were studied. Extrusion runs were conducted using a twin-screw extruder. Properties of corn curl and pet food extrudates were affected significantly by corn samples obtained from different parts of the country (Nebraska, Illinois, and Texas), even though grinding and extrusion parameters were held constant. The type of grinder used to grind the corn had an effect on extrusion properties. The volumetric expansion index (VEI) of extrudate from pin-milled samples was lower than that of extrudate from the same corn ground in a hammer mill or roller mill. Small particle size, obtained by grinding corn in a hammer mill with different screen sizes, produced extrudate with a significantly higher VEI than extrudate from coarse- or medium-sized particles.

High-temperature short-time (HTST) extrusion cooking of foods has developed in recent years into an important processing technique. Extrusion cooking is a continuous HTST process that uses both temperature and pressure for expansion (Hoseney 1994). The treatment of raw materials containing starch and protein with thermal and mechanical energy leads to changes in the properties of the extrudate. These changes depend on the type and amount of energy transferred (Meuser et al 1987). The reactions taking place in the extruder are influenced by a large number of variables related to the machine and raw materials. This is especially true when raw materials containing starch are processed together with other components such as proteins, lipids, and other carbohydrates.

The effect of various process variables on the quality of extrudates has been established (Meuser et al 1987, van Lengerich 1990). In extrusion systems, cereal grains contribute to product expansion, binding, caloric value, texture, and flavor. They are the major ingredients in most food or feed formulations. With constant processing parameters, the day-to-day variability in the extrudate properties may be attributable to variation in the properties of the cereal grain used. Faubion and Hoseney (1982a,b) have shown that significant changes in wheat flour components cause significant changes in extrudate properties.

The overall goal of this research was to understand the relationship between properties of ground cereal meal and the properties of cereal-based extruded foods. The primary focus of this research was to determine the functionality of corn meals as components in corn curls or extruded pet food. The specific objectives of this study were to determine the effects of corn samples, grinder type (mill type), and particle size of ground corn on product parameters of extruded corn curls and pet food.

MATERIALS AND METHODS

Materials

Commercial corn samples were obtained from locations in Nebraska (NE), Illinois (IL), and Texas (TX). The corn curl formulation used ground corn and water. A generic pet food formula provided by Friskies Research and Development Center, St. Joseph, MO, consisting of ground corn and a proprietary base mix (whole corn, poultry by-product meal, corn gluten meal, soybean meal, and salt) was used in the study to produce extruded pet food.

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Corn Curl Extrusion

Meal for production of corn curls was first hammer-milled using a Jacobson tear drop hammer-mill through a 4/64-in. (1.5-mm) screen and then reground through the same mill but with a 3/64-in. (1.125-mm) screen. To determine the effect of grinder type, corn was ground through a hammer mill (3/64-in. [1.125-mm] screen), a Roskamp roller mill (three sets of rolls with differentials of 1:1, 1:1.5, 1:1.5), or a pin mill (Alpine). To determine the effect of particle size, corn was ground with a hammer mill using 4/64-in. (1.5 mm), 3/64-in. (1.125 mm), or 2/64-in. (0.75 mm) screens. The ground corn was stored in drums until used.

High-temperature short-time (HTST) extrusion cooking was conducted using a twin-screw model TX-52 extruder (Wenger Manufacturing, Sebatha, KS) with a screw setup for corn curl production recommended by the manufacturer. Before each run, the extruder feeder was calibrated to provide a constant feed rate of 2.7 lb (1,225.8 g)/min (db). The amount of water added at the extruder barrel was adjusted to compensate for moisture differences in the samples. The extruder processing conditions were preconditioning cylinder (Wenger model DC) speed of 200 rpm (exit temperature 87–93°C); extruder screw speed of 375 rpm; and extruder water flow rate of 72.6 g/min. Temperatures were 45°C at heads one, two, and three; 55°C at head four; 95°C at head five; and 75°C at head six. The die plate had one die insert with three holes of 3.9 mm diameter. The feed screw speed was set as determined by the calibration test. The extruder was allowed to run and stabilize for 20 min using a warm-up corn meal. The extruder was allowed to stabilize for 10 min with each treatment meal before data collection began.

To collect wet extrudate samples for evaluating expansion indices, knife speed was reduced to 25% and samples were collected on a tray (to avoid sticking together and, hence, bending) and transferred to zip-lock bags. Dried samples of the extrudates also were collected for analysis of extrudate properties using a gas-powered two-pass dryer (Wenger model 4800) with drying conditions of 230°F (110°C) air temperature, 14-min drying time, and 5-min cooling time.

Pet Food Extrusion

The corn for pet food extrusion was first hammer-milled using a Jacobson tear drop hammer mill through a 4/64-in. (1.5-mm) screen and then reground with the same mill but through a 3/64-in. (1.125-mm) screen. Ground corn was mixed with the base mix (1:1) and blended using a Wenger ribbon batch mixer (capacity: 250 lb, 113.5 kg) for 15 min per batch. The mixed corn plus base mix then was stored in cardboard drums until used.

For the initial run, the steam rate to the preconditioner was adjusted to achieve a meal temperature of 87–93°C at the exit of the preconditioner barrel. Then the steam rate to the extruder barrel was adjusted to achieve a target bulk density of 304–384 g/L (19–24 lb/ft^3) for the wet extrudate. These steam rates were maintained constant for subsequent runs.

A standard TX-52 configuration code for pet food as given by Wenger Manufacturing was used for screw configurations in all pet food extrusion runs. Before each run, the extruder feeder was calibrated to provide a constant feed rate of 8.0 lb (3.623 kg)/min (db). The extruder processing conditions were preconditioning cylinder (Wenger model DC) speed of 190 rpm; extruder screw speed of 400 rpm; and extruder water flow rate of 163 g/min. Temperatures were 60°C at heads two and three; 70°C at head four; 90°C at head five; and 100°C at heads six and seven. The die plate had one die insert with one hole 6.5 mm in diameter. The feed screw speed was set as determined by the calibration test. The extruder was allowed to run and stabilize for 20 min using a warm-up feed. The extruder was allowed to stabilize for 10 min with each treatment meal before data collection began.

To collect wet extrudate samples for evaluation of expansion indices, the knife speed was reduced to 25% and the samples were collected on a tray (to avoid sticking together and hence bending) and transferred to zip-lock bags. Dried samples of the extrudates also were collected for analysis of extrudate properties. The dryer used was a Wenger model 4800 (gas-powered two-pass). The drying conditions were 230°F (110°C) air temperature, 14-min drying time, and 5-min cooling time.

Proximate Analyses

Proximate analyses of corn and extrudates (moisture content, fat, protein, and ash) were determined using Approved Methods 44-15A, 30-10, 46-13, and 08-12, respectively (AACC 1995). Moisture content was expressed as percentage wet basis. Fat, protein, and ash contents were expressed as percentages on a 14% moisture basis.

Methods

Ground corn was analyzed for starch damage using Approved Method 76-31 (AACC 1995). Damaged starch granules were hydrated and then hydrolyzed to maltosaccharides and limit dextrins with fungal α-amylase. Amyloglucosidase then was used to convert dextrins to glucose. Glucose was measured with a glucose oxidase-peroxidase reagent mixture using a spectrophotometric procedure (MegaZyme International Ireland, Wicklow, Ireland). Results were expressed as % flour weight on an as-is basis.

The particle size of ground corn was analyzed using ASAE method S319.2 using a Ro-Tap sifter. Because finely ground corn blinded the sieves, an Alpine air sifter was used for particle size measurement of finer samples. The particle size was calculated using a computer program and expressed as geometric mean diameter (GMD).

Bulk density (BD, g/L) of wet extrudates was determined by weighing 1 L of extrudate collected directly from the die exit.

The volumetric expansion index (VEI) of wet extrudate was determined using the method of Alvarez-Martinez et al (1988). The VEI of the extrudates was calculated as the product of the sectional expansion index (SEI) and the longitudinal expansion index (LEI). For these measurements, long pieces of extrudate were produced by reducing the knife speed.

The breaking strength (BS) of extrudates was determined using a TA.XT2 texture analyzer (Texture Technologies Corp., Scarsdale, NY). Long pieces of extrudates were tested for BS using a three-point break test. The samples were stored in zip-lock plastic bags before testing. The support bridge spacing was 10 mm, and the deformation rate was 5 mm/sec for all treatments. A wedge-shaped plexiglass probe (51 mm wide, 40 mm high, 5.8 mm thick) was used. Ten measurements were made and averaged.

The water absorption index (WAI) and water solubility index (WSI) were determined as described by Mason and Hoseney (1986). A 2.5-g sample of ground product (<60 mesh) was suspended in 30 mL of water at 30°C. The sample was stirred intermittently over a period of 30 min using a vortex mixer (Scientific Products, McGaw Park, IL) and then centrifuged at 1,000 × *g* for 10 min. The supernatant was dried, and the amount of solubles expressed as a percent of the original dry sample weight (WSI). The ratio between the total weight of the pellet and the weight of the solids in the pellet then was calculated as WAI.

A procedure developed by the manufacturer (Publication 030989, Wenger Mfg., Sebatha, KS) was used for the determination of extrudate degree of cook. One portion of the sample was slurried in cold water, and the second portion was autoclaved. The starch in each sample was hydrolyzed with glucoamylase. The glucose produced in each portion was measured with an industrial analyzer (model 27, Yellow Springs Instrument Co., Yellow Springs, OH) and used to calculate the amount of starch gelatinized. The sample slurried in cold water (gelatinized starch) yields the amount of starch cooked during extrusion processing. The autoclaved sample gives the total starch:

$$\text{Degree of cook} = (\text{gelatinized starch \%} / \text{total starch \%}) \times 100$$

Specific mechanical energy (SME) utilized during extrusion was calculated using the procedure outlined by Wenger Manufacturing:

$$\text{SME (kJ / kg)} = Q_{me}\,[(\text{kJ / hr}) / \text{FR (kg / hr)}]$$

where FR is the feed rate (db) and Q_{me} is the mechanical energy input:

$$Q_{me} = (kW_e \times L_e \times rpm_a / rpm_f \times 36)\ \text{kJ / hr}$$

where kW_e is the rated power of extruder drive in kW (22.4 kW for the TX-52 extruder), L_e is the load on extruder motor (%), rpm_a is the actual rpm of the extruder shaft, and rpm_f is the full speed rpm of extruder shaft (336 rpm for the TX-52 extruder).

RESULTS AND DISCUSSION

Chemical and physical properties of commercial corn samples are shown in Table I. The particle sizes expressed as GMD, and starch damage of ground corn for the different treatments are given in Table II. The pin mill produced the smallest particle size. As anticipated, smaller screen sizes produced finer particles in the hammer-mill study. The Roskamp roller mill and the pin mill samples had the greatest starch damage (Table II), presumably because of the higher shear.

Effect on Corn Curls

Significant differences ($P < 0.05$) occurred in the VEI among the corn curl extrudates produced using samples from NE, IL, and TX (Table III). The sample from NE gave an extrudate with the highest VEI (11.92). Extrusion of the corn sample from IL utilized a significantly higher SME than extrusion of the other samples. The corn samples had no significant effect on the BS of corn curls or the degree of cook of corn curl extrudates.

In a comparison of effects of grinder type and particle size, corn ground using a pin mill produced an extrudate with a significantly lower VEI than extrudates from the same corn sample ground by the roller mill or hammer mill (Table IV). The grinder type did not have any significant effect on the BS of the extrudates. SME during extrusion was significantly higher with the hammer-milled corn sample than with the roller-milled or pin-milled corn. The extrudate from corn ground using a pin mill had a significantly lower degree of cook than that from hammer-milled or roller-milled corn samples.

The study of mill type was confounded by the possible effect of particle size. Therefore, corn was ground in a hammer mill but with different screen sizes to produce a range of particle sizes. Fine-ground corn samples produced extrudates with significantly higher ($P < 0.05$) VEI than the extrudate from coarse- and medium-ground samples (Table V). Corn ground to different particle sizes did not have any significant effect on the BS or degree of cook of corn curl extrudates. The SME during extrusion was significantly lower with coarse ground corn than with medium- or fine-ground samples. The coarse particles may have generated a lower dough viscosity in the extruder barrel, which resulted in a lower motor load.

Effects on Pet Food Extrudates

The effects of different corn samples on extrudate properties of pet food are given in Table VI. Hammer-milled commercial corn samples from NE, IL, and TX produced extrudates with significantly different BD and BS ($P < 0.05$). Corn from NE or IL produced an extrudate that had a significantly higher VEI with a significantly lower SME when compared with extrudate from the TX sample. The corn sample from NE produced an extrudate with significantly lower degree of cook and WAI when compared with extrudates from IL or TX samples. The corn sample from IL produced an extrudate with significantly higher WSI when compared with extrudates from NE or TX samples.

The effect of hammer, roller, and pin mills on properties of pet food extrudates are given in Table VII. The commercial corn sample from NE ground using a roller mill produced an extrudate that had a significantly higher VEI with a significantly lower SME

TABLE I
Analysis of Commercial Corn Samples Obtained from Three Different Growing Locations[a,b]

Sample	Moisture (%)	Fat (%)	Protein (%)	Ash (%)	HKW (g)
NE	13.7a[c]	2.66a	7.7a	1.23a	33.74a
IL	12.5b	2.80b	7.7a	1.11b	35.85b
TX	10.7c	3.53c	8.9b	1.12b	34.57a

[a] Nebraska (NE), Illinois (IL), and Texas (TX).
[b] Values are averages of three readings. Analytical values are on a 14% moisture basis. HKW = hundred kernel weight.
[c] Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

TABLE II
Particle Sizes Expressed as Geometric Mean Diameter (GMD) and Starch Damage from Ground Corn Samples Obtained from Three Different Growing Locations[a,b]

Sample	Mill	Screen Size (mm)	GMD (μm)	Starch Damage (%)
NE	Roller	· · ·	401	8.3a[c]
NE	Pin	· · ·	95	7.6a
NE	Hammer	1.500	351	1.9df
NE	Hammer	1.125	264	3.4b
NE	Hammer	0.750	164	3.6b
IL	Hammer	1.500	357	2.8b–d
IL	Hammer	1.125	290	2.9bc
IL	Hammer	0.750	198	2.8b–d
TX	Hammer	1.500	332	1.5f
TX	Hammer	1.125	287	2.3cdf
TX	Hammer	0.750	194	2.4cdf

[a] Nebraska (NE), Illinois (IL), and Texas (TX).
[b] Values are averages of two readings.
[c] Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

TABLE III
Properties of Corn Curl Extrudates from Samples Obtained from Three Different Growing Locations[a,b]

Sample	Mill	VEI (kg)	BS (kJ/kg)	SME (%)	Cook
NE	Hammer	11.92a[c]	2.63a	608.4a	96.12a
IL	Hammer	9.13b	2.44a	640.1b	96.64a
TX	Hammer	7.64c	2.65a	613.7a	95.75a

[a] Nebraska (NE), Illinois (IL), and Texas (TX).
[b] Values are averages for extrudates produced from coarse-, medium-, and fine-ground corn. VEI = volumetric expansion index; BS = breaking strength; SME = specific mechanical energy; Cook = degree of cook of extrudate.
[c] Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

TABLE IV
Effect of Grinder Type on Properties of Corn Curl Extrudates from Samples Obtained from Three Different Growing Locations[a,b]

Sample	Mill	Screen Size (mm)	VEI (kg)	BS (kJ/kg)	SME (%)	Cook
NE	Hammer	1.125	10.39a[c]	2.87a	634.9a	96.28a
NE	Roller	· · ·	12.33b	2.46a	492.0b	96.98a
NE	Pin	· · ·	9.34c	2.82a	584.1c	94.08b

[a] Nebraska (NE), Illinois (IL), and Texas (TX).
[b] VEI = volumetric expansion index; BS = breaking strength; SME = specific mechanical energy; Cook = degree of cook of extrudate.
[c] Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

TABLE V
Effect of Corn Particle Size on Properties of Corn Curl Extrudates[a]

Screen Size (mm)	VEI (kg)	BS (kJ/kg)	SME (%)	Cook
1.500	9.80a[b]	2.60a	592.5a	96.34a
1.125	8.47b	2.61a	640.2b	96.27a
0.750	10.42c	2.51a	629.6b	95.89a

[a] Values are averages for the extrudates produced using corn samples from Nebraska, Illinois, and Texas. VEI = volumetric expansion index; BS = breaking strength; SME = specific mechanical energy; Cook = degree of cook of extrudate.
[b] Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

TABLE VI
Properties of Pet Food Extrudates from Corn Samples Obtained from Three Different Growing Locations[a,b]

Sample	BD (g/L)	VEI (kg)	BS (kJ/kg)	SME (%)	Cook	WAI	WSI
NE	369.74a[c]	2.51a	4.94a	294.1a	85.46a	2.70a	15.23a
IL	378.54b	2.48a	3.82b	296.7a	86.78b	2.75b	16.59b
TE	391.88c	2.43b	3.32c	311.0b	86.09ab	2.74ab	15.43a

[a] Nebraska (NE), Illinois (IL), and Texas (TX).
[b] Values are averages for extrudates produced from coarse-, medium-, and fine-ground corn. BD = bulk density of wet extrudate; VEI = volumetric expansion index; BS = breaking strength; SME = specific mechanical energy; Cook = degree of cook of extrudate; WAI = water absorption index of dried extrudate; WSI = water solubility index of dried extrudate.
[c] Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

TABLE VII
Effect of Grinder Type on Properties of Pet Food Extrudates[a]

Mill	BD (g/L)	VEI (kg)	BS (kJ/kg)	SME (%)	Cook	WAI	WSI
Hammer[b]	360.5a[c]	2.55a	5.53a	292.6a	84.19a	2.71a	14.71a
Roller	359.3a	2.61b	4.63b	273.5b	84.49a	2.81b	14.39a
Pin	407.5b	2.25c	3.59c	319.5c	95.94b	3.12c	15.48b

[a] BD = bulk density of wet extrudate; VEI = volumetric expansion index; BS = breaking strength; SME = specific mechanical energy; Cook = degree of cook of extrudate; WAI = water absorption index of dried extrudate; WSI = water solubility index of dried extrudate.
[b] Screen size 1.125 mm.
[c] Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

TABLE VIII
Effect of Corn Particle Size on Properties of Pet Food Extrudates[a]

Screen Size (mm)	BD (g/L)	VEI (kg)	BS (kJ/kg)	SME (%)	Cook	WAI	WSI
1.500	385.03a[b]	2.37a	3.91a	288.9a	85.04a	2.65a	16.19a
1.125	373.00b	2.47b	4.16a	309.1b	85.68a	2.72b	15.71ab
0.750	382.13a	2.49b	4.10a	303.7b	87.61b	2.81c	15.35b

[a] Values are averages for the extrudates produced using corn from Nebraska, Illinois, and Texas. BD = bulk density of wet extrudate; VEI = volumetric expansion index; BS = breaking strength; SME = specific mechanical energy; Cook = degree of cook of extrudate; WAI = water absorption index of dried extrudate; WSI = water solubility index of dried extrudate.
[b] Values followed by the same letter in the same column are not significantly different ($P < 0.05$).

than extrudates from the hammer-milled or pin-milled corn. Pin-milled corn produced an extrudate with significantly higher BD, degree of cook, and WSI when compared with extrudates from hammer-milled or roller-milled corn.

Hammer-milled corn produced extrudates with significantly higher BS followed by roller-milled and pin-milled corn samples. Pin-milled corn produced extrudates with significantly higher WAI than extrudates from roller-milled or hammer-milled corn. This generally follows the degree of starch damage that occurred during grinding of corn (Table II).

Commercial corn from NE produced extrudate with a significantly lower BD when compared with extrudates produced using the same sample ground to coarse or fine particle size (Table VIII). Medium- or fine-ground corn produced an extrudate that had a significantly higher VEI with higher SME than extrudates from coarse-ground samples. Corn particle size had no significant effects on the extrudate BS. Fine-ground corn produced an extrudate with a significantly higher WAI than extrudate from medium- or coarse-ground corn. Fine-ground corn produced an extrudate with a significantly lower WSI than extrudate from coarse-ground corn.

CONCLUSIONS

Corn samples obtained from different parts of the country resulted in different extrusion properties, even though grinding and extrusion parameters were held constant. Results also showed that the use of different mills to grind the corn affected the extrusion properties of corn, even when the corn and extrusion parameters were held constant. Particle size of the grits was an important variable, even though the corn, type of mill, and extrusion parameter were held constant.

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LITERATURE CITED

Alvarez-Martinez, L., Kondury, K. P., and Harper, J. M. 1988. A general model for expansion of extruded products. J. Food Sci. 53:609-615.

American Association of Cereal Chemists. 1995. Approved Methods of the AACC, 9th ed. Method 08-12 approved April 1961, revised October 1981, reviewed October 1994; Method 30-10 approved April 1961, revised October 1975 and October 1981, reviewed October 1994; Method 44-15A approved October 1975, revised October 1981 and October 1994; Method 46-13 approved October 1976, revised October 1986, reviewed October 1994; Method 76-31 approved January 1995. The Association: St. Paul, MN.

Faubion, J. M., and Hoseney, R. C. 1982a. High-temperature short- time extrusion cooking of wheat starch and flour. I. Effect of moisture and flour type on extrusion properties. Cereal Chem. 59:529-533.

Faubion, J. M., and Hoseney, R. C. 1982b. High-temperature short-time extrusion cooking of wheat starch and flour. II. Effect of protein and lipid on extrudate properties. Cereal Chem. 59:533-537.

Hoseney, R. C., ed. 1994. Principles of Cereal Science and Technology. 2nd ed. Am. Assoc. Cereal Chem.: St. Paul, MN.

Mason, W. R., and Hoseney, R. C. 1986. Factors affecting the viscosity of extrusion-cooked wheat starch. Cereal Chem. 63:436-441.

Meuser, F., Pfaller, W., and Van Lengerich, B. 1987. Technological aspects regarding specific changes to the characteristic properties of extrudates by HTST-extrusion cooking. Pages 35-53 in: Extrusion Technology for the Food Industry. C. O'Connor, ed. Elsevier Applied Science: New York.

Van Lengerich, B. 1990. Influence of extrusion processing on in-line rheological behavior, structure, and function of wheat starch. Pages 421-471 in: Dough Rheology and Baked Product Texture. H. Faridi and J. M. Faubion, eds. Van Nostrand Reinhold: New York.

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