Factors Affecting Expansion of Corn Meals with Poor and Good Expansion Properties[1]

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ABSTRACT

Two corn meals, one with good and one with poor expansion properties, were used to study the critical factors responsible for poor expansion during corn curl extrusion. Screening tests revealed that the corn meal with poor expansion had a slightly larger particle size. This sample also had a larger proportion of opaque particles compared to the corn meal with good expansion. Extrusion of coarse corn grits showed that larger particle size alone could cause poor expansion. Water diffusion tests showed that the sample containing more opaque particles was more competitive for water. As a result, in corn that contained both opaque and vitreous particles less water was available to the vitreous particles. The underplastisized (dry) vitreous particles remained glassy (unmelted) during extrusion, resulting in reduced expansion of the extrudates. The results suggest that addition of water to the conditioning cylinder of the extruder would overcome poor expansion.

Extrusion technology has been used in the cereal grain industry for years. The engineering involved in this technology is relatively advanced, as indicated by diverse extruder designs, screw configurations, dies, automation, and other features. However, studies of raw materials and their effects on extrusion are limited. There is a great demand in the food industry for a better understanding of raw material properties and how they affect performance during extrusion.

Corn is used widely to produce extruded snack foods (e.g., corn curls). The quality of corn curls can be evaluated by their expansion properties. To determine expansion, Alverez-Martinez et al (1988) used three calculated indices: longitudinal expansion (LEI), sectional expansion (SEI), and volumetric expansion (VEI). LEI and SEI provided information about axial and radial expansion of extrudate at the die, whereas VEI (LEI × SEI) provided information about overall expansion.

Corn endosperm contains discrete protein bodies and a matrix protein (Hoseney 1994). The protein bodies are mainly prolamins (zein). Approximately 44% zein and 17% cross-linked zein occur in corn endosperm on a weight basis (Robutti et al 1974). Zein is soluble in alcohol, whereas cross-linked zein is soluble in alcohol plus mercaptoethanol. Cross-linked zeins are polypeptides cross-linked by disulfide bonds.

Most studies of protein behavior during extrusion are related to soy protein because of its wide use in manufacturing meat analogs. Faubion et al (1982) reported that addition of soy protein isolate (up to 8%) to wheat starch caused an increase in expansion, whereas similar levels of added wheat gluten caused a reduction in expansion. Martinez-Serna and Villota (1992) observed a 30% decrease in extrusion expansion with the addition of 10% whey protein isolate to corn starch. No reports on the effects of varying the amount or type of corn protein on corn curl expansion were found.

Under normal extrusion conditions, the high molecular weight amylopectin (AMP) in corn meal is fragmented, as shown by gel filtration chromatography (Wen et al 1990). This decrease in AMP size ranges from 17 to 60%, depending on the moisture content of dough and the screw speed of the extruder.

Starch amylose (AM) and AMP contents have a marked impact on extrusion expansion. Waxy corn has superior expansion properties compared to other corn types (Mercier and Feillet 1975). On the other hand, high AM corn has very poor expansion properties (Bhattacharya and Hanna 1987).

De Muelenaere and Buzzard (1969) extruded degermed corn grits (low lipid content) and whole corn meal (high lipid content) and found that degermed corn grits had much greater expansion capabilities than whole corn. However, other factors, such as fiber (bran), confounded these results.

Information on the effect of raw material properties on extrusion performance is limited, especially for corn. Factors such as protein, lipid, and endosperm characteristics have not been studied. The objective of this study was to determine what raw material factors cause certain corn meals to expand poorly in extrusion processing.

MATERIALS AND METHODS

Corn Meals

Two corn meals were used in this study, one with good expansion (VEI = 10) and one with poor expansion (VEI = 7) under normal extrusion conditions. The corn meal with good expansion was obtained from ConAgra (Omaha, NE) and had a protein content (N × 6.25) of 6.42% and a lipid content of 0.13% (both at 14% moisture basis [mb]). This corn meal was used as the control and designated as good corn meal or corn meal 1. The corn meal with poor expansion (corn meal 2) was obtained from Frito-Lay (Dallas, TX) and had a protein content of 6.85% and lipid content of 0.28% (both at 14% mb). The small variation in protein level was assumed not to affect expansion, and the percent lipid was far below the 3% level, which may cause poor expansion (P. Neumann, *personal communication*).

Corn Grits

Corn grits (large particle) were obtained from Crete Mills (Crete, NE). The grits had a moisture content of 11.4%, protein content of 7.5%, and lipid content of 0.7% (both at 14% mb). A second sample of corn grits was obtained from Illinois Cereal Mills (Paris, IL).

Protein Distribution

The distributions of protein classes in the two corn meals were determined by the stepwise method of solvent extraction described by Robutti et al (1974). The purpose was to determine whether corn meal 2 contained more cross-linked zein than corn meal 1.

Particle Size Analysis

Particle sizes of corn meals and grits were determined with a Ro-Tap sifter (W. S. Tyler Co., Cleveland, OH) with a series of sieves.

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A 100-g sample was sifted for 5 min. The overs on each sieve were weighed and expressed as the percent total weight.

Extrusion

High-temperature short-time extrusion cooking was conducted with a twin-screw model TX-52 extruder (Wenger Manufacturing, Sebatha, KS) with a screw setup for corn curl production recommended by the manufacturer. Extruder conditions were 1,226 g/min (dry basis) feed rate; 200 rpm conditioning cylinder speed; 375 rpm extruder screw speed; 72.6g/min extruder water flow rate; and temperature settings of 45°C at heads 2 and 3, 55°C at head 4, 95°C at head 5, and 75°C at head 6. The die plate had one die insert with three 3.9-mm holes. The extruder was allowed to warm-up for 20 min with warm-up meal and to stabilize for 10 min with treatment meal before data collection. The expansion indices of extrudates were determined by the method of Alvarez-Martinez et al (1988).

Water Vapor Absorption

Two narrow particle size ranges (501–593 and 594–704 mm) were obtained from each of the two corn meals by sieving as described above. A 2-g sample from each particle size range was placed in a desiccator maintained at 97.3% rh with saturated K_2SO_4 solution. The weight gain of the sample was recorded at 1-hr intervals for 44 hr. Water vapor absorption was determined as the weight gain of the sample and expressed as milligrams of uptake per gram of sample (as is basis). The as is sample weight was used because moisture contents of the two corn meals were similar (13.7% for corn meal 1 and 13.3% for corn meal 2).

Liquid Water Diffusion

A 10-g sample from each particle size range was placed in a glass jar, and water was added to bring the sample to 18% moisture. The jar was sealed and hand-shaken to achieve even moisture distribution. Small portions (≈1 g) of the sample were collected every 3 min, and their water activity (a_w) was measured by a Decagon (Pullman, WA) CX-1 water activity meter. The a_w was expected to decrease after water was added and eventually become constant when liquid water diffusion was completed and the system reached equilibrium.

Particle Size and Tempering

Coarse particle grits (Crete Mills) were ground into flour (fine particle) with a comminutor (Fitzpatrick Co., Elmhurst, IL) equipped with a 508-mm screen. After grinding, the moisture content (mc) of the fine particle sample was 10.7%. Both the coarse parent particles and the resulting fine particles were tempered to 18% mc at room temperature for 22 hr. This design produced four treatments: coarse and untempered, fine and untempered, coarse and tempered, and fine and tempered. For the untempered samples, water was added at the extruder barrel to bring the grits to 18% mc. Paired comparisons among these treatments provided information on particle size and tempering effects. The four samples were extruded, and their expansion indices were determined.

In a separate investigation, a second sample (Illinois Cereal Mills) of coarse corn grits (12.1% mc) was studied over a series of tempering times (all tempering moistures were targeted at 18%). The tempering times were 20 sec (water addition at the extruder barrel), 2 min (water addition at the conditioning cylinder), 30 min, 60 min, and 120 min. For tempering times of 20 sec and 2 min, water was added by the water pump, and the amount of added water was measured by a flow meter. For tempering times of 30, 60, and 120 min, a 18.16-kg sample of grits was mixed in a Wenger mixer, while water was sprayed on the sample with a spray jar. After water was added, mixing was continued for another 5 min to promote uniform water distribution. Samples were sealed in plastic bags and held for an appropriate length of time. After

TABLE I
Protein Distribution of Two Corn Meals (% total protein)

Corn Meal	W + S[a]	EtOH[b]	ME[c]	SDS[d]	Residue	Recovery (%)
1	3.8a[e]	47.0a	12.2a	33.2a	0.1a	96.3
2	5.1b	41.0b	12.5a	35.4b	0.2a	94.2

[a] W = water for extraction of albumin, S = salt solution (0.5*M* NaCl) for globulin.
[b] Ethanol (70%, v/v) with 0.5% Na acetate (w/v) for zein (prolamin).
[c] Mercaptoethanol (0.6%, v/v) in a Na_2CO_3-$NaHCO_3$, pH 10, buffer for cross-linked zein.
[d] Sodium dodecyl sulfate (0.5%, w/v) in a Na_2CO_3-$NaHCO_3$, pH 10, buffer for glutelin.
[e] Means followed by different letters in a column are significantly different ($P < 0.05$).

TABLE II
Particle Size Distribution (%) of Two Corn Meals

	U.S. Sieve (µm)				
Corn Meal	No. 20 (841)	No. 30 (594)	No. 40 (420)	No. 50 (297)	Pan
1	0	31.8	66.4	1.4	0.4
2	0	42.7	55.2	1.5	0.6

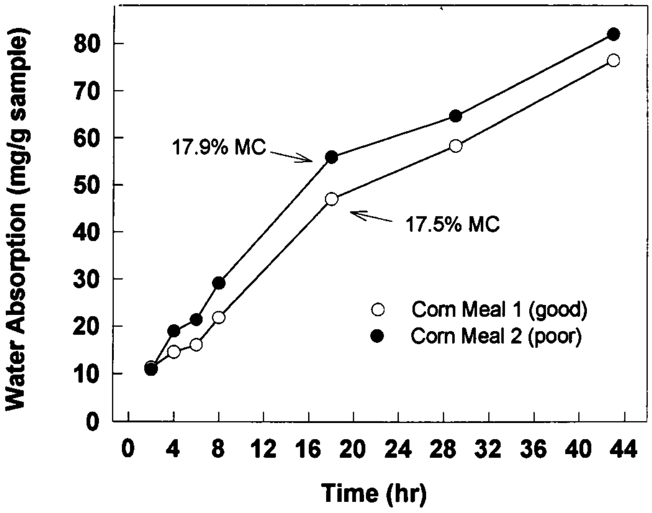

Fig. 1. Water vapor absorption (97.3% rh) of two corn meals with a particle size range of 501–593 µm.

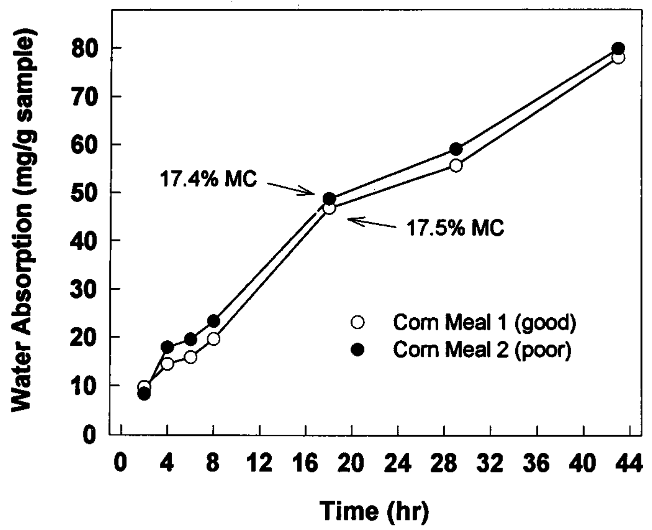

Fig. 2. Water vapor absorption (97.3% rh) of two corn meals with a particle size range of 594–704 µm.

tempering, the samples were extruded, and the resulting expansion was determined.

Statistical Analysis

Statistical results were obtained using SAS procedures (SAS Institute, Cary, NC). Results, including protein distribution data and VEI values, were analyzed by analysis of variance. Duncan grouping was applied to compare means for VEI values.

RESULTS AND DISCUSSION

Visual Examination of Corn Meals and Their Products

Visual examination revealed that corn meal 2, which had poor expansion properties, had a larger number of opaque particles than corn meal 1, which had good expansion properties. In preliminary experiments, a dye was added to determine the amount of time the material spent in the extruder. Corn meal 1 and the continuous part of corn meal 2 had a pink color that was caused by the dye. However, with corn meal 2, the extrudate had small discontinuous yellow particles throughout the pink background, indicating the corn particles were not melted completely during extrusion. The particles may have been too large and, thus, not completely hydrated during extrusion.

Protein Distribution

Corn samples containing more high molecular weight (MW) protein fractions might produce a stronger protein network that would increase the viscosity of the extruding material at the die compared to corn samples containing less of those protein fractions. This would result in higher resistance to expansion and, therefore, reduced expansion. The yields of protein by solubility classes for the two corn meals are shown in Table I. The high MW cross-linked zein fraction of corn meal 2 was not significantly different from that of corn meal 1. Although the glutelin component of the poor corn meal was statistically higher than that of the good corn meal, the difference was quite small (2.13 vs. 2.42% on 14% mb, calculated based on percent distribution and total percent protein). Based on these results, protein distribution appears unlikely to be the factor responsible for observed differences in expansion.

Particle Size of Two Corn Meals

The particle size distribution of the two corn meals is shown in Table II. Corn meal 2 had a larger particle size (11% more on the no. 30 sieve) than corn meal 1. The presence of these larger particles could be a factor that caused poor expansion. During corn curl extrusion, water was added in the extruder barrel, but the meal remained in the barrel for only 20 sec during processing. If particle size was too large, this retention time may have been too short to allow water to completely penetrate the particles. Thus, the large particles may have remained in a hard (glassy) state because of incomplete plasticization by water and may have failed to melt (or become plastic) and remained as intact particles in the final product.

Water Vapor Absorption

Water vapor absorption curves for two particle size fractions sieved from the two corn meals are shown in Figs. 1 and 2. Approximately 18–20 hr were required for the samples to reach 18% mc by vapor absorption. The poor corn meal had a higher vapor absorption rate than the good corn meal. A decrease in particle size enhanced the difference in vapor absorption between the two corn meals.

Liquid Water Diffusion

Plots of a_w versus time (a liquid water diffusion test) are shown in Figs. 3 and 4. The time required for these systems to reach equilibrium was ≈30 min, much shorter than the times required by vapor absorption (20 hr). Therefore, we concluded that liquid diffusion played a major role in tempering, whereas vapor absorption made only a minor contribution and could be ignored.

Approximately 20–25 min was required for liquid water diffusion to reach equilibrium (Figs. 3 and 4) for the smaller (501–593 mm) particle system and 30 min for the larger (594–704 mm) particle system. In addition, corn meal 2 had a lower a_w than did its counterpart (corn meal 1) throughout the course of diffusion. This was probably due to the large number of opaque particles present in the poor corn meal. Opaque particles have a porous structure that can act as capillaries. Concave liquid surfaces may form in these capillaries and decrease vapor pressure (Aberty 1983). As a result, opaque particles absorbed more water, leaving less water available for the vitreous particles in the sample. The vitreous particles were less plasticized by water, remained in a hard (glassy) state, and did not melt (become plastic) during extrusion but passed through the extruder unchanged, resulting in poor expansion.

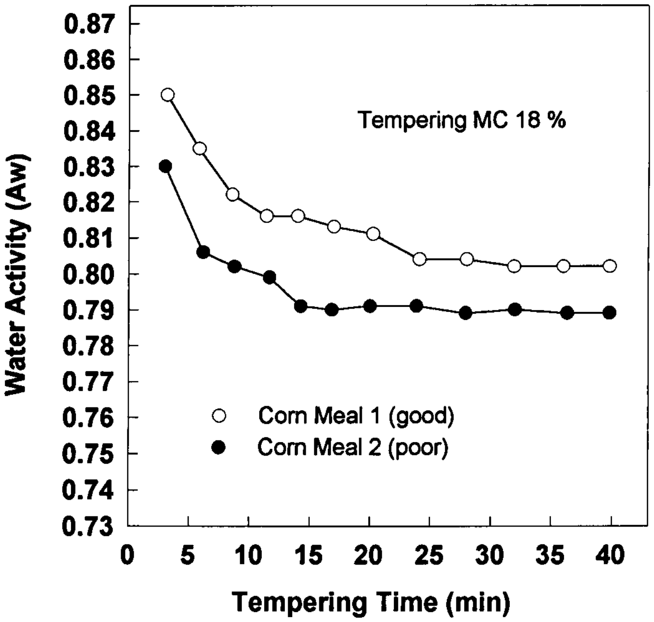

Fig. 3. Changes in water activity (a_w) during tempering of two corn meals with a particle size range of 501–593 µm. MC = moisture content.

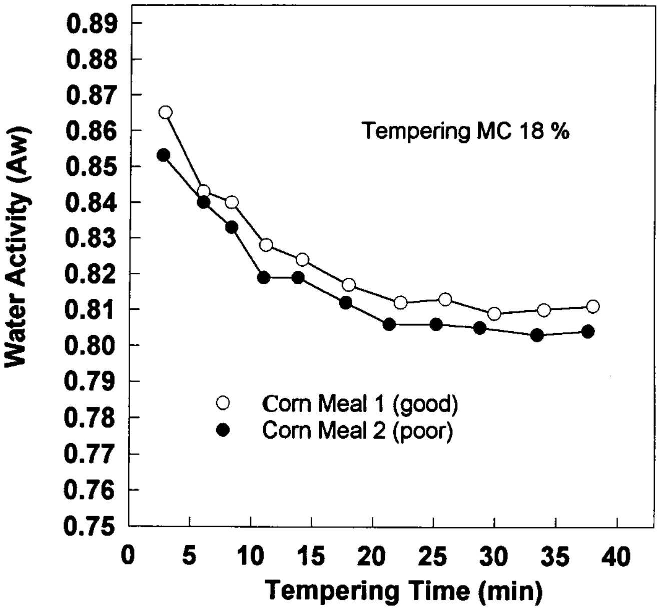

Fig. 4. Changes in water activity (a_w) during tempering of two corn meals with a particle size range of 594–704 µm. MC = moisture content.

Particle Size and Tempering Effects

The particle size distributions of the corn grits and flour were quite different (Table III). In general, the particle size of the corn grits was larger than 420 mm, with 65% of the population in the range of 841 to 1,410 mm. Corn flour had particle sizes smaller than 420 mm.

The expansion results showed that the VEI of the coarse and untempered sample (4.03) was significantly ($P < 0.05$) smaller than that of the fine and untempered sample (12.63). The extrudate of the coarse and untempered sample also had small unmelted (nonplasticized) corn grits in the product, as was seen with corn meal 2, confirming that particle size was an important factor, and large particle size alone could cause poor expansion. The poor expansion of corn meal 2 may have been caused, at least partially, by its larger particle size relative to control corn meal 1. However, the particle size of the grits was much larger than that of the poor meal (comparison of Tables II and III).

The coarse and tempered sample had a significantly larger VEI (15.90) than the coarse and untempered sample (4.03, Table III). This was true even though both samples were extruded at 18% mc. The difference in tempering time was from 20 sec (water added at extruder barrel) to 22 hr. Therefore, tempering was an effective means of overcoming the expansion problem of corn meal with larger particle sizes. Moreover, it supports the hypothesis of incomplete water diffusion into large particles. The coarse and tempered sample had a larger VEI (15.90) than the fine and untempered sample (12.63), suggesting that more uniform moisture absorption was beneficial for good expansion.

The extrusion conditions for corn grits and its flour are shown in Table IV. The motor load required by the coarse and tempered grits (47%) was much lower than that (62%) for the fine and untempered sample, suggesting tempering might be a more economical choice than size reduction, especially if the energy used in milling is considered. The pressure at the sixth head and die for the coarse and untempered grits was lower than that for the other treatments (Table IV). This is explained by incomplete water absorption by some larger particles that resulted in more water being available to the melted (plasticized) part and decreasing the viscosity of the plastic melt at the die, resulting in decreased pressure.

The effects of tempering time on expansion are shown in Fig. 5. Extrudates with a tempering time of 30 min possessed the largest VEI (≈13). Adding water at the conditioning cylinder (2 min retention) produced an extrudate with VEI = 9. This was close to VEI = 10, which is ideal for subsequent drying operations (P. Neumann, *personal communication*). Extruded curls with a VEI > 10 may have a weak structure and be susceptible to breakage during transport and drying. Because the corn grits used in this study had larger particle sizes than the corn meal normally used for corn curl production, we concluded that poor expansion could be corrected by addition of water in the conditioning cylinder instead of the conventional addition of water in the extruder barrel. These results also show that the tempering time (25–30 min), estimated by a_w measurement, was fairly reasonable (Figs. 3 and 4).

As tempering time increased, the pressure at the sixth head and die increased (Table V). It was not clear what caused this increase. However, expansion after 120 min of tempering was lower (VEI = 9.6) than that after 30 min of tempering (VEI = 13). If materials being extruded were fully melted and, therefore, homogeneous, expansion appeared to be controlled by a balance between material viscosity at the die and pressure drop across the die. Materials with high viscosities require high pressure for an ideal expansion and vice versa. If high viscosity combines with low pressure, the result will be reduced expansion. If low viscosity combines with high pressure, air cells will rupture easily and result in poor expansion.

TABLE III
Particle Size Distribution (%) of Corn Grits and Flour

	U.S. Sieve (µm)						
Sample	**No. 14 (1,410)**	**No. 20 (841)**	**No. 30 (594)**	**No. 40 (420)**	**No. 50 (297)**	**No. 60 (250)**	**No. 100 (150)**
Grits	65.0	31.0	1.0	…	…	…	0.5
Flour	…	…	0.8	42.3	4.3	26.4	26.2

TABLE IV
Extrusion Results for Tempered and Untempered Coarse and Fine Particle Corn Grits

	Coarse		Fine	
Variable	**Untempered**	**Tempered**	**Untempered**	**Tempered**
VEI[a]	4.03	15.90	12.63	15.79
Motor load (%)	43	47	62	52
Zone temp.[b] (°C)				
Second head	32	30	31	32
Third head	32	30	31	32
Fourth head	60	62	61	60
Sixth head	123	128	122	130
Die	125	129	121	131
Pressure (MPa)				
Sixth head	7.585	9.308	9.653	9.653
Die	6.895	7.992	8.066	8.618

[a] Volumetric expansion index.

[b] Data for the fifth head not available because of malfunction of thermocouple.

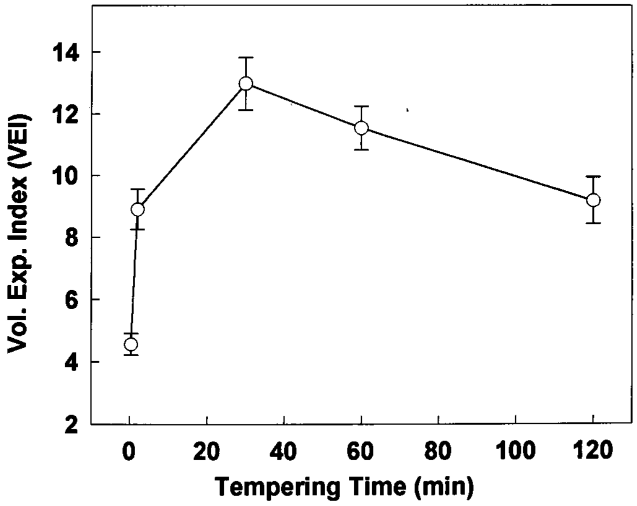

Fig. 5. Effect of tempering time on extrudate expansion of corn grits.

TABLE V
Extrusion Conditions of Corn Grits Used to Study Optimum Tempering Time

	Tempering Time				
Variable	**20 sec**	**2 min**	**30 min**	**60 min**	**120 min**
Motor load (%)	52	50	57	55	52
Zone temp. (°C)					
Second head	24	25	26	24	25
Third head	24	25	26	24	25
Fourth head	43	41	34	36	39
Fifth head	95	95	95	95	95
Sixth head	130	130	130	30	130
Die	155	151	151	159	159
Pressure (MPa)					
Sixth head	7.585	7.585	8.274	8.274	8.826
Die	7.585	7.585	7.585	7.585	8.826

CONCLUSIONS

The small differences in protein and lipid content of the corn meals with poor and good expansion properties were assumed not to be responsible for their different extrusion properties. The difference in distribution of protein classes between the two samples also was small and, therefore, was considered unlikely to be responsible for the differences in extrusion properties.

The corn meal that produced a poorly expanded corn curl had a larger particle size combined with a larger number of opaque particles. Large particle size alone caused poor expansion; however, the difference in particle size between the good and poor corn meals was relatively small and not completely responsible for the difference in expansion. The poor meal also had a larger number of opaque particles. The small voids in opaque endosperm act as capillaries and lower the a_w of the meal plus water. As a result, less water was available for hydration of the vitreous particles. In the limited time available, this left those particles insufficiently plasticized by water. The particles did not melt during extrusion and retained their original state in the final product. The presence of unmelted vitreous particles resulted in poor expansion.

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