Relationship Between Amylose Content and Extrusion-Expansion Properties of Corn Starches[1]

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ABSTRACT

Corn starches with 0–70% amylose contents (db) were extrusion cooked at different temperatures and moisture contents. The product quality measures of expansion ratio, shear strength, and bulk density were studied in relation to starch amylose contents. The expansion ratio of starch increased from 8 to 16.4 as amylose content increased from 0 to 50% (db), and then decreased. Low- and high-amylose starches mixed to obtain various amylose levels and pure amylose/amylopectin mixes showed expansion property patterns similar to native corn starches but with lower expansion ratios (9.9–11.4). Different native corn starches had different optimum temperatures for expansion, i.e., 130°C for 0% amylose, 140°C for 25% amylose, 150°C for 50% amylose, and 160°C for 70% amylose starch. Overall, the highest expansion (16.4) was obtained with 50% amylose starch at 150°C. All starches had a uniform moisture content optimum of 13–14% (db) for maximum expansion. The bulk density of the extrudates decreased with increased amylose contents of starches. In contrast, shear strength of starch extrudates increased with amylose content of starch but decreased with expansion ratio.

Expanded snack foods, ready-to-eat cereals, and dry pet foods are manufactured from cereals and starches by high-temperature short-time extrusion cooking. Quality of such expanded foods is judged from their crispness, which in turn is determined by their expanded volume. Expanded volume of cereals and starches is generally governed by extrusion cooking parameters such as extruder barrel temperature, screw speed, diameter of the die-nozzle orifice, and moisture content of the feed material (Anderson et al 1969, 1970; Mercier and Feillet 1975; Meuser et al 1982; Davidson et al 1985; Owusu-Ansah et al 1983; Chinnaswamy and Hanna 1987a,b), as well as the protein (Faubion et al 1982, Peri et al 1983), lipid (Mercier et al 1980, Colonna and Mercier 1983), and starch (Anderson et al 1969, 1970; Mercier and Feillet 1975; Kim and Rottier 1980) composition of the feed materials.

Expanded volumes of cereals and starches decrease with increasing amounts of proteins (Faubion et al 1982, Peri et al 1983) or lipids (Mercier et al 1980, Linko et al 1981) in the feed material, but increase with increasing starch content (Linko et al 1981). Further, it has been reported that among different types of starches, only a few types expand better than the others (Mercier and Feillet 1975). Thus, it appears that starch content and quality factors (amylose and amylopectin) most significantly affect expansion properties. However, the relations of starch qualities to expansion properties are not completely understood.

Mercier and Feillet (1975) observed that starches with low- (waxy) and high-amylose contents expand best at 135 and 225°C, respectively. Bhuiyan and Blanshard (1982), however, reported that corn flours and grits with a 35% amylose content expand best. In contrast, Bhattacharya and Hanna (1988) recently reported that waxy corn starch expands better than normal corn starch. Thus, the effect of quality factors on expansion of starches is still not clear. The objective of this systematic study was to understand the effect of amylose and amylopectin on the expansion properties of corn starches and to determine whether expansion volume of starch varieties that expand poorly could be increased by altering extrusion cooking conditions.

MATERIALS AND METHODS

Starch

The corn starches used in this study, waxy (0% amylose), normal (25% amylose), amylomaize V (50% amylose), and amylomaize VII (70% amylose), were provided by American Maize Products Company, Hammond, IN. The proximate compositions of the corn starches including their amylose contents were supplied by the manufacturer (Table I). These starches henceforth will be referred to by their respective amylose contents, i.e., 0% amylose starch for waxy, 25% amylose starch for normal corn starch, and so on. Pure amylose and amylopectin (both prepared from corn) were purchased from Sigma Chemical Company, St. Louis, MO. The starch powders were granulated before extrusion. The desired moisture contents of 10–30% (db) of the samples were adjusted by blending with distilled water. All experiments were conducted with samples having 14% (db) moisture content unless otherwise mentioned in the text.

Starch Blends

To simulate the amylose contents of native starches, the different native corn starches (0, 25, 50, and 70% native amylose starches) were mixed in the appropriate ratios to result in overall mixture amylose levels of 10–65% (db). Four blends were prepared: blend I from the 0 and 70% amylose native starches; blend II from the 0, 25, and 70% amylose native starches; blend III from the 0, 50, and 70% amylose native starches; and blend IV from the 0, 25, 50, and 70% amylose native starches. Within each blend, starch samples with amylose levels of 10, 25, 50, and 65% (db) were prepared. These samples will be referred to in the text as a 10% amylose blend, 25% amylose blend, and so on. The exact percentages of the various native starches mixed to attain these amylose levels are given in Table II.

Amylose and Amylopectin Mixes

To see the effect of linear amylose on expansion properties, pure amylose and amylopectin (both prepared from corn) were mixed to

TABLE I
Composition of Various Corn Starches[a]

	Starch Sample			
Component	Waxy	Normal	Amylomaize V	High Amylose VII
Amylose, % (db)	0	25	50	70
Protein, % (db)	0.2	0.3	0.5	0.8
Phosphorous, mg/100 g	4.2	14.0	22.8	19.1
Fat, g/100 g	0.1	0.1	0.4	0.3
Ash, g/100 g	0.1	0.2	0.1	0.1
Moisture, % (db)	10.6	9.5	11.0	10.6

[a] Manufacturer's specifications.

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result in 0, 25, 50, 75, and 100% pure amylose levels in the mixtures. These samples are referred to as pure amylose or pure amylose/amylopectin mixes in the text.

Starch Mixes

To study the effect of starch types, irrespective of their final amylose levels, 25, 50, and 70% amylose native starches were mixed on a dry weight basis with 0% amylose native (waxy) starch. Starch mixes were made by mixing 25% native amylose and 0% native amylose starch, 50% native amylose and 0% native amylose starch, and 70% native amylose and 0% native amylose starch. Within each of these mixtures there was a subset of four samples, i.e., 25, 50, 75, and 100% content of the respective nonwaxy starch. These samples are referred to as either a nonwaxy starch or a 25% amylose starch mix when 25% native amylose starch was mixed, and 50% amylose starch mix when 50% native amylose starch was mixed, etc.

All starch blends, pure amylose/amylopectin mixes, and starch mixes were adjusted to 14% (db) moisture before extrusion.

Extrusion

A C. W. Brabender laboratory extruder (model 2802) with a 1.90-cm barrel diameter and a 20:1 ratio of barrel length to diameter was used. The extruder screw had a compression ratio of 3:1. The barrel temperatures of the compression and die sections were either held at 140°C or varied from 110 to 200°C when desired, while the feed section was held constant at 80°C. Starch samples were fed at a rate of 60 g/min, keeping the screw speed constant at 160 rpm (Chinnaswamy and Hanna 1987b). The die-nozzle diameter was 3 mm.

Expansion Ratio

Expansion ratios of the extrusion-cooked starches were calculated by dividing the average cross-sectional area of the extrudates by the cross-sectional area of the die-nozzle orifice. Each value was an average of 10 readings. In general, the expansion ratio values were highly reproducible. For example, 25% amylose starch, which was processed on several occasions for different studies, gave a mean expansion ratio of 13.54 with a coefficient of variation (C.V.) of 2.8 ($n = 37$).

Shear Strength

Dry strands of extruded products were placed across the width of an Allo-Kramer shear cell (model 500-412D). The force required to shear the product was recorded with an Instron universal testing machine (model TM). Shear stress was calculated by dividing the shear force by the total cross-sectional area of the extrudate sheared. Each value was an average of five readings.

Bulk Density

Thirty grams of the extrudate, ground in a Wiley mill (standard model no. 3) to pass through a no. 6 sieve but not through a no. 14 sieve, were placed in a graduated cylinder and tapped lightly 30 times. The product density was obtained by dividing the mass of the sample by the final volume. Each value was an average of duplicate readings.

RESULTS AND DISCUSSION

Effect of Amylose Content

Amylose contents and proximate composition of the corn starches are given in Table I. The starch amylose contents ranged from 0 to 70% (db). Residual protein content, as well as the phosphorous content of some corn starches, increased with increasing amylose content of starch.

All corn starches were extruded under the optimal conditions specified by Chinnaswamy and Hanna (1987b): 140°C barrel temperature, 160 rpm screw speed, and 60 g/min feed rate. The relationship between expansion ratio and amylose content of native starches is shown in Figure 1. The physical characteristics of typical extrudates are exemplified in Figure 2. The expansion ratio of the different native starches varied from 7.0 to 16.4. Expansion ratio initially increased from 8.3 to 16.4, as amylose content of native starch increased from 0 to 50%, and then decreased sharply. The blended starch samples (constituted by blending native starches to achieve amylose levels of 10–65% [db]) showed trends similar to those of the native starches when they were extruded under optimal conditions, but with much lower expansion ratios as shown in Figure 1. Mercier and Feillet (1975) observed in a similar experiment that the expansion ratio of a 50% amylose blended starch was lower than the expansion ratio of 50% amylose native starch. The maximum expansion ratio obtained with the 50% amylose blended starch samples, for example, was 11.8, which was far lower than the corresponding expansion ratio of 16.4 for 50% amylose native starch. The differences in expansion ratios for blended starch samples and native starches at the same amylose levels show that amylose content alone was not controlling the expansion of the starch. Amylose did, however, have some influence on starch extrusion expansion, as the optimum amylose content for greatest expansion remained at 50% (db) for all the

TABLE II
Blending of Starches

Amylose Content of Blended Starch (%, db)	Blend Type	Proportion of Native Starches in the Mixture (%)[a,b] 0	25	50	70	Expansion Ratio[c]
10	I	85.7	···	···	14.3	5.6
	II	79.3	10.0	···	10.7	6.2
	III	82.9	···	10.0	7.1	7.3
	IV	76.4	10.0	10.0	3.6	9.0
25	I	64.0	···	···	36.0	8.6
	II	58.0	10.0	···	32.0	8.8
	III	61.0	···	10.0	29.0	9.5
	IV	55.0	10.0	10.0	25.0	9.7
50	I	29.0	···	···	71.0	9.9
	II	22.0	10.0	···	68.0	10.4
	III	26.0	···	10.0	64.0	10.8
	IV	19.0	10.0	10.0	61.0	11.8
65	I	7.1	···	···	92.9	6.5
	II	0.7	10.0	···	89.3	7.9
	III	4.9	···	10.0	85.1	9.1
	IV	2.5	5.0	5.0	87.5	6.9

[a] Percentage (db) of various native starches in the blended starch samples.
[b] Amylose contents (db) of native starches are indicated by column headings.
[c] Expansion ratios of blended starches were obtained at optimal extrusion conditions, i.e., 140°C barrel temperature and at 14% moisture content.

samples studied.

To identify more specifically the role of linear (unbranched) amylose in the expansion properties of starch, pure amylose and amylopectin (both from corn) were mixed in appropriate ratios to obtain amylose levels of 0–100% (db) and then extruded. The expansion ratios for the various pure amylose/amylopectin mixes were between 5.3 and 11.4. Interestingly, the relationship between pure linear amylose content and expansion ratio remained the same as that of native and blended starches, with maximum expansion still remaining at a level of 50% (db) (Fig. 1). However, these pure amylose/amylopectin mixes showed lower expansion ratios when compared with native starches having corresponding amylose levels (Fig. 1). The maximum expansion ratio obtained at the optimum amylose level of 50% for pure amylose/amylopectin mix was 11.4, which was very low compared with the 50% amylose native starch expansion of 16.4.

Among the blended starches, the extent of expansion varied with type or types of native starches mixed with 0% native amylose (waxy) starch (Fig. 1). The lowest expansion ratio was obtained when 70% native amylose starch (blend I) was mixed with 0% native amylose starch to obtain a 70% amylose blend. However, the expansion ratio increased by 1–3 units when the better expanding starches, i.e., 25% (blend II) or 50% (blends III and IV) native amylose starches, were mixed with 0 and 70% native amylose starches to get the desired amylose levels. These proportions are given in Table II; one can see that when the 25 or 50% amylose native starches were part of the mixture, the 70% native amylose starch concentration decreased. Thus, the differences in expansion ratios of blended starches with the same overall amylose content were due to dilution of the poorer expanding starch types, to an increase in the amount of better expanding starch types in the mixture, or both. Therefore, a separate experiment was designed with native starches, specifically to answer the above question.

This time, the native starches were mixed with 0% amylose (waxy) native starch to levels of 25–100% content by weight (db) of 25, 50, or 70% native amylose starches in mixtures irrespective of their final amylose values. The mixtures were then extruded. The results are presented in Figure 3. Among these starch samples, the expansion ratio value varied from 6.1 to 15.9. Interestingly, expansion ratio increased with an increasing amount of 25 and 50% native amylose starches in the mix but decreased with increasing amounts of 70% native amylose starch. Overall, the 50% amylose starch mix had higher expansion ratio values than the 25% amylose starch mix (Fig. 3). It is apparent that starch type, in addition to amylose content, plays an important role in determining the expansion characteristics during extrusion cooking. The data in Figures 1–3 also show that whereas the amylose content of starches has a noticeable effect on the expansion of the starch, such factors as structural differences among native starch amylose or amylopectins may also be affecting the expansion volume.

Overall, our results are in agreement with those of Mercier and Feillet (1975). Native starches having 50% amylose levels expanded best. Generally, it is reported that the expansion of corn grits (Bhuiyan and Blanshard 1982) and rice flour (De Mosqueda et al 1986) increase with increasing amylose content. It is of interest to note that Chinnaswamy and Bhattacharya (1983, 1984, 1986), in a detailed study on rice expansion, showed clearly that all high expanding rice varieties have high mean molecular weight amylopectins. It should be noted that such structural differences among corn starch amylopectins and amyloses (lightly branched)

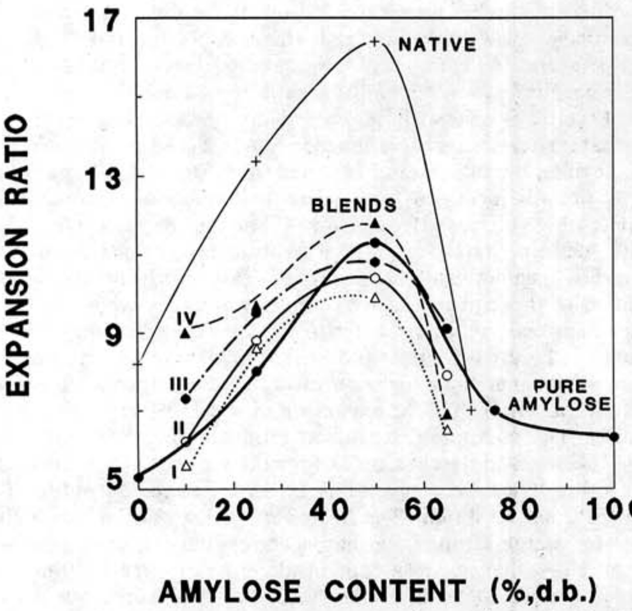

Fig. 1. Relationship between amylose content and expansion ratio of native corn starches, starch blends and pure amylose/amylopectin mixes. The starch blends were prepared as shown in Table II and are indicated in Roman numerals.

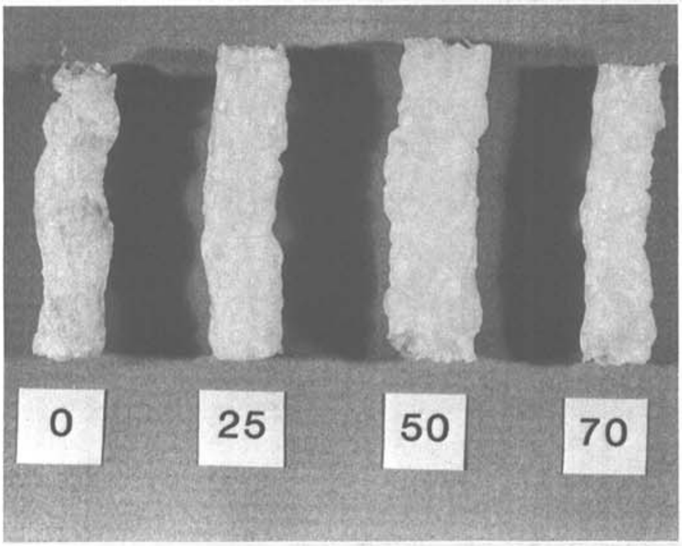

Fig. 2. Physical appearance of various native corn starch extrudates (amylose contents indicated).

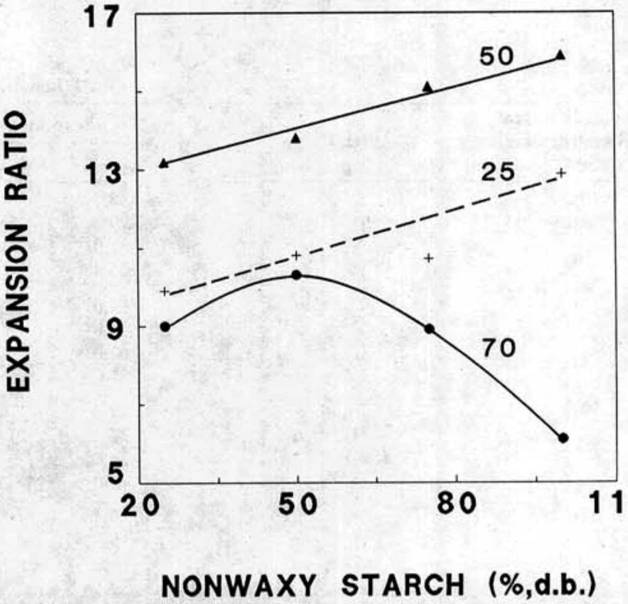

Fig. 3. Effect of nonwaxy starch on the expansion properties of starch mixes. Starch types (25, 50, and 70% amylose starches) mixed (by weight) with 0% amylose starch are indicated.

are well documented (Banks and Greenwood 1975, Young 1984). Therefore, it is reasonable to speculate that in addition to amylose content of starch, the structure and molecular weight of amylopectin are also involved in determining the expansion volume of starch. A detailed study on the structural differences among different corn starches, specifically in relation to their expansion properties, would answer this question.

Product Qualities

The relationships between amylose content and bulk density of the extruded native starches and the pure amylose/amylopectin mixes are given in Figures 4 and 5, respectively. Bulk density values ranged from 163 to 348 kg/m^2. In general, the bulk density values decreased with increasing amylose content. However, extrudates prepared from blended native starches, as well as amylose/amylopectin mixes, showed lower bulk density values than the corresponding native starches. This behavior is, more or less, similar to what we saw earlier between amylose content of starch and expansion ratios (Fig. 1). The behavior of bulk density in relation to starch amylose content may be interpreted as the higher the amylose content, the harder the extrudate, and thus the finer the grind. The reverse was true for low amylose starch extrudates. The shear strength of starch extrudate, in contrast, increased with increasing amylose content of starch (Fig. 5 and 6) but decreased with expansion ratio (Fig. 7). The shear strength of the starch extrudates ranged from 0.52 to 3.58 MPa for the native and blended starches and pure amylose/amylopectin mixes. The 100% pure amylose extrudate had the maximum shear strength (3.58 MPa). It was interesting to note that the shear strength increased exponentially when the expansion ratio value of the extrudate went below 7–8 (Fig. 7). Thus, it was apparent that the shear strength of the extrudate was affected by both amylose content and expansion ratio. Owusu-Ansah et al (1984) showed that shear strength is inversely proportional to expansion ratio, which is in agreement with our results.

Effect of Temperature

To see whether poorly expanding native starches, i.e., 0, 25, and 70% amylose native starches, could be made to expand more by altering the processing temperature, all native starches were extruded at barrel temperatures ranging from 110 to 200°C. The results are presented in Figure 8. For all native starches, the

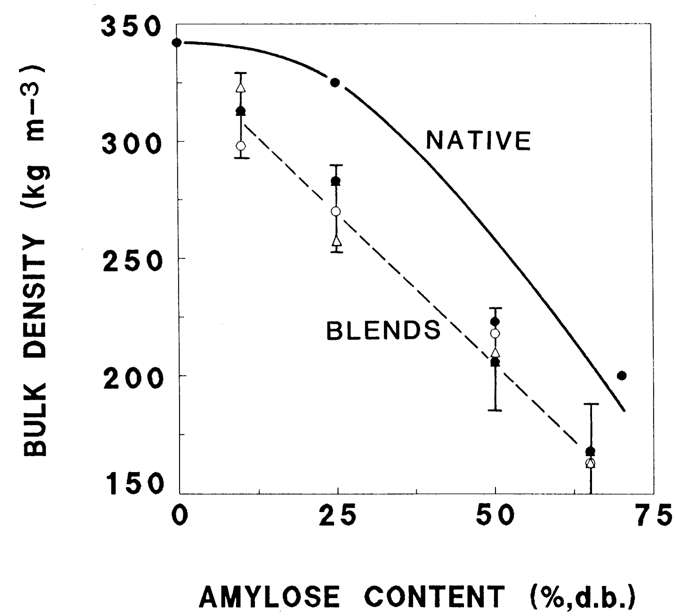

Fig. 4. Relationship between bulk densities of starch extrudates (native and starch blends) and their amylose contents.

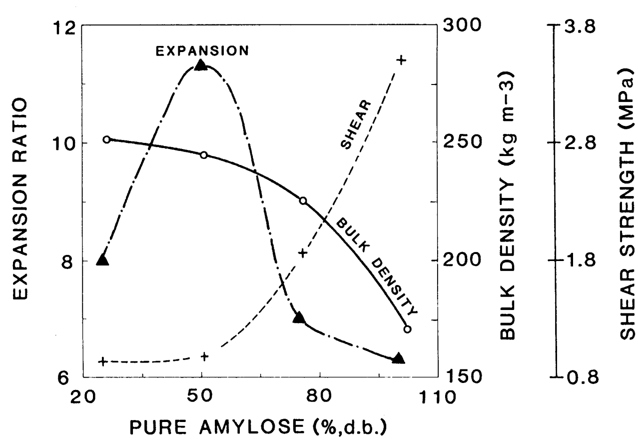

Fig. 5. Properties of various pure amylose/amylopectin extrudates.

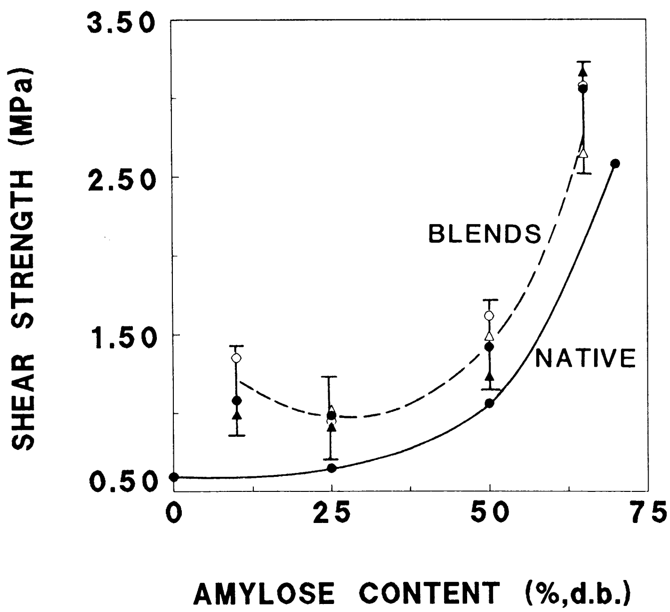

Fig. 6. Relationship between shear strength of starch extrudates (native and blends) and amylose content.

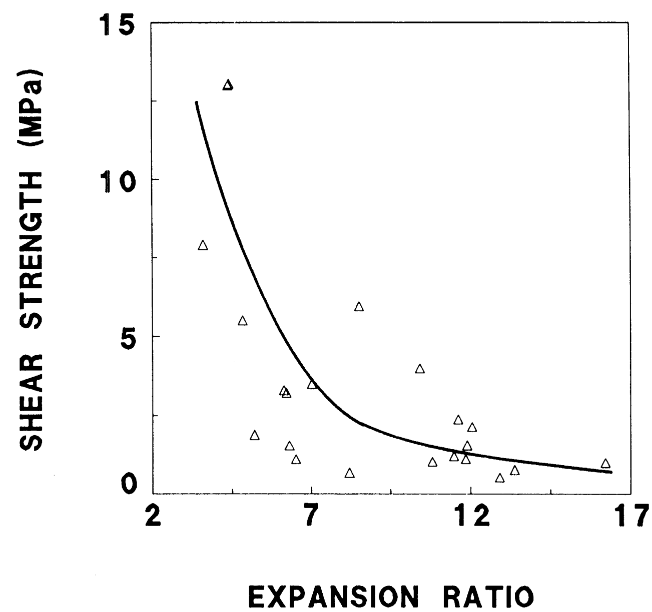

Fig. 7. Effect of expansion ratio on the shear strength of various starch extrudates (native, starch blends, mixes, and pure amylose/amylopectin mixes).

expansion ratio increased from 3.4 up to 16.4 with increasing barrel temperature. However, the maximum expansion ratio for each native starch type varied from 11.2 to 16.4 and occurred at different temperatures. The maximum expansion ratios obtained with the different native starches were 11.9 for 0% native amylose (waxy), 14.2 for 25% native amylose, 16.4 for 50% native amylose, and 11.8 for 70% native amylose starch, occurring at temperatures of 130, 140, 150, and 160°C, respectively. The overall greatest expansion (16.4) was obtained with 50% amylose native starch extruded at 150°C barrel temperature.

Extrusion temperature affects various properties of starch. Mercier and Feillet (1975) reported the appearance of a new structure similar to butanol-amylose complex at different extrusion temperatures for different starches. Launay and Lisch (1983a) observed a relationship between the viscoelastic properties of melted starch in the extruder and expansion ratio. The viscoelastic and flow properties of melted starch increased with increasing amylose contents (Launay and Lisch 1983b). Such differences in flow properties of starches could alter the residence time in the extruder and eventually their degree of gelatinization, which is known to affect expansion (Linko et al 1981). This could be a reason why our starches, with different amylose contents, expanded better at different extrusion cooking temperatures.

Shear strength of the starch extrudates prepared at different barrel temperatures are given in Figure 9. As discussed earlier, the shear strength of starch extrudate depended on both expansion ratio and amylose content. Shear strength was low for all native starches at their respective optimal extrusion temperatures for maximum expansion.

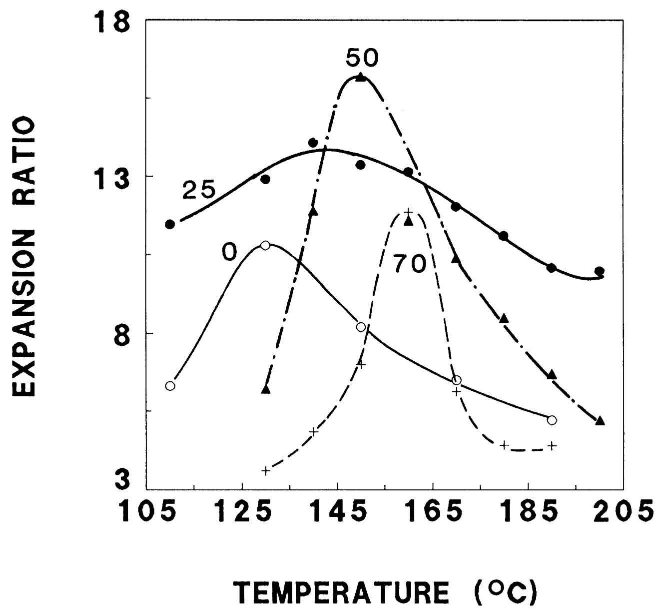

Fig. 8. Effect of extrusion temperature on the expansion properties of native corn starches (amylose contents indicated).

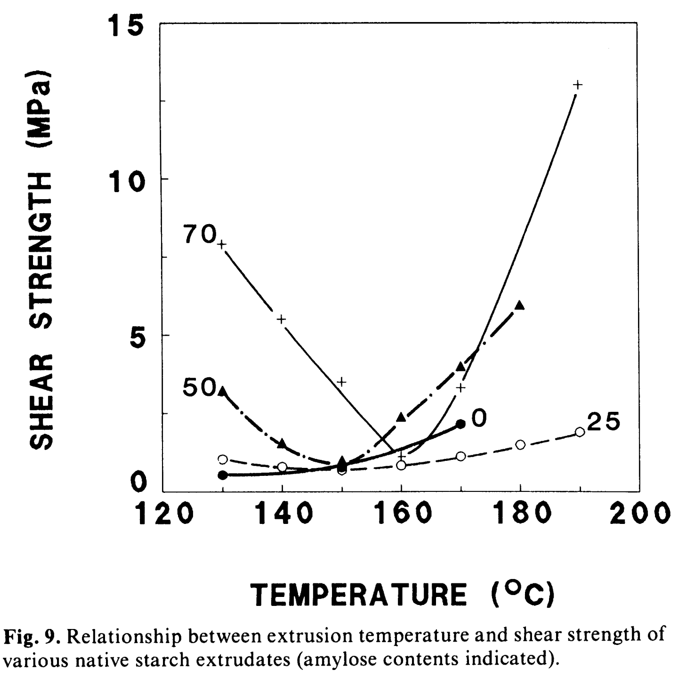

Fig. 9. Relationship between extrusion temperature and shear strength of various native starch extrudates (amylose contents indicated).

Effect of Moisture

Moisture content of the starch before extrusion was an important factor controlling the expansion volume of starch (Chinnaswamy and Hanna 1987b). It was of interest to see whether optimum moisture content for starch expansion (like barrel temperature as seen earlier) varied for different starches. Figure 10 clearly shows that all starches expanded most at a uniform moisture content of 13–14% (db). The overall greatest expansion was still obtained with 50% amylose content starch; therefore, it appears that the expansion ratio of poorly expanding starches can not be improved by changing starch moisture content.

CONCLUSIONS

The expansion ratios of different native corn starches varied from 8.3 to 16.4. The highest expansion of 16.4 was obtained with 50% amylose starch. However, studies with blended starches and pure amylose/amylopectin mixes showed that corn amylopectin properties may also contribute to starch expansion.

Extrusion temperature affected the expansion properties of starches. Different corn starches have different optimum extrusion temperatures for their best expansion. The expansion volume of poor expanding starch types such as those with 0 and 70% native amylose starch can be increased by one and five units, respectively, by selecting the optimum extrusion temperature. All starch types, however, showed a uniform optimum moisture content at 13–14% (db) for best expansion.

The extruded product qualities such as bulk density and shear strength were related to both amylose content of starch and expansion ratio.

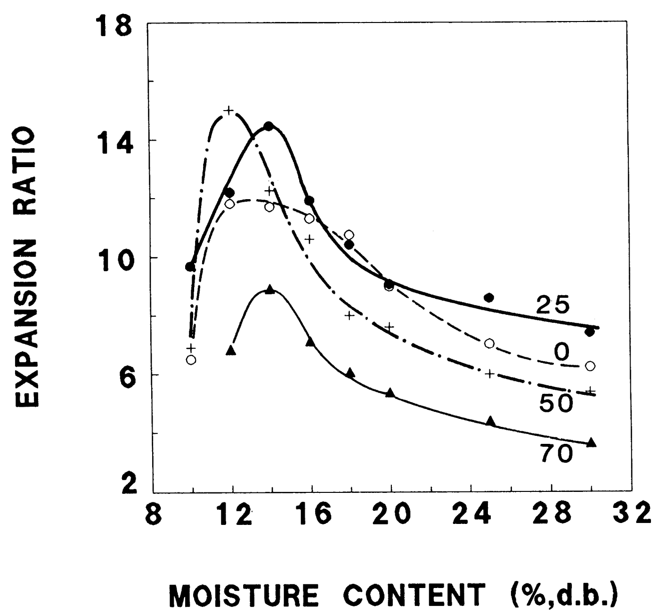

Fig. 10. Effect of moisture content of starch samples before extrusion on the expansion properties of various native starches (amylose contents indicated).

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