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MODIFICATION OF CARBOHYDRATE COMPONENTS BY EXTRUSION-COOKING OF CEREAL PRODUCTS[1]

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ABSTRACT

Cereal starches (corn with various amylose contents, wheat, rice) and corn semolina were extruded in a semi-industrial-sized French extruder. Different parameters involved during processing, such as temperature of extrusion, moisture content of the product before extrusion, and amylose content of the product, were studied. Starch was solubilized, without any formation of maltodextrin, and the amount was dependent on temperature of extrusion, moisture content of starch before extrusion, and the amylose:amylopectin ratio. A relation was observed between expansion of the extruded product and its amylose content, the amount of water-soluble carbohydrate, and the susceptibility to α-amylase.

Use of extrusion-cooking in cereal technology has steadily increased during the last 10 years. Considerable efforts have been concentrated on developing new products as snacks, baby foods, cereal breakfast foods, pet foods, or modified starches. As already outlined by Lawton *et al.* (1), the literature on extrusion-cooking is limited, primarily related to practical problems, and contains little information on fundamental aspects of the process.

Effects of processing conditions on gelatinization of starch and texture of the extruded product have been recently studied by several workers (1–6). Gelatinized materials with different starch viscosity, water solubility, and water absorption have been prepared by altering the moisture content of the raw product and the temperature or the pressure in the extruder (6).

However, no information is available on the physicochemical changes which occur in the carbohydrate components after extrusion-cooking. Therefore, this study was carried out to determine the amount and structure of the aqueous ethanol- and water-soluble carbohydrates in various extruded products from corn grits and commercial starches. Simultaneously, starch viscosity and water absorption, as well as breaking strength, were measured on the same samples.

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[2]Cooperative investigation between the Station de Biochimie et de Physicochimie des Céréales, 91305 Massy Cedex, France (C.M.), and the Laboratoire de Technologie des Blés Durs et du Riz, 34060 Montpellier Cedex, France (P.F.).

MATERIALS AND METHODS

Corn Grits

A commercial sample of corn grits obtained from Ets Dumortier Frères was used except when otherwise stated.

In one experiment, samples of corn were artificially dried at air temperatures of 90°, 110°, and 150°C, and by dryeration before milling with laboratory equipment (7).

Starch Samples

Commercial samples of corn, waxy corn, amylomaize with 52 and 61% amylose (Amylon 5 and 7), rice, and common starch were studied.

Samples with different amylose:amylopectin ratios were obtained by mixing commercial Waxilys (99% amylopectin content) and Amylon 7 (61% amylose content). For comparative purposes, amylose contents were determined by the method of Larson *et al.* (8) at 20°C.

Extrusion-Cooking

Extrusion was carried out in a small French extruder developed by Creusot Loire (Departement Matières Plastiques-42700, Firminy, France) in a collaborative study with Centre Technique de l'Union (1 rue Montgolfier, Paris, France).

This extruder is fitted with intermeshing twin screws which rotate in the same direction. Extrusion of most products can be accomplished without water addition. The barrel is heated by the patented induction system "Indutherm." The screws rotate at variable, adjustable speeds between 20 and 120 rpm. The extrusion-cooking time is, depending on screw speed, adjustable from 20 sec up to 2 min. The pressure inside the barrels is about 100 bars.

Samples were extruded at different barrel temperatures, between 70° and 250°C, with moisture content between 10.5 and 28.5% by weight.

Preparation of Samples

After extrusion-cooking, all samples were ground in a laboratory Buhler mill cooled with Dry Ice, except when measurements of breaking strength and certain α-amylase susceptibilities were carried out.

Expansion of Extruded Products

Expansion is expressed as the ratio between the cross-sectional area of the rod-shaped product and the area of the die.

Breaking Strength

Breaking strength was determined with a laboratory testing instrument (9). Samples were placed on a plate covering a load-cell table and sheared by lowering a special blade at the rate of 4.7 cm per min; a slot was designed in the plate to avoid direct action of the blade on the plate. The shear force was recorded during the operation and the maximum value chosen as an index of breaking strength. Results, expressed in kilograms, are the median of 10 measurements.

Water Absorption, Water Solubility, and Final Cooked-Paste Viscosity

The extruded products were analyzed by determination of water absorption index (WAI, gram of gel obtained per gram of dry sample), water-solubility index (WSI, water-soluble product as per cent of dry sample), and Brabender viscoamylograph viscosity (BU) under the conditions of Anderson *et al.* (2) with slight modification in the temperature program of the amylograph test: the temperature was raised from 25° to 95° C in 47 min, was held at 95° C for 20 min, and then decreased to 50° C in 30 min before finally holding at 50° C for a further 10 min. WAI is a measure of cold-paste viscosity and WSI is a measure of gelatinization. Final cooked-paste viscosity at 50° C was determined from the amylograph curve (10).

Aqueous Ethanol-Soluble Carbohydrate

To 0.5 to 2 g of extruded product, 30 ml 80% aqueous ethanol was added and the mixture agitated for 15 min on a magnetic stirrer at room temperature. The suspension was then centrifuged at 1800 × *g* for 10 min. The supernatant was decanted and the residue was re-extracted under the same conditions, until no more carbohydrate was removed. The total sugar content in the combined supernatants was determined by the anthrone method. Carbohydrates derived from starch and total starch were measured by an enzymatic method using glucoamylase and glucose oxidase according to Thivend *et al.* (11) and expressed in gram per cent of starch.

Water-Soluble Carbohydrate

After ethanol extraction, 30 ml distilled water was added to the residue. The mixture was agitated under the same conditions as previously described. The number of extractions was dependent on the amount of soluble carbohydrates which were measured by the enzymatic method and expressed in gram per cent of starch.

Structural Studies of Water-Soluble Carbohydrate

Measurement of the wavelength of peak absorption (λ max) of iodine-soluble carbohydrate complexes was carried out as by Bourne *et al.* (12), and the degree of β-amylolysis was determined according to Mercier and Whelan (13).

Bacillus subtilis α-Amylase Susceptibility

The susceptibility to α-amylase of the whole and milled extruded product was carried out as described by Tollier and Guilbot (14). *Vi* represents the initial rate of α-amylolysis corresponding to the amount of starch hydrolyzed during the first 5 min (expressed in gram per cent of starch); *F* is the easily degradable starch fraction, represented by extrapolation to zero of the linear part of the α-amylolysis curve.

RESULTS AND DISCUSSION

Effects of Extrusion Temperature

Corn Grits. Corn grits with an initial moisture content of 18.2% by weight were extruded at 65°, 90°, 129°, 170°, 202°, 225°, and 250° C. Modifications of some characteristics of the extruded products are seen in Fig. 1.

When extrusion temperature is increased, water-solubility index increases while final cooked-paste consistency (viscosity at 50° C) and breaking strength decrease. Changes in water absorption index and expansion are similar with a maximum value between 180° and 200° C.

Other products were obtained by extrusion of corn grits (16.8% moisture content) at 50°, 207°, 227°, and 247° C (Table I). With increasing extrusion temperature, a decrease in ethanol-soluble carbohydrate content was observed and, as shown by thin-layer chromatography, preexisting sugars (fructose, glucose, sucrose, and raffinose) were present in a lower amount; an increase in water-soluble carbohydrate content was noticed and no formation of oligosaccharides, such as maltodextrins, was detected. The water-soluble carbohydrate is a high-molecular-weight polysaccharide, similar to swollen starch, as shown by its having the same λ max and β-amylolysis limit as the unprocessed control semolina.

Furthermore, the starch content of grits before and after treatment, as measured by enzymatic assay, was not modified by extrusion.

Cereal Starches. Cereal starches (22% moisture content) were extruded at different temperatures between 70° and 225° C. Waxy corn, corn, common wheat, rice, Amylon 5, and Amylon 7 starches were compared. Physical aspects of corn starches extruded between 70° and 225° C are shown in Fig. 2.

Changes in final cooked-paste viscosity (50° C), water absorption index, and water-solubility index of extruded products as related to increasing extrusion temperatures are given in Table II and Figs. 3 and 4. The viscosity of waxy corn, common wheat, and rice products has a maximum value after extrusion around 100° C while viscosity of the corn product decreases regularly. The viscosities of Amylon 5 and 7 remain low and unmodified. Water absorption index data indicate a maximum index value around 180° C with corn, common wheat, and rice products. The water absorption index of the waxy corn product decreases from 70° to 225° C whereas that of extruded Amylon 5 and 7 does not change until 200° C, then sharply increases. The water-solubility index of corn and common wheat products steadily increases with extrusion temperature. A dramatic effect is observed on waxy corn water-solubility index which reaches 70 at 135° C and 90 at 170° C. Rice water-solubility index has a maximum value at 185° C whereas that of Amylon 5 and 7 is not modified until 200° C.

In agreement with the change in water-solubility index, water-soluble carbohydrates of corn starch increased with increasing extrusion temperature (Fig. 5). No ethanol-soluble fraction was formed, indicating that extrusion solubilizes corn starch without degradation into maltodextrins. This effect was confirmed by the behavior of the soluble fraction. The four extruded samples (95°, 135°, 170°, and 225° C) had a β-amylolysis limit around 55 to 58%, similar to native starch (57%). The λ max of the water-soluble material was 590 nm, identical to native solubilized corn starch.

A relation between expansion, water solubility, and susceptible starch fraction (F value) could be observed. Maximum expansion occurred when the water-soluble carbohydrate content reaches 30% and the F value 75%.

Similar phenomena were observed with starches from other sources (waxy corn, common wheat, rice, Amylon 5, and Amylon 7). As for the water-solubility index, the water-soluble carbohydrate content of extruded waxy corn starch becomes very high as soon as an extrusion temperature of 135° C is reached (Fig. 3).

Susceptibility to bacterial α-amylase increases with increasing extrusion

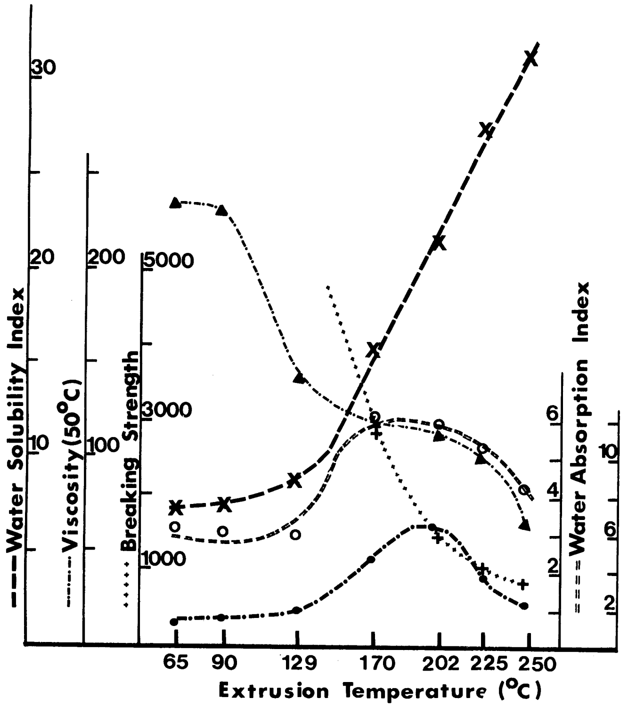

Fig. 1. Effects of extrusion temperature (65°, 90°, 129°, 170°, 202°, 225°, and 250° C) on expansion (●), breaking strength (+), viscosity at 50° C (▲), water absorption index (o), and water-solubility index (x) of extruded products from corn grits. Initial moisture content before extrusion was 18.2% by weight.

TABLE I
Effects of Extrusion Temperature on Some Characteristics of Extruded Products from Corn Grits[a]

	Unprocessed Semolina	Extrusion Temperature (° C)			
		50	207	227	247
Ethanol-soluble carbohydrate	1.02	0.82	0.48	0.56	0.70
Water-soluble carbohydrate	0.85	9.7	20.5	19.8	28.1
λ max (nm) of water-soluble carbohydrate	590	590	590	590	590
β-amylolysis limit	60.0	. . .	60.5	60.2	61.0
α-amylolysis					
Vi	4.0[b]	20.7	21.5	20.4	22.0
F	17.5[b]	64.5	69.5	68.0	74.0

[a]Initial moisture content before extrusion was 16.8% by weight: starch content of corn grits was 87.0%.
[b]gram per cent of starch.

temperature but was different depending on whether determinations were made on the whole extruded products or after milling.

For an extrusion temperature of 135° C, the initial rate of α-amylolysis of the milled extruded products (Fig. 3, *Vi*-milled) was similar for waxy corn, normal corn, wheat, and rice, corresponding to 20% of starch being degraded in the first 5 min. *Vi* was lower for Amylon 5 and 7. The same phenomenon was observed for the easily degradable fraction of starch, *F* (Fig. 3, *F*-milled).

For whole extruded products, the results were different. The initial rate, *Vi*, was reduced to half (10% of waxy corn starch degraded in the first 5 min) that of milled products. Furthermore, a significant difference has been observed between starches. Whereas whole or milled extruded waxy corn did not show any difference for *F*, this last parameter decreased significantly from normal corn to Amylon 5 and 7. At this low extrusion temperature, expansion was reduced as shown in Figs. 2 and 3. Therefore, it is likely that attack by α-amylase, which depends on penetration of the enzyme into the substrate, is much faster and easier on the milled extruded product than on the whole extruded one, for the surface available to the enzyme is much greater.

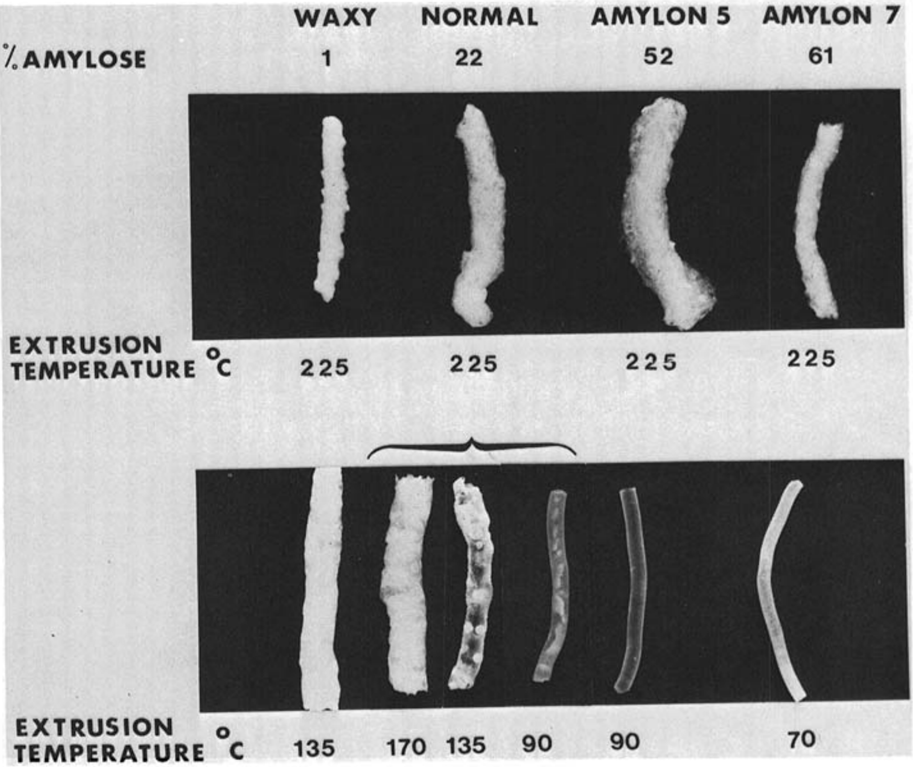

Fig. 2. Physical aspects of extruded Amylon 5, Amylon 7, waxy corn, and normal corn starches under different conditions of extrusion. Initial moisture content before extrusion was 22% by weight.

No significant difference was observed for the parameters *Vi* and *F* (Fig. 4) for both whole and milled extruded products extruded at 225° C. At this extrusion temperature, the extruded products were expanded in such a way that they were rapidly dispersed in the digest, leading to easy penetration of the enzyme into the product.

Effects of Moisture Content before Extrusion

Results shown in Table III indicate a decrease in water-solubility index (35 to 20) and expansion (6.2 to 1.5) with an increase in moisture content of corn grits before extrusion (10.5 to 28.5 by weight) at 225° C; on the contrary, breaking strength, final cooked-paste viscosity (50° C), and water absorption index increase with increasing moisture content. The ethanol-soluble carbohydrate fraction decreased after extrusion cooking, but there was no effect of moisture content of grits. The preexisting sugars of grits were present and no maltodextrins were detected. The molecular weight of the water-soluble carbohydrate is high as confirmed by the β-amylolysis limit and λ max (590 nm).

TABLE II
Effects of Extrusion Temperature on Final Cooked-Paste Viscosity at 50° C (BU), Water Absorption Index (WAI), and Water-Solubility Index (WSI) of Extruded Products from Cereal Starches[a]

Starch Sample	Parameters	Unprocessed Starch	Extrusion Temperature (° C)						
			70	95	135	170	185	200	225
Waxy corn	BU	330[b]	165	215	115	75	20	. . .	15
	WAI	2.3[c]	3.8	3.7	2.5	1.4	0.9	. . .	0.8
	WSI	0.4[d]	35	34	70	90	93	89	94
Corn	BU	815	560	340	225	240	230	160	60
	WAI	2.1	4.9	5.2	7.0	8.3	8.2	7.0	4.9
	WSI	0.2	13	15	17	21	24	33	35
Common Wheat	BU	1140	240	280	505	430	370	305	220
	WAI	2.1	4.6	5.5	7.0	7.7	7.7	7.4	7.4
	WSI	0.8	17	19	16	23	24	26	28
Rice	BU	710	325	380	240	180	220	200	145
	WAI	2.1	5.1	5.6	6.7	8.3	7.4	7.5	7.4
	WSI	0.7	9	9	12	23	27	24	20
Amylon 5	BU	50	40	35	30	35	30	40	40
	WAI	2.4	3.6	3.3	3.6	3.7	3.7	3.7	4.3
	WSI	0.4	11	7	10	11	11	15	29
Amylon 7	BU	10	25	15	10	10	20	15	25
	WAI	2.5	3.4	3.3	3.4	3.2	3.4	3.3	5.5
	WSI	0.3	4	4	6	5	6	5	8

[a]Initial moisture content before extrusion was 22% by weight.
[b]BU = Brabender Units.
[c]Hydrated sample, gram per gram dry sample.
[d]Per cent of dry sample.

Effects of Amylose Content of Starch

Results obtained by Charbonniere *et al.* (15) have shown that, on extrusion-cooking, starch forms a new structure similar to the "butanol-amylose complex." This structure appeared at 135° C for normal corn, wheat, and rice starches (22 to 25% amylose), at 90° C for Amylon 5 (52% amylose), at 70° C for Amylon 7 (61% amylose), and was not observed for waxy corn (1% amylose).

The effects of amylose content of starch on the characteristics of the extruded products have been studied at the temperature of appearance of the new structure as well as at 135° and 225° C. Results are presented in Figs. 3,4,6, and 7 and in Tables IV and V.

At an extrusion temperature corresponding to the temperature for formation of the new structure (Fig. 6), expansion, water-soluble carbohydrate content, and susceptibility to α-amylase of extruded corn starch decreased with increasing amylose content. Absence of an ethanol-soluble fraction, the degree of β-amylolysis, and the λ max value confirm that extrusion-cooking solubilized

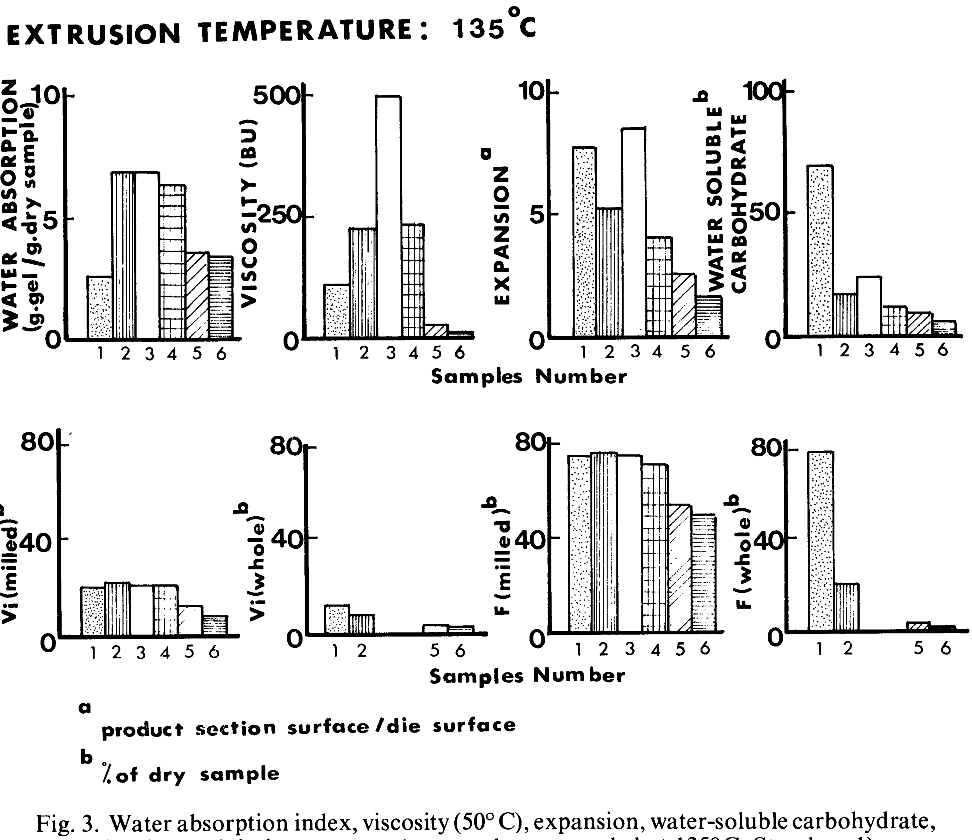

Fig. 3. Water absorption index, viscosity (50° C), expansion, water-soluble carbohydrate, *Vi*, and *F* (α-amylolysis parameters) on products extruded at 135° C. Starches: 1) waxy corn; 2) corn; 3) common wheat; 4) rice; 5) Amylon 5; 6) Amylon 7. Initial moisture content before extrusion was 22% by weight.

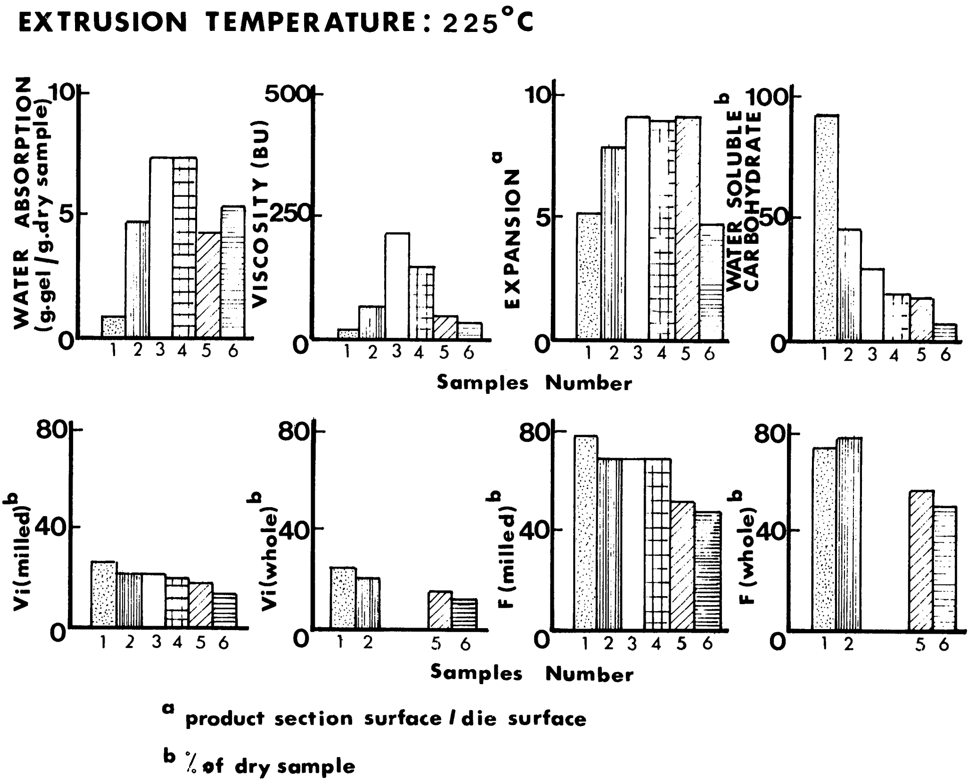

Fig. 4. Water absorption index, viscosity (50° C), expansion, water-soluble carbohydrate, *Vi*, and *F* (α-amylolysis parameters) on products extruded at 225° C. Starches: 1) waxy corn; 2) corn; 3) common wheat; 4) rice; 5) Amylon 5; 6) Amylon 7. Initial moisture content before extrusion was 22% by weight.

TABLE III
Effects of Initial Moisture Content before Extrusion on Some Characteristics of Extruded Products from Corn Grits[a]

	Initial Moisture Content before Extrusion (% by Weight)					
	10.5	13.9	18.2	22.0	25.4	28.5
Expansion	6.2[b]	6.8	5.8	3.6	2.4	1.5
Breaking strength	1500[c]	2400	2650	2700	3600	4550
Final cooked-paste viscosity (50° C)	50[d]	95	105	130	165	135
Water absorption index	4.4[e]	5.3	5.6	6.0	6.6	6.7
Water-solubility index	35[f]	26	24	23	17	20

[a]Extrusion temperature: 225° C.
[b]Surface of product section/surface of die.
[c]Kilograms.
[d]Brabender Units.
[e]Hydrated sample, gram per gram dry sample.
[f]Per cent of dry sample.

corn starches in its macromolecular form. No parameter value seems characteristic of this particular extrusion temperature.

When corn starches were extruded at 225°C (Fig. 7), water-soluble carbohydrate content and *Vi* value decreased with increasing amylose content in the same way as when starches were extruded at low temperature. Maximum values were noticed at 52% amylose for expansion and at 22% amylose for *F*. No ethanol-soluble fraction was detected indicating again that no maltodextrin was formed, which was confirmed by β-amylolysis limit and λ max of the water-soluble fraction.

To confirm the influence of amylose content on the characteristics of extruded corn starches, five samples containing 1, 15, 30, 46, and 61% amylose were prepared by mixing Waxilys and Amylon 7 and extruding these (named "reconstituted corn starches") at 225° C with 22% initial moisture content (Table IV).

The water-solubility index and water-soluble carbohydrate content decreased with increasing amylose content. In all cases, this fraction was high-molecular-

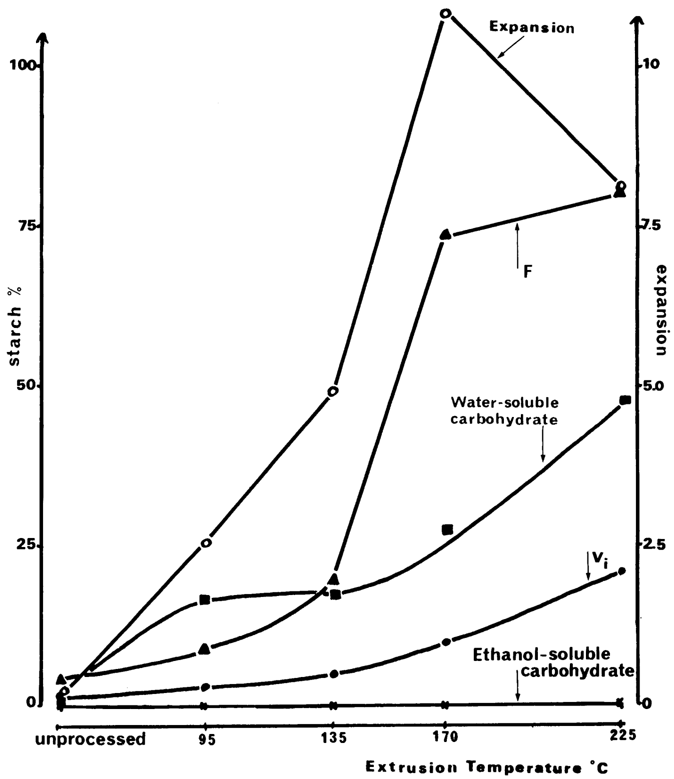

Fig. 5. Effects of extrusion temperature (95°, 135°, 170°, and 225° C) on expansion (o), water-soluble (■) and ethanol-soluble (x) carbohydrates, *Vi* (•), and *F* (▲) (α-amylolysis parameters) of extruded products from corn starch. Initial moisture content before extrusion was 22% by weight.

TABLE IV
Effects of Amylose Content on Characteristics of Extruded Products from Reconstituted Corn Starches[a]

	Amylose Content (% db)[b]				
	1	15	30	46	61
Expansion	13[c]	9	8	7	11
Breaking strength	6200[d]	5500	2300	2500	4800
Final cooked-paste viscosity (50° C)	40[e]	20	15	15	25
Water absorption index	1.0[f]	1.8	2.2	3.1	4.3
Water-solubility index	90[g]	71	47	30	12
Ethanol-soluble carbohydrate	0.2[g]	0.2	1.4	0.9	1.2
Water-soluble carbohydrate	91.8[g]	72.3	48.0	25.4	6.4
λ max (nm)	530	535	545	575	595
β-amylolysis limit	57.0	52.5	55.3	54.3	65.0
α-amylolysis[h]					
Vi	30.0[g]	30.0	30.0	30.0	19.0
F	91.5[g]	75.5	65.5	63.0	50.0

[a]Extrusion temperature: 225° C. Initial moisture content before extrusion: 22% by weight.
[b]Calculated from the percentages of Amylon 7 (61% amylose) and Waxilys (1% amylose) in the starch sample.
[c]Surface of product section/surface of die.
[d]Kilograms.
[e]Brabender Units.
[f]Hydrated sample, gram per gram dry sample.
[g]Per cent of dry sample.
[h]Performed on the whole extruded product before milling.

TABLE V
Relative Values of Expansion, Water Absorption Index, and Water-Solubility Index as a Function of Amylose Content of Reconstituted Corn Starch and Temperature of Extrusion[a]

	Extrusion Temperature (° C)	Amylose Content (% db)				
		1	15	30	46	61
Expansion	130	100[b]	40	23	13	12
	180	100	81	78	66	17
	225	100	68	61	52	83
Water absorption index	130	100[b]	134	127	121	123
	180	100	102	128	202	198
	225	100	170	209	300	410
Water-solubility index	130	100[b]	30	22	17	2
	180	100	80	50	27	2
	225	100	78	52	33	13

[a]Initial moisture content before extrusion: 22% by weight.
[b]Relative reference units.

weight polysaccharide, as the β-amylolysis limit and λ max were similar to those of starch before extrusion. No ethanol-soluble carbohydrate was observed. Susceptibility to α-amylase showed an increase in the easily degradable fraction (*F*) with decreasing amylose content. However, the initial rate (*Vi*) of degradation did not depend on the amylose content, except for 61% amylose.

Water absorption index increases with amylose content. Expansion is minimum at 46% amylose, breaking strength at 30%, and final cooked-paste viscosity (50° C) at 30 to 46%.

These results are not in complete agreement with those reported in Fig. 7 which might be explained by differences in overall starch properties since the physical structure of starch is different in the "reconstituted corn starch" or by uncontrolled variations in moisture or in the temperature of extrusion. As shown in Table V, extrusion temperature may modify the expansion, water absorption index, and water-solubility index values as a function of amylose content.

Cereal starches with similar amylose content (22 to 25%) have been compared. As shown in Figs. 3 and 4, extruded products processed from normal corn,

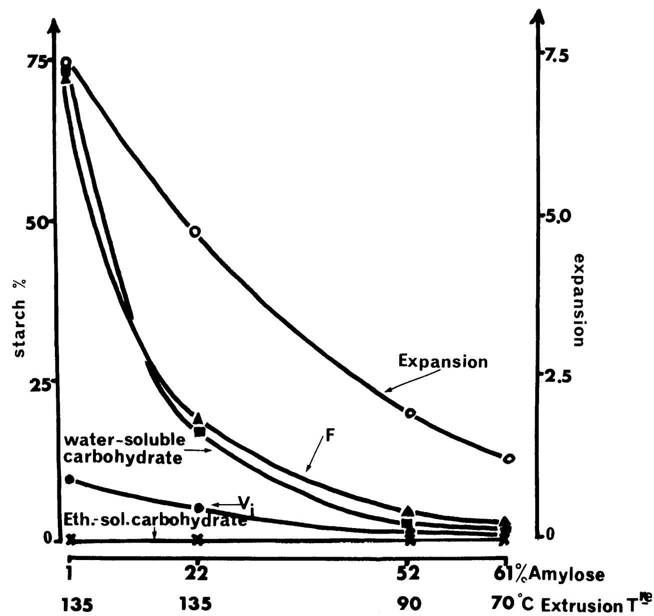

Fig. 6. Effects of amylose content of corn starch on expansion (o), water-soluble (■) and ethanol-soluble (x) carbohydrates, *Vi* (•), and *F* (▲) (α-amylolysis parameters) of extruded products. Extrusion temperature was temperature of "butanol-amylose complex" structure formation (15). Initial moisture content before extrusion was 22% by weight.

common wheat, and rice starches had some different properties either at 135° or 225° C.

At 135° C, corn and rice products were similar and differed mainly from wheat products by a lower expansion, final cooked-paste viscosity (50° C), water-solubility index, and water-soluble carbohydrate content. However, no significant difference was observed for water absorption and susceptibility to α-amylase.

At 225° C, breaking strength, final cooked-paste viscosity (50° C), and water absorption index of corn products were lower than those of rice and wheat products; water-soluble carbohydrate content was higher. Expansion and α-amylolysis parameters were similar for the three starches.

Effects of Drying Conditions of Corn after Harvesting

Studies of the influence of drying conditions after harvesting on the industrial value of corn (wet and dry milling) have shown the harmful effects of high temperature. In this work, five grits samples, obtained from corn dried in one

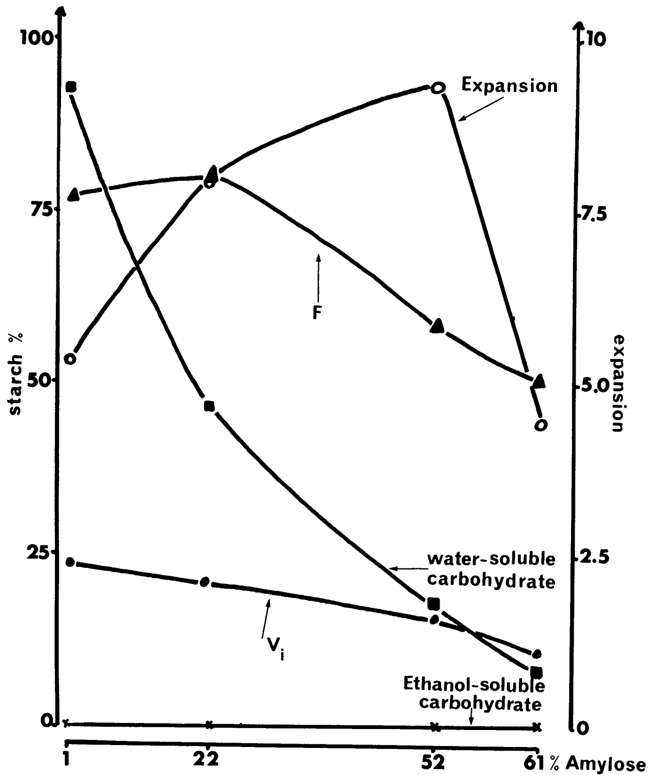

Fig. 7. Effects of amylose content of corn starch on expansion (o), water-soluble (■) and ethanol-soluble (x) carbohydrates, *Vi* (•), and *F* (▲) (α-amylolysis parameters) of extruded products. Extrusion temperature was 225° C. Initial moisture content before extrusion was 22% by weight.

TABLE VI
Effects of Drying Conditions of Corn after Harvesting on the Characteristics of Extruded Products from Corn Grits[a]

	Conditions and Air Temperature (°C) of Drying				
	1 Step	Dryeration	2 Steps		
	90	90	90	110	150
Expansion	13.2[b]	16.2	19.1	16.5	16.5
Breaking strength	2400[c]	1900	3900	2100	2300
Final cooked-paste viscosity (50°C)	60[d]	50	50	40	30
Water absorption index	7.3[e]	7.2	7.3	7.3	7.0
Water-solubility index	26[f]	25	25	26	30
Ethanol-soluble carbohydrate	2.9[f]	17.6	8.0	6.4	12.0
Water-soluble carbohydrate	33.5[f]	28.5	31.2	33.7	32.2
λ max (nm)	590	590	590	590	590
β-amylolysis limit	62.6	60.5	58.7	60.7	63.9

[a]Extrusion temperature: 230°C. Initial moisture content before extrusion: 14% by weight.
[b]Surface of product section/surface of die.
[c]Kilograms.
[d]Brabender Units.
[e]Hydrated sample, gram per gram sample.
[f]Per cent of dry sample.

step or by dryeration at 90°C, or in two steps at 90°, 110°, and 150°C, were extruded at 225°C with 14% moisture content.

As is evident from Table VI, there is no important effect of drying conditions on characteristics of the extruded products. Nevertheless, we observed a slight effect on final cooked-paste viscosity (50°C). Formation of water-soluble carbohydrate was similar for the five samples (28 to 33.7%). Although this water-soluble fraction was identified as swollen starch by β-amylolysis limit and λ max, some oligosaccharides, derivatives of starch, could be detected in the ethanol-soluble fractions after dryeration or drying at 150°C. The absence of such oligosaccharides before extrusion leads to the conclusion that they are formed during extrusion cooking. Further work will be necessary to explain this phenomenon.

CONCLUSION

Different parameters involved during the process of extrusion-cooking (temperature of extrusion, moisture content of the product before extrusion, amylose content of the product) are important and interrelated.

All cereal starches studied (corn with various amylose contents, wheat, rice) have shown a maximum of expansion at an extrusion temperature of 170° to 200°C, which confirms the temperature of 170°C observed for wheat starch by Seib and Stearns (6).

Starch is solubilized under the treatment without formation of maltodextrin. Under the same conditions of extrusion, waxy corn starch became most soluble followed by normal corn, wheat, rice, Amylon 5, and Amylon 7. Corn grits behave similarly. The soluble starch retains its macromolecular form as shown by the β-amylolysis limit and λ max of the solution.

The amount of soluble starch increased with increasing extrusion temperature and with decreasing moisture content of the product before extrusion. Conversely, it decreased with increasing amylose content of starch. A relation was observed between expansion of the final product and its amylose content, amount of water-soluble carbohydrate, and susceptibility to α-amylase.

In a preliminary study, conditions of drying corn before extrusion do not seem to affect the characteristics of the extruded product.

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