GELATINIZATION OF STARCH IN EXTRUDED PRODUCTS[1]

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Cereal Chem. 54(3): 436-443

ABSTRACT

Some of the important factors affecting starch gelatinization during extrusion of wheat flour, such as moisture content of raw materials, temperature, screw speed, and die nozzle size were investigated. The interaction of temperature and moisture significantly affected starch gelatinization. Increasing extrusion temperatures increased starch gelatinization when moisture contents were between 18 and 27%. Moisture contents did not significantly affect starch gelatinization at low temperatures (65° and 80° C), but affected gelatinization at high temperatures (95° and 110° C). Increasing shear rate (screw speed) decreased starch gelatinization. Increasing the die nozzle size decreased starch gelatinization. Results showed that the (2→1) glycosidic bonds of sucrose and raffinose and the (1→4) glycosidic bonds of malto-oligosaccharides and starch are broken when cereal products are extruded.

Gelatinized starches have numerous industrial, nonfood uses such as in drilling oil wells, sizing textiles, making paper, briquetting charcoal, and in water-base paints (1). In food, gelatinized starches can be used almost any time thickening is desired. The gelatinization of starch also significantly affects the characteristics and quality of food such as loaf volume and crumb of bread (2), the elasticity and softness of paste products, digestibility and palatability, the tolerance of batter properties in cake, frostings, and doughnut mixes, the sugar crystal growth in foods (1), and the texture, volume, shelf-life, and freeze-thaw stability of bread and cakes (3).

Extrusion cooking in recent years has become one of the most popular new processes developed by the food and feed industries. Its basic principle is to convert a solid material to a fluid state by applying moisture and heat, then to extrude the material through a die to form a product of predetermined geometric and physical characteristics. The literature on extrusion-processed foods is ample (4–10); but most of it emphasizes production of a specific product rather than adding to the basic understanding of starch gelatinization during the process. Here, some of the important factors affecting starch gelatinization during the extrusion process, such as moisture content of raw materials, temperature, screw speed, and die nozzle sizes, are discussed.

MATERIALS AND METHODS

Hard red winter wheat-flour samples were used. Their proximate analyses included: Kjeldahl (N × 5.7) protein, 10.5%; ash, 0.45%; and moisture, 13.5%. The flour samples were tempered to desirable moisture levels, refrigerated 12 hr to allow the moisture to equilibrate, and brought to room temperature before being extruded.

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TABLE I
Analyses of Variance of the Effect of Extrusion Factors on Starch Gelatinization

Source of Deviation	df	F	α Hat
Temperature	3	5333.5	0.00
Moisture	3	165.3	0.00
Screw speed	2	41.0	0.00
Temperature and moisture	9	119.8	0.00
Temperature and shear rate	6	1.5	0.22
Moisture and shear rate	6	1.5	0.222
Error	18	...	...
Total	47	...	...

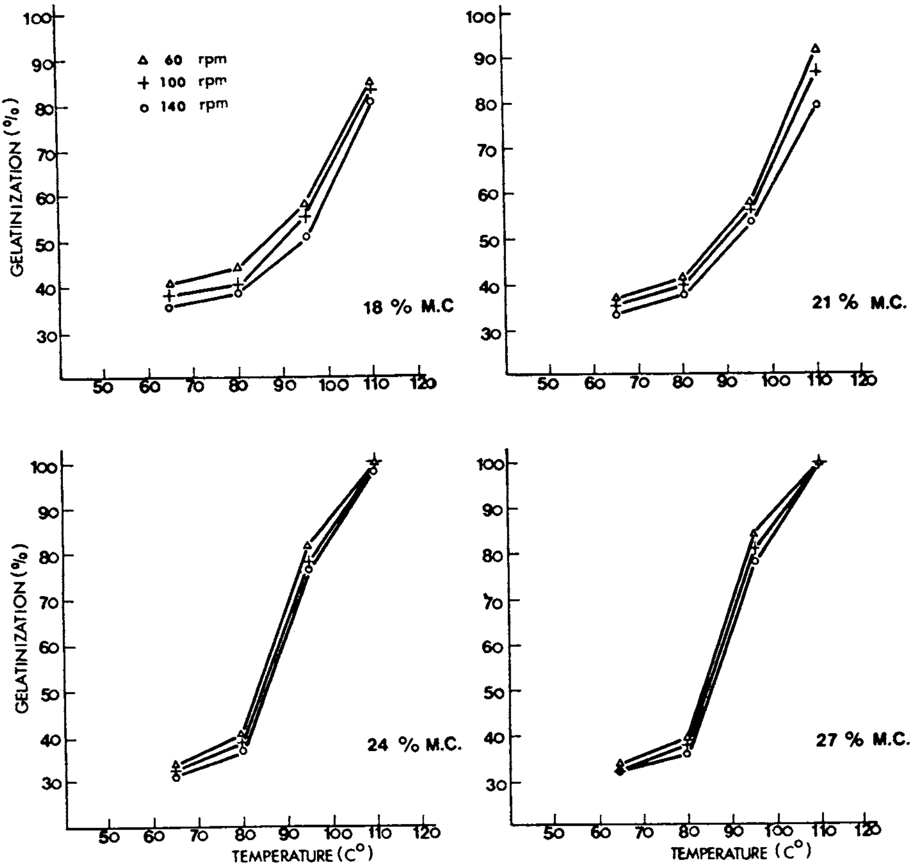

Fig. 1. Effects of temperature on starch gelatinization.

The extrusion equipment was a 3/4-in. laboratory single-screw extruder (L/D = 25/1), Model 2503 (C. W. Brabender Co., South Hackensack, N.J.). It was equipped with thermocouples at the end of each heating zone (3 zones) to measure product temperature inside the barrel.

A three-factor, experimental design was used to study starch gelatinization during extrusion. The variables included four moisture contents (18, 21, 24, and 27%), four temperatures in the last zone (65°, 80°, 95°, and 110°C), and three screw speeds (60, 100, and 140 rpm). Four die nozzle sizes, 2/16, 3/16, 4/16, and 6/16 in., were used with extrusion conditions constant at 20% moisture content, 100°C temperature, 100 rpm screw speed, and 3:1 screw compression ratio.

When each sample was extruded, approximately 50 g was collected, and air-dried at 50°C for 20 hr. The extruded samples were ground in a Wiley Laboratory mill and sieved through a 60-mesh screen. Percentage of gelatinized starch in the extruded product was determined by the method of Chiang and

TABLE II
Interations between Temperature and Moisture on Starch Gelatinization (Least Significant Differences)

Treatment	Means[a]	Nonsignificant Differences Connected by Column of Asterisks
T_4M_4 (110°C, 27%)	100.0	*
T_4M_3 (110°C, 24%)	99.6	*
T_4M_2 (110°C, 21%)	87.0	
T_4M_1 (110°C, 18%)	82.8	*
T_3M_4 (95°C, 27%)	81.0	**
T_3M_3 (95°C, 24%)	78.8	*
T_3M_2 (95°C, 21%)	56.4	*
T_3M_1 (95°C, 18%)	55.1	*
T_2M_1 (80°C, 18%)	41.3	*
T_2M_2 (80°C, 21%)	40.1	**
T_2M_3 (80°C, 24%)	38.5	**
T_1M_1 (65°C, 18%)	38.2	**
T_2M_4 (80°C, 27%)	37.6	**
T_1M_2 (65°C, 21%)	35.7	*
T_1M_3 (65°C, 24%)	33.2	*
T_1M_4 (65°C, 27%)	33.0	*

[a]Least significant difference, 0.05% level = 2.175.

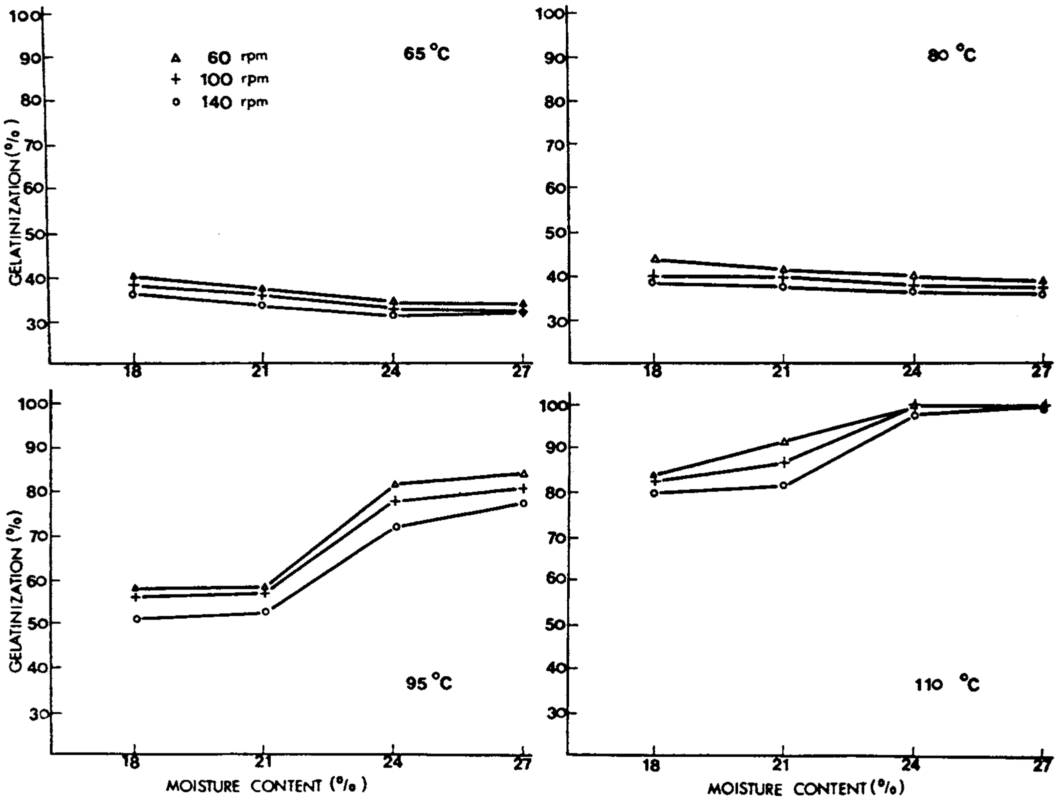

Fig. 2. Effects of moisture content on starch gelatinization.

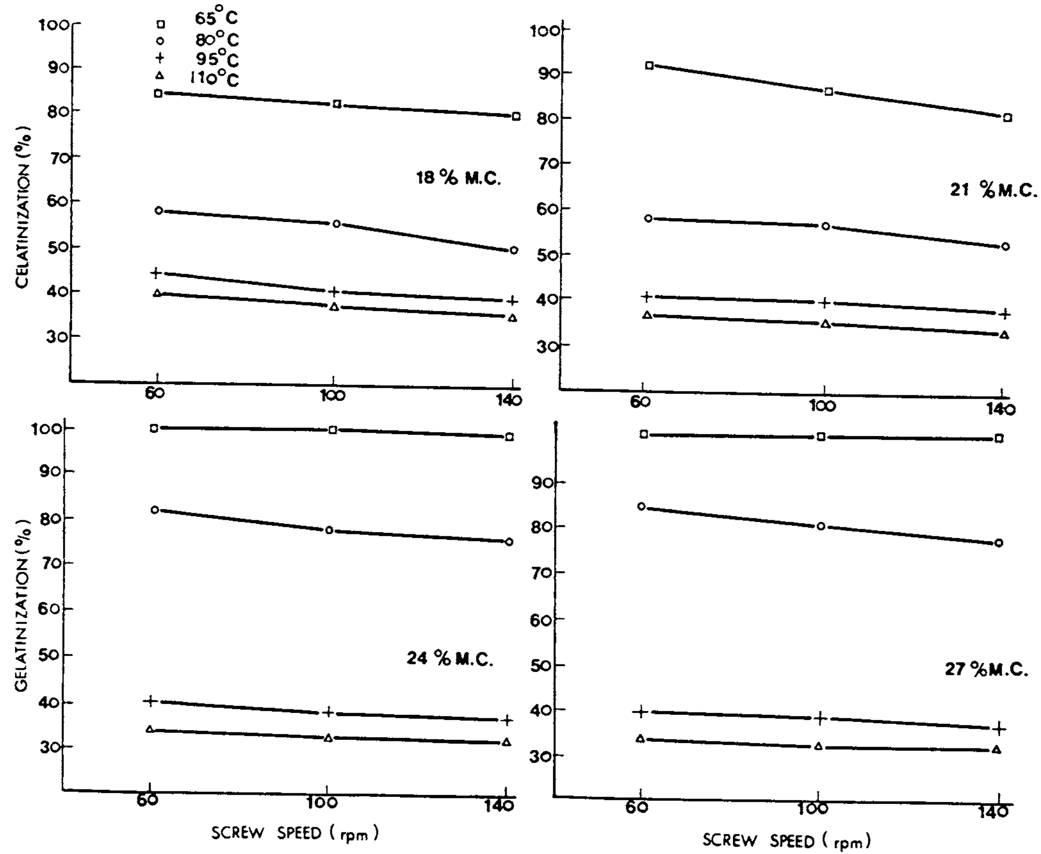

Fig. 3. Effects of screw speed on starch gelatinization.

Johnson (11).

The mono- and oligosaccharides in the sample (10 g) were extracted with 200 ml 80% ethanol. The extracted solution was concentrated by a rotary evaporating flask to 10 ml, and 75 μl of concentrated solution was spotted on Whatman No. 4 chromatographic paper. The paper was developed in 1-butanol–glacial acetic acid–water (4:1:1) for 48 hr. The sugars were detected by the silver nitrate dip reagent (12) and identified by comparison of their mobilities with those of authentic samples.

RESULTS AND DISCUSSION

Statistical analyses indicated that temperature, moisture content, screw speed, and interaction between temperature and moisture significantly affected starch gelatinization during extrusion (Table I).

Starch gelatinization increased sharply with increasing temperature when moisture contents were 24 or 27%, but increased more gradually when moisture contents were 18 or 21% (Fig. 1). Table II details effects on starch gelatinization of combinations of moisture contents and extrusion temperatures.

Starch gelatinization decreased slightly with increased moisture content at low extrusion temperatures (65° and 80°C), but at higher temperatures (95° and

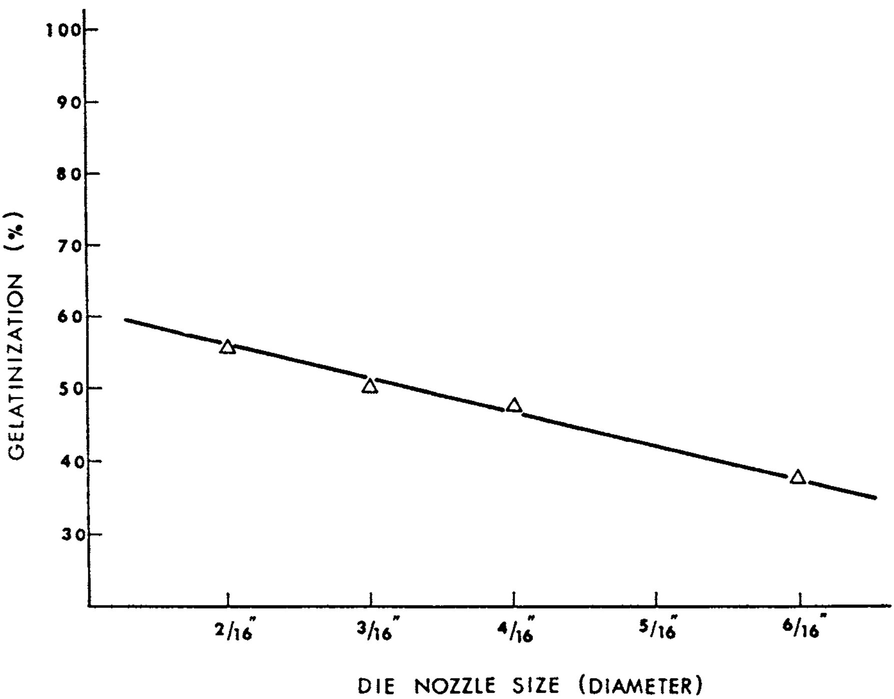

Fig. 4. Effects of die nozzle size on starch gelatinization.

110° C), increased moisture content significantly increased starch gelatinization (Fig. 2).

As screw speed increased, starch gelatinization decreased (Fig. 3). Increased screw speed decreased the retention time of the sample in the extruder, which presumably resulted in the decreased starch gelatinization. As die nozzle size increased, starch gelatinization decreased (Fig. 4). Perhaps pressure and surface shear decreases caused decreased starch gelatinization because of reduced residual time of the flour in the extruder.

Mono- and oligosaccharides in the raw ingredients of a second extruded product are shown in Fig. 5. Significant increases during processing were found for fructose, glucose, melibiose, maltose, maltotriose, and maltotetraose, suggesting that polysaccharides were degraded during extrusion. The melibiose, which was not detectable in the raw ingredients by paper chromatography, may have been formed by degradation of raffinose during extrusion. The sharp increase of fructose in the extruded product was anticipated from the degradation of sucrose and raffinose. The sharp increases suggest that the (2→1)

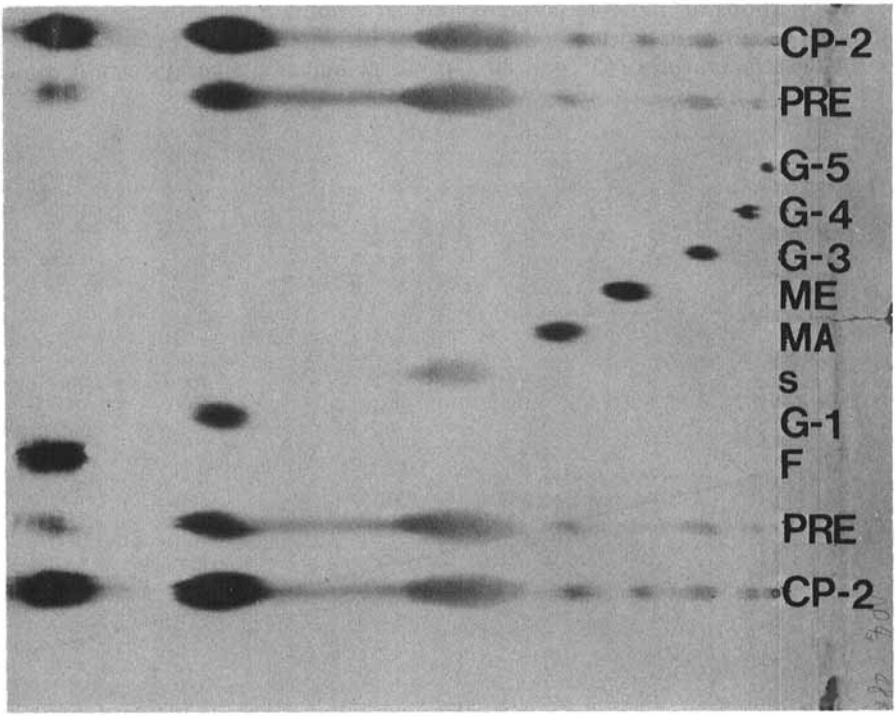

Fig. 5. Paper chromatograph of sugars formed during extrusion. F = Fructose; G-1 = glucose; S = sucrose; MA = maltose; ME = melibiose; G-3 = maltotriose; G-4 = maltotetrose; G-5 = maltopentose; Pre = the raw material before extrusion (75% white corn flour, 15% oat flour, 9% sucrose, and 1% salt); and CP-2 = the product of the raw material after extrusion (moisture 19.6%, extrusion temperature 225° C, and screw speed 200 rpm).

glycosidic bonds of sucrose and raffinose and the (1→4) glucosidic bonds of malto-oligosaccharides and starch are broken by the combined action of high temperature, high pressure, and severe shearing during the extrusion process.

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[Received June 18, 1975. Accepted July 30, 1976]