COMPONENT INTERACTIONS IN THE EXTRUSION COOKING PROCESS. I. PROCESSING OF CHLORINATED AND UNTREATED SOFT WHEAT FLOUR[1]

D. PATON and W. A. SPRATT, Food Research Institute, Agriculture Canada, Ottawa, Ont. K1A 0C6

ABSTRACT

Cereal Chem. 55(6): 973-980

The effects of extrusion cooking on the behavior of chlorinated and untreated soft wheat flour has been investigated. Analysis of extrudates on a starch basis indicates that chlorination increases the flour viscosity relative to an untreated sample, and viscosity values approach those of pure untreated wheat starch when extruded under identical conditions. Results are discussed in relation to the viscosity of slurries of uncooked flours and also the behavior of these in the cake batter system.

In the baking of cakes, the overall effect of flour bleaching by chlorine gas is to facilitate the cooking of the starch component, which, in combination with the other cake mix ingredients, contributes to the formation of a stable aerated physical structure (1). Chlorination has been shown to interact with wheat flour lipids (2) and has also been implicated in the breaking of sulfhydryl bonds of wheat proteins (3). The layer cake system has been examined extensively, with a view to understanding the bleaching phenomenon and the role of associated ingredients in the formation of the cake structure. Like cake baking, the extrusion cooking process is a limited water system. The mechanisms of this process, however, are not so well understood.

Most dry expanded extruded foods, either for human or animal consumption, are prepared under operational conditions of high shear and limiting moisture content. Generally, the resulting product is one possessing either an aerated texture as in snack foods or a compact structure as in dry pet food products.

Although corn grits or meal are commonly used in the manufacture of extruded products, many processes employ mixtures of different cereal grains and oilseeds. Ingredient interactions in such mixtures seldom are understood well, and may be due to several factors: 1) Food extrusion is a comparatively new process vis-à-vis baking technology. 2) Food extrusion is a much more complex system than extrusion of plastics on which the process is based. 3) Most extrusion information is either proprietary in nature or covered by patents. 4) Until recently, there has been a lack of well-instrumented small laboratory extruders having the flexibility to study a wide range of processing conditions.

Most of the early work has dealt with extrusions of a specific nature. Anderson et al (4) and Conway et al (5) described the behavior of corn-soy flour blends suitable for foreign aid programs. Conway (6) later described the effects of extrusion cooking on the viscoelastic properties of corn and soy grits, but did not relate these to starch. Lawton et al (7) studied the effects of extruder variables on the gelatinization of cornstarch. Replication appeared difficult to achieve and may have been due in part to low screw speeds and inconsistent product feed. A recent article by Timbers et al (8) describes extensive modifications of a Brabender laboratory extruder that minimize such problems. One of the most

---

[1] Contribution No. 339 Food Research Institute, Agriculture Canada, Ottawa, Ont.

0009-0352/78/000109$03.00/0
©1978 The American Association of Cereal Chemists

recent, and perhaps most comprehensive, studies on extruded starch is that of Mercier and Feillet (9) who examined carbohydrate modifications relating to process conditions. They found that starch was solubilized without producing maltodextrins and that extrusion temperature, moisture, and starch composition influenced such changes. The extruder used in this study was of a new twin-screw design; little indication was given in the report of screw geometry, speed, or size and type of die used. This omission does not allow adequate comparison with results from the more conventional single screw extruders.

The work presented here is part of an examination of the interaction of cereal starches with other cereal components during extrusion cooking under operating conditions of relatively low pressure and low shear.

Since chlorination is known to improve flour functionality in cake baking, it is logical to begin the present study with an investigation of the behavior of bleached flour in the extrusion cooking process, with particular reference to the starch component.

MATERIALS AND METHODS

Wheat starch was obtained from Industrial Grain Products Ltd., Montreal, Que., and the chlorinated (pH 4.93) and untreated (pH 5.70) soft wheat flours were obtained from Ogilvie Flour Mills, Montreal.

Extrusion

Moisture was adjusted to either 20.0 or 27.0% (db) by spraying water gently into a 3-kg batch of flour or starch stirred by a Hobart food mixer. After 30 min, the mass was screened through a 1.5 mm mesh wire grid and refrigerated for 1 hr before extrusion. In those cases in which the humidity of the environment was high, flours were blended in a Patterson-Kelley Twin-Shell Elbow mixer to obtain the required moisture levels. Flours and starches were extruded at the desired moisture levels using a Brabender model 2002 laboratory plastics extruder ($^L/d$ – 20:1, die 0.25 in. diameter) with modified feed system (8). Start-up was accomplished with a temperature of 65°C on all three zones; actual running conditions were set after the extrudate first appeared at the die face. Only the temperature of the metering zone and the die were varied. Each change in operating conditions requires equilibration before sampling the product, which is determined by viewing the continuous torque curve. All samples were collected, coded, and stored in plastic bags for further analysis. The range of extruder operating conditions is illustrated in Table I.

TABLE I
Extruder Conditions and Selected Variables

	Conditions							
Variables	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
RPM	50	100	100	50	50	100	50	100
Zone 2 (°C)	120	120	163	163	163	163	120	120
Die (°C)	120	120	120	120	163	163	163	163

Preparation of Extrudates for Analysis

Extrudates were broken or cut into 2-cm long pieces, placed in 1-L beakers, and steeped overnight in acetone; solvent was removed and extrudates ground in fresh acetone for 1 min in a Waring Blendor. Each slurry was filtered under mild suction, washed twice with acetone, and air dried. This procedure reduced the moisture in the samples to less than 10.0%. Although acetone treatment may remove lipid material, all samples were similarly treated and examined on a dry starch basis only. Thus, any effect of free lipid is minimized for all samples. The dried extrudates were powdered in a Retsch mill fitted with a 0.5-mm screen; further sieving produced a fraction of suitable particle size in the range of 0.177–1.025 mm.

Analysis of Extrudates

The pasting properties of powdered extrudates were used to analyze the influence of flour treatment and extrusion conditions on the starch component of each. All samples were compared on an equal basis by preparation as 9% (dry matter starch basis) slurries in distilled water and were related to the pasting properties of untreated wheat starch itself. The instrument used was the Ottawa Starch Viscometer (10), which requires only a 70-g sample of slurry. Thus, the amount of extrudate required is given by the formula:

$$x(\text{gm}) = \frac{6.3}{100 - (\text{protein} + \text{water})}$$

In the present experiments, no allowance was made for pentosan or lipid content of the wheat flours, which would constitute approximately 3.0% total.

Each powder was added slowly to the water with agitation, using a Virtis homogenizer at 3,000 rpm for 5 min. This apparatus was modified by installing a geared-tooth wheel and magnetic pickup so that rotational speed could be monitored digitally. Fine adjustment of stirring speed was accomplished by placing a variable voltage transformer between the homogenizer and the power supply to provide control to within 3% accuracy. The cutting blades on the shaft were replaced with twin aluminum propeller-type blades for a mixing rather than a cutting action. Unpublished work in this laboratory has shown that in rehydrating precooked starch-based products with any laboratory-type propeller stirrer, shaft speed decreased rapidly as the solution viscosity increased. Samples hydrated at variable rates of shear are difficult to compare. A monitored approach reduces this concern and makes comparisons more valid. Since slurries of pregelled starch products exhibit pseudoplastic or thixotropic behavior or both, sufficient time must be allowed to lapse following slurry preparation and before viscosity determination. This permits recovery from shear thinning; a 30-min resting period was found adequate and sufficiently short to avoid severe retrogradation or toughening of the pastes.

The viscometer water bath temperature was set initially at 60° C, the sample bowl inserted, and the temperature raised to 98° C at a rate of approximately 3.5° C/min. In analyzing the starting materials, chlorinated and untreated wheat flour, a bath temperature of 98° C was used. Rotational speed of the bowl was 200 ± 1 rpm with a 1-mm gap between the bowl inner surface and the paddle.

Viscosity (torque) was sensed by the paddle, amplified, and recorded on a strip chart recorder. Viscosity values at selected points on the curves were noted and results compared with other flours and with wheat starch.

RESULTS

In measuring viscosity versus time or temperature curves for cooked or partially cooked starch products, many different shapes were obtained. Since reproducing all of the curves for each material subjected to several process variables would be impossible, only the initial and hot peak viscosity values were used and are shown in Table II. These results illustrate the effects of screw speed, moisture content, and process temperature on the cold and hot paste viscosity of powdered extrudates prepared from untreated wheat starch and from chlorinated and untreated soft wheat flour.

Extrusion Cooking of Wheat Starch

Wheat starch was substantially altered when extruded according to the conditions of Table I. At 27% moisture and a temperature of 120°C on the metering zone and the die, screw speed showed little effect on viscosity values, whereas screw geometry resulted in lower values at a higher compression ratio. When the metering zone temperature was increased from 120–163°C, starch plasticity increased lessening the shear effect and resulted in high cold viscosity values. A corresponding lowering of the hot peak value occurred. Increasing the die temperature to 163°C resulted in still higher cold water viscosity values; screw speed showed less of an effect except when the screw compression ratio was also changed. When the metering zone temperature was reduced to 120°C, cold viscosity values were much lower. Considerable viscosity overlap was noticed in wheat starch extruded at 27% moisture with either a 3:1 or 1:1 compression screw.

Lowering the moisture level to 20% had noticeable effects; both cold and hot peak viscosity values were considerably lower. At high process temperature, an unexplained anomaly occurred (20% H_2O, 3:1 screw); viscosity values were comparable with those obtained with a 3:1 screw and 27% moisture content.

Extrusion Cooking of Untreated Flour

Regardless of moisture content, screw speed, or screw geometry, little or no cooking of the starch component occurred at the lower temperatures. When the metering zone temperature was increased to 163°C, higher viscosity values were found only for flour processed at 27% moisture using a 3:1 compression screw. This was also the case when temperature of the die was increased to 163°C. Lowering of the metering zone temperature to 120°C resulted in the starch component's returning to the uncooked state.

Extrusion Cooking of Chlorinated Flour

At low extrusion temperatures, the starch component of this flour was cooked just slightly. The cold water viscosity values were somewhat higher than those found for the untreated flour. When the metering zone temperature was increased to 163°C, cold water viscosity values were almost as high as those found for untreated wheat starch itself. This effect was lessened somewhat as the

TABLE II
Viscosities of Extrudates as Function of Processing Conditions

Sample	Viscosity (cmg)	Extruder Condition															
		1		2		3		4		5		6		7		8	
		A[a]	B[b]	A	B	A	B	A	B	A	B	A	B	A	B	A	B
Wheat starch																	
27% H_2O	1:1 Screw	88	76	87	80	174	78	221	85	240	90	245	93	120	108	52	58
	3:1 Screw	35	65	36	57	209	81	251	95	173	104	94	78	71	83	50	77
20% H_2O	1:1 Screw	34	76	62	63	118	49	98	52	147	76	120	72	65	74	82	74
	3:1 Screw	64	52	62	45	159	53	156	47	196	54	165	52	190	76	226	54
Chlorinated wheat flour																	
27% H_2O	1:1 Screw	3	126	9	106	157	87	159	71	106	82	62	120	42	115	11	113
	3:1 Screw	17	123	29	128	192	85	226	69	223	69	173	81	89	68	61	119
20% H_2O	1:1 Screw	23	122	21	108	95	74	95	63	85	65	103	90	12	94	21	106
	3:1 Screw	3	113	3	114	130	105	111	90	109	75	102	89	34	99	23	110
Untreated wheat flour																	
27% H_2O	1:1 Screw	3	112	3	114	17	119	75	85	96	95	29	103	3	115	6	112
	3:1 Screw	9	128	8	124	111	107	130	117	136	108	123	115	11	117	8	123
20% H_2O	1:1 Screw	4	99	8	79	23	67	31	81	34	81	52	81	9	106	19	106
	3:1 Screw	3	112	6	102	68	92	81	86	89	83	85	95	16	99	14	107

[a] A = initial cold-water viscosity.
[b] B = viscosity at hot peak.

die temperature was raised to 163°C. The lower screw speed resulted in higher viscosity values in cold water. When the metering zone temperature was reduced to 120°C, a trend toward lower cold water values and higher hot peak viscosity values was observed. Starch in the flour was cooked almost to the same degree as pure untreated wheat starch itself, but over a much narrower range of processing conditions.

The differences observed for wheat starch and the two types of wheat flour might be highlighted further by considering the curves for all three materials processed at 27% moisture content with a 3:1 compression screw, metering zone, and die temperature of 163 and 120°C, respectively (Fig. 1).

Figure 2 illustrates the pasting curves for chlorinated and untreated soft wheat flour. Although the temperature of initial swelling differs little, the extent, as

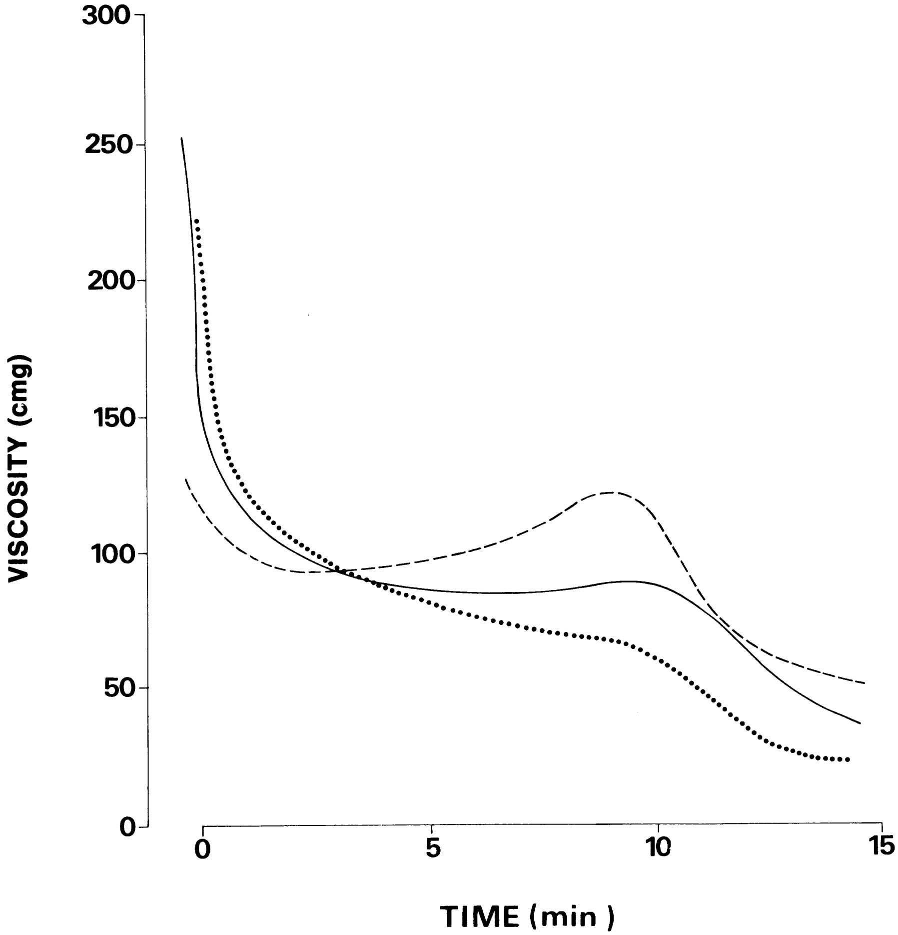

Fig. 1. Viscosity cooking curves for extruded wheat starch———, chlorinated soft wheat flour ....., and unchlorinated soft wheat flour - - - - -. (See text for extrusion details.)

measured by increased viscosity, is greater for chlorinated flour. A higher peak viscosity is also attained, but at a temperature 2°C lower than for the untreated flour. The numbers on the figure represent the time in decimal minutes and shows that less time is taken to complete the cooking cycle when the flour has been chlorinated. Previous work (10) has shown that these small differences are highly repeatable and significant and are a function of the extremely rapid heat transfer rates from the water bath through the bowl to the test sample.

DISCUSSION

From the foregoing results, the rheologic behavior of extrudates from chlorinated flour is apparently not unlike that of extruded wheat starch. Untreated flour, on the other hand, behaves quite differently from either chlorinated flour or wheat starch. This might be better understood from

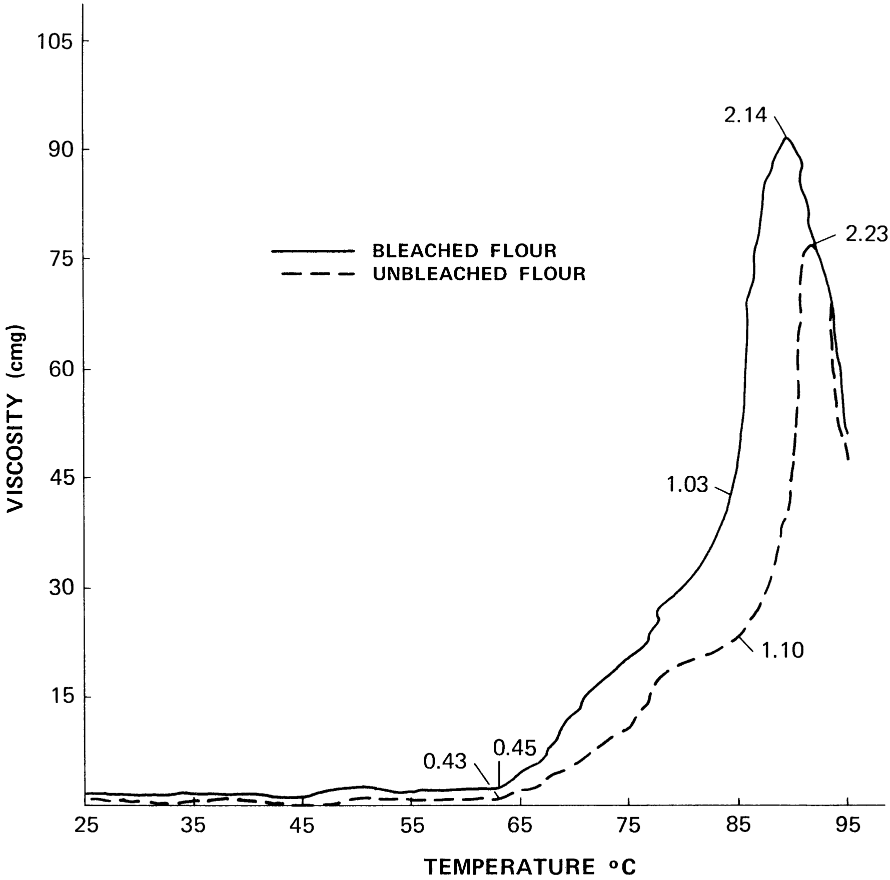

Fig. 2. Viscosity cooking curves for chlorinated and unchlorinated soft wheat flours. (See text for details of method.)

considering Fig. 1. The untreated flour does not attain the same high initial viscosity as does the chlorinated flour or wheat starch. This result is similar to what has been found for these flours in dilute solution (Fig. 2). To our knowledge, the results in Fig. 1 and 2 are the first recorded direct demonstration of the effects of chlorination on the cooking properties of soft wheat flour, and clearly show the differences involved. A reasonable assumption is that these differences would be magnified as the amount of water in a system is reduced substantially, such as in the extrusion cooking process or in cake production. The results presented in the present study would seem to verify this.

Differences in the viscosity characteristics of extruded products are likely to be a function of the distribution of water in the system and may be influenced by the effects of chlorine on wheat flour lipids and on the sulfhydryl bonds in wheat protein. Either of these mechanisms could contribute to the observed differences in viscosity of the starch component of chlorinated and untreated wheat flour. Further work is in progress using mixtures of wheat starch and gluten and in examining the effects of selective chlorination of those fractions on the viscosity characteristics of the extruded products.

Literature Cited

1. WOOTTON, J. C., HOWARD, N. B., MARTIN, J. B., McOSKER, D. E., and HOLME, J. The role of emulsifiers in the incorporation of air into layer cake batter systems. Cereal Chem. 44: 333 (1967).
2. SOLLARS, W. F. Cake and cookie flour fractions affected by chlorine bleaching. Cereal Chem. 35: 100 (1961).
3. EWART, J. A. D. Action of glutaraldehyde, nitrous acid or chlorine on wheat proteins. J. Sci. Food Agric. 19: 370 (1968).
4. ANDERSON, R. A., PFEIFER, V. F., BOOKWALTER, G. N., and GRIFFIN, E. L., Jr. Instant CSM food blends for worldwide feeding. Cereal Sci. Today 16: 5 (1971).
5. CONWAY, H. F., LANCASTER, E. B., and BOOKWALTER, G. N. How extrusion cooking varies product properties. Food Eng. 9: 102 (1968).
6. CONWAY, H. F. Extrusion cooking of cereals and soybeans. 1. Food Prod. Dev. 5: 27 (1971).
7. LAWTON, B. T., HENDERSON, G. A., and DERLATKA, E. J. The effects of extruder variables on gelatinization of corn starch. Can. J. Chem. Eng. 50: 168 (1972).
8. TIMBERS, G. E., PATON, D., and VOISEY, P. W. Modifications to improve the efficiency, process control and versatility of the Brabender laboratory extruder. J. Can. Food Sci. Technol. 9: 232 (1976).
9. MERCIER, C., and FEILLET, P. Modification of carbohydrate components by extrusion cooking of cereal products. Cereal Chem. 52: 283 (1975).
10. VOISEY, P. W., PATON, D., and TIMBERS, G. E. The Ottawa starch viscometer—A new instrument for research and quality control applications. Cereal Chem. 54: 534 (1977).

[Received December 27, 1977. Accepted April 10, 1978]