Simulated Approach to the Estimation of Degree of Cooking of an Extruded Cereal Product[1,2]

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

ABSTRACT

Cereal Chem. 58(3):216–220

A simulation method has been developed to estimate the degree of cooking of cereal products during the thermal extrusion process. The method is based upon analysis of the viscosity curves of known mixtures of precooked and uncooked starch as these are heated to 97° C and subsequently cooled to room temperature. By recording viscosity directly against temperature with the Ottawa Starch Viscometer and an X-Y recorder, curve shape differences can be readily identified. As the amount of uncooked starch in the mix increases, so does the area difference between the portions of the cooling and heating curves located between the Y axis and the curve intersection point. For uncooked starch concentrations of up to 30% in the mix, the data best fits a power equation of the form $Y = aX^b$. The possible application of this approach to extruded products is illustrated and discussed.

The degree of cooking of any extruded cereal-based product is an increasingly important industrial variable because an incomplete cook is believed to be involved with unsatisfactory storage stability, palatability, and digestibility of extruded products. This is especially important in the pet food industry, which uses large quantities of cereals in producing extruded products and which has an estimated value in North America in 1980 of more than $4 billion. Recognition of the importance of a means to determine the degree of cooking is relatively recent, and therefore only a few references are available. Suggested methods have included determining the loss of starch granule birefringence (Schoch and Maywald 1967), determination of starch damage by glucoamylase (Thivend et al 1972), estimation of the amount of soluble amylose (Wootton et al 1971), visual comparison of amylograph curves, and determination of water retention and the water solubility index (WSI) of extruded products (Anderson et al 1969).

A commonly occurring difference of opinion exists in the

---

[1] Presented in part at the AACC 64th Annual Meeting, Washington, DC, September 1979.

[2] Contribution 416 of the Food Research Institute.

---

literature as to what is meant by the terms "degree of gelatinization" and "degree of cook." The former term, which is the more widely recognized and quoted, should be used to express the extent of some limited change in the physical integrity of starch granules. Most often this is indicated by a limited increase in the starch granule diameter under the influence of heat and moisture. However, starch granules can undergo 100% loss of optical birefringence and yet not be 100% cooked. The degree of cook, therefore, is a more advanced state, which is generally associated with irreversible swelling and eventually with the complete rupture of the starch granule, often under the influence of mechanical shear, and which normally results in some measure of functional behavior. Thus at present only methods that take these factors into account, eg, viscosity curves, WSI, and water hydration index (WHI), can be considered valid potential indicators of "degree of cook" in extruded cereal products. This paper describes a simulation model that estimates degree of cook of starch and extends this idea in discussing how it may be used for the analysis of extruded products with more complex formulation.

MATERIALS AND METHODS

Raw and precooked wheat starch were obtained from Industrial Grain Products Ltd., Montreal, Quebec, Canada. The precooked starch, Redigel II, had high viscosity and would swell in cold water. Soft wheat flour (10.5% protein) was obtained from Ogilvie Flour Mills Ltd., Montreal, Quebec.

Analysis of Wheat Starch Blends

Precooked and raw wheat starches were dry blended over a range of ratios and each composite was analyzed in the following manner. Starch slurries were made of all composites at the 9% total starch level in distilled water, pH 6.8, using a modified virtis homogenizer designed to rapidly stir but not chop the suspensions. Each slurry (70 g) was then pasted in the Ottawa Starch Viscometer (Voisey et al 1977) at a bowl speed of 200 rpm, a torque calibration of 375 cm·g, full scale recorder defection on the Y axis, a temperature calibration of 25–97°C on the X axis, and an initial water bath temperature of 60°C. At the start of each test, the bath heaters were switched on and the temperature allowed to rise progressively from 60 to 97°C. The rate of heat transfer was such that the sample temperature rose from 25 to 97°C in approximately 8 min. Following a 3-min hold period at 97°C, the water bath was drained of hot water and replaced with cold running tap water to initiate the cooling cycle. Total analysis time did not exceed 20 min. Care was taken to ensure that the temperature of the cold tap water was low enough to effect adequate cooling. The water temperature was kept at 10–15°C.

The loop area on the recording chart—that bounded by the Y axis (at X = 25°C) and the intersection of the heating and cooling curves—was measured for each blended starch sample. Using a previously constructed calibration curve, the percent uncooked product was determined from the area of the loop. This value was then subtracted from 100, giving the percent of cook.

Extruded Wheat Starch and Soft Wheat Flour

Wheat starch and soft wheat flour were extruded under different combinations of screw geometry and moisture content but at a constant barrel temperature profile of 65, 120, and 163° on feed, metering, and die zones of the barrel, respectively. The extruder was a ¾ in., 20:1 L/D single screw, Brabender plastics extruder with modified feed and torque monitoring system (Paton and Spratt 1978). All extrudates were recovered in a powdered form by cutting the product at the die face, immersing it in liquid N_2 for 1 min, grinding the frozen sample in a coffee grinder, and sieving it through a 180-μm screen. This technique facilitated particle size reduction without appreciable heat generation. Pasting curves of the extruded materials were determined on the viscometer at 9% solids (starch basis) as described.

RESULTS AND DISCUSSION

Development of Working Model

The theoretical behavior of three types of fully cooked starches is shown in Fig. 1. The presentation of the pasting curves in this format is a departure from the traditional Brabender Amylograph curve but is necessary for the purpose of this discussion. A type of hysteresis loop is produced from the torque-temperature response; the cool-back curve (indicated by the directional arrow) is always lower than the heating curve and does not intersect it. The difference in position of the curves in Fig. 1 is a function of the amount of mechanical shear to which each sample has been subjected in the processing preparation, the corn-puff example

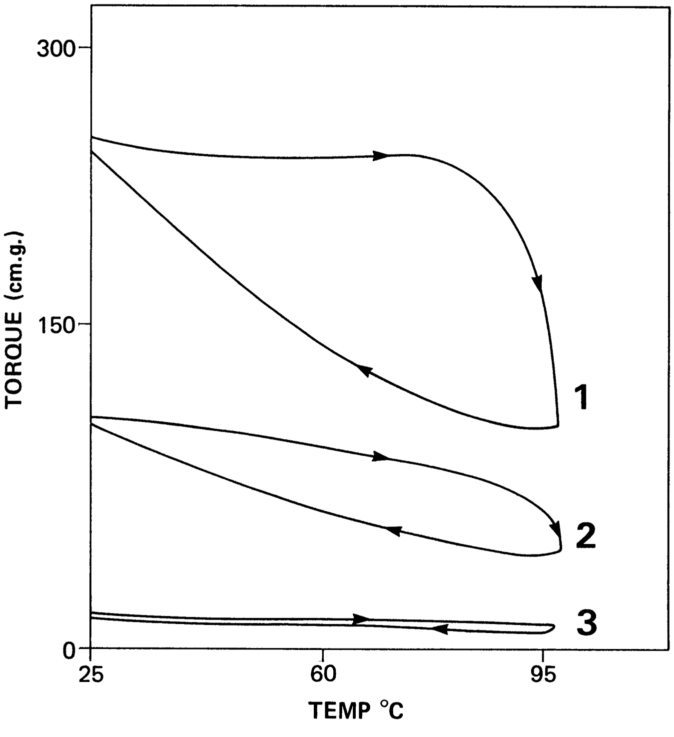

Fig. 1. Examples of completely cooked starch products. **1,** Drum-dried pregelatinized starch; **2,** extruded wheat starch; **3,** powdered corn puffs.

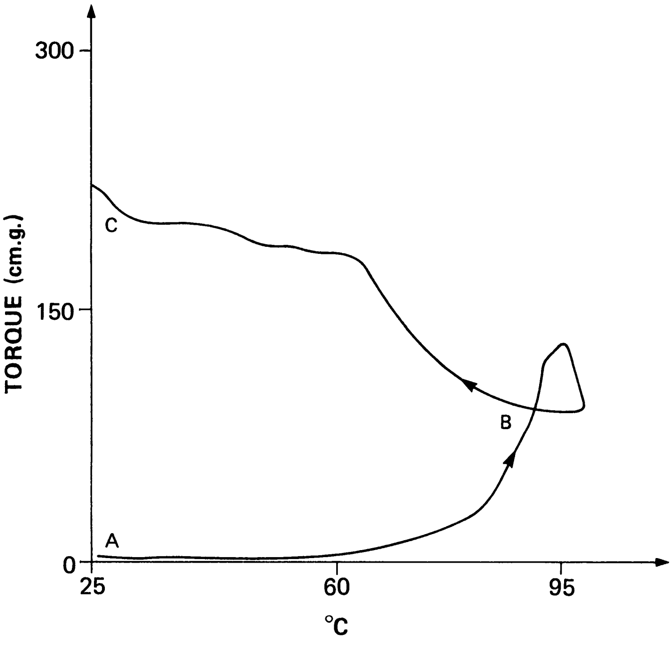

Fig. 2. Pasting curve of 9% solids wheat starch suspension, pH 6.8. **A,** starting value; **B,** intersection of heating and cooling curves; **C,** final value; **ABC,** loop area.

being the most severe. By relating these curve shapes to known functional characteristics of the products, all three curves in Fig. 1 are classed as fully cooked. Figure 2 illustrates a typical pasting curve for a native wheat starch. The initial viscosity is almost zero and rises through a maximum before cooling. On cooling, the resultant curve rises to intersect the heating curve and finishes with a final value considerably higher than the initial starting value. A rather large loop (ABC), bounded by the Y axis (at Y = 25° C) and the intersection of the heating and cooling curves becomes evident.

When a precooked starch (Fig. 1A) is blended with native starch in increasing proportions of the latter, a rather interesting family of curves is produced, only a few of which are represented in Fig. 3. As the amount of native starch in the blend increases, so does the loop area. Figure 4 is a calibration curve that plots these areas as a function of percent of raw or native starch in the blend. All data points were found to fit a straight line equation with a correlation coefficient of r = 0.96; however, the data better fitted a power function of the type $Y = aX^b$, in which a and b are constants, Y is the loop area, and X is percent raw starch in the blend. The correlation coefficient for this equation was 0.9917 and it more accurately determined the percent uncooked starch in the 0–30% range. When conducted in triplicate, good reproducibility was obtained (Table I). All replicate values fell within two standard deviations of the mean, and over the entire range of concentrations examined, the coefficient of variance did not exceed 6%.

TABLE I
Influence of Composition of Precooked Starch-Raw Starch Blend on Size (mg) of Loop Area[a]

	Raw Starch in Blend, %				
Sample	**10**	**15**	**20**	**25**	**30**
1	52.3	132.7	269.4	429	644
2	53.4	126.7	287.0	457	639.5
3	57.5	140.4	271.0	408	586.6
$\overline{X}$	54.4	133.3	275.8	431.5	623
SD	2.74	6.87	9.73	24.3	31.9
Coefficent of variance (%)	5.03	5.15	3.53	5.63	5.12

[a] Area bounded by Y axis (at X = 25° C) and heating and cooling curves (eg, Fig. 2, ABC).

Extension of Model to Extruded Products

When any cereal mix is processed by some type of thermal treatment, three possible situations can result: no cooking, partial cooking, or total cooking. In some specific food processes, product acceptability may not require the starch component to be fully hydrated and extensively swollen. For example, in the manufacture of potato chips or cookies, the extent of starch granule swelling may only reach a little above that displayed by the loss of optical birefringence, whereas in the manufacture of a low density cornpuff snack food, the starch granule structure must be disrupted by intensive shear. Thus the term "degree of cook" is relative and should be defined for each specific system. In relation to semimoist and dry extruded pet foods, edible snacks, and precooked starches and flours, degree of cook is defined as the extent of disruption or conversion of granular starch into forms having altered structure or functional properties. The ability to achieve complete cooking, as just defined, is obviously a function of extruder operating conditions and material formulation. Unless very mild cooking conditions have been selected, most cereal-based extruded products will exhibit little or no starch birefringence. Thus analytical methods based on optical properties or even on enzyme susceptibility are of questionable value in determining the degree of cook. Anderson et al (1969) used a visual comparison of viscosity pasting curves to assess extrusion cooking efficiency but were not able to derive any mathematical relationship. Our model used a mixture of precooked and uncooked starches and plotted differences in their pasting curve characteristics to establish a mathematical approximation of the degree of cook.

As a first approximation, the relationship of Fig. 4 was used to estimate degree of cook of several laboratory-produced extrudates; those pasting curves are shown in Figs. 5A and B. The products made from starch did not respond in the same way as those from flour under identical extruder conditions. This is due to the competition for available water among the starch, the protein, and the soluble flour component. Furthermore, when the 1:1 screw is used, increasing the moisture content of the feed has the effect, in flour, of merely supplying more lubrication within the barrel. The result is that the product is less cooked. As a more compressive screw

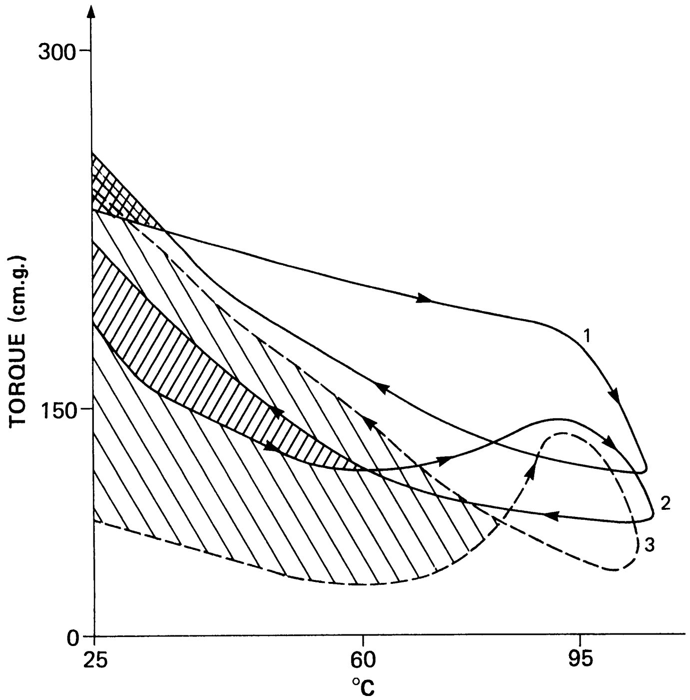

Fig. 3. Pasting curves of mixtures of precooked and uncooked wheat starch. **1,** 95% precooked, 5% uncooked; **2,** 85% precooked, 15% uncooked; **3,** 65% precooked, 35% uncooked.

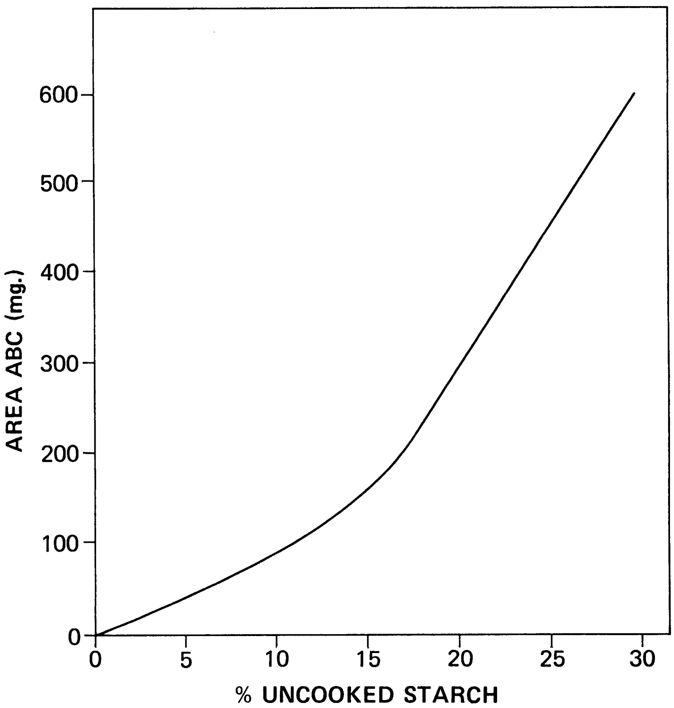

Fig. 4. Calibration curve of loop area as a function of the amount of uncooked starch in the blended standards.

is used, cooking is increased, depending on the moisture content. Some compromise between shear and thermal effects always occurs, and in certain instances this can result in the same degree of cook for different extruder conditions. Loop area calculations performed on these curves allows an approximate percent of uncooked starch—or, inversely, the degree of cook—to be read from Fig. 4. Although some discrepancy may exist between the model and an actual system, the nature of the product pasting curves gives a reasonable indication of the presence and amount of uncooked material.

Extension of Model to Analysis of Commercially Extruded Products

Some drawbacks in this procedure are 1) the time and effort required to establish the calibration curve, 2) the need for a recording viscometer that will *rapidly* plot torque against temperature *directly*, and 3) the need to ensure that the temperature of the cooling water is low enough (10–15°C). For a processor to be able to use these approaches, the exact composition of the starting formulation must be known so that the starch content can be calculated. Furthermore, a processor must obtain a sufficient quantity of precooked formulation to establish a calibration curve. Precooking may readily be performed in a small steam-jacketed kettle and the product recovered on a pilot model drum dryer. This operation need be performed only once unless formulations are changed. For smaller companies, an alternative approach might be to avoid any actual determination of degree of cook but to ensure that the viscosity profile of any product is checked regularly against an acceptable standard.

For maximum usefulness, any routine methodology must be rapid. The procedure described in this paper satisfies this criterion. However, some alternatives to the Ottawa Starch Viscometer are possible.

Alternatives to the Ottawa Starch Viscometer

The Brabender amylograph, which is universally used for starch and flour paste viscosity determinations, could be used if certain modified approaches were adopted. For example, if the size of the cooling coil were enlarged and the heating and cooling cycles were run with the clutch lever in the neutral position, a more rapid amylogram would be produced. The chart paper would have to be folded at the end of each run to produce the loop normally developed with X-Y recorders. Alternatively, a modified Rapid Amylograph procedure may be possible. If a cooling coil were provided here or some means designed so that the water could be rapidly exchanged in the outer bowl, the analysis time could be similarly reduced. The Corn Industries Viscometer may also prove useful, provided that the heating fluid could be rapidly exchanged and that a thermocouple/signal amplification system could be installed. Some drawbacks of this viscometer have previously been discussed by deWilligen (1953).

We have also investigated the use of indices such as WHI and WSI as indicators of degree of cook (data not shown). Different viscosity curve profiles are possible from fully cooked products (Fig. 1). Because their viscosity profiles differ in magnitude, so do their WHI and WSI. In addition, certain extrudates may have a WHI very close to that of the control feed formulation. Thus WHI and WSI are indices closely related to the effects of mechanical shear on the fully cooked product and cannot be considered true indicators of degree of cook. The approach described here for the determination of the degree of cook of extruded cereal-based products is only tentative and undoubtedly will require further refinement before it can be considered for practical use by industry. However, a functional property analysis appears to be a more relevant indicator of degree of cook than many of the previously published methods.

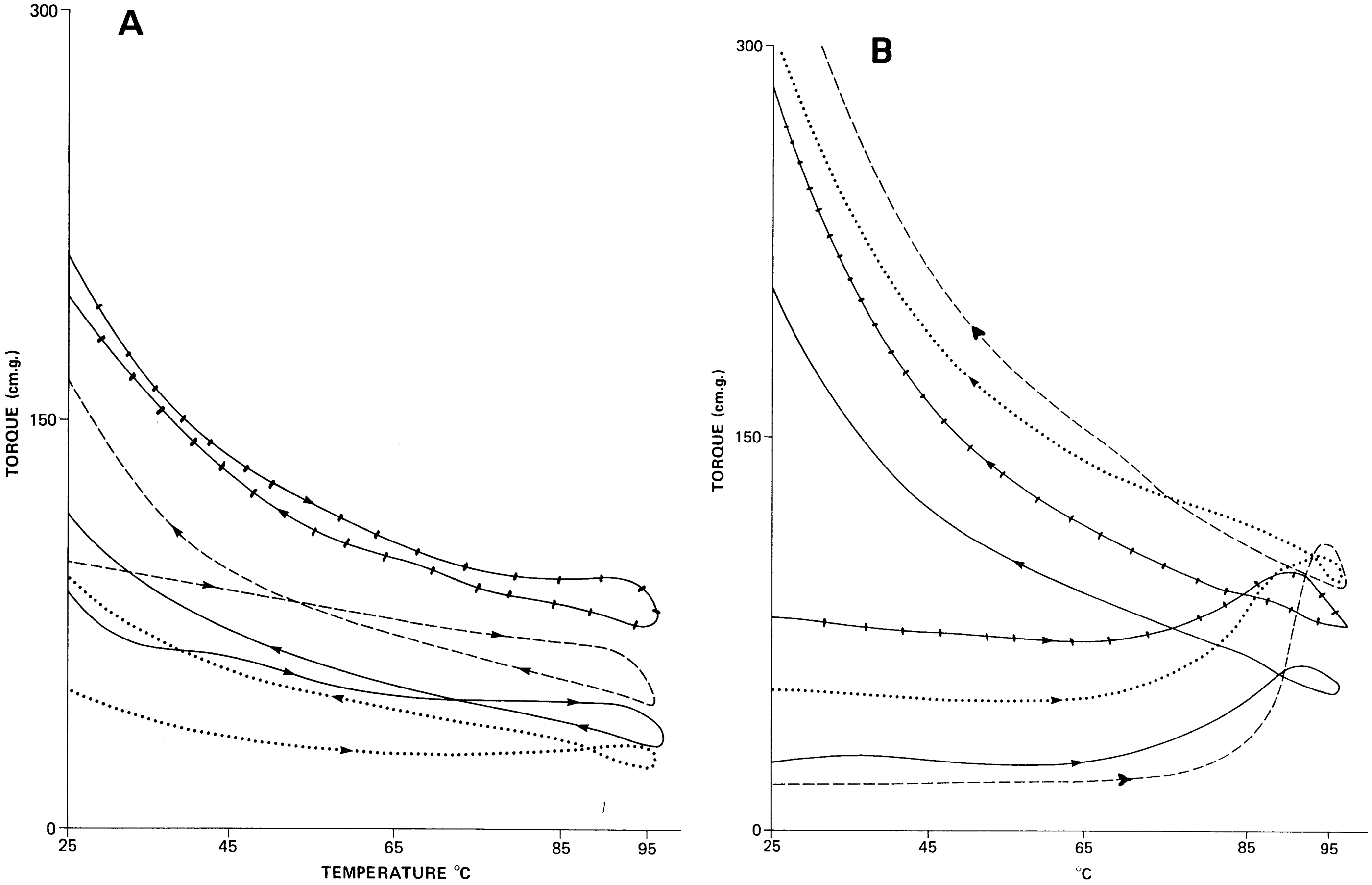

Fig. 5. A, Pasting curves for extruded wheat starch. Screw, H_2O, and percent cook: ___ = 1:1, 20%, 88.0; _ _ _ = 1:1, 27%, 87.5; ..... = 3:1, 20%, 82.5; ┼┼┼ = 3:1, 27%, 100.0. **B,** pasting curve for extruded soft wheat flour. Screw, H_2O, and percent cook: ___ = 1:1, 20%, 59.0; _ _ _ = 1:1, 27%, 5.0; ..... = 3:1, 20%, 35.0; ┼┼┼ = 3:1, 27%, 70. Barrel temperature profile constant at 65, 120, and 163°C for feed, meter, and die, respectively, in all cases.

LITERATURE CITED

ANDERSON, R. A., CONWAY, H. F., PFEIFER, V. F., and GRIFFIN, E. L. 1969. Gelatinization of corn grits by roll and extrusion cooking. Cereal Sci. Today 14(1):4.

DeWILLIGEN, A. H. A. 1953. Pasting of potato starch in the corn industries viscometer. Anal. Chem. 25(2):314.

PATON, D., and SPRATT, W. A. 1978. Component interactions in the extrusion cooking process. I. Processing of chlorinated and untreated soft wheat flour. Cereal Chem. 55:973.

SCHOCH, T. J., and MAYWALD, E. C. 1967. Industrial microscopy of starches. Page 639 in: Whistler, R. L., and BeMiller, J. N., eds. Methods in Carbohydrate Chemistry, Vol: 2. Academic Press: New York.

THIVEND, P., MERCIER, C., and GUILBOT, A. 1972. Determination of starch with glucoamylase. Page 102 in: Whistler, R. L., and BeMiller, J. N., eds. Methods in Carbohydrate Chemistry, Vol. 6. Academic Press: New York.

VOISEY, P. W., PATON, D., and TIMBERS, G. E. 1977. The Ottawa Starch Viscometer—A new instrument for research and quality control applications. Cereal Chem. 54:534.

WOOTTON, M., WEEDEN, D., and MUNK, N. 1971. A rapid method for the estimation of starch gelatinization in processed foods. Food Technol. Aust. 12:612.

[Received June 2, 1980. Accepted October 24, 1980]

Functional Properties of Surfactants in Breadmaking. III. Effects of Surfactants and Soy Flour on Lipid Binding in Breads[1]

O. K. CHUNG,[2] C. C. TSEN, and R. J. ROBINSON, Department of Grain Science and Industry, Kansas State University, Manhattan

ABSTRACT

Cereal Chem. 58(3):220-222

[illegible]

[illegible]

MATERIALS AND METHODS

Materials

[illegible]

Baking Procedure

[illegible]