

EFFECT OF CORN SYRUPS
IN CAKE PRODUCTION

by

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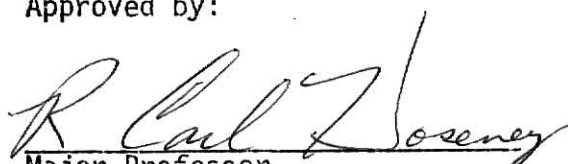
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TABLE OF CONTENTS

INTRODUCTION.....	1
LITERATURE REVIEW.....	1
METHODS AND MATERIALS.....	9
Materials.....	9
Cake Baking Method.....	13
Visco-Amylograph.....	13
Butanol Extraction.....	15
Ultraviolet Spectroscopy.....	15
High Performance Liquid Chromatography.....	16
Moisture Determination.....	17
RESULTS AND DISCUSSION.....	17
Characterization of Flours.....	17
Baking Properties of Syrups.....	18
Amylograph Properties of Corn Syrups.....	21
Amylogram Properties of Sugars.....	33
Effect of Water Activity on Amylograms and Baking Properties.....	39
Fractionation of High Maltose Syrup.....	51
Effect of Corn Starch Lipids.....	60
BIBLIOGRAPHY.....	70
ACKNOWLEDGEMENTS.....	72

INTRODUCTION

With the advent of higher sucrose prices, alternative sources of sweeteners for bakery products are being considered. One source of sweetener is corn syrups which have remained lower in price (based on solids). Corn syrups have some of the desirable properties of sucrose-fermentability, aid in browning reaction of the final product, and sweetness. The sweetness and desired composition of the syrups are controllable during manufacture. The high fructose corn syrup was developed to produce a sweetness level equal to or sweeter than sucrose. Presently the high fructose corn syrup is replacing sucrose as the sweetener in bread, soft rolls, sweet dough, and cookies. Our area of research was then to investigate the total replacement of sucrose by corn syrups in cakes.

LITERATURE REVIEW

Early researchers believed the quality of cakes to be dependent only on the flour. Bohn (1) stated that the following factors influenced cake quality: quality and quantity of the flour protein, yield of flour, maturing and bleaching agents, granulation, moisture content, color of the flour, ash content, and glutens which are difficult to wash but still have good elasticity. Finer granulated flours were found to give better cakes.

Garnatz (2) evaluated Soft Winter Wheat flour as a cake flour. He stated that a cake flour needed to be able to form a soft gluten

that would not become elastic during mixing, would have a degree of strength and would still be able to contribute to the final cake structure. Other desirable cake characteristics were: an ash content of 0.34% to 0.38%, a protein content of 7-9%, fine granulation and a pH of 5.1-5.3. Garnatz believed there was no definite correlation between the viscosity of a flour and its cake-making qualities, although most cake flours had a viscosity of 40-50 MacMichels.

Loving (3), however, believed the quality of the cake flour to be dependent on the wheat selected and the flour milling process. Analytical and baking performance tests determine the quality of cakes. The wheat selected should have a high test weight, a white starchy endosperm, and be free of vitreousness.

Research on the actual baking of cake flours has been rather limited. Patterson (4) believed a uniform cake texture was desirable. To obtain a uniform cake texture there should be consistency in the size of the flour particles. The ideal cake texture would have each individual starch granule be separated from neighboring starch granules. The closer this condition is approached, the finer the particles of flour become yielding a cake with a lighter and more delicate texture.

A lean formula cake method which could be used to classify selections and varieties of wheat was developed by Kissell (5). The formula was demonstrated to be sensitive to the amount of bleaching, amount of liquid, flour particle size, length of patent extraction, and protein content differences.

The baking cycle was broken down into three stages by Howard (6). The three were: "aeration during batter mixing, early stages of baking while batter emulsion is still fluid, and starch gelatinization stage." Ingredients were separated in terms of being essential and non-essential. Essential ingredients required for the formation of a layer cake structure are : proteins (flour, egg, and milk), carbohydrates (starch from cake flour), lipids (emulsifiers and egg yolk lipids in yellow cakes), and others (leavening acids, sodium bicarbonate and water). Non-essential ingredients include sucrose, thickeners, shortening, milk and flour lipids, sodium chloride, color and flavor.

Studies using air-classification, granulation, flour particle size, fractionation and reconstitution of cake flours were made to examine what is in cake flour that influences the quality.

Wichser (7) examined the cake quality of four air-classified flour fractions. Of the fractions used- conventionally milled parent flour, fines high-protein fraction, fraction containing various sizes of chunk-endosperm particles and fines low-protein starch- the latter produced the best cake. The fines high-protein fraction (20% protein) produced a better cake than the lower protein (11.5% protein) chunk-endosperm fraction.

Bode (8) fractionated by air-classification a Soft Red Winter flour into mean particle diameters of 6, 12, 19, and 22 microns. The second fine fraction (19 microns) produced a cake of greater volume than the parent flour. With air-classified Hard Red Winter Wheat (same

particle sizes) the 2nd, 3rd, and 4th fine fractions (19, 12, and 6 microns, respectively) cakes had greater volume than the parent flour. However, only the 12 μ and 16 μ particle fractions produced cakes that had cell structures comparable to the parent flour cakes.

Bean (9) baked cakes with three low-protein fractions of the five varieties of Kansas Hard Red Winter Wheats. The three fractions were bleached with chlorine gas and then baked in cakes using a high-sugar ratio formula. Differences in the cake volumes were believed to be caused by the parent flour. The parent flour was believed to be influencing the baking behavior of the low-protein fractions. All of the air-classified fractions did yield cakes with finer grain than the commercial flour but were not necessarily the better flour. Bean believed the finer textures were due to the finer granulation and air-classification of the flour.

Miller (10) found starch damage increased as the endosperm particles were reduced in size although pin-milling increased cake quality. The quality of the flour seemed to deteriorate as the number of pin-millings increased. Pin-milled flours had high absorption values and produced optimum cakes. The optimum cake quality was associated with a minimum hydration viscosity, minimum in particle size, and starch damage of approximately 5%. Absorption was found to increase 0.45% for each 1% increase in starch damage caused by pin-milling.

The relation between cake properties and flour particle size

was further examined by Shellenberger (11). A Soft Red Winter Wheat was fractionated into three particle size groups: 37μ or less, 37μ to 53μ , and particles greater than 53μ . The 0- 37μ group contained the lowest ash and protein level and was of the lowest viscosity in batter. The 37 - 53μ group contained the highest ash and protein level and was intermediate viscosity in batter. The 53μ or greater group contained intermediate levels of ash and protein and was of highest viscosity in batter. Of all three grades of flour used, the 0- 37μ group had the best cakes. Cake quality was found to be improved with a decrease in particle size.

Yamazaki (12) found a high correlation between the wheat particle size index and cake volume. Wheats with different inherent granularity that are milled and wheats which granulate more finely tend to produce flours which with chlorination will have greater cake volume.

Sollars (13) fractionated and reconstituted cake flours to observe cake quality. Commercially bleached flour (pH 4.9) was fractionated by acetic acid into water-solubles, gluten, tailings starch, and prime starch. Baking tests were then attempted with the flour reconstituted in the proportions as in the original flour. The reconstitution process required forming a dough of blended fractions plus water before adding the other ingredients. Particle size distribution appeared to be the same in the reconstituted flour as in the original flour. The cakes baked from reconstituted flour were considered satisfactory when compared to normal flour cakes.

Donelson (14) fractionated and reconstituted soft wheat flours to determine the effect of quantity of the flour fractions on cake quality. An unbleached, commercially milled 48% extraction soft wheat flour was fractionated into water solubles, gluten, starch tailings, and prime starch by a batter method. The dry components were mixed in the proportions desired and then bleached with chlorine gas. Since the process required a preliminary dough mixing step, the final cake volume was affected by the dough mixing times and the liquid level. Once the process was established all factors but one were held constant to observe how the altering proportions altered the cake quality. Since all of the flour fractions came from the same source this kept the quality of the fractions constant.

The flour components were added in the following ranges: water solubles-1 to 7%, gluten-5 to 17%, starch tailings-3 to 20%, and prime starch-65 to 82%. Water solubles tended to decrease layer volume. A small increase in the concentration of gluten increased the layer volume slightly. Much greater or smaller amounts of gluten resulted in much smaller cakes. With prime starch a small decrease in concentration increased layer volumes slightly. Much greater or smaller amounts of prime starch resulted in much smaller cakes. The tailings increased the volume and produced fine internal structure. Generally the larger cakes had large amounts of tailings.

Donelson (15) repeated the same experiment but observed flour-fraction interchange upon cake quality. This time the flour composition

was held constant and the quality of the fractions varied. A good quality unbleached cake flour and a poor quality cake flour were fractionated into water-solubles, gluten, starch tailings, and prime starch. The reconstituted flours were bleached with chlorine gas. Layer volumes were the measure of the cake quality. Variables controlled were the liquid level, extent of chlorine treatment, and protein content. Responses of the fractions measured their contribution to the cake volume. The prime starch fraction is a small contributor to cake volume. Gluten is the major fraction which determines cake volume. The tailings and water-soluble fractions are moderate factors in determining cake volume. The main conclusion was that gluten, tailings, and water-solubles determined the quality of the cake. Good quality starch produced a better cake than poor quality starch if the other fractions were equal. However, if the other fractions were of poor quality, a good quality starch had no effect on the cake quality.

Baldi (16) fractionated a bleached cake flour to observe the effect and proportion of flour components on the cake structure. The fractions used were water-solubles, gluten, starch tailings, and prime starch. Several ratios were investigated: tailings/prime starch; gluten and water solubles/prime starch; gluten and water-solubles/starch tailings. The cake formulas used 100 and 125% sucrose levels. Structural quality was measured by cake volume. Results of the experiment were:

- 1.) As the proportion of tailings to prime starch

increased, the cake volume increased to a minimum.

2.) With structural gluten protein at a fixed level, and reducing the proportions of tailings the batter and cake structure were weakened.

3.) When the tailings amount was above the normal proportion, the cakes were fine and silky in texture, had small cells with fine cell walls, and very moist and tender.

4.) A low proportion of tailings caused the cake to fall during the last stages of baking, have coarse crumb texture, and thick cell walls.

5.) Protein levels above normal had a slight effect on cake volume; but if the proportion of protein was decreased by more than 20%, the cakes had a definitely lower volume and a flat or concave top.

6.) With the protein fraction at a normal or higher level, the high-ratio cakes were moist, fine in texture, small celled, and with thin cell walls. In low-ratio cakes the internal structure was of good quality.

7.) As the protein levels increased still higher in low-ratio cakes, the crumb became more compact and drier. As the protein level decreased considerably, the crumb was coarse with thick cell walls until at the lowest level the cake was tough and gummy.

8.) Replacing the protein fractions with starch tailings caused a decrease in cake volume. This seemed to indicate an interaction between the sugar-water level and tailings fraction.

Corn syrups are produced from corn starch by acid hydrolysis, enzymes, or a combination of both methods. Manufacture can be controlled to produce a variety of sugar combinations in the syrups. Patents covering this area are discussed by Petersen (17).

Corn syrups are rated by their D. E., Dextrose Equivalent. Dextrose Equivalent is the total reducing sugar content of the dissolved solids in a starch hydrolysate expressed as percent dextrose.

Presently corn syrups have come into use as a replacement for sucrose in bakery products. This is due to the high cost of sucrose. Saussele et al. (18) replaced sucrose in a 120% sugar white layer cake

with varying amounts of high fructose corn syrup. At 15 and 25% replacement levels, the color was found to be darker and the texture good.

Henry (19) also recommended 10-30% replacement of sucrose in white cakes.

Volpe (20) increased the usage of corn syrups to 60% (high fructose corn syrups) with increased amount of leavening source. Three different leavened systems were used in a white shortened layer cake formula. The increased leavening agents slowed the browning reaction by decreasing the pH. Bean (21) stated that reducing the water content 10-20% gave optimum grain and contour using high fructose corn syrups.

However, researchers are trying only to correct the problem of using corn syrups by changing the formula. The area of research to be investigated was then total replacement of sucrose by corn syrups.

METHODS AND MATERIALS

MATERIALS

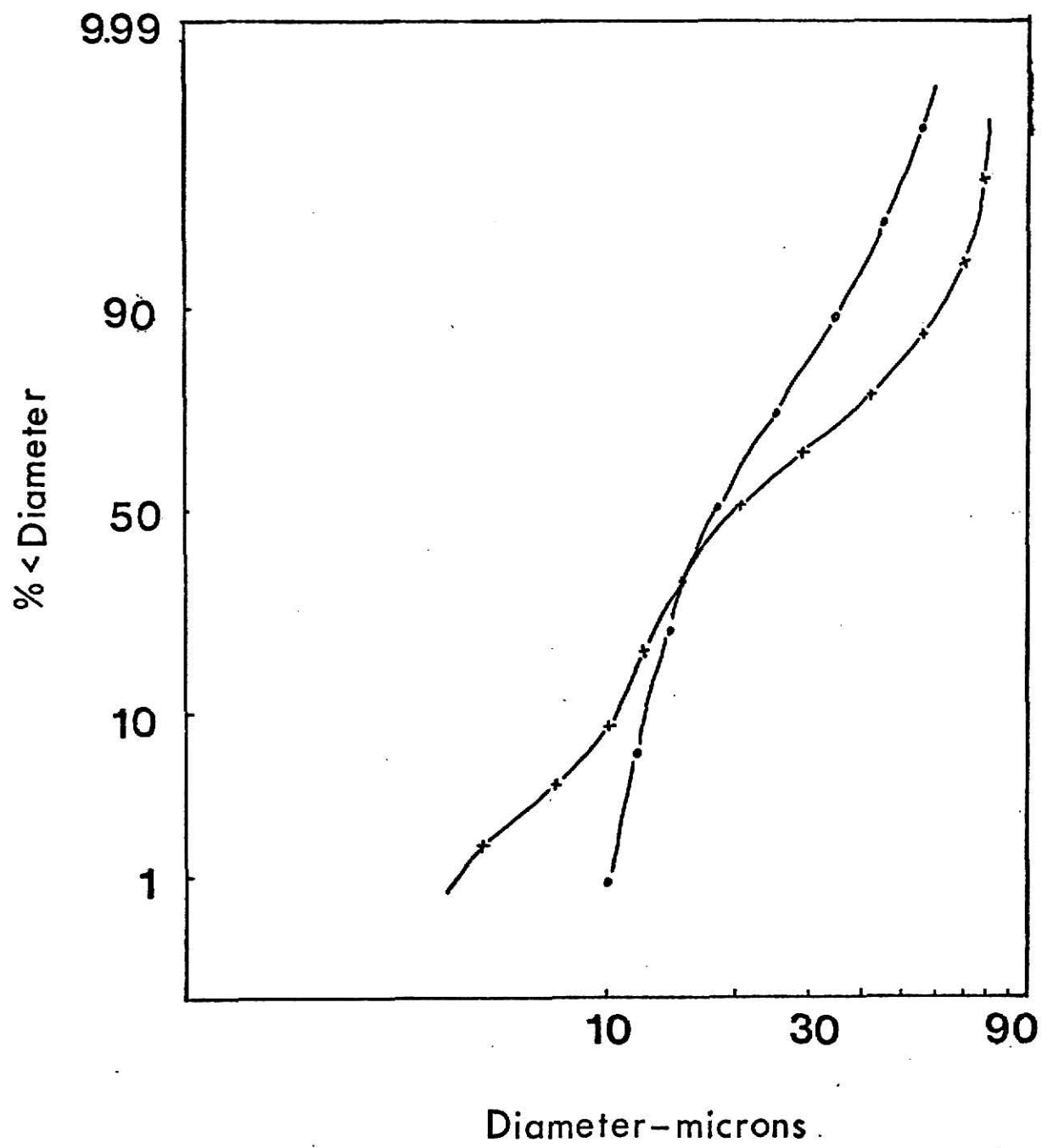
Four turbo-milled flours (Pillsbury) were used for baking cakes. Two of the flours were Soft Wheat flours, bleached (SWB) and unbleached (SWNB). The remaining two were Hard Wheat cake flours bleached (HWB) and unbleached (HWNB). Ash, protein, and moisture values were determined by the AACC Methods 08-01, 46-11, and 44-15A, respectively (Table 1). Starch damage was determined by the Farrand method (22). The particle size of each flour was determined by Whitby Centrifugal Sedimentation Size Analysis (Fig. 1).

Four corn syrups and one crystalline sugar (furnished by A. E. Staley) were used in the research. They were:

Table 1. Analytical Data For the Four Flours.

FLOUR	PROTEIN %	MOISTURE %	ASH %	pH	STARCH DAMAGE %
HWNB	7.3	10.0	0.41	5.85	28.3
HWB	7.3	10.4	0.44	4.65	25.2
SWNB	8.9	11.5	0.42	5.82	0.3
SWB	8.8	11.4	0.39	4.72	1.8

Figure 1. Whitby Centrifugal Sedimentation Size Analysis of two flours-
Hard Wheat Bleached Turbo Milled Cake Flour (•) and Soft Wheat
Bleached Turbo Milled Cake Flour (x).



- 1.) High Maltose (HM)
- 2.) Low Dextrose Equivalent-43 DE (LDE)
- 3.) High Dextrose Equivalent-64 DE (HDE)
- 4.) High Fructose (HF)
- 5.) Crystalline Dextrose.

The composition of the four corn syrups and crystalline dextrose are given in Table 2. Additional sugars used in the research were: maltose (Hayashibara Biochemical Laboratories, Inc.), β -D-lactose (Eastman Kodak Company), lactositol (ICI America Inc.), D-sorbitol and D-fructose (Fisher Scientific Company).

CAKE BAKING METHOD

The Kissell lean formula (5) was used to bake the cakes with the water levels optimized for the flour used. The volume of the baked cake was determined by a rape seed displacement method. Whenever the corn syrups or the additional sugars were used in place of sucrose, the sucrose was replaced on a solids basis.

AMYLOGRAPH METHODS

A mixture of 40 grams of soft wheat bleached cake flour, 350 ml of carboxymethylcellulose solution (1.5%), and 162 gm of sucrose or other sweetener was used for each amylogram. This empirical formulation gave a lower sugar to water ratio than is in the cake formula. The amylograms were run on a Brabender Amylograph-Viscograph. The temperature range was from 30 ° C to 95 ° C with the instrument's water cooling unit on.

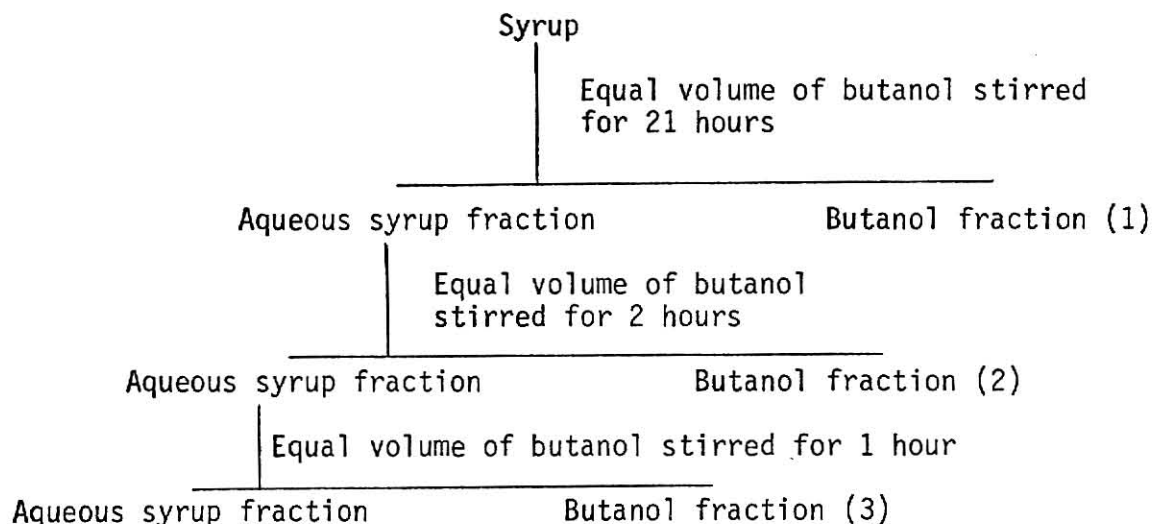
Table 2. Composition of The Corn Syrups and Crystalline Glucose.

Syrup	Dextrose %	Maltose %	Triose %	Oligosaccharides %
High Fructose	50 ^a	1.5	Trace	5.0
Crystalline Glucose	91			
High Maltose	10	46	24	20
Low Dextrose Equivalent	20	14	12	54
High Dextrose Equivalent	39	33	12	16

a/ In addition contains 42% fructose.

BUTANOL EXTRACTION

The butanol treatment of the high maltose syrup was as follows:



The three butanol fractions were then combined and rotary evaporated at 40 ° C on a Büchi Rotovapor. The aqueous syrup fraction was then rotary evaporated to remove residual butanol and reduce the water content. The butanol control involved adding an equal amount of butanol to the syrup and then removing it by rotary evaporation. Syrups were treated with chloroform in the same manner as butanol.

ULTRAVIOLET SPECTROSCOPY

Ultraviolet spectroscopy was run on 5% solutions (solids basis) of the corn syrups using a Varian Techtron UV-Vis Spectrophotometer, Model 635. The wavelength scan of 350-190 nm was recorded on a Houston Instrument OmniScribe_{TM} Recorder. The slit was 1.0 nm, chart speed was 2.5 cm/min, and absorption was on a scale of 0 to 1.0.

HIGH PERFORMANCE LIQUID CHROMATOGRAPHY

High Performance Liquid Chromatography (HPLC) was used to observe the movement of glucose and sucrose in a starch slurry and to determine the composition of the butanol residue. The HPLC system consisted of a high-pressure tank of nitrogen, a pressure regulator, a stainless steel solvent reservoir (500 ml) and a No. 316 stainless steel column (4.6 mm ID x $\frac{1}{4}$ " OD x 25 cm) packed with silica gel (average particle size $10\mu\text{m}$) to which was bonded a cyano-polar phase (Partisil-10 PAC, Whatman Inc., Clifton, New Jersey). A precolumn (2.2 mm ID x $\frac{1}{4}$ " OD x 5 cm) packed with a larger particle bonded cyano-polar phase (Co Pell PAC $37\text{--}50\mu\text{m}$) was used to help protect the analytical column from contamination. Refractive Index was measured by a Varian Refractive Index Detector with a $10\mu\text{l}$ flow cell ($1\text{--}128 \times 10^{-5}$ refractive index units, Varian Instrument Company, Model 001528-00, Walnut Creek, California). The mobile phase was a mixture (70/30, v/v) of acetonitrile (Certified ACS Grade, Fisher Scientific Company, Pittsburgh, Pennsylvania) and 2.5mM aqueous (demineralized, distilled water) potassium hydrogen phosphate previously adjusted to pH 5 using dilute aqueous phosphoric acid. The flow rate was 1.0 ml/hr and the column pressure was 320 p.s.i.. Samples of 10, 20, and $30\mu\text{l}$ were injected with a 0.05 micron syringe (Hamilton Company, Whittier, California) using a stop-flow injector. The detector was operated at an attenuation setting of x1, x2, and x4. A standard solution of glucose, maltose, sucrose, and fructose (0.020 M in water) was used for the determination of the components of the butanol residue. The mixtures run on HPLC were 1% butanol residue, 5% high maltose, low

dextrose equivalent, high fructose, and charcoal-filtered high fructose corn syrups.

MOISTURE DETERMINATION

The method used for determining the solids in the high maltose syrup, low dextrose equivalent, butanol-treated high maltose syrup, and chloroform-treated high maltose and low dextrose equivalent syrups was similar to the Method 29.143, 144 for Sugar and Sugar Products in the Official Methods of Analysis of the Association of Official Agricultural Chemists (23). Commercial grade Celite 545^R (Fisher Scientific Company) was washed with HCl and then with distilled water, and dried in an oven at 120 °C. Aluminum dishes containing 20 gm of the Celite and a glass stirring rod were dried to constant weight. Corn syrups (10 gm) were weighed into disposable weighing dishes and 10 ml of hot distilled water added and stirred to dissolve the syrup. The solution was added to the tared dishes containing the dried Celite. The dishes were then washed with three 4 ml portions of water and added to the Celite. The glass stirring rod was then used to incorporate the solution with the Celite into a damp mass. The lids were replaced loosely and the aluminum dishes placed in the oven (120 °C) and dried to a constant weight.

RESULTS AND DISCUSSION

CHARACTERIZATION OF FLOURS

The flours were characterized by baking cakes using the Kissell lean formula (5). Both the Hard Wheat Bleached (HWB) and Soft Wheat

Bleached (SWB) cake flours produced good quality cakes. The good quality cakes had rounded tops, smooth sides, and a fine snowy grain. The same flours but unbleached (HWNB and SWNB) produced less desirable cakes. The less desirable cakes were characterized by water rings in the center of the cake, an open coarse grain, a series of striations in the grain, and rough-textured sides. Two types of shortenings were compared (Table 3), a hydrogenated vegetable oil with no emulsifiers (Crisco, Proctor and Gamble) and a hydrogenated vegetable oil with mono- and diglycerides (Betrkake, Durkee). Using the soft wheat flour the two shortenings gave comparable cakes. However, the hard wheat cake flour gave a higher volume cake with the nonemulsified shortening. The cake volume data show excellent reproducibility using any combination of flours or shortenings. For the bleached soft wheat cake flour and both shortenings a standard deviation of 12.56 cc in cake volume was obtained.

BAKING PROPERTIES OF THE SYRUPS

Cakes were baked using the four flours and the emulsified shortening but with corn syrups and crystalline glucose replacing all or part of the sucrose. Crystalline glucose was made into a syrup and used to replace 50% of the sucrose (on a solids basis) and baked into cakes. The use of crystalline glucose with all four flours (Table 4) as 50% of the sweetener gave lower volumes, darker exterior colors, and a pale brown grain. Characteristically, the cakes gave flat tops with water rings in the center, and extremely poor grain. The bleached hard wheat cake flour had a slightly higher volume, a finer grain, and a whiter

Table 3. Cakes Baked with Hard Wheat Bleached and Soft Wheat Bleached Flours and Emulsified and Nonemulsified Shortenings.

Shortening	Volumes (CC)	
	Soft Wheat	Hard Wheat
Emulsified	850	890
	850	880
	850	870
	850	880
	860	850
Nonemulsified	870	990
	870	950
	870	1000
	860	980
	830	940

Table 4. Cakes Baked with 50% of the Sucrose Replaced by Glucose.

Flour	Volume (CC) ^a	
	50% Glucose	50% Sucrose
Soft Wheat Bleached	650	760
Soft Wheat Unbleached	440	600
Hard Wheat Bleached	670	800
Hard Wheat Unbleached	460	640

a/ 8" cake pans

grain than the other flours. From the results it appeared that 50% of the sucrose could not be replaced by glucose without a major adjustment in the formula. The LDE and HM syrups at 50% replacement (Table 5) produced cakes of better quality than did the other syrups.

A series of cakes were baked using the soft wheat bleached flour and certain corn syrups at 100% replacement (Table 6). The high maltose (HM) syrup produced an acceptable cake. The cake was slightly lower in volume, evenly browned on the outside, gave no water ring on top, had a very fine grain, but a slightly chewy texture. Two other corn syrups, a higher dextrose equivalent (HDE) and a low dextrose equivalent (LDE) gave cakes of lower volume and poorer grain. The high fructose (HF) syrup gave cakes with much lower volumes, water rings on top, open grain, and dark brown exterior.

AMYLOGRAPH PROPERTIES OF CORN SYRUPS

From the cake baking results it appeared that substitution of corn syrups or crystalline glucose would not produce good quality cakes. The amylograph was used to study the effect of the syrups on the gelatinization and pasting properties of the cake flour. The effect of each syrup was studied at 100% replacement of sucrose and then at 50% replacement of sucrose.

Figure 2 is an example of an amylogram with certain parameters identified. The first stage gelatinization temperature (Point A, Fig.2) is the temperature at which an increase in viscosity is first noticeable. The second stage gelatinization temperature (Point B, Fig. 2) is the

Table 5. Cakes Baked from Soft Wheat Flour with 50% Replacement of Sucrose with Certain Corn Syrups.

Sweetener	Volume CC	Grain
Sucrose	540 ^a	Fine
High Maltose	530 ^a	Fine
Low Dextrose Equivalent	500 ^a	Fine
High Dextrose Equivalent	470 ^a	Open
High Fructose	420 ^a	Open
Glucose	650 ^b	Open
Sucrose	850 ^b	Fine

a/ 6 inch cake pan

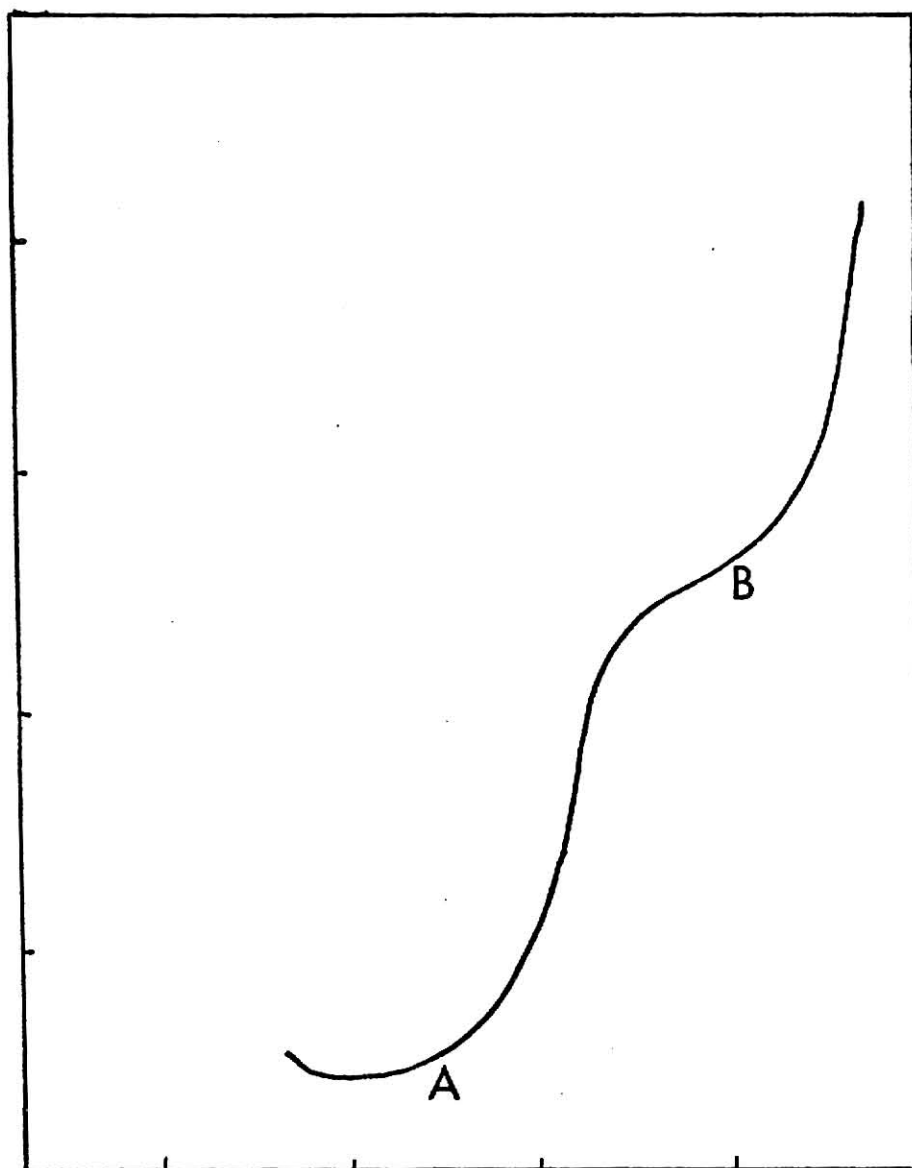
b/ 8 inch cake pan

Table 6. 100% Replacement of Sucrose by Certain Corn Syrups in Cakes Baked with Soft Wheat Bleached Cake Flour

Sweetener	Volume CC	Grain
Sucrose	580	Fine
	580	Fine
High Maltose	550	Fine
	550	Fine
Low Dextrose Equivalent	530	Semi-fine
	510	Semi-fine
High Dextrose Equivalent	530	Semi-fine
	530	Semi-fine
High Fructose	430	Coarse
	410	Coarse

Figure 2. An idealized amylogram showing viscosity (Brabender Units-B.U.) as a function of temperature.

VISCOSITY - B. U.



TEMPERATURE - °C

temperature at which the second increase in viscosity is evident. The area between Points A and B is the first stage viscosity. The area after the second stage gelatinization temperature is the second stage viscosity increase.

Sucrose had a first stage gelatinization temperature of 72° C (Fig. 3) and a second stage gelatinization temperature of 90° C. The first stage viscosity was 420 B. U. and the second stage gelatinization rate was 83 B. U./° C.

Dextrose, in comparison, at the same concentration (0.46 gm/ml), had the lower first stage gelatinization temperature (68° C) and a higher first stage viscosity. The second stage gelatinization temperature was also lower than that for sucrose. The curves for the two sugars were essentially parallel but the gelatinization with glucose occurred at a lower temperature.

The high maltose (HM) syrup (0.46 gm/ml) had a higher first stage gelatinization temperature (74° C) than sucrose (Fig. 4) and a much lower first stage viscosity. There was a pronounced delay before the second stage gelatinization. At 95° C the viscosity was less than 400 B.U.. If the temperature was held at 95° C for ten min. the viscosity increased to 1000 B. U.. The amylogram for the HM syrup showed that a higher temperature was required for gelatinization and that gelatinization proceeded at a slower rate than with sucrose. The LDE syrup (0.46 gm/ml) gave an amylogram similar to the HM syrup.

The HDE syrup (0.46 gm/ml) and the HF syrup (0.46 gm/ml) both had lower first stage gelatinization temperatures than sucrose (Fig. 5).

Figure 3. Amylograms of Sucrose (Suc) and Glucose (Glu).

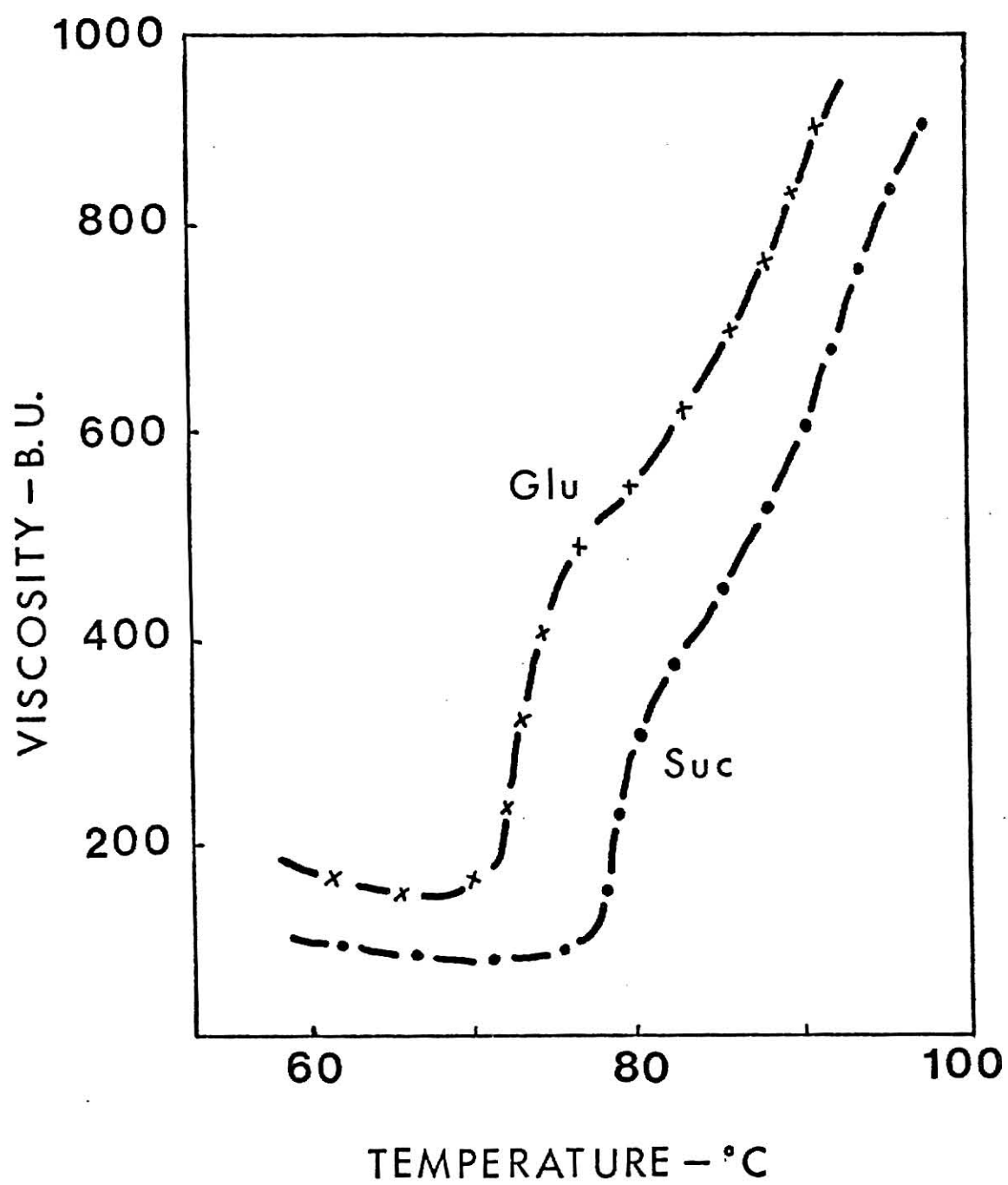


Figure 4. Amylograms of Sucrose (Suc), the Low Dextrose Equivalent Corn Syrup (LDE), and the High Maltose Corn Syrup (HM).

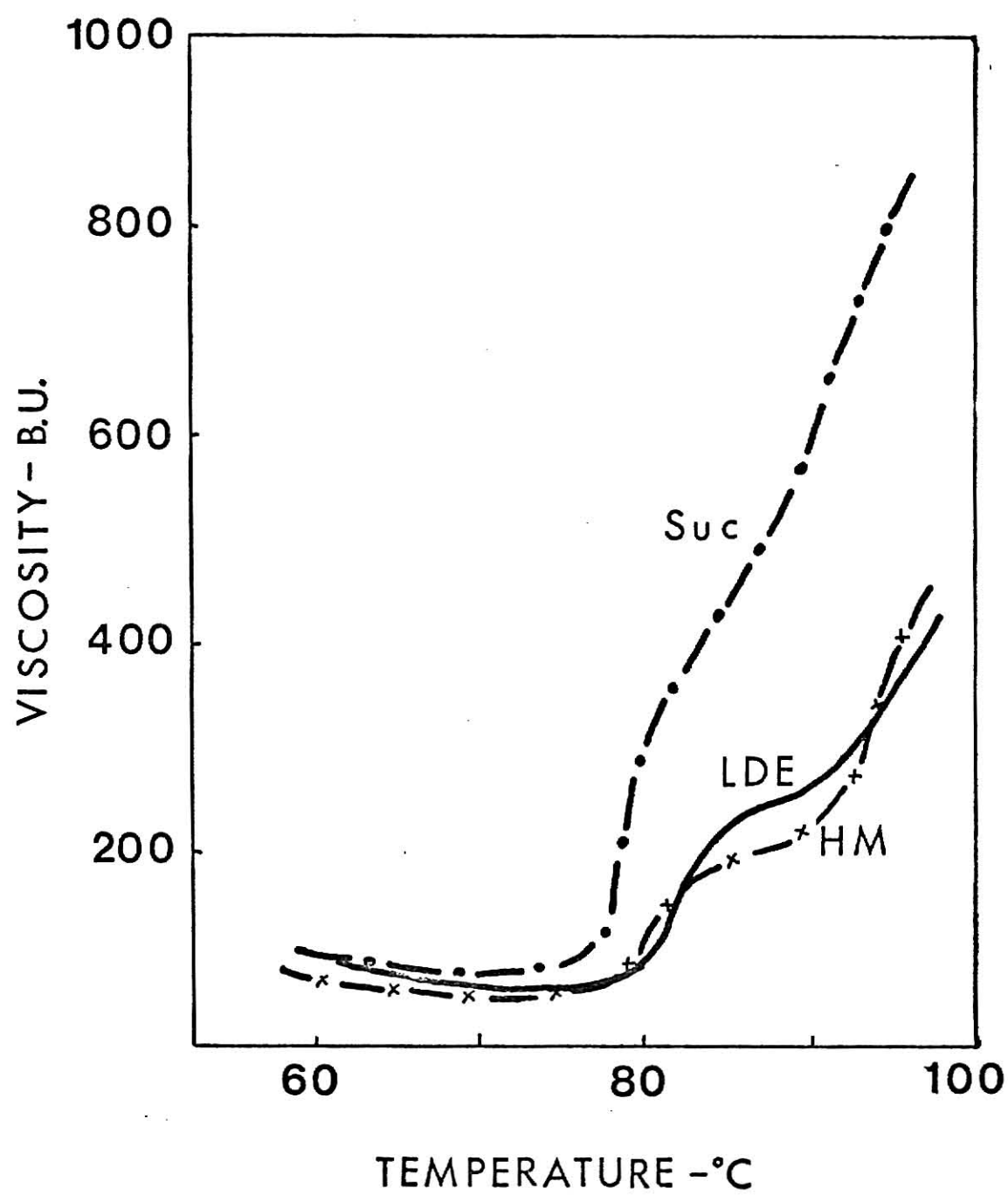
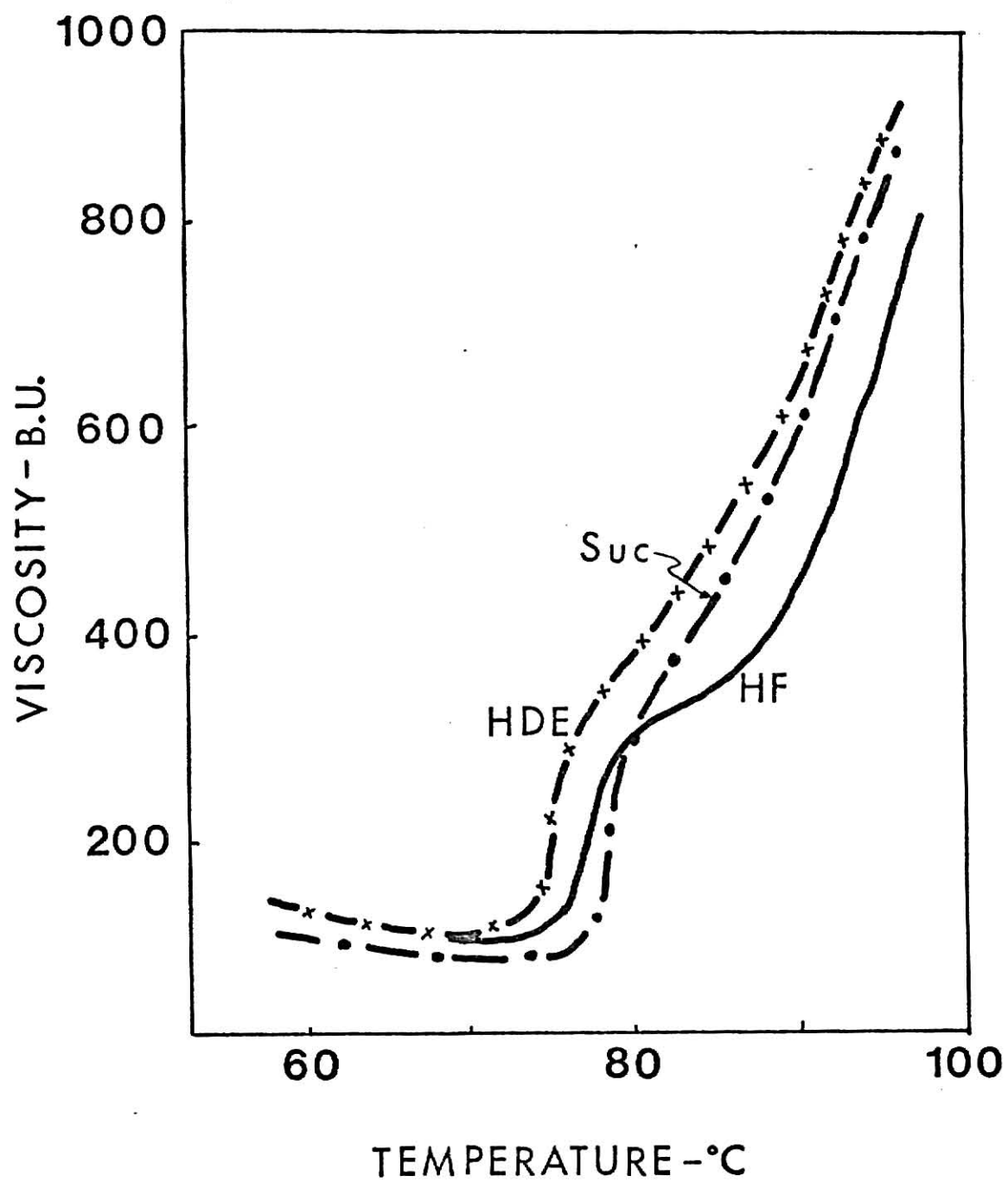


Figure 5. Amylograms of Sucrose (Suc), the High Dextrose Equivalent Corn Syrup (HDE), and the High Fructose Corn Syrup (HF).



Those two syrups also gave a delayed second stage gelatinization as was noted for the HM and LDE syrups. Amylograms for the 50:50 mixtures of the corn syrup and sucrose gave curves between those for 100% sucrose and 100% of the corn syrup in question.

From the amylograms, it was apparent that the corn syrups and crystalline dextrose affected the gelatinization of the cake flours differently than did sucrose. None of the curves obtained for the corn syrups and crystalline dextrose approximated the curve for sucrose. The first stage gelatinization temperature appeared to depend on the composition of the sugars present in the corn syrup. The LDE and HM corn syrups which contained larger amounts of high molecular weight sugars (oligosaccharides) had a delayed first stage gelatinization temperature (higher temperature). The HF and HDE corn syrups which contained larger amounts of low molecular weight sugars (mono- and disaccharides) had earlier first stage gelatinization temperatures (lower temperature).

Adding crystalline glucose to the HM and LDE syrups, while maintaining a constant sugar to water ratio, adjusted the first stage gelatinization temperature downward (lower temperature). As the amount of glucose added was increased, the first stage gelatinization temperature progressively decreased. The overall shape of the amylogram was relatively unchanged by the addition of glucose.

AMYLOGRAM PROPERTIES OF SUGARS

The effect of certain sugars and sugar alcohols on the gelatinization

properties of cake flours was also studied. The curves for sucrose and glucose have already been presented (Fig. 3). It is a well known fact that sugars delay the gelatinization of starch. This phenomenon is generally thought to be the result of osmotic pressure of the sugar solution. At the same solids concentration, glucose would have essentially twice the osmotic pressure of sucrose. However, sucrose (Fig. 3) delays the gelatinization temperature more than does glucose.

Maltose, at the same solids level, gave essentially the same curve as did glucose (Fig. 6). Maltose has the same molecular weight as sucrose and therefore essentially equal osmotic pressure. Thus, it appears that the osmotic pressure of the solution was not the factor affecting the first stage gelatinization temperature.

Lactose, which also has a molecular weight equal to sucrose, had a first stage gelatinization temperature essentially equal to glucose. However, the amylogram was quite different, principally because of the very high cold viscosity (65°C) (Fig. 6).

Sucrose is also different from the other sugars because it is a nonreducing sugar. To see if the reducing group was a factor, two sugar alcohols were studied.

Sorbitol, a nonreducing sugar alcohol of molecular weight essentially equal to glucose, had the lowest first stage gelatinization temperature (63°C) of the materials studied (Fig. 7). Lactositol, a nonreducing sugar alcohol of molecular weight equal to sucrose, also had a low first stage gelatinization temperature essentially equal to sorbitol.

Figure 6. Amylograms of Sucrose (Suc), Maltose (Mal), and Lactose (Lac).

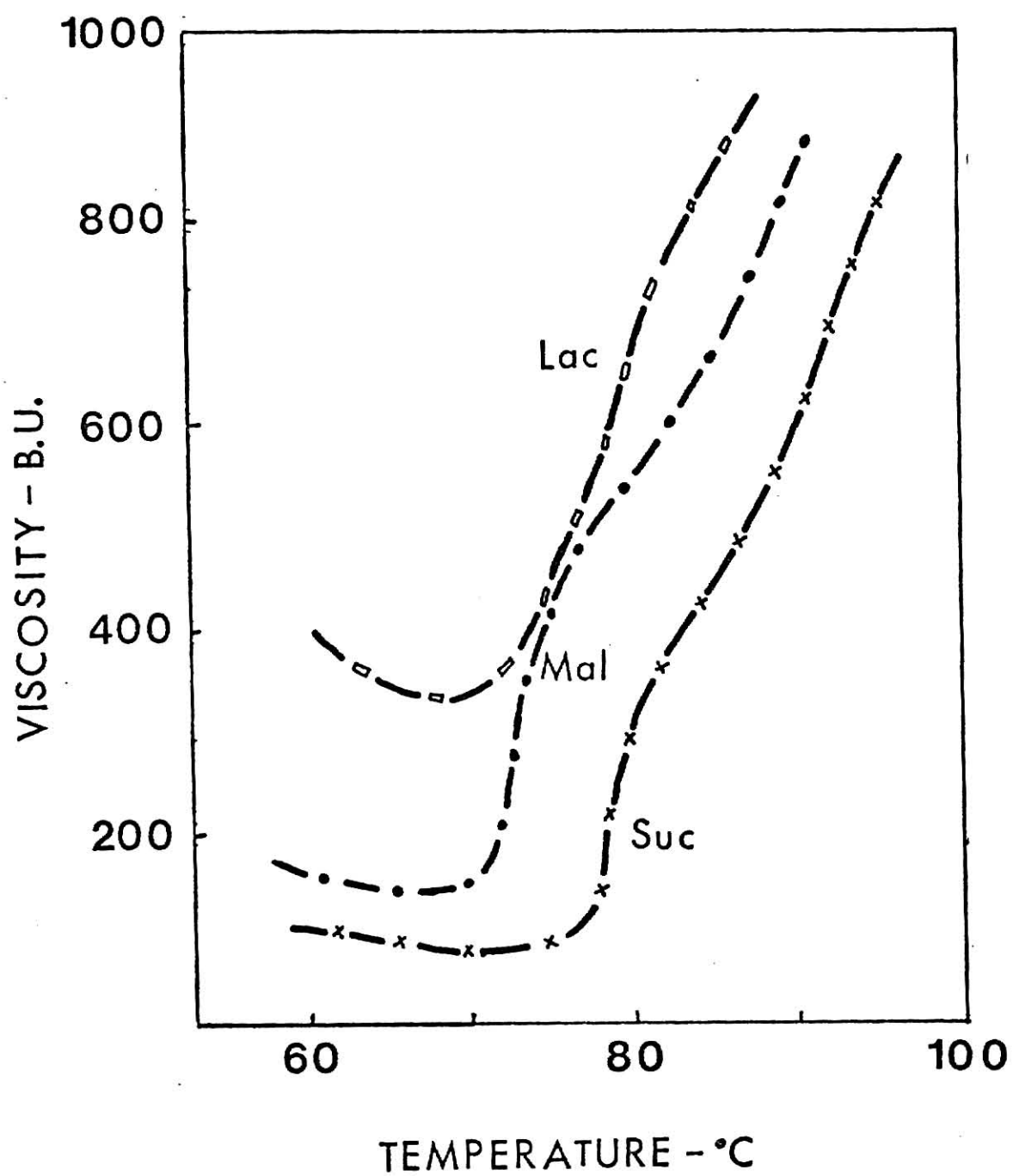
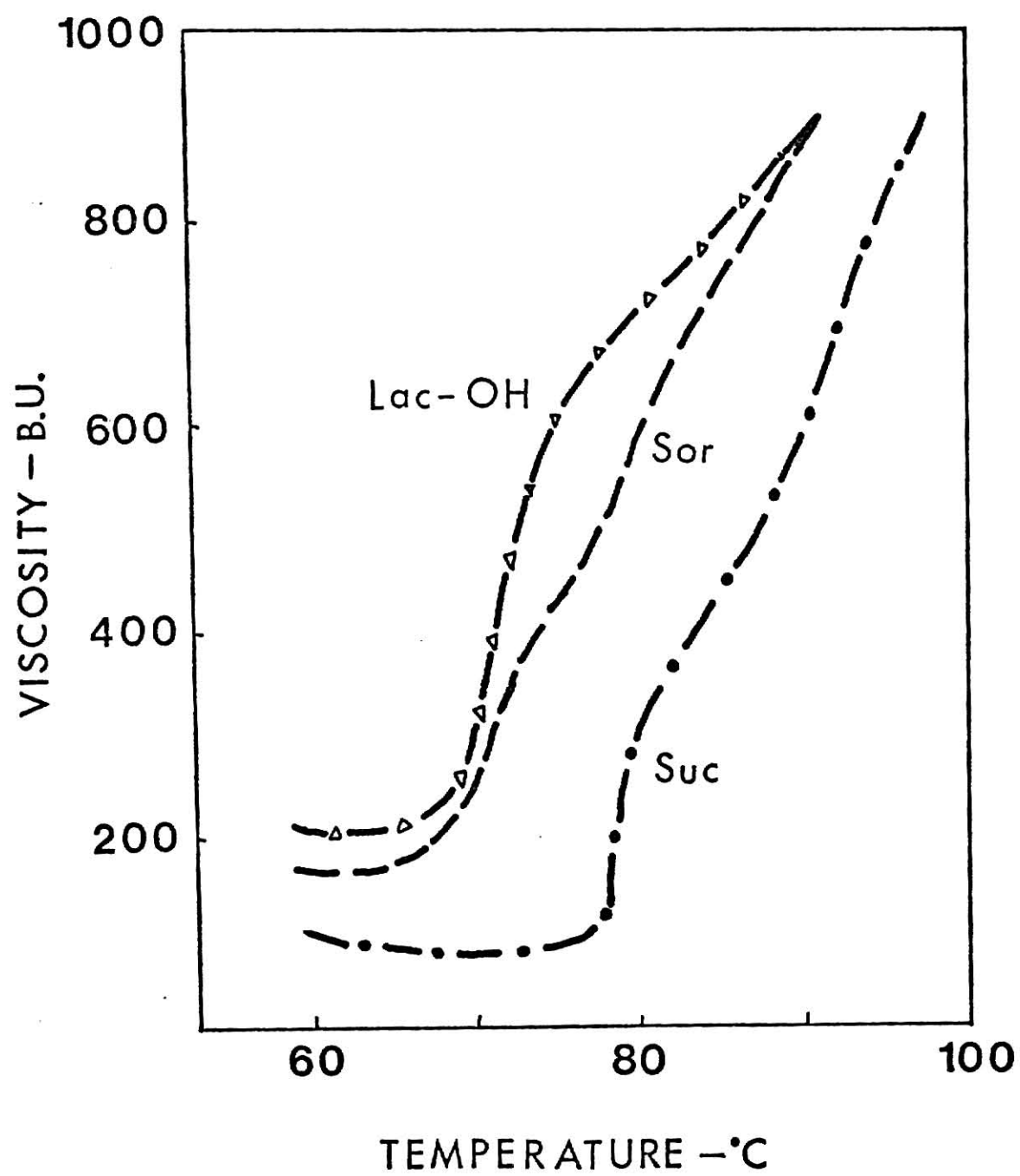


Figure 7. Amylograms of Sucrose (Suc), Sorbitol (Sor), and Lactositol (Lac-OH).



The first stage viscosity was very high with lactositol, much higher than for the other sugars (Fig. 7). Thus, the effect of reducing groups does not explain the delayed first stage gelatinization temperature of sucrose.

The above sugars were used to investigate what chemical properties of the sugars were affecting the first stage gelatinization temperature of the cake flour. Neither the reducing groups nor the osmotic pressure appear to explain the results. Thus the factor affecting the gelatinization temperature remains unknown.

It was postulated that sucrose may have a stereo structure that would, at least in part, exclude it from entering a starch granule as freely as glucose or water. This would create an osmotic gradient between the sucrose solution and the interior of the starch granule that might effect the first stage gelatinization temperature. If the hypothesis was true, a slurry of dry starch in a sucrose solution after centrifugation should show an increase in sucrose concentration in the supernatant. However, when such slurries were prepared with both sucrose and glucose and the supernatants were examined by High Performance Liquid Chromatography, there was no difference in the sugar concentration of the supernatants. Also, the sugar concentrations were equal to that of the original sugar solution. Thus both sucrose and glucose freely enter the starch granule.

EFFECT OF WATER ACTIVITY ON AMYLOGRAMS AND BAKING PROPERTIES

Sugars have been used in the food industry to lower water

activity (24, 25). Sugars ^{decrease} (increase) water activity as the concentration increases, however, the rate of change of water activity per unit concentration varies with different sugars (Fig. 8).

The amylograph data in the preceeding section also showed that gelatinization temperature varied with the individual sugars, even though the sugar to water ratio was held constant. Therefore, we plotted the gelatinization temperature vs. water activity (at the concentration of sugar used in the amylograph) for several sugars (Fig. 9). There appears to be a relationship between water activity and gelatinization temperature. Therefore to achieve the same gelatinization temperature with glucose as obtained with sucrose the amount of glucose would need to be increased.

Based on the above, cakes were baked with increasing glucose levels, but holding the water constant (Fig. 10, Table 7). The volume of the cakes increase with increased glucose levels up to 450 gm. At levels higher than 450 gm the volume decreased rapidly and progressively. The grain of the cakes progressively improved up to 311 gm of glucose. Above 311 gm the grain became progressively more coarse and darker in color. At the higher levels of glucose, the cake would rise to the top of the pan in the oven, however upon cooling would give an unusual amount of shrinkage. The glucose cakes all had a wet appearance at all levels.

For comparison purposes, cakes were baked with increasing levels of sucrose but holding the water level constant (Fig. 10, Table 8). The volume of the cakes increased gradually until the 195 gm level

Figure 8. Rate of Change of Water Activity Per Unit Concentration of Glucose (Glu) and Sucrose (Suc).

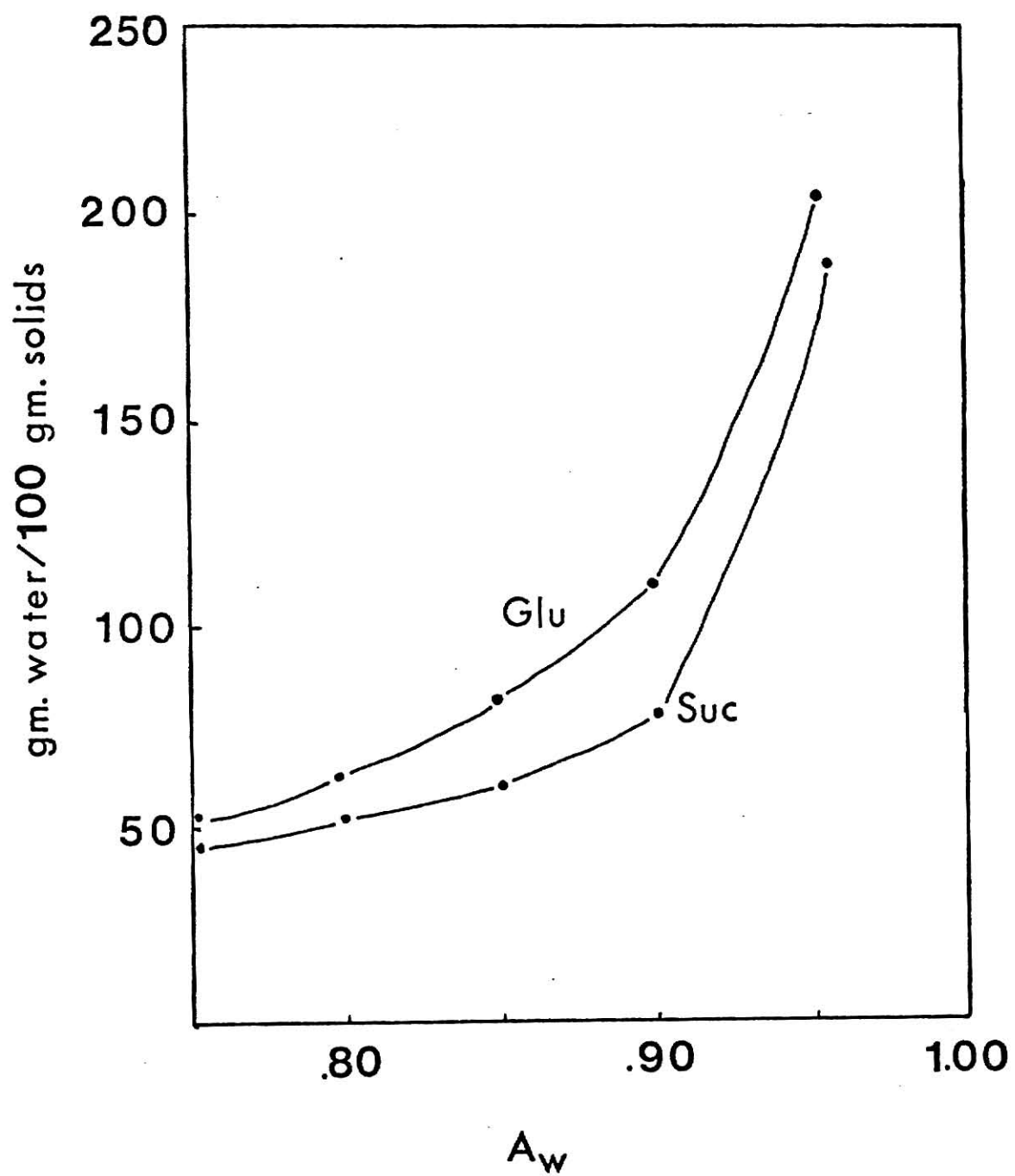


Figure 9. Gelatinization Temperature vs. Water Activity of Sucrose (Suc), Glucose (Glu), Lactose (Lac), Fructose (Fru), and Sorbitol (Sor).

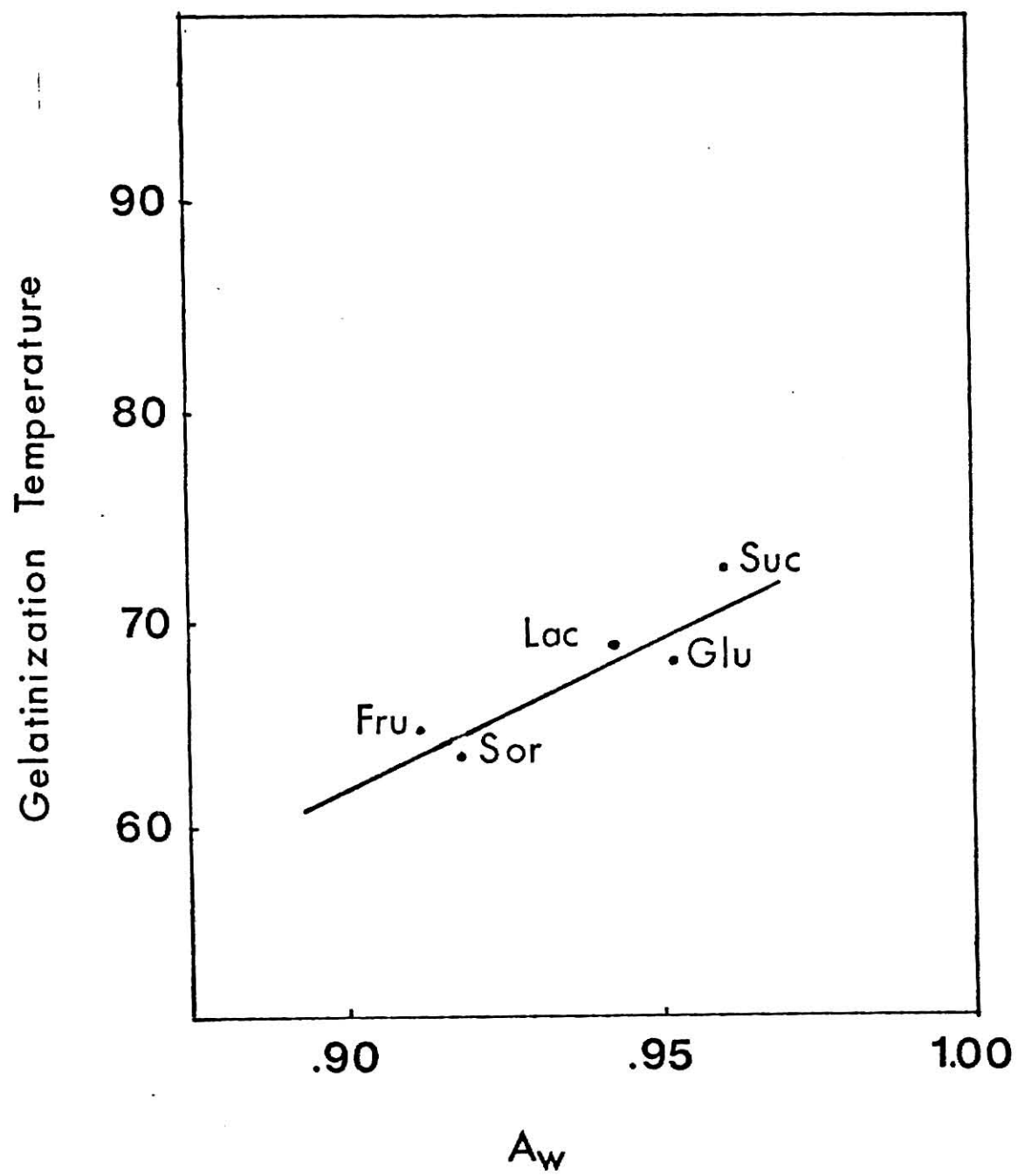


Figure 10. Cake Volume vs. Grams of Sugar Used in Baking, Sucrose (x) and Glucose (●).

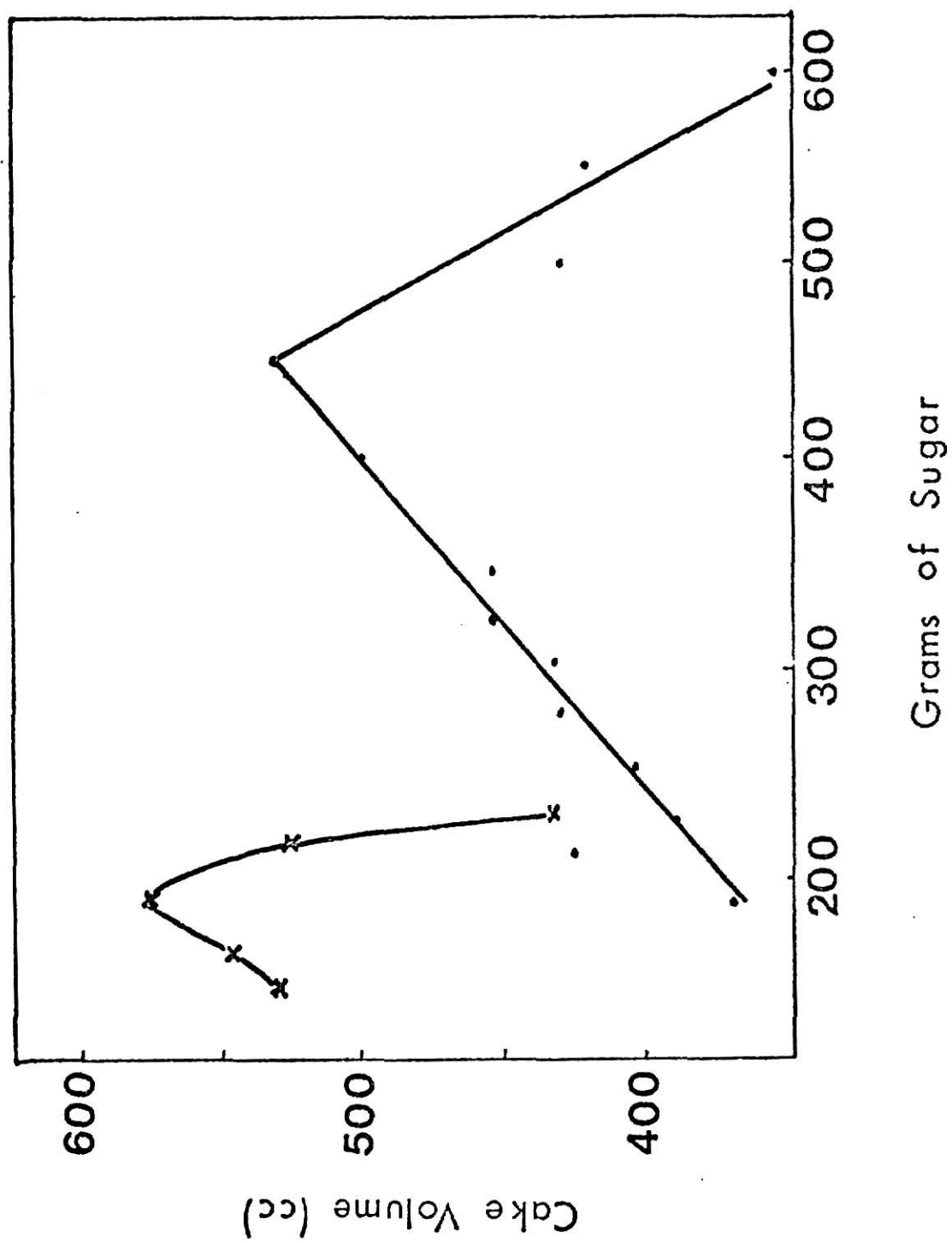


Table 7. Cakes Baked with Various Levels of Glucose.

Glucose (gm)	Volume (CC)	Grain
195	370	Compact
215.94	430	Increasing fineness
239.94	385	
263.93	405	
287.92	435	Fine
311.91	437.5	Fine
335.91	460	Coarse
359.90	460	Coarse
400	500	Coarse
450	535	Coarse
500	430	Coarse
550	420	Coarse
600	345	Coarse

Table 8. Cakes Baked with Various Levels of Sucrose.

Sucrose (gm)	Volume (CC)	Grain
143	535	Fine
167.9	545	Fine
195 ^a	575	Fine
215.94	530	Coarse
239	435	Coarse

(normal level) and then rapidly decreased. Cakes with less than 195 gm of sucrose had a peaked center, smooth sides, and fine snowy grain. Cakes with more than 195 gm of sucrose had a depression in the center of the cake. The depression increased in size as the amount of sugar was increased. At high sucrose concentrations the sides became less smooth and the grain extremely coarse.

The high maltose (HM) corn syrup was also baked at different levels of solids. The data (Table 9) show that the volume is equal to that of a cake baked with the normal level (195 gm) of sucrose. At the highest level used (239 gm) the volume was lower. However, the cake volume was not as sensitive to the concentration of HM syrup as it was to the concentration of sucrose. The cakes at the lowest level used were noticeably peaked, with golden crust color, and with an off-white semi-fine grain. The peak became less apparent as the amount of syrup was increased, until at the highest level used a dip became apparent in the center of the cake. The highest level used had a coarse grain with a light brown color.

From experiments optimizing the water level for cake flours using sucrose, we found that the cake texture was affected by the amount of water used in the formula. As the amount of water was increased above the optimum level, the cakes had a dip in the center and open coarse grain. As the amount of water was decreased below the optimum level, the cakes were flat across the top or with a slight dip in the center and had open cells or striations.

Bean (21) has reported that cakes with good contour and grain

Table 9. Cakes Baked with High Maltose (HM) Syrup at Various Solids Levels.

HM Corn Syrup (gm)	Volume (CC)	Grain
195 ^a	570	Fine
205	575	Fine
215	570	Fine
239	510	Coarse

a/ Control

could be produced with high fructose syrup if the water was reduced 10 to 20%. We tried a similiar experiment using crystalline glucose as the total sugar. The amount of glucose (311 gm/150 gm of flour) used was higher than the normal sucrose level but was the level of glucose that gave cakes with the best grain. Water was then removed from the formula in 10% increments. The data (Table 10, Fig. 11) show a slight increase in volume when water was removed up to 30% of the total. The cakes with 0, 10, and 20% of the water removed had flat tops, golden brown crust color, a wet appearing crust, smooth sides, and a semi-fine snowy white grain. The cakes produced with 30% of the water removed gave a good volume and grain but still had a flat contour and a wet, golden brown crust. All the cakes tended to rise to the top of the pan during baking but would shrink and pull away from the sides of the pan upon cooling. With 40 and 50% of the water removed, the cakes were collapsed in the center, golden brown with brown dots throughout the wet crust. The interior was coarse, dry looking and had golden spots throughout (probably due to internal browning).

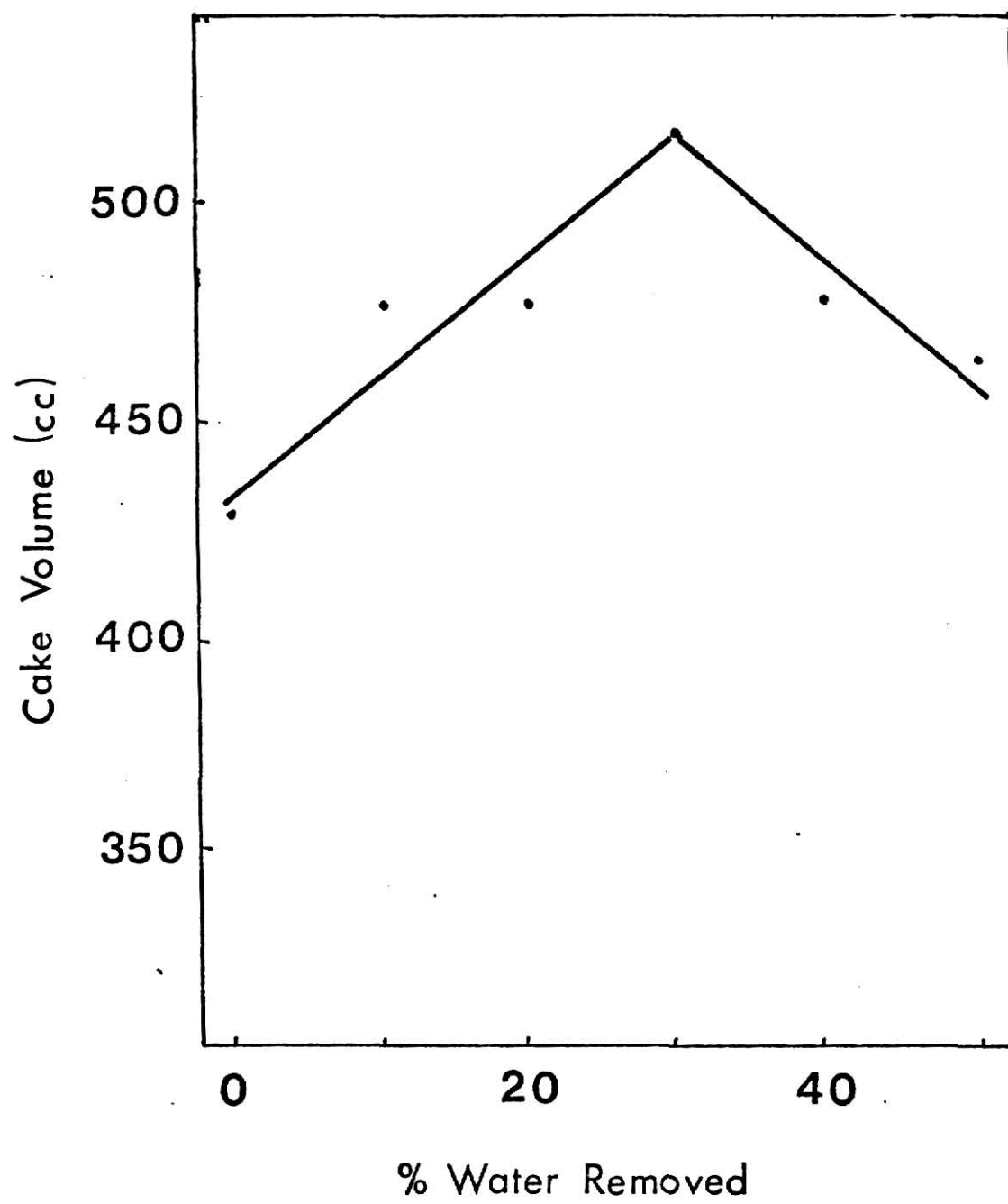
FRACTIONATION OF HIGH MALTOSE SYRUP

The HM syrup was selected for a fractionation study to identify the component responsible for the delayed second stage gelatinization temperature. The syrup was treated with an equal volume of butanol and stirred for 20 hours. The butanol layer was removed in a separatory funnel and the syrup was extracted two more times with an equal volume of butanol for two and one hours, respectively. The combined butanol fractions were concentrated to dryness in a rotary

Table 10. Cakes Baked with Glucose (311 gm) and the Water Level Gradually Decreased.

% Water Removed	Volume (CC)	Grain
0	430	Slightly fine
10	475	Slightly fine
20	475	Slightly fine
30	550	Fine
40	475	Coarse
50	460	Coarse

Figure 11. Cake Volume vs. % Water Removed Using Glucose (311 gm).



evaporator (40 ° C). The aqueous syrup fraction was reduced in volume by 50% to remove residual butanol. The resulting syrup was evaluated in the amylograph on a constant solids basis. The amylogram of the resulting syrup (Fig. 12) had a first stage gelatinization temperature essentially unchanged from the original syrup. The first stage viscosity was considerably higher and the second stage gelatinization temperature lower. When the butanol soluble fraction was combined with the butanol extracted syrup, supposedly to yield a reconstituted HM syrup, the amylogram (BuOH + S) was materially different from the unfractionated HM syrup (Fig. 12). Evidently, something was lost or altered during the fractionation procedure. Therefore, the HM syrup was treated with an equal volume of butanol, stirred and the total system concentrated under vacuum. The amylogram produced from the resulting syrup (Fig. 13) had a second stage gelatinization temperature that was lower than the unfractionated HM syrup. It is obvious that the treatment was affecting the system possibly by removing volatile species.

It was also possible that residual butanol in the condensed syrup affected the amylogram. Therefore the HM syrup was treated with 2 and 4 ml per 150 gm of flour and the amylograms determined. Neither level of butanol significantly influenced the amylograms. It was obvious that something in the butanol soluble fraction was responsible for the lower first stage viscosity and the delayed second stage gelatinization temperature.

The carbohydrates in the butanol soluble fraction were identified by paper chromatography and High Performance Liquid Chromatography to be glucose, maltose, maltotriose, and essentially no higher oligosaccharides.

Figure 12. Amylograms of the High Maltose Corn Syrup (HM), the 20 hr. treatment of the High Maltose Corn Syrup with Butanol (BuOH), and the 20 hr. treatment of the High Maltose Corn Syrup with Butanol with the Solubles removed by the Butanol Added Back (BuOH + S).

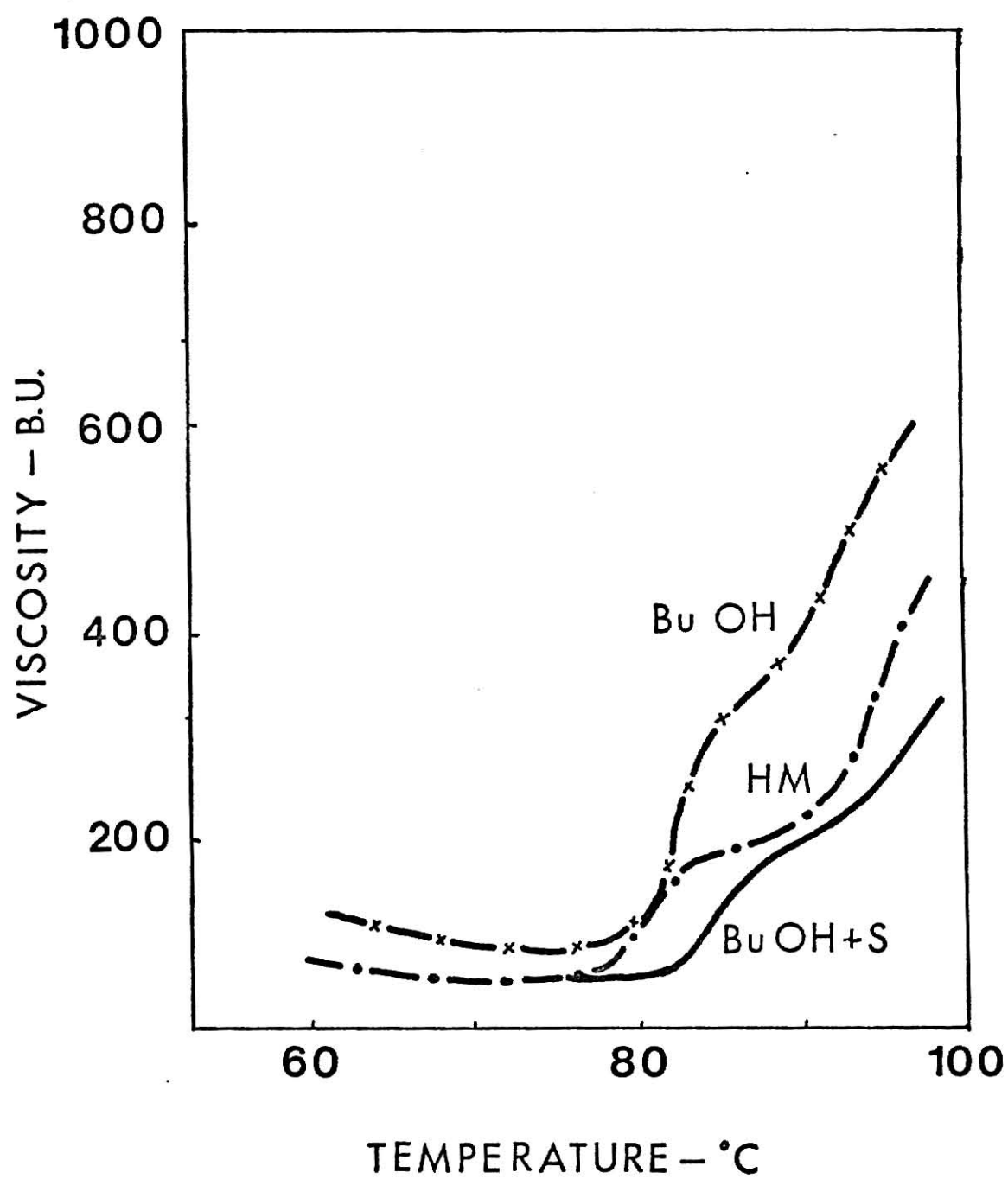
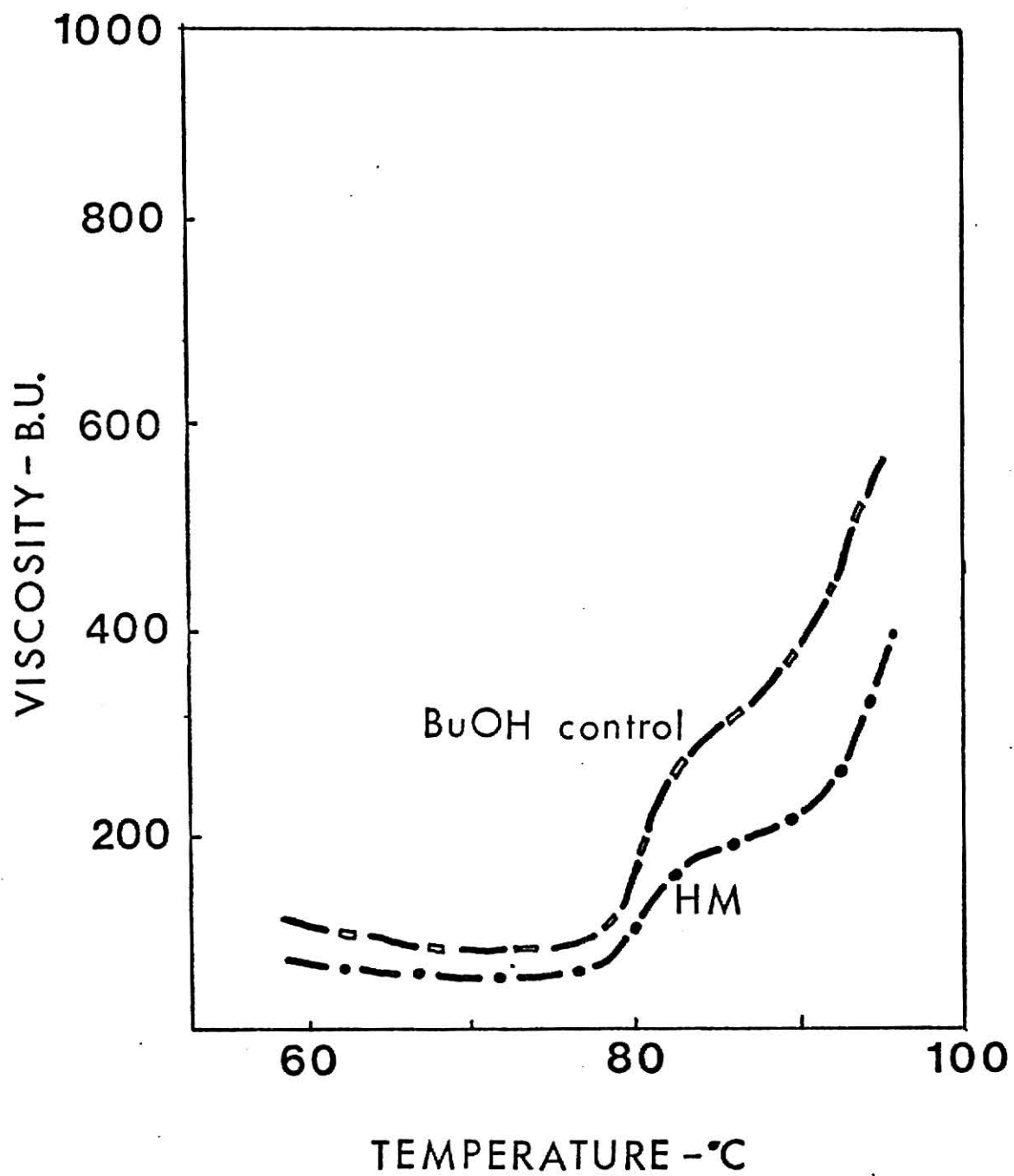


Figure 13. Amylograms of the High Maltose Corn Syrup (HM) and the High Maltose Corn Syrup Treated with Butanol (BuOH Control).



Those sugars were not believed to be the components affecting the amylogram because the pure sugars did not delay the second stage gelatinization temperature. The butanol extract was examined by ultraviolet spectroscopy and found to have an absorbance peak at 280 nm. All corn syrups examined had an absorbance peak at 280 nm. However, the crystalline dextrose from corn starch gave no U. V. absorbance of 280 nm.

The high fructose corn syrup (HF) had a fairly strong absorbance at 280 nm. This absorption was removed by charcoal treatment. The charcoal-filtered HF syrup gave an amylogram which had a first stage gelatinization temperature essentially equal to the untreated syrup (Fig.14). The first stage viscosity was lower, 200 B. U. compared to 280 B. U. for the unfiltered syrup. The second stage gelatinization temperature was higher than that of the untreated syrup.

AFFECT OF CORN STARCH LIPIDS

The gelatinization of starch has been shown to be affected by the lipids present (26, 27). Because the syrups we were working with are derived from corn, the lipid from corn starch was extracted with methanol. The corn starch lipids (0.5% based on the amount of wheat flour used) were then added to a sucrose solution and run on the amylograph (Fig. 15). The first stage gelatinization temperature was lowered to 70 °C, the first stage viscosity decreased, and the second stage gelatinization temperature increased. Corn starch lipids definitely affected the amylogram curve and in certain respects it was similar to the effect of corn syrups. The effect was to lower the first stage viscosity and to delay the second stage gelatinization

Figure 14. Amylograms of the High Fructose Corn Syrup (HF) and the Charcoal-filtered High Fructose Corn Syrup (C.F. HF).

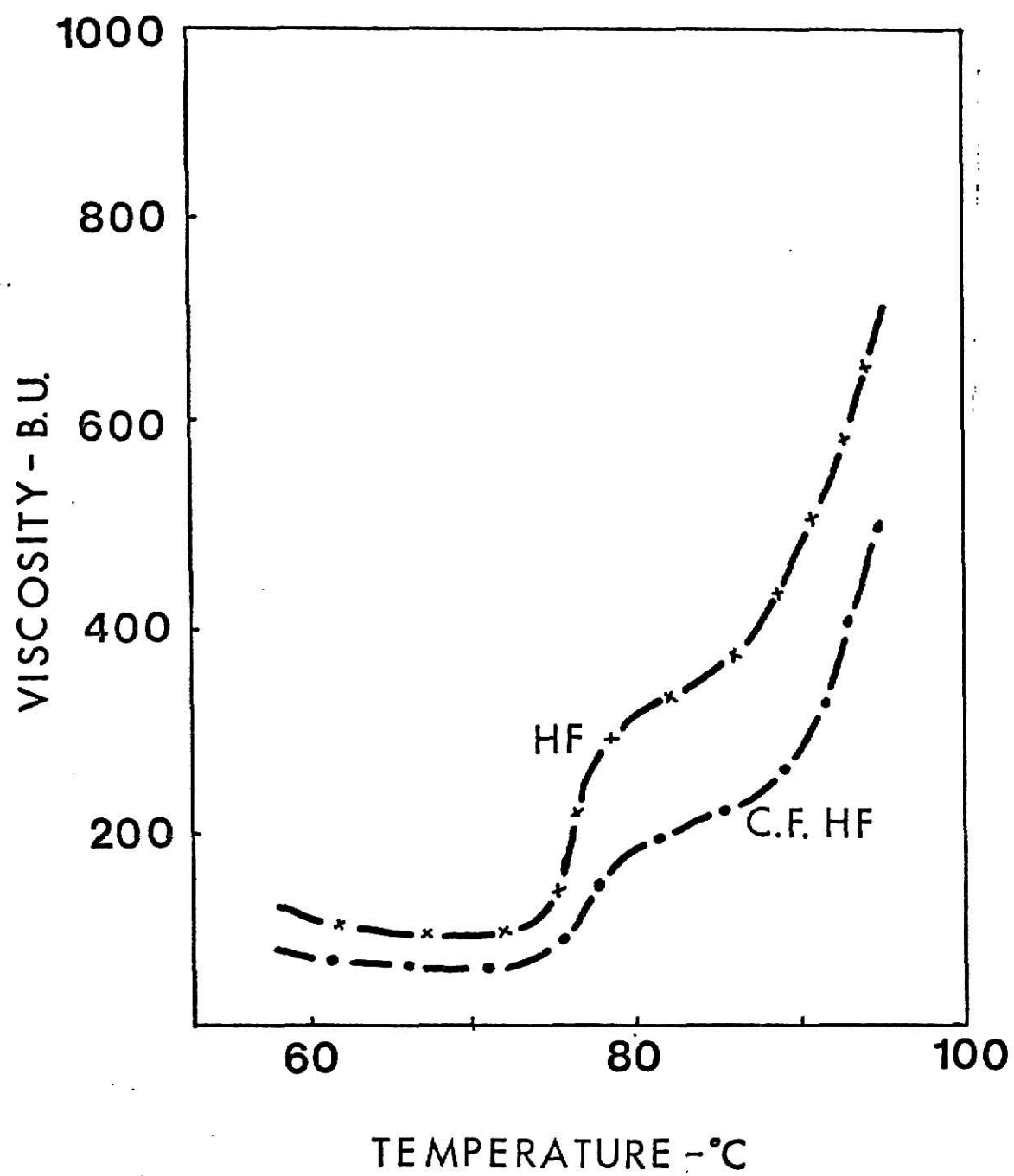
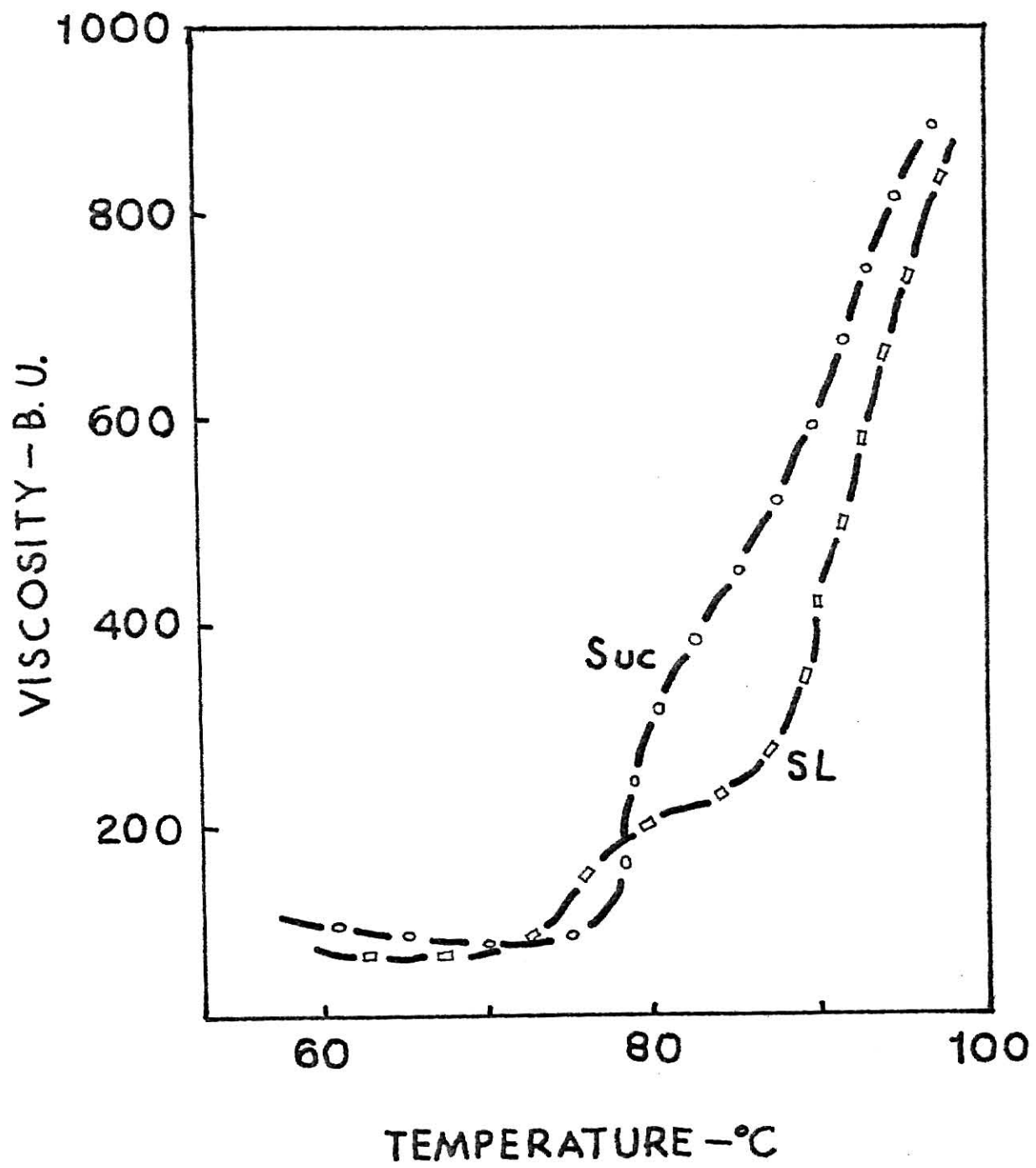


Figure 15. Amylograms of Sucrose (Suc) and Sucrose Plus Corn Starch Lipids (SL).



temperature.

Because the corn starch lipids may also be in the syrup and thereby cause those effects, the HM syrup was treated with chloroform in the manner similar to that described for the butanol treatment. After concentrating to remove the residual chloroform, the syrup fraction was run on the amylograph. The amylogram curve (Fig. 16) was radically changed. The first stage gelatinization temperature was unchanged, but the first stage viscosity was much higher and the second stage gelatinization temperature decreased. The amylogram was similar to that obtained with sucrose.

A series of cakes were then baked with the chloroform-treated HM corn syrup to see if the removal of the corn starch lipids would affect the cakes as it had the amylogram. The data (Table 10) show that the volume of the cakes was very comparable to the volume of sucrose cakes. From external appearances the cakes were quite good. At 190 gm of the treated syrup, the cakes had the peaked appearance which occurred in earlier studies when the sugar solids level was too low. The cakes had a pale yellow crust, and a fine white grain with small holes. At 195 gm the cakes were like the sucrose cakes in appearance with a raised cake, a slightly golden crust, and a fine grain. At 205 gm the cakes were beginning to show a dip which is characteristic of cakes with above optimum levels of sugar. The cakes also had a coarse grain, a golden crust, and the grain a light brown color. The cakes with the chloroform-treated HM syrup were then more sensitive to changes in the level of the syrup than cakes baked with

Figure 16. Amylograms of the High Maltose Corn Syrup (HM), the High Maltose Corn Syrup Treated with Chloroform (CHCl_3), and Sucrose (Suc).

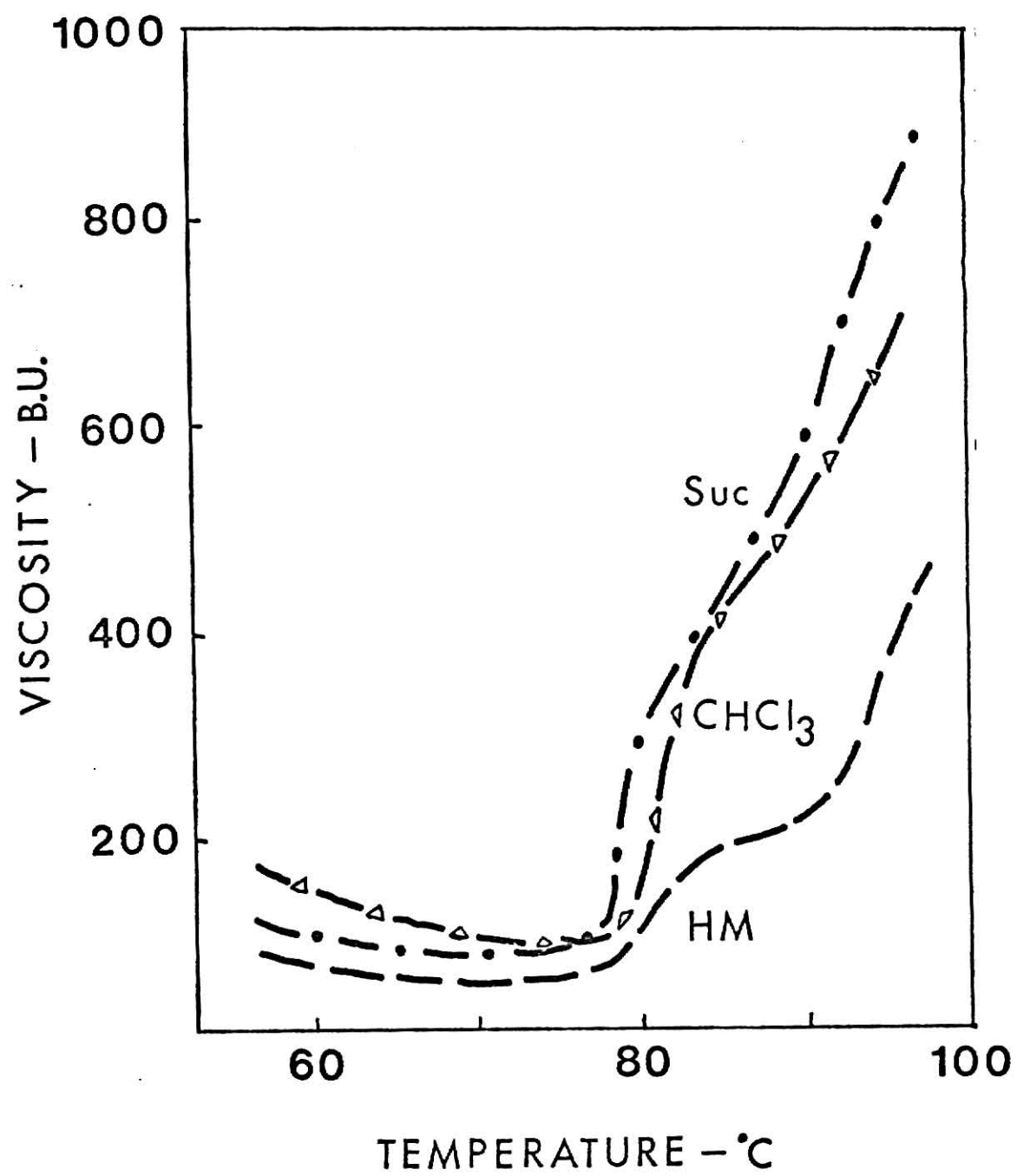


Table 10. Cakes Baked with Chloroform-Treated High Maltose Corn Syrup.

Sugar	Volume CC	Grain
Sucrose	620 ^a	Fine
High Maltose	580 ^b	Fine
High Maltose (190 gm)	565 ^c	Fine
High Maltose (195 gm)	630 ^c	Fine
High Maltose (205 gm)	630 ^c	Coarse

sucrose or glucose. The ideal cake would than contain between 190 and 195 gm of the chloroform-treated high maltose corn syrup.

A untrained test panel (4 to 2) rated the chloroform-treated high maltose corn syrup cake as less gummy and less chewy than the high maltose cake. It is possible that the treatment with chloroform removes the factor responsible for the gummy mouth feel. However, the sucrose cakes were still rated as superior in mouth feel.

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EFFECT OF CORN SYRUPS
IN CAKE PRODUCTION

by

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AN ABSTRACT

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Manhattan, Kansas

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ABSTRACT

Four corn syrups and crystalline dextrose were used for the replacement of sucrose in high-ratio cakes. At the 50% replacement level only the high maltose and low dextrose equivalent corn syrups gave acceptable cakes. At the 100% replacement level only the high maltose corn syrup gave an acceptable cake.

The amylograph was then used to study the effect of corn syrups on starch pasting characteristics. With corn syrups the first stage gelatinization temperature depended on the amount of high and low molecular weight sugars present. Greater amounts of low molecular weight sugars gave lower gelatinization temperatures while the high molecular weight sugars delayed gelatinization. Several sugars were used to study the effect of reducing groups and osmotic pressure on the starch pasting characteristics. From the results neither reducing groups, molecular weight, or osmotic pressure explains the difference in the curves of the various sugars. Corn starch lipids removed from corn starch by methanol were added to flour-sucrose and run on the amylograph. The amylogram was similar in appearance (but not gelatinization temperature) to the curves given by the corn syrups.

The high maltose syrup was selected for an in-depth study. Because corn starch lipids were believed to cause the restricted first stage swelling, the syrup was fractionated with butanol. The fractionation procedure removed a volatile compound which allowed the starch

pasting curve to approach that given with sucrose. A similar treatment of the high maltose syrup with chloroform caused the starch pasting curve to be quite similar to that of sucrose.

Cakes baked with the chloroform-treated high maltose corn syrup tended to be less gummy than the untreated syrup but were not equal in mouth feel to sucrose cakes.