Effects of Corn Sweeteners on Cookie Quality[1]

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ABSTRACT

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The replacement of granular sucrose with high-fructose corn syrup (HFCS) in a sugar-snap cookie affects dough rheology (stickiness), surface cracking, and the characteristic snap associated with this type of cookie. A soft, sticky dough results when sucrose is replaced with HFCS; the significance of this change is dependent on the amount of corn syrup substituted. If small amounts of sucrose are replaced with corn syrup, the typical cracked surface of the baked cookie is lost, and a smooth surface

results. Measurement of water loss during baking shows no differences between cookies baked with 100% sucrose and with 50% HFCS. The rate of internal water diffusion might cause the difference in surface characteristics of the cookies. Sugar cookies develop a characteristic "snap" within five days after baking. The time required for the snap to develop increases with increasing levels of corn syrup. This delay in snap development appears to coincide with sugar recrystallization.

As a consequence of rising sugar prices, cookie manufacturers have sought alternate sweeteners in an effort to lower production costs. High-fructose corn syrup (HFCS) is currently the most widely used sucrose substitute because of its availability, low cost, comparable sweetening power, and similar flavor characteristics.

The amount of sucrose that can be replaced by HFCS in a cookie formula is often limited by the amount of water in the syrup exceeding the total water in the formula. Therefore, the degree of substitution of HFCS for granular sucrose is dependent on the cookie formulation and type. Its use in hard cookies creates many problems for the cookie manufacturer.

High-fructose corn syrup is a standardized product containing 42% fructose and 71% solids (Schanot 1981a). It can be used as a partial replacement for sucrose in cookies; levels reported by Henry (1976) are 60–75% of the total sweetener for soft cake-type cookies and 10–30% for hard cookies. Cookies produced with the two sweeteners are different. The most important difference is tenderness. The monosaccharides in HFCS—fructose and dextrose—are the most hygroscopic sugars commonly used in baking (Henry 1976). They combine with other ingredients in the cookie dough to form a more fragile and tender structure (Schanot 1981b). In hard, crisp cookies, it is the humectant property of HFCS that limits its use. The replacement of small amounts of sucrose with HFCS in a cookie formulation also produces a change in the surface characteristics of the baked cookie. The surface cracking commonly associated with certain types of cookies does not occur in cookies containing corn syrup.

An explanation for those differences could not be found in the literature. We therefore studied the effects of corn syrups on cookie dough rheology, baking performance, and physical characteristics of cookies after baking.

MATERIALS AND METHODS

Materials

Cookies were made with two commercial soft wheat cookie flours from Mennel Milling Co. (both containing 9.2% protein and 0.58% ash) and superfine granulated sucrose (C. and H. Sugar). In some cases, up to 50% of the sucrose was replaced with IsoSweet 100 HFCS from A. E. Staley Manufacturing Co. (The manufacturer's stated composition was 71% solids, 50% dextrose, and 42% fructose.) Also used was a high-maltose corn syrup (HMCS; A. E. Staley Manufacturing Co.'s Neto 7350) with a stated composition of 80.5% solids, 8% dextrose, 44% maltose, and 23% maltotriose.

Cookie Baking

The method and formula used to bake cookies were those described by Finney et al (1950) as Micro Method III. For a portion of this study, an alternate leavening system was used; 1.0% double-acting baking powder was added with the flour in place of 0.75% ammonium bicarbonate. When syrups were used to replace some of the sucrose solids, the water in the formula was adjusted to compensate for the water present in the corn syrup.

Dough Stickiness

Dough stickiness was measured with the Instron Universal Testing Machine (model 1122) in the tension mode. The Instron was set to give a full-scale deflection at 2 kg. The head speed was set at 10 mm/min and the chart speed at 200 mm/min. The circular, stainless steel probe was 36 mm in diameter. Cookie dough was mixed, completely covered to prevent surface drying, and left to equilibrate for approximately 10 min. Dough was then sheeted and cut to regular size (60 mm). The cookie cutter was left in place to center the dough piece under the plunger and prevent spreading of the dough during compression. Dough samples were compressed to a force of 1 kg; the head was then reversed, and the area of the tension curve was used as a measure of stickiness. The area under the curve was measured with a planimeter. Four doughs of each treatment were prepared separately, and each dough provided enough sample for two measurements. Dough stickiness was reported as the average of eight measurements.

Time-Lapse Photography

The method of time-lapse photography was a modification of the procedure of Yamazaki (1956). Cookies were cut to regular size, and a metal ruler was positioned at the center of the cookie sheet between two cookies. The cookie sheet was placed on a stationary oven shelf in a reel-type oven with an internal light source. Cookies were baked for 10 min, and photographs were taken at 1-min intervals through a glass window in the oven door.

Water Loss

Water loss during baking was measured at 1-min intervals. Cookie doughs were placed on a cookie sheet of known weight, and the cookie sheet plus cookies were weighed before baking. After baking for the desired time, the cookies on the cookie sheets were removed from the oven, and each cookie was immediately covered with a tared petri dish. After the doughs and cookie sheet were completely cool, total cookie sheet, petri dishes, and cookies were weighed a second time. Water loss was the change in total weight between the unbaked and baked cookies.

Cookie Snap

Cookie snap was measured on the Instron Universal Testing Machine (model 1132) in the compression mode. A compression cell of 50 kg maximum load was used. The Instron was set to give a full-scale deflection of 10 kg. Crosshead speed was set at 2.5 cm/min and chart speed at 25 cm/min. A blade attachment of ¼-in.

Plexiglas was used. The lower edge of the blade was sharpened to a 1/16-in. blunt and was 2.0 in. in length. Cookie samples were centered on top of two supports to create a "bridge" with a span of 2.5 in.

Cookie samples were baked, cooled to room temperature, and stored in Zip-Loc plastic bags. Measurements were taken at one, three, and five days postbake. Cookie snap was monitored by changes in the approximate area of the compression curve over time. This area was calculated by multiplying the height of the curve, in centimeters, by the width of the curve at its half-height, in centimeters. Eight observations of each cookie treatment were measured, and cookie snap was reported as the mean of eight measurements.

Differential Scanning Calorimetry (DSC)

A Perkin-Elmer DSC-2 with an Intra Cooler II was used as described previously (Abboud and Hoseney 1984). Approximately 10 mg of cookie dough was transferred to previously weighed aluminum DCS pans. The pans were sealed and reweighed. The sample was then placed in the DSC with an empty pan as a reference. The samples were cooled to 7°C and then heated to

107°C at a rate of 10°/min. Sensitivity of 0.5 mcal/sec and chart speed of 10 mm/min were used.

Water Activity

Water activity was measured with Beckman water-activity meter with a model VFB Hygroline Recorder. The range chosen for this

Fig. 3. Dough stickiness as a function of percent granular sucrose solids replaced by high-fructose corn syrup in cookie dough. The standard deviation among means of replicates ranged from 5.26 to 8.6 cm².

TABLE I
Effect of Levels of High-Fructose Corn Syrup (HFCS) on Cookie Diameter and Thickness

Sucrose Replaced by HFCS (%)	Cookie Diameter (cm)	Cookie Thickness[b] (mm)
0[a]	9.45	15.50
10	9.15	16.30
20	9.10	17.95
30	8.90	18.00
40	8.55	19.75
50	8.45	20.60

[a]Control.
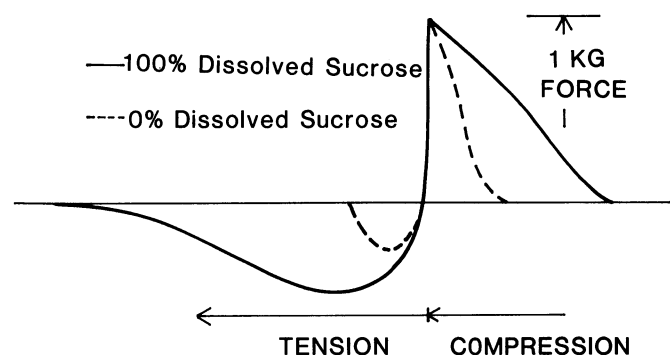[b]Measurements are the thickness of two cookies.

Fig. 1. Instron tension curves for dough stickiness. - - - = 0% dissolved sucrose. ———— = 100% dissolved sucrose.
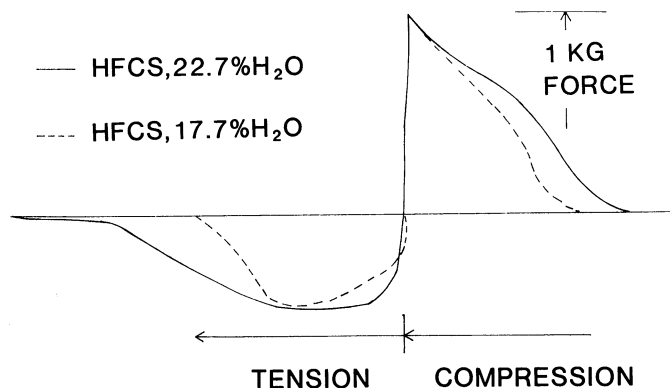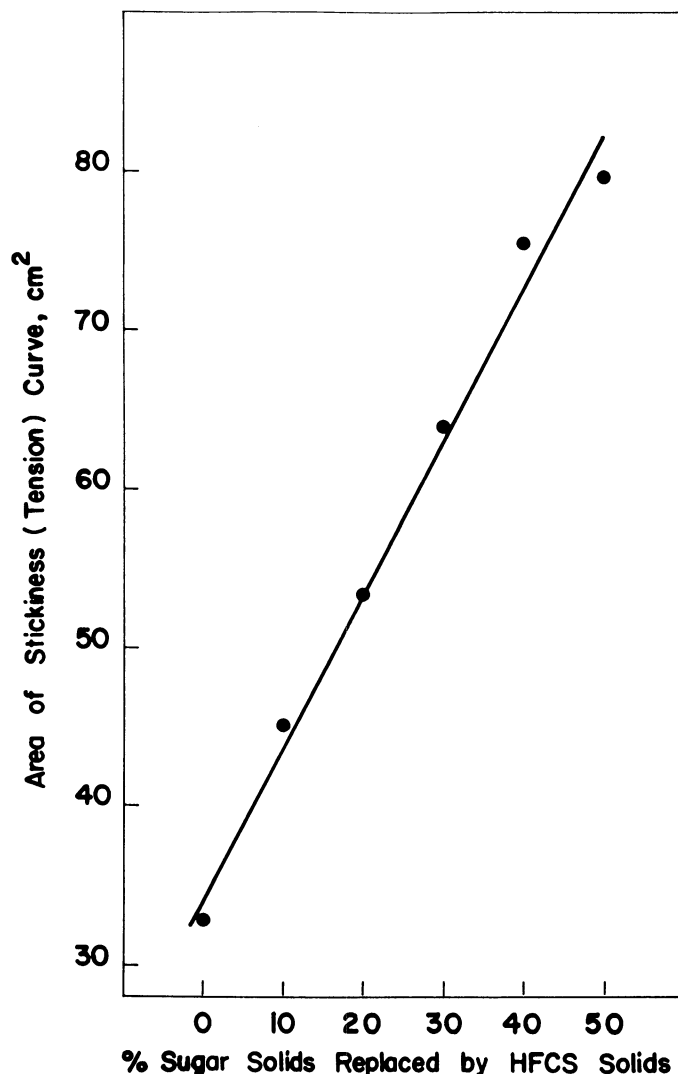
Fig. 2. Effect of water level (percent based on flour weight) on dough stickiness of cookie doughs containing high-fructose corn syrup.
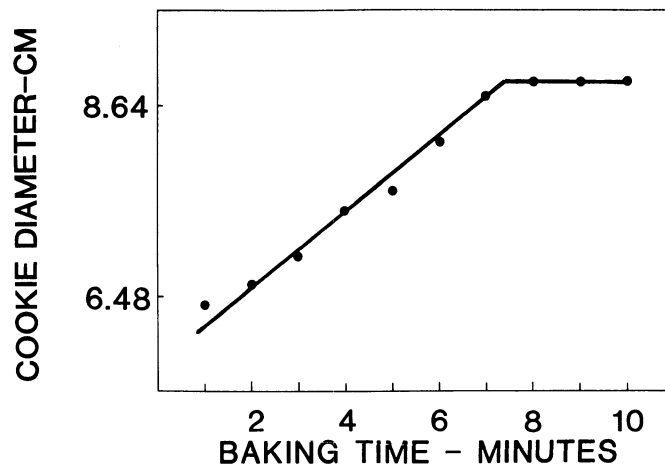
Fig. 4. Changes in cookie diameter during baking for a granular-sucrose cookie.

procedure was 10–100% rh. Chart speed was set at 1 in./hr. Cookies were baked, allowed to cool on wire racks at room temperature for 1 hr, made into crumbs using a mortar and pestle, 3 g of crumbs was placed in the sample dish, and a_w was measured continuously for 72 hr. A standard salt solution was simultaneously measured in another sample dish to assure accuracy.

RESULTS AND DISCUSSION

Dough Stickiness

Abboud and Hoseney (1984) used differential scanning calorimetry to show that only part of the sugar in a sugar-snap formula dissolves during mixing. The remainder dissolves during baking. When comparing cookies made from sucrose and corn syrups, we are comparing different amounts of dissolved sweeteners in the dough. If all of the sucrose is dissolved before mixing, a sticky dough results.

The two curves shown in Fig. 1 represent doughs made with 0 and 100% dissolved sucrose. The dough with 0% dissolved sucrose was firm and manageable. During measurement on the Instron, the plunger made a quick and clean release from the dough. The dough with 100% dissolved sucrose was very sticky and unmanageable. During its measurement on the Instron, the plunger made a slow release, carrying part of the dough with it.

When 50% of the granular sucrose was replaced with HFCS, the resultant dough was as sticky and unmanageable as the dough made with 100% dissolved sucrose. In addition, the dough was very soft. Instron measurement of that dough gave a curve (solid line, Fig. 2) similar to that obtained from the dough with 100% dissolved sucrose (Fig. 1).

When sucrose is dissolved in water, it displaces part of the water, giving more total volume (Ghiasi et al 1983). In cookie dough, this increased displacement of water (increase in total solution volume) results in softer and stickier dough. When water in the HFCS dough system was reduced from 22.7 to 17.7% (based on the flour weight) the dough lost most of its soft and sticky characteristics
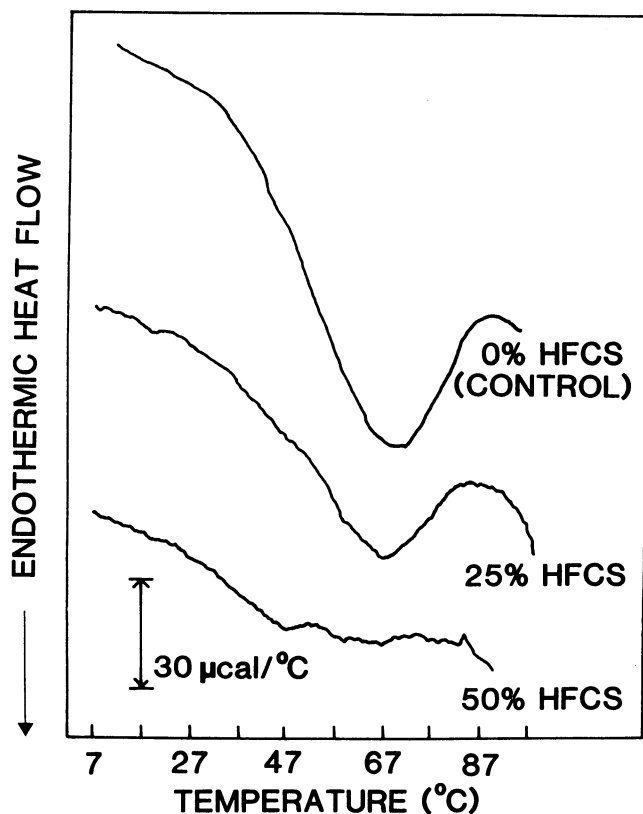

Fig. 5. Effect of level of high-fructose corn syrup (percent sucrose solids replaced by high-fructose corn syrup solids) on the amount of sugar dissolving in cookie dough in the differential scanning calorimeter.
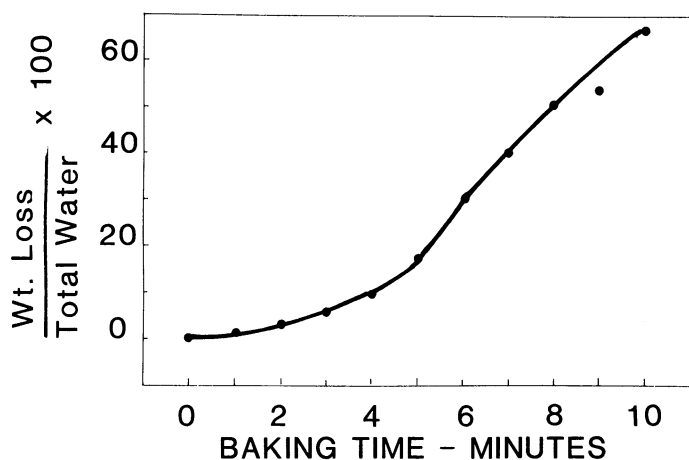
TABLE II
Effect of Different Sweeteners on the Spreading Rate and Set Time of a Cookie

Sweetener	Spreading Rate (cm/min)	Set Time (min)
Granular sucrose (100%)	0.52	7.4
Dissolved sucrose (50%)	0.61	8.2
HFCS[a] (50%)	0.55	6.6
HMCS[b] (50%)	0.64	7.7

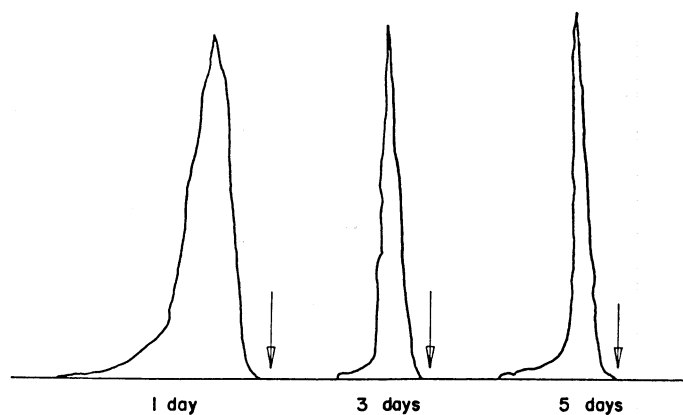[a] High-fructose corn syrup.
[b] High-maltose corn syrup.

Fig. 7. Instron curves for compression of sugar-snap cookies showing effect of time on curve area. Arrows indicate the starting points.

Fig. 6. Water loss from a granular-sucrose cookie during baking.
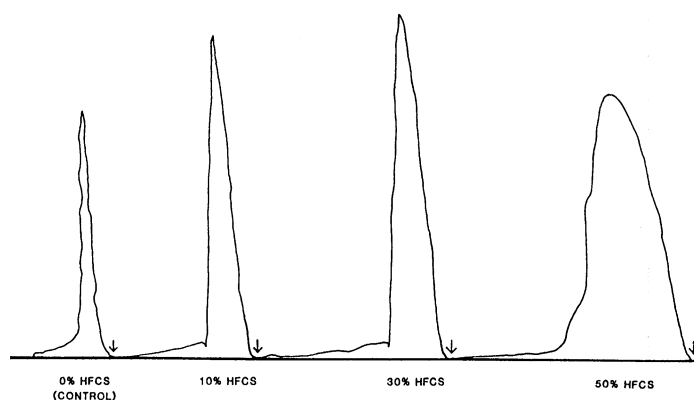

Fig. 8. Instron curves for compression of sugar-snap cookies containing 0, 10, 30, and 50% high-fructose corn syrup. Arrows indicate the starting points.

even though the sugar concentration in the water increased. The dough was slightly tacky but not tacky enough to affect its manageability. During measurement, the Instron plunger made a clean release that was quicker than that with the original (22.7% HFCS) dough (Fig 2).

A similar experiment (reducing the water in the dough) with 100% dissolved sucrose dough gave a similar change in the tension curve. Thus, it is apparent that the volume of total solution in a cookie dough system directly influences its degree of softness and stickiness.

Cookie doughs containing increments of HFCS from 0 to 50% showed a concurrent increase in dough stickiness with each increase in the amount of HFCS (Fig. 3). When granular sucrose was replaced by HFCS at levels greater than 50%, the resultant dough was so soft and sticky that it could not be manipulated by machine.

Baking Performance

Replacing sucrose with HFCS changed the appearance of the baked cookies. Cookie color darkened as the level of HFCS increased. This color change results from the reducing sugars in the corn syrup.

Cookie Spread

Cookie diameter and thickness were measured for cookies made with HFCS (0–50%), replacing granular sucrose solids (Table I). Cookie diameter gradually decreased, and cookie thickness increased as the level of HFCS solids increased. Dough handling became more difficult, and uniformity of shape decreased as the level of HFCS was increased.

Spreading Rate and Set Time

To study how replacement of granular sucrose with fluid sweeteners affects the spreading rate and set time of cookies, cookie diameter measured by time-lapse photography was plotted against baking time. The fluid sweeteners were sucrose dissolved in water, HFCS, and HMCS. The performance of the 100% granular sucrose cookie (control) is shown in Fig. 4. Set time of the dough was 7.4 min, and spreading rate (slope of the ascending line) was 0.52 cm/min. Similar graphs were constructed for each sweetener, and set times and spreading rates determined (Table II). The results show that cookies made with different sweeteners vary in both spreading rate and set time.

The fluid sweeteners had faster spreading rates than did granular sucrose. The increase in spreading rate may be a function of the amount of sugar dissolved during mixing. As mentioned earlier, only part of the sugar in a sugar-snap formula dissolves during mixing. The remainder dissolves during baking (Abboud and Hoseney 1984). When fluid sweetener is used to replace 50% of the granular sweetener, the amount of sugar that dissolves during mixing may be larger than the amount that dissolves when 100% granular sucrose is used. That allows for greater dough mobility (lower viscosity) during the earlier stages of baking and a faster spreading rate (Yamazaki 1959).

According to Potter (1978), a mixture of sucrose and invert sugar has greater solubility in water than does sucrose alone. Cookie doughs were examined on the differential scanning calorimeter to determine whether the amount of sugar dissolving during baking differed between doughs with and without corn syrup. Three different doughs were examined (0, 25, and 50% replacement of sucrose with HFCS). Thermograms showed differences in the amount of sugar that dissolved during heating (Fig. 5). As the HFCS substitution level increased, the amount of sugar that dissolved during baking decreased (the sugar had dissolved during mixing). The greater amount dissolved during mixing allowed for greater dough mobility during the earlier stages of baking and explains the faster spreading rates observed with the fluid sweeteners.
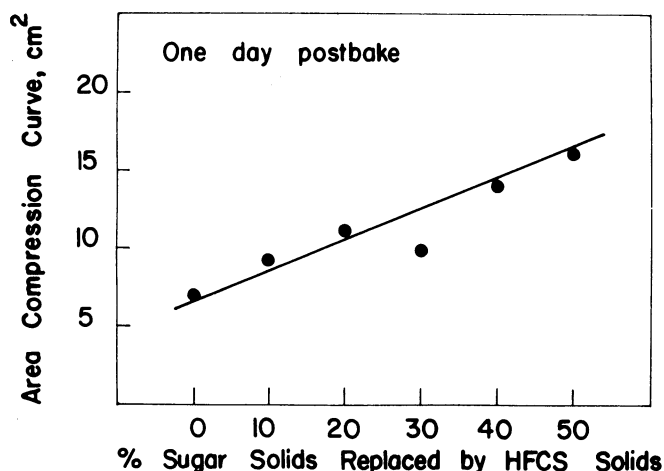

Fig. 9. Effect of high-fructose corn syrup on the area of the Instron compresssion curves for cookies one day postbake.
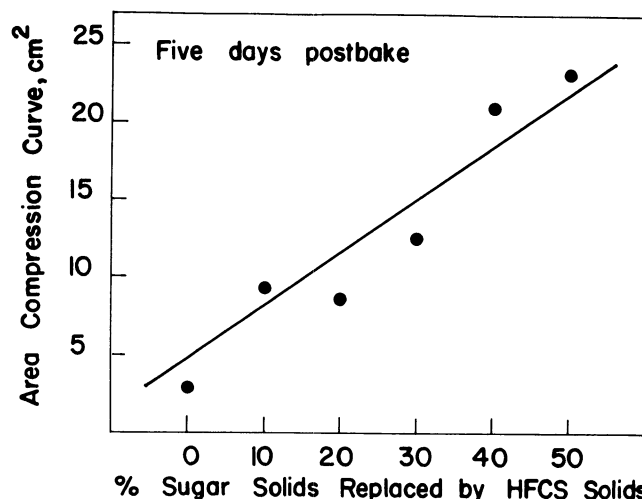

Fig. 10. Effect of high-fructose corn syrup on the area of the Instron compression curves for cookies five days postbake.

TABLE III
Effect of High-Fructose Corn Syrup (HFCS) Levels and Time on the Area of the Instron Compression Curve

Sucrose Replaced by HFCS (%)	Area Compression Curve, cm^2		
	One Day Postbake Mean SD[a]	Three Days Postbake Mean SD[a]	Five Days Postbake Mean SD[a]
0	7.00 ± 2.18	4.23 ± 2.05	2.95 ± 0.94
10	9.05 ± 1.10	3.22 ± 0.74	9.29 ± 1.76
20	11.00 ± 0.92	7.76 ± 4.42	8.80 ± 1.54
30	9.90 ± 4.47	19.09 ± 4.65	12.70 ± 2.60
40	14.06 ± 2.11	15.07 ± 4.36	21.04 ± 3.99
50	15.96 ± 3.41	20.17 ± 4.96	23.12 ± 4.05

[a]Standard deviation.

Set time data show that the HFCS cookie had the earliest set time and the 50% dissolved sucrose cookie the latest. The fluid sweeteners did not collectively differ in set time from that of the granular sweetener. However, the set times of the sweeteners differed more from each other than did their spreading rates. No reason for those differences in set time is apparent.

Water Loss During Baking

The amount of water lost during baking was measured for cookies containing 100% granular sucrose and three fluid sweeteners (sucrose dissolved in water, HMCS, and HFCS, used at the 50% replacement level). About 70% of the water present in the granular sucrose cookie dough was lost during baking (Fig. 6). Similar curves were constructed for the three fluid sweeteners, and no significant differences were found between any of the sweeteners in the water loss during baking. At the end of baking, all cookies had lost about the same amount of water.

Surface Cracking

Time-lapse photographs taken during cookie baking showed that the outer surface of the granular-sucrose cookie dried rapidly and cracked when the cookie started to spread. This drying produces the typical top grain on sugar-snap cookies. The outer surface of HFCS cookies did not dry but remained moist during the early stages of baking. Thus cookies containing HFCS do not have a good top grain. Surface cracking appears, therefore, to be a function of the rate of surface drying. Rate of surface drying apparently is controlled by internal water diffusion to the cookie surface rather than the rate of vaporization at the cookie surface because, as shown above, the water loss from the cookie was constant.

These data suggest that the internal diffusion rate is governed by the presence of a continuous liquid phase in the dough. Apparently, sucrose crystals together with a sucrose syrup give a discontinuous liquid phase in cookie doughs, whereas sucrose crystals together with corn syrups give a continuous liquid phase under the same conditions.

Cookie Snap

When corn syrup replaced small amounts of sucrose in sugar-snap cookies, the character of the snap changed. The effect of time on snap development in the granular sucrose (control) cookie is shown by the change in the area of the Instron curve with time (Fig. 7). The change in the width of the curve between one and three days postbake represents a change in the ability of the cookie to bend under the application of force. The change in the cookie's ability to bend coincides with snap development. The snap sharpens at a point somewhere between one and three days postbake. No further change in the snapping characteristic of this cookie occurred, as shown by the similarity in the area of the three- and five-day curves.

Although a change in the area of the Instron curves occurred between one and three days postbake, the height of the two curves did not change. Curve heights are interpreted as a measurement of cookie hardness. Because there were no differences in the heights of these curves, the snapping characteristic of the cookie was not considered a function of cookie hardness.

To study snap development in the granular-sucrose cookie, a different cookie flour was used. Instron compression curves of those cookies indicated that snap development occurred before one day postbake. The area under the curve did not change for cookies measured at one, two, and three days postbake. Thus, flour also influences snap development.

A change in snapping characteristics over time also occurred in cookies containing HFCS; however, the development of the snap did not appear to coincide with a decrease in the area of the Instron curves over time (Table III). When measured on the Instron, the HFCS cookies produced compression curves with larger areas than those from granular-sucrose cookies. As the level of HFCS solids increased, the area of the compression curves also increased (Fig. 8).

The increase in the area of curves coincides with an increase in the width of the curves. The height of the curve changed little. This suggests that cookie hardness is not lost at these lower substitution levels of HFCS solids. The cookie's ability to bend, however, does increase with an increase in HFCS solids. The cookies therefore lose their snap.

At higher levels of HFCS substitution, the area of the compression curves increased with time. A plot of percent HFCS solids against area of the compression curve shows a positive linear relationship at both one day (Fig. 9) and five days (Fig. 10) postbake. This change may relate to the movement of free water within the cookie.

A hypothesis based on the work of Youngquist and Brabbs (1982) has been developed to explain change in snapping characteristics with time. Upon removal from the oven, the sugar in a cookie is in a supersaturated solution. Upon cooling and with time, sucrose begins to crystallize. The change from dissolved sugar (syrup) to crystalline sugar coincides with snap development. As a result of crystallization, sugar gives up water that is rapidly absorbed by other dry cookie components (starch).

To test this hypothesis, we measured water activity in baked cookies over time. Water activity increased from 0.305 at 1.5 hr postbake to 0.335 at 64 hr postbake. This increase also coincided with snap development. The water activity data appear to support the hypothesis of Youngquist and Brabbs (1982).

When HFCS is added to the formula, the concentration of fructose and glucose—both of which inhibit sucrose crystallization—is increased. With less sugar crystallization, the cookie has different snapping characteristics because the presence of syrup within the cookie makes it softer and allows it to bend under compression.

LITERATURE CITED

ABBOUD, A. M., and HOSENEY, R. C. 1984. Differential scanning calorimetry of sugar cookies and cookie dough. Cereal Chem. 61:34.

FINNEY, K. F., MORRIS, V. H., and YAMAZAKI, W. T. 1950. Micro versus macro cookie-baking procedure for evaluating the cookie quality of wheat varieties. Cereal Chem. 27:42.

GHIASI, K., HOSENEY, R. C., and VARRIANO-MARSTON, E. 1983. Effects of flour components and dough ingredients on starch gelatinization. Cereal Chem. 60:58.

HENRY, R. E. 1976. High fructose corn syrup—New sweetener for the baker. Bakers Dig. 52(2):25.

POTTER, N. N. 1978. Food Science. Avi Publ. Co., Westport, CT.

SCHANOT, M. A. 1981a. Sweeteners. AIB Research Dept. Technical Bulletin, Vol. 3, No. 3. Am. Inst. Baking, Manhattan, KS.

SCHANOT, M. A. 1981b. Sweetener Functionality. AIB Research Dept. Technical Bulletin. Vol. 3, No. 4. Am. Inst. Baking, Manhattan, KS.

YAMAZAKI, W. T. 1956. Recent soft wheat quality research. Bakers Dig. 30(5):35.

YAMAZAKI, W. T. 1959. The application of heat in the testing of flours for cookie quality. Cereal Chem. 36:59.

YOUNGQUIST, R. W., and BRABBS, W. J. 1982. Single-dough cookies having storage stable texture. U. S. Patent 4,344,969.