205

EFFECTS OF CORN SWEETENERS ON COOKIE QUALITY

by

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In 1974 the price of sugar increased dramatically. Although it has fluctuated since that time, the price of sugar still remains significantly higher than the pre-1974 price. As a consequence, production costs for the cookie manufacturer have also risen. Thus, cookie bakers sought an alternate sweetener to replace some of the sugar in their formulations. 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 substituted for is limited, however, because HFCS is a fluid. The degree of substitution of high fructose corn syrup for granular sucrose is dependent on the cookie formulation. Its use in hard cookies creates many problems for the cookie manufacturer. A better understanding of what causes those problems would be valuable to the cookie manufacturer.

The objective of this study is to identify the changes resulting from the substitution of high fructose corn syrup for granular sucrose in a sugar-snap cookie formulation and how this substitution influences the cookie's dough rheology, baking performance, and its physical characteristics after baking.

LITERATURE REVIEW

Sugar is an essential ingredient in cookies and provides them with both sweetness and functionality. It contributes to flavor through its sweetness and via caramelization and the maillard browning reactions. Sugar also contributes to crust color development or darkening through those same browning reactions and the caramelization reactions. The most important contribution that sugar provides, however, is through its functionality.

Sugar is considered to be the most important tenderizing material in cookies. Although its presence in cookies lends to crispness, it also acts as a softening agent through its ability to retain water in the cookie when used at moderate levels (Thelen 1949; Schanot 1981b).

Sugar directly influences the spread or flow of most cookies (Thelen 1949). In the cookie dough system, there are three basic ingredients, flour, sugar, and water. According to Fuhr (1962), the cookie spread mechanism is a function of total availability of water in which the sugar and flour compete for water. The ability of flour to compete for water is largely dependent upon the amount of damaged prime starch (Yamazaki 1962), and the amount of soluble pentosans (Sollars 1956).

When a cookie bakes, undissolved sugar in the cookie dough dissolves resulting in a fluid system which spreads on the baking surface (Shanot 1981b). Thus, the greater the amount of sugar which is dissolved during baking, the greater the spread (Fuhr 1962). Finney et al (1950b) studied the effects of varying quantities of sugar on the spreading of sugar snap cookies and found that increasing the sugar concentration from 50% to 80% also increased cookie diameter.

Cookie spread is also influenced by sugar granulation (Thelen 1949). In the literature cited, conflicting reports were found on the effect of sugar granularity on cookie spread. Thelen (1949) and Schanot (1981b) both report that the coarser the sugar granulation, the greater the cookie spread. They support this association with the explanation that it is the amount of sugar solution formed during baking which governs spread. Fine granulated sugar dissolves quite readily during mixing thus allowing very little sugar to dissolve during baking which, in turn, produces little spread. Coarse sugar granules, on the other hand, do not totally dissolve during the dough mixing stage and consequently produce greater spread. Contrary to this theory, Kissell et al (1973) found that cookie spread increased with decreasing mean particle size of sugar. His supporting explanation behind the association between granulation and spread relates to the flour-sugar-water ratio in the dough and to the time-rate of solution. In his explanation, Kissell states that during mixing and handling, flour and sugar compete for the available water. In the creaming stage, sugar particles are coated with fat and further hindered from solution. Thus, as sugar particle size increases, surface area in the system decreases and becomes a limiting factor in achieving ultimate spread potential.

Sugar content and granulation also affect surface texture of the cookie. Although the effect of sugar on surface cracking is not completely understood, Finney et al (1950) found that the widths of the cracks increased with increasing sugar levels; less than 55% sugar gave an inferior top grain. Schanot (1981b) reported that the surface cracking pattern is influenced by sugar granulation. According to his report, it is the recrystallization of sugar during baking which causes the surface cracking. Consequently, little or no cracking is observed when finer sugar granulations are used because there isn't a migration of sugar crystals to the surface of the cookie.

Up until now, the use of the term sugar in this discussion has implied granular sucrose. However, granular sucrose is not the only sugar currently being used in cookie formulation. Together with rising sucrose prices, the development of corn syrups, especially high fructose corn syrup, has given the cookie industry an alternate source for sugar. High fructose corn syrup is a standardized product containing 42% fructose and 71% solids (Schanot 1981). It is produced via continuous isomerization of dextrose into fructose using immobilized enzyme technology (Schanot 1981a). High fructose corn syrup can be used as a partial replacement for sucrose in cookies. Replacement levels reported by Henry (1976) are 60 to 75% for soft cake-type cookies and 10 to 30% for hard cookies.

The function of corn syrup in cookies is similar to that of sucrose. It provides sweetness at levels considered to be equivalent to that of sucrose (Henry 1976). Cookies made with corn syrup are generally darker in color due to the presence of reducing sugars (Saussele et al 1976). The largest and most important difference between cookies produced from these two sweeteners is tenderness. The monosaccharides present in high fructose corn syrup (dextrose and fructose) are considered to be the most hygroscopic sugars commonly used in baking (Henry 1976). They combine with other ingredients in the cookie dough to form a more fragile or tender structure (Schanot 1981b). In hard crisp cookies, it is the humectant property of high fructose corn syrup that limits its use. Soft cookies however do not have this same limitation and commercial applications indicate that the replacement of sucrose with high fructose corn syrup can provide extended shelf life and substantially reduced ingredient cost (Schanot 1981b).

The replacement of small amounts of sucrose with high fructose corn syrup in a cookie formulation also produces a change in the surface characteristics of the baked cookie. The surface cracking commonly associated with some cookies is not seen on cookies containing corn syrup. An explanation for this change in surface characteristics could not be found in the literature.

MATERIALS & METHODS

Materials

Flour. A commercial soft wheat cookie flour obtained from Mennel

Milling Company, Fostoria, Ohio, was used (9.2% protein, 0.58% ash, and 14.2% moisture).

Sugar. A commercial pure cane granulated superfine sugar from C. and H. Sugar Co., San Francisco, California was used.

Shortening. The commercial hydrogenated all vegetable shortening, "Crisco", from Procter & Gamble was used.

High Fructose Corn Syrup. IsoSweet 100 High Fructose Corn Syrup from A. E. Staley Manufacturing Co. was used. It contains 71% solids; carbohydrate components include 50% dextrose, 42% fructose and other higher saccharides.

High Maltose Corn Syrup. Neto 7350 High Maltose Corn Syrup from A. E. Staley Manufacturing Co. was used. It contains 80.5% solids; carbohydrate components include 8% dextrose, 44% maltose, 23% maltotriose, and other higher saccharides.

Baking Powder. For a portion of this study the commercial double-acting baking powder, "Calumet" from General Foods Corporation was used.

Methods

Cookie Baking. The method used to bake cookies followed Micro Method III, a procedure by Finney et al (1950a). For a portion of this study an alternate leavening system was used to accomodate the use of a fluid sweetener; 1.0% double-acting baking powder, undissolved, was added with the flour in place of 0.75% ammonium bicarbonate. When high fructose corn syrup was used to replace some of the sucrose solids, the water in the formula was readjusted to compensate for the water present in the corn syrup.

Dough Stickiness. Dough stickiness was measured on the Instron Universal Testing Machine (Model 1122) in the tension mode. The Instron was set to give a full scale force of 2 kg. The head speed was set at 10 mm/min and the chart speed at 200 mm/min. Dough samples were compressed by a constant force of 1 kg and the area of the tension curve was used to measure stickiness. The plunger used was made of stainless steel and had a base diameter of 36 mm. Cookie dough was mixed, completely covered to prevent surface drying, and left to requilibrate for approximately ten min. The dough was then sheeted and cut to regular size. To center the dough piece under the plunger and prevent spreading of the dough during compression, the cutter was left in place.

The area of the tension curve was measured with a planimeter. Four samples of each dough were prepared separately and each sample provided enough dough for two separate measurements. Dough stickiness was reported as an average of those eight measurements.

Time Lapse Photography. The method used followed the procedure by Yamazaki (1956) with a few modifications. Cookies were cut to size and a metal ruler was positioned between the two cookies at the center of the cookie sheet. The cookie sheet was placed on a stationary oven shelf in a reel type oven with an internal light source. Cookies were baked for ten min and photographs were taken through a glass window in the oven door at one min intervals.

Water Loss. Water loss during baking was measured at 1 min intervals. Cookie doughs were placed on a cookie sheet of known weight and weighed prior to baking. After baking for the desired time, the doughs were removed from the oven and immediately covered with a petri dish, also of known weight, to prevent moisture loss. Once the doughs and cookie sheet were completely cool, the doughs were weighed a second time. Water loss was calculated using 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 force of 10 kg. The crosshead speed was set at 2.5 cm/min and the chart speed was set at 25 cm/min. The blade attachment used was made of plexiglass. The lower edge of the blade was narrow and blunt and was 2.0 inches in length. Cookie samples were centered on top of two supports to create a "bridge" with a span of 2.5 inches.

Cookie samples were baked, cooled, 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. The approximate area of the curve was calculated by multiplying the height of the curve, in cm, by the width of the curve at its midpoint, in cm. Eight samples of each cookie were measured and cookie snap was reported as an average of those eight measurements.

Differential Scanning Calorimetry (DSC). A Perkin Elmer DSC-Z with an Intra Cooler II was used. The DSC had been previously calibrated with distilled water and indium. Leavening was omitted from the cookie dough formulation. The gas produced by leavening could potentially force open the hermetically sealed sample pans.

Approximately 10 mg of cookie dough was transferred to previously weighed aluminum DSC pans, the pans sealed, and then reweighed. The sample was then placed in the DSC with an empty pan used as a reference.

The samples were cooled to 7^{0}C and then heated to 107^{0}C at a rate of 10^{0}/min; a sensitivity of 0.5 mcal/sec and a chart speed of 10 mm/min were used.

The thermograms obtained were used to determine relative differences in the amount of sugar dissolving for doughs with 0%, 25%, and 50% replacement or sucrose solids with HFCS solids.

Water Activity (a_w). A Beckman water activity meter, model VFB Hygroline Recorder was used. The range units chosen for this procedure were for 10% - 100% r.h.; chart speed was set at 1 in/hr.

Water activity was measured on baked cookies. In the procedure, cookies were baked and allowed to cool on wire racks at room temperature for 1 hr. The cookies were then made into crumbs using a mortar and pestle. Three gm of crumbs were 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 in the measurements being taken. The change in a_w over time was used to monitor sugar crystallization after baking.

RESULTS & DISCUSSION

Dough Stickiness

Replacing sucrose with high fructose corn syrup (HFCS) results in many changes both for the dough and the baked cookies. One of the most notable changes was an increase in dough stickiness; this resulted in impaired dough handling characteristics.

Thermal studies on the differential scanning calorimeter (DSC) by Abboud (1983) showed that only part of the sugar in a sugar snap formula dissolves during mixing; the remainder dissolves during baking. When comparing sucrose with syrup, a comparison of different amounts of dissolved sweeteners is assumed. Thus, to give a better comparison, sucrose was dissolved before mixing. If all of the sucrose is dissolved before mixing, a sticky dough results.

To quantify the changes that occur in dough stickiness when all of the sucrose is dissolved, a method of measuring cookie dough stickiness was developed using the Instron Universal Testing machine in the tension mode. Dough samples were compressed with a constant 1 kg force and stickiness was measured using the area under the tension curve. This method was found to give reproducible results.

The two curves shown in Figure 1 represent doughs made with 0% dissolved sucrose (solid line). The 0% dissolved sucrose dough was firm and manageable and during its measurement on the Instron, the plunger made a quick and clean release from the dough. The 100% dissolved sucrose dough was very sticky and unmanageable and during its measurement on the Instron, the plunger made a very slow release carrying some of the dough with it. This indicates that the adhesive forces between the dough and the plunger were greater than the cohesive forces within the dough.

Cookie doughs containing increments of dissolved sucrose from 50% to 100% showed a concurrent increase in dough stickiness with each increase of dissolved sucrose (Fig. 2).

To further analyze the affect of a fluid sweetener on cookie dough stickiness, fifty percent of the granular sucrose was replaced with high fructose corn syrup. When this substitution was made, the resultant dough was as sticky and unmanageable as a dough with 100% dissolved sucrose and also gave a softer dough. Measurement of this dough on the Instron gave a curve (solid line, Fig. 3) similar to that obtained with the 100% dissolved sucrose dough (Fig. 1).

When sucrose is dissolved in water, the sucrose displaces part of the water. For exmaple, when one gram of sucrose is dissolved in one milliliter of water, 1.6 milliliters of sugar solution results. In a cookie dough

Figure 1. Instron tension curves for dough stickiness. Dotted line shows 0% dissolved sucrose. Solid line shows 100% dissolved sucrose.

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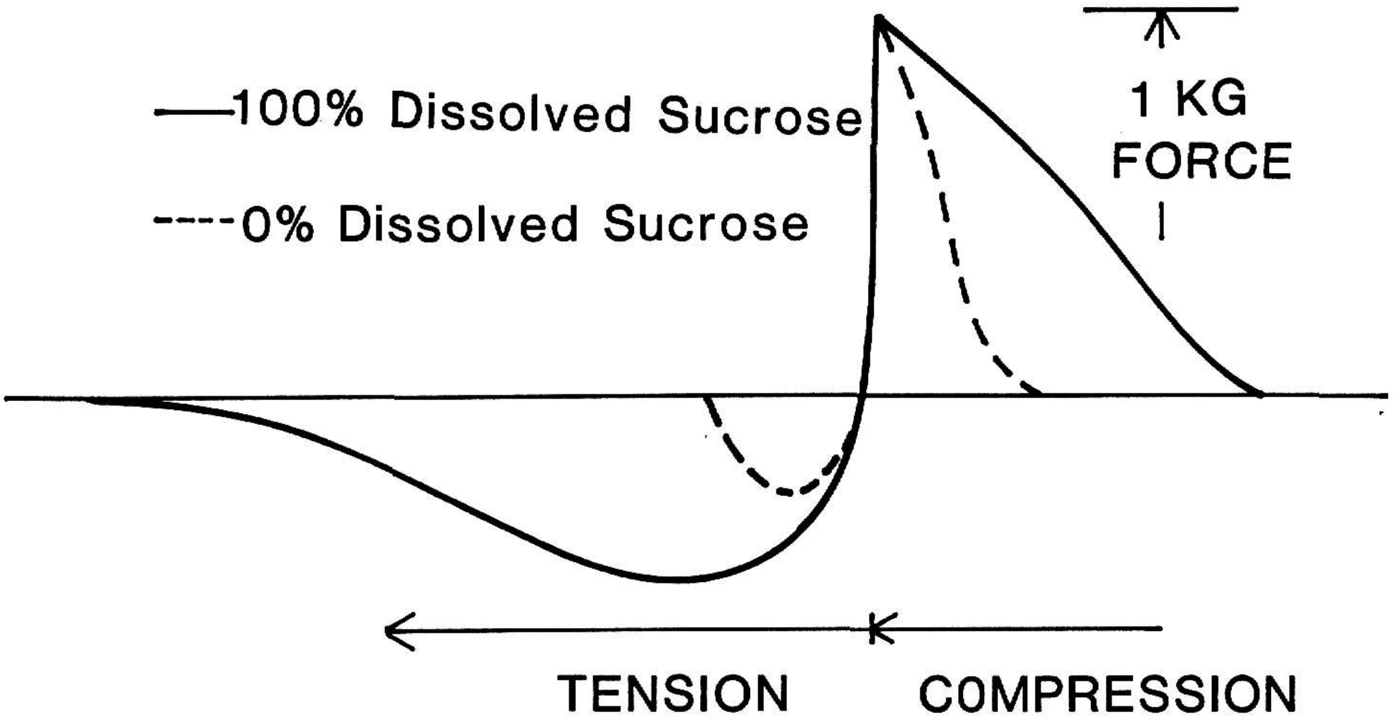

—100% Dissolved Sucrose
----0% Dissolved Sucrose
1 KG
FORCE
TENSION
COMPRESSION

Figure 2. Dough stickiness as a function of percent granular sucrose solids replaced by dissolved sucrose solids in cookie dough. The standard deviation among means of the replicates ranged from 1.97 cm^2 at 0% dissolved sucrose solids to 11.32 cm^2 dissolved sucrose solids.

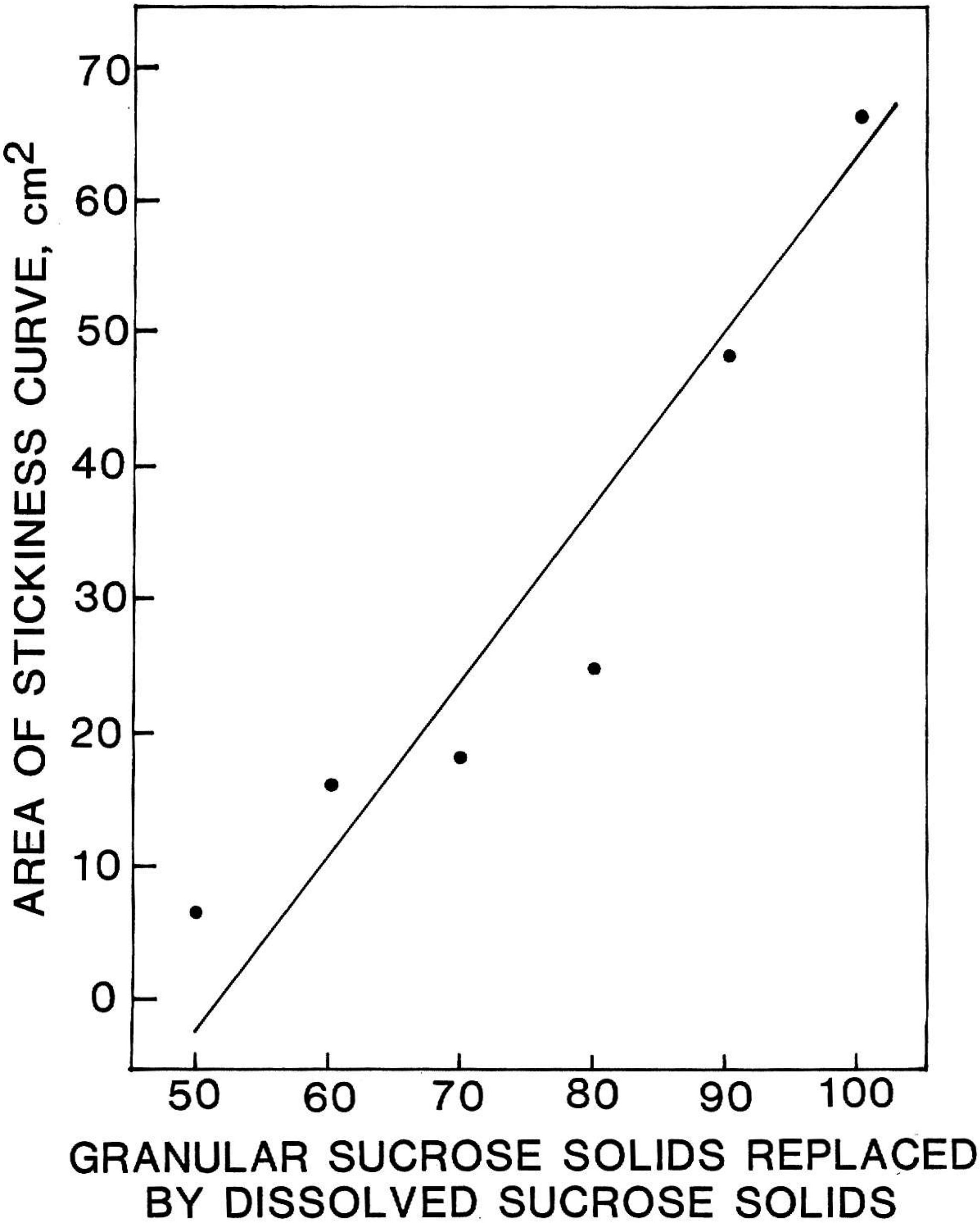
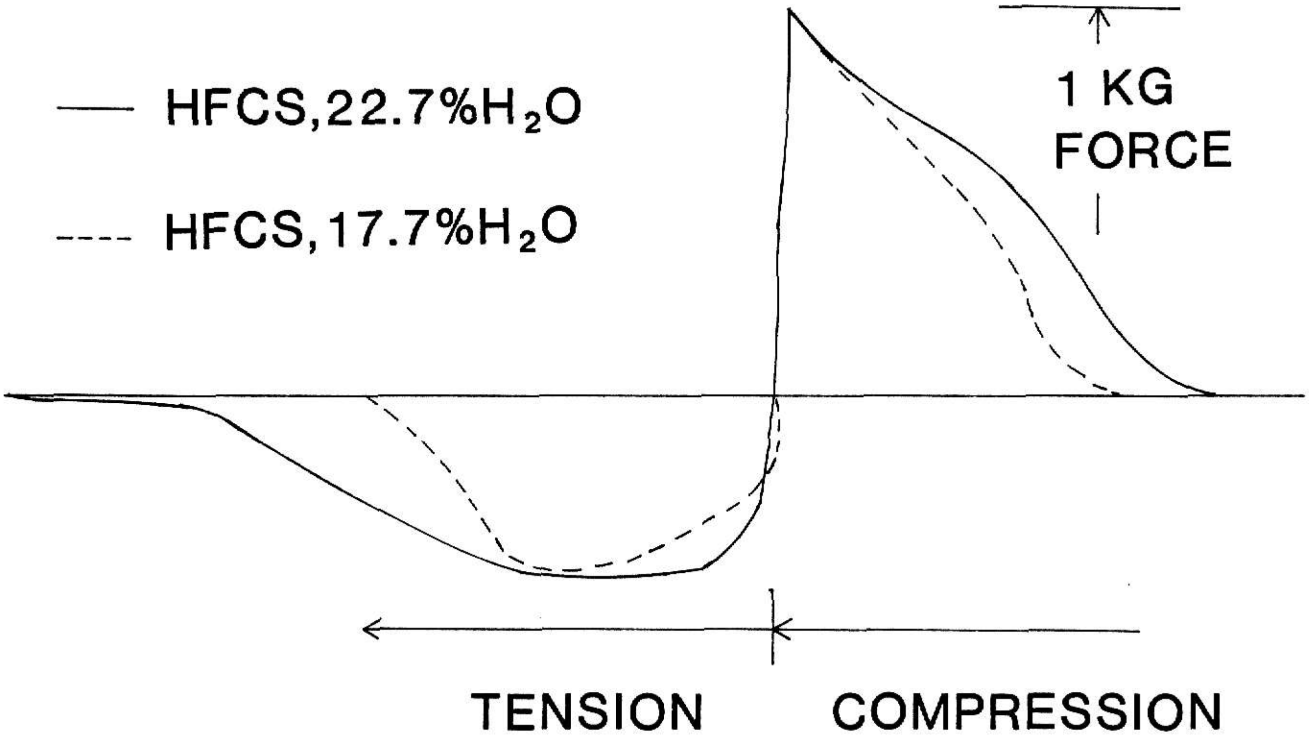

AREA OF STICKINESS CURVE, cm^2
70
60
50
40
30
20
10
0
50
60
70
80
90
100
GRANULAR SUCROSE SOLIDS REPLACED BY DISSOLVED SUCROSE SOLIDS

Figure 3. Effect of water level (% based on flour weight) on dough stickiness of HFCS containing cookie doughs.


HFCS,22.7%H2O
HFCS,17.7%H2O
1 KG FORCE
TENSION
COMPRESSION

system, the displacement of water results in a softer and stickier dough. In an effort to lessen the softness and stickiness of high fructose corn syrup doughs, water was removed from the dough system. When the water was reduced from 22.7% to 17.7% (based on the flour weight) the dough lost its soft and sticky characteristics. The dough was slightly tacky but not enough to affect its manageability. When measured on the Instron, the plunger made a clean release that was quicker than the original high fructose corn syrup dough (dotted line, Fig. 3). Thus the adhesive forces between the dough and plunger decreased dramatically.

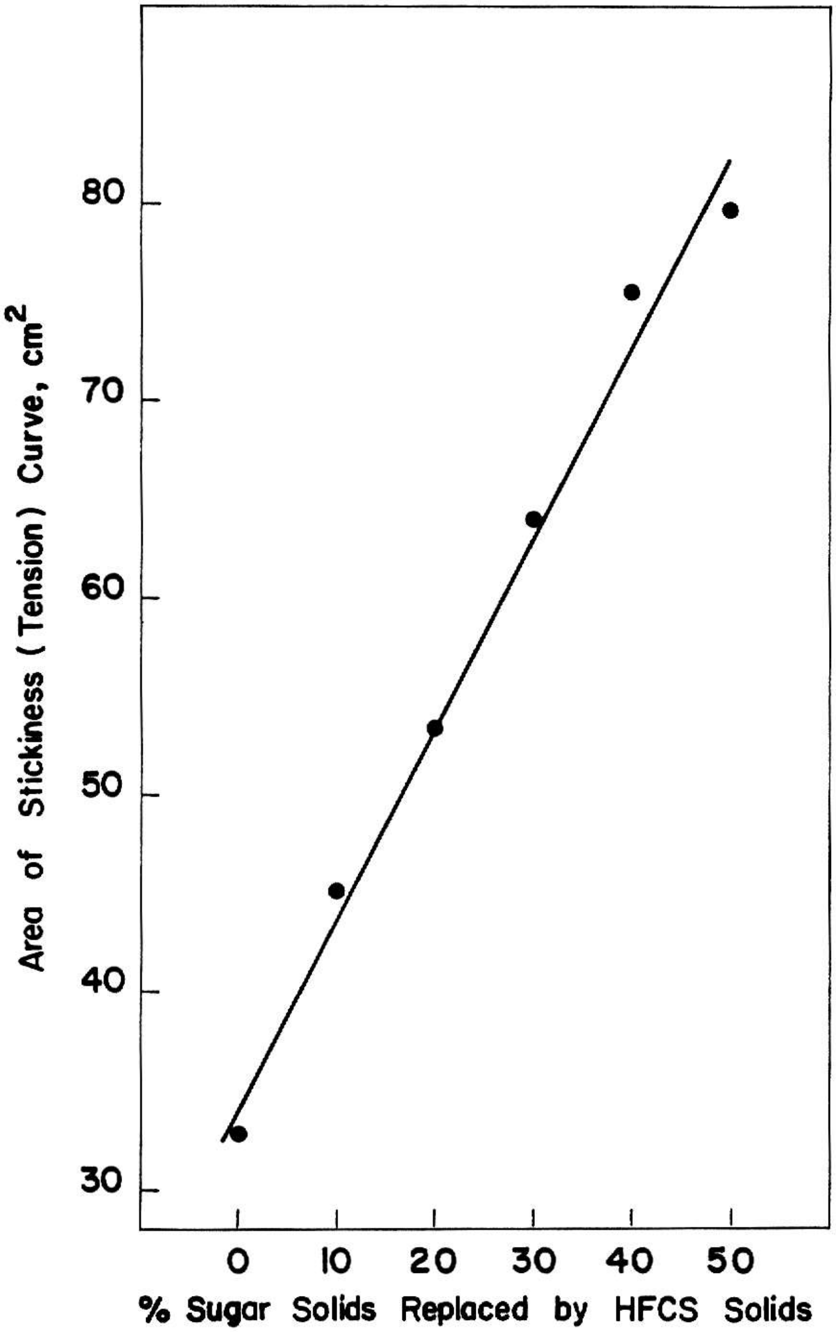
A similar experiment with 100% dissolved sucrose dough gave a similar change in the tension curve. From those results, it is apparent that the amount of total solution in a cookie dough system directly influences its degree of softness and stickiness.

Cookie doughs containing increments of high fructose corn syrup from 0% to 50% showed a concurrent increase in dough stickiness with each increase in high fructose corn syrup level (Fig. 4). When granular sucrose is replaced by high fructose corn syrup at levels higher than 50%, the resultant dough is so soft and sticky that it is not considered to be machineable. Consequently dough stickiness measurements were only completed through the 50% replacement level.

Baking Performance

The replacement of sucrose with high fructose corn syrup in a cookie formulation also influences cookie baking performance. This is obvious from the appearance of the baked cookie. The cookie baking procedure used to study those changes was the Micro Method III of the AACC Cookie Spread test developed by Finney et al (1950a). In the procedure, cookie dough is sheeted on an aluminum baking sheet. Two cookies, 2 13/32 inches in diameter, were cut from the dough and the cookies were baked in a reel type oven for ten

Figure 4. 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 cm^2 to 8.6 cm^2.


Area of Stickiness (Tension) Curve, cm^2
30
40
50
60
70
80
0
10
20
30
40
50
% Sugar Solids Replaced by HFCS Solids

min at 204^{o}C.

Replacing sucrose with high fructose corn syrup changes the appearance of the baked cookie (Fig. 5). Cookie color became darker as the level of high fructose corn syrup was increased. This change in color is due to the presence of reducing sugars in the corn syrup. Reducing sugars are known to brown more readily than nonreducing sugars.

Cookie Spread

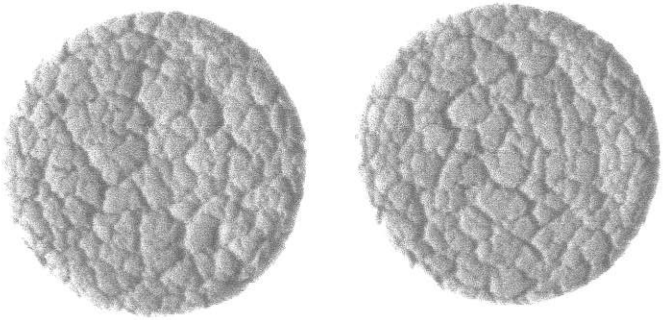
The use of high fructose corn syrup in a sugar snap cookie formulation affects cookie spread. Cookie diameter and thickness were measured on cookies containing high fructose corn syrup from 0% to 50% replacement of granular sucrose solids. Only slight differences were found (Table I). There was a gradual decrease in cookie diameter as the level of high fructose corn syrup solids increased. Cookie thickness, on the other hand, increased as the level of high fructose corn syrup solids increased.

Uniformity of shape is also affected by the presence of high fructose corn syrup. As explained earlier, the use of fluid sweetener results in the formation of a very soft and sticky dough with impaired dough handling characteristics. Consequently, as the level of high fructose corn syrup increases, dough handling becomes increasingly more difficult and uniformity of shape decreases.

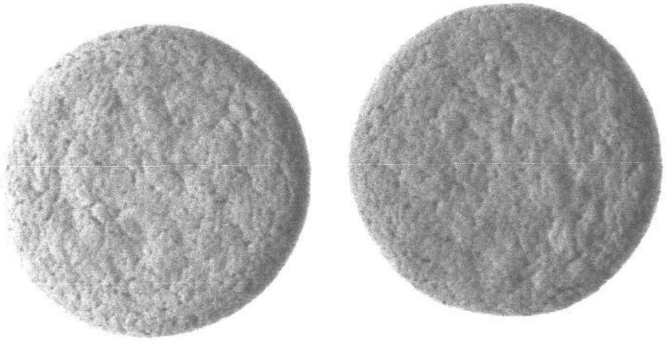
Spreading Rate and Set Time

When small amounts of sucrose are replaced with HFCS solids, the typical surface cracking characteristics of a sugar snap cookie is lost. To determine why that change occurs, the influence of various kinds of fluid sweeteners on the spreading rate and set time of cookies was examined. Three fluid sweeteners were chosen for this study and all of them were used at the 50% replacement level; they included sucrose dissolved in water, high fructose

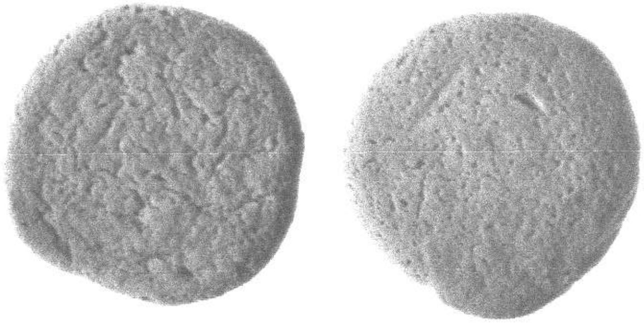
Figure 5. Photograph of baked sugar snap cookies containing 0%, 10%, and 50% replacement of granular sucrose solids by high fructose corn syrup solids.



0% HFCS
CONTROL



10% HFCS



50% HFCS

Table 1. Effect of HFCS Levels on Cookie Diameter and Thickness.

Sucrose replaced by HFCS %	Cookie Diameter cm	Cookie Thickness[a] mm
0 (Control)	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] Thickness measurements are of 2 cookies.

corn syrup (HFCS), and high maltose corn syrup (HMCS).

Data was obtained using time lapse photography (Yamazaki 1956). In the procedure, a reel-type oven with an internal light source was used. A camera was positioned on a rod fixed very close to the oven door. Before baking, the cookie sheet was centered on a stationary oven shelf. The baking process was observed and photographed through a glass window in the oven door. The cookies were baked at 204°C for 10 min and pictures were taken at one min intervals. During the baking period, cookie diameter was measured by the metal ruler fixed at the center of the baking sheet.

The cookie diameter was plotted against baking time. The performance of the 100% granular sucrose (control) cookie is shown in Fig. 6. From the curve, the set time of the cookie was 7.4 min and the spreading rate (slope of the line) was 0.52 cm/min. Similar graphs were constructed for each of the other sweeteners. The data given in Table II was taken from those graphs. The results show differences between sweeteners.

A comparison of the spreading rates show that the fluid sweeteners have faster spreading rates than does the granular sweetener. 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, 1983). When a fluid sweetener is used to replace 50% of the granular sweetener, the amount of sugar which dissolves during mixing may be larger than the amount which dissolves when 100% granular sucrose was used. Consequently, less sugar dissolves during baking. That allows for greater dough mobility during the earlier stages of the baking cycle and a faster spreading rate.

According to Potter (1978), a mixture of sucrose and invert sugar has

Figure 6. Changes in cookie diameter during baking for a granular sucrose cookie.

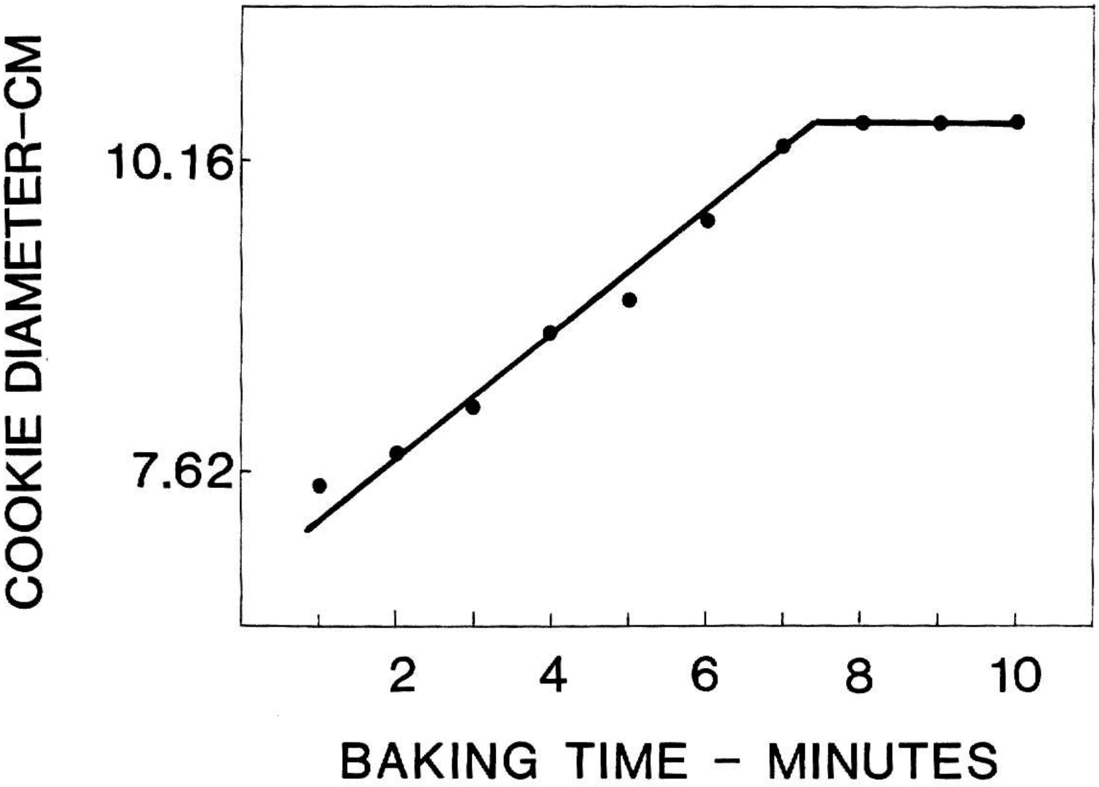

COOKIE DIAMETER-CM
10.16
7.62
2
4
6
8
10
BAKING TIME - MINUTES

Table II. Effect of Different Sweeteners on the Spreading Rate and Set Time of a Cookie.

Sweetener	Spreading Rate (cm/min)	Time Set (min)
G. Sucrose (100%)	.52	7.4
D. Sucrose (50%)	.61	8.2
HFCS (50%)	.546	6.6
HMCS (50%)	.635	7.7

greater solubility in water than sucrose alone. Cookie doughs were examined on the differential scanning calorimeter to determine if the amount of sugar dissolving during baking differs between doughs with and without corn syrup. Three different doughs were examined; they included 0%, 25%, and 50% replacement of sucrose solids with HFCS solids.

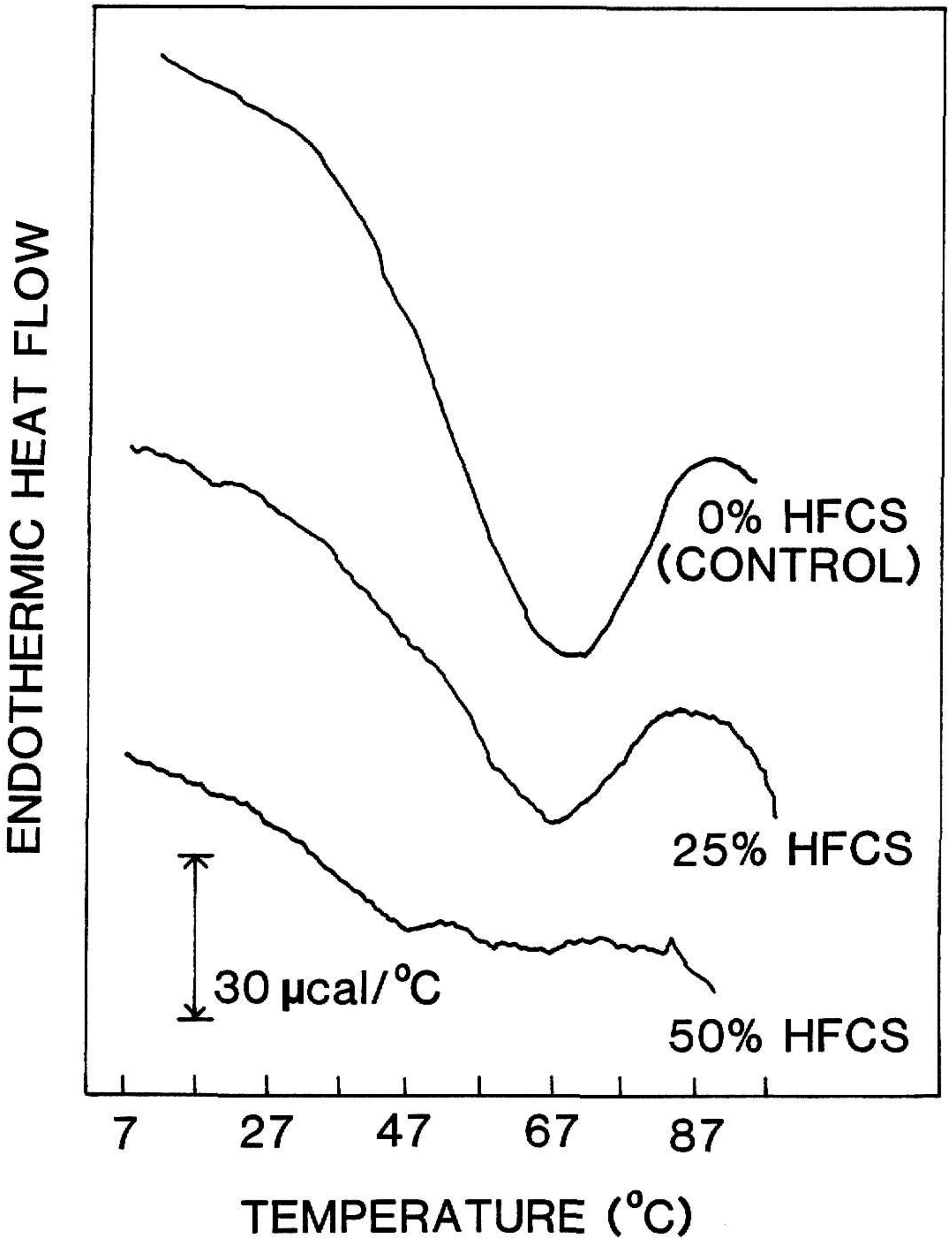
The thermograms obtained showed relative differences in the amount of sugar dissolving (Fig. 7). As the HFCS substitution level increased, the amount of sugar that dissolves during baking decreased (the sugar had dissolved during mixing). This allows for greater dough mobility during the earlier stages of the baking cycle and explains the faster spreading rates observed with the fluid sweeteners.

A review of the set time data shows that the HFCS cookie has the earliest set time and the dissolved sucrose cookie the latest. In this data, the fluid sweeteners do not collectively differ from the granular sweetener. It is, however, apparent that the set times of the sweeteners differ more from each other than do their spreading rates. An explanation for those differences has not yet been determined.

Water Loss during Baking

The differences found between sweeteners in the spreading rate-set time study were not substantial enough to explain the large differences in surface cracking characteristics observed. A careful study of the time lapse photographs taken during the baking cycle revealed a difference in the apparent dryness of the dough surface for cookies made from granular sucrose versus fluid sweeteners. Thus, the amount of water lost during baking was measured for cookies containing 100% granular sucrose and three different fluid sweeteners, all used at the 50% replacement level; they included sucrose dissolved in water, high maltose corn syrup, and high fructose corn

Figure 7. Effect of HFCS level (% sucrose solids replaced by HFCS solids) on the amount of sugar dissolving in cookie dough during baking.


ENDOTHERMIC HEAT FLOW
0% HFCS
(CONTROL)
25% HFCS
50% HFCS
30 µcal/°C
7
27
47
67
87
TEMPERATURE (°C)

syrup.

In the procedure, cookies of known weight were baked for different amounts of time ranging from 1 to 10 min. As the cookie sheet was removed from the oven, a petri dish was used to cover the cookie to prevent further moisture loss. The weights of the petri dish, cookie sheet, and baked and unbaked cookie were known. Water loss was calculated using the change in total weight between the unbaked and baked cookies.

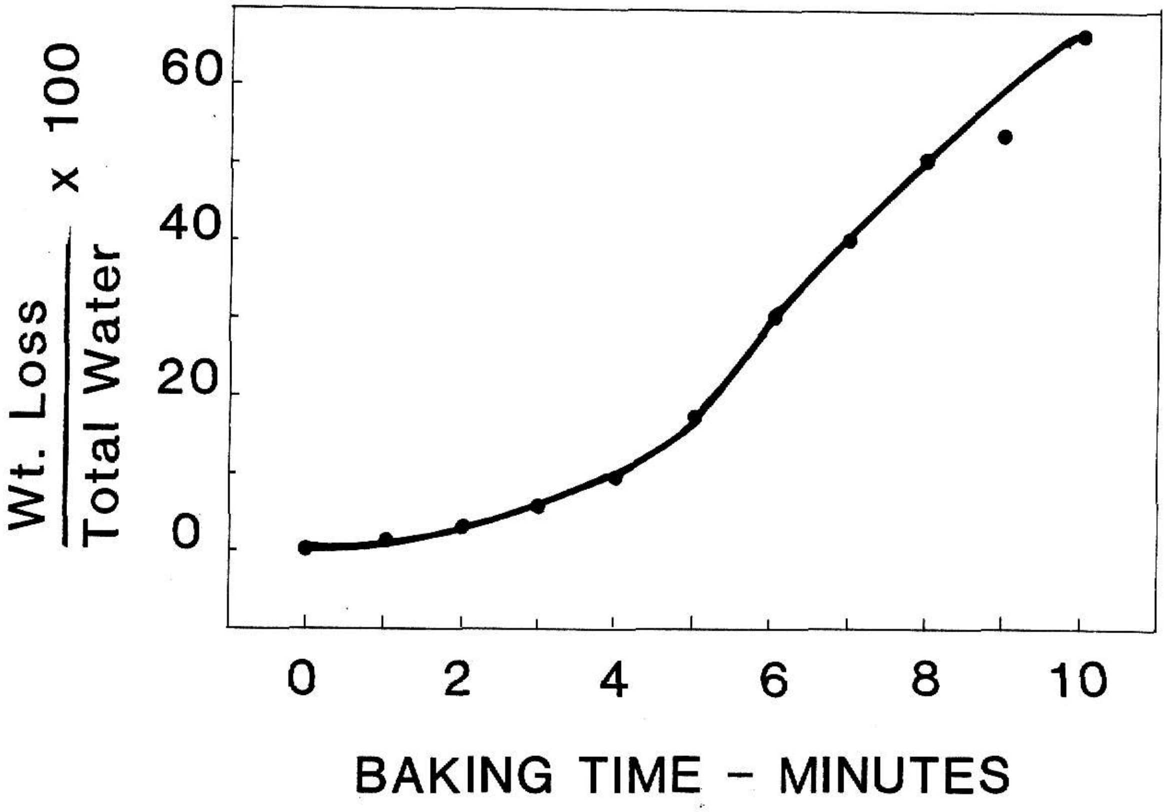
The amount of water lost was plotted against baking time. About 70% of the water present in the cookie dough was lost during baking (Fig. 8). Similar curves were constructed for the three fluid sweeteners and no significant differences were found between any of the sweeteners in the rate of water loss during baking. Thus, the rate of water loss during baking does not explain the changes in surface cracking characteristics observed when a fluid sweetener is present in the cookie system. At the end of the baking cycle the cookie containing the various sweeteners had lost the same amount of water (Table III).

Surface Cracking

A review of the time lapse photographs taken during cookie baking shows that with the granular sucrose cookie, the outer surface of the cookie dries rapidly and cracks when the cookie starts to spread. The outer surface of the HFCS cookie does not dry but remains moist during the early stages of baking. Surface cracking appears to be a function of the rate of surface drying. The rate of surface drying is apparently controlled by the internal water diffusion to the cookie surface rather than the rate of vaporization at the cookie surface because, as shown above, the rate of water loss from the cookie is constant.

To explain this hypothesis on the internal rate of water diffusion in

Figure 8. Water loss from a granular sucrose cookie during baking.



Wt. Loss / Total Water x 100
60
40
20
0
0
2
4
6
8
10
BAKING TIME - MINUTES

Table III. Effect of Different Sweeteners on Water Loss from a Cookie During Baking.

Sweetener	Total Water Loss, %
Granular Sucrose, 100%	66.5
Dissolved Sucrose, 50%	67.0
HFCS, 50%	67.5
HMCS, 50%	68.0[a]

[a] Measurement taken after 9 min of baking.

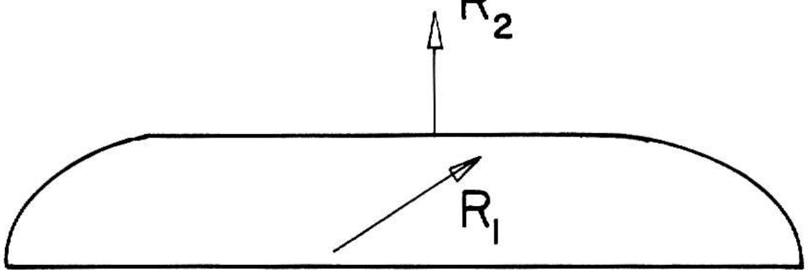
[b] Average standard deviation for moisture loss: 0.215 gm.

cookies, refer to Figure 9. In the diagram, R_1 represents internal rate of water diffusion and R_2 represents moisture loss during baking. R_2 is governed by the temperature and moisture in the oven and it is the same for cookies made with either fluid or granular sweeteners. However, R_1 is not the same for both cookies; R_1 for a fluid sweetener (ie. high fructose corn syrup) is greater than R_1 for a granular sweetener. This would explain the difference in surface dryness between the fluid and granular sweeteners.

The idea presented here suggests that R_1 is governed by the presence of a continuous liquid phase in the dough. When sucrose crystal are present with a sucrose syrup a discontinuous liquid phase results. As mentioned earlier, only part of the sugar in a sugar snap cookie dissolves during mixing and the remainder dissolves during the early stages of baking (Abboud, 1983). In cookies made with corn syrup a continuous liquid phase exists even though sucrose crystals are present. Apparently sucrose crystals together with a sucrose syrup gives a discontinuous liquid phase in cookie doughs while sucrose crystals together with corn syrups give a continuous liquid phase under the same conditions.

The presence or absence of the discontinuous liquid phase controls the diffusion rates in dough. To explain this phenomenon, picture a cookie dough as containing discontinuous crystals. During mixing, the flour and sugar compete for water and most of the water surrounds the discontinuous sugar crystals. The diffusion of water through the discontinuous dough would be relatively slow compared to diffusion through a continuous system. Thus, the internal diffusion rate would determine whether we have a dry or moist surface during the early stages of baking. At present, the basis for this hypothesis is theoretical.

Figure 9. Water diffusion in a cookie during baking.


R2
R1

Cookie Snap

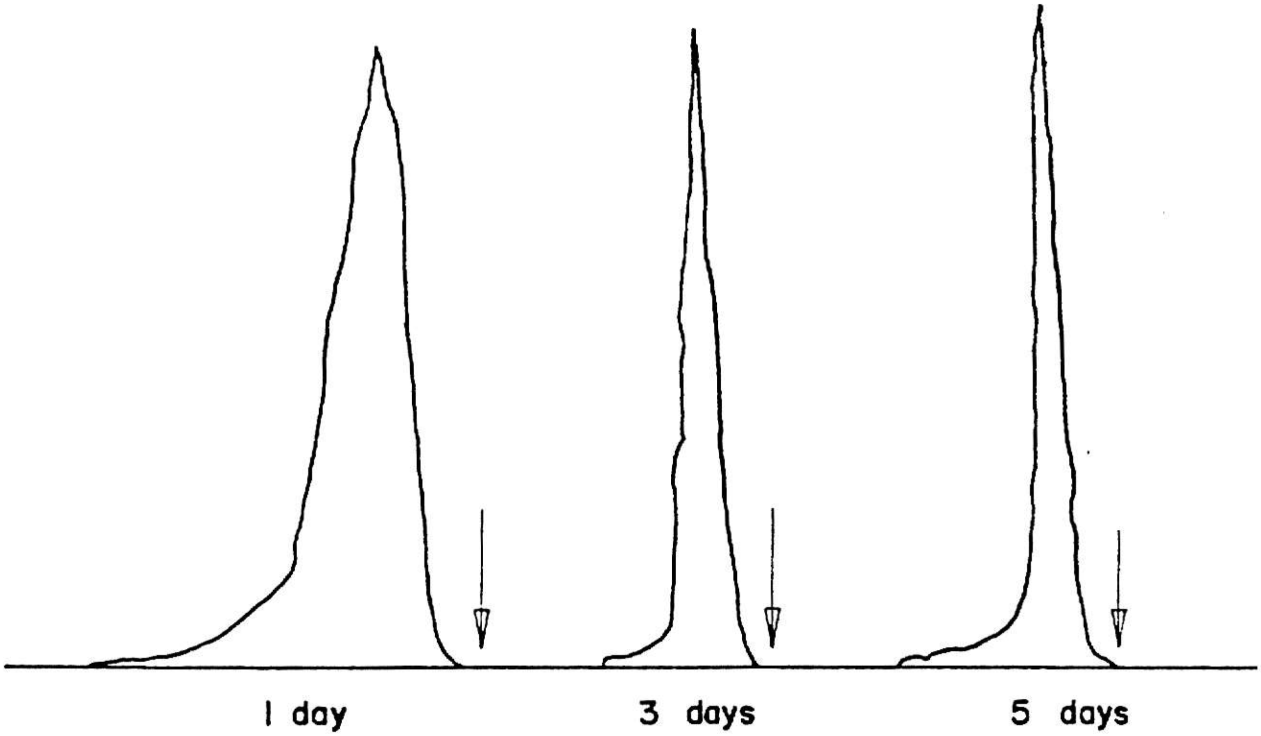
Substitution of sucrose by high fructose corn syrup (HFCS) in a sugar snap cookie formulation changes the physical characteristics of the baked cookie. One of the most obvious changes involves the snapping characteristic of the sugar snap cookie. When small amounts of corn syrup are used to replace sucrose in the sugar snap cookie formula, the character of the snap changes.

A method was developed to measure cookie snapping characteristics with the Instron Universal Testing Machine in the compression mode. The method gives reproducible results. Cookie snap has been measured on samples containing 0% through 50% replacement of sucrose solids by high fructose corn syrup solids; each sample was measured at one, three, and five days postbake. The data indicates that the snap develops with time.

The effect of time on snap development in the granular sucrose (control) cookie is represented by a change in the area of the Instron curve over time (Fig. 10). As shown in this figure, the curve for a cookie one day postbake is wider than the curves for three and five days postbake. This difference in width represents a change in the ability of the cookie to bend with the application of force. At one day postbake, the cookie will bend before breaking whereas at three and five days postbake, the cookie does not bend; it breaks with application of sufficient compressive force. This change in the cookie's ability to bend coincides with snap development. Thus, at a point somewhere between one and three days postbake, the snap sharpens. No further change in the snapping characteristic of this cookie occurs as represented by the similarity in the area of the curves for three and five days postbake.

It should be noted that although a change in the area of the Instron

Figure 10. Instron curves for compression of sugar snap cookies showing effect of time on curve area.


I day
3 days
5 days

curves occurs between one and three days postbake, the height of the two curves does not change. When measuring cookies on the Instron, curve heights are interpreted as measurement of hardness. Because there are no differences in the heights of these three curves, the snapping characteristic of a cookie should not be considered as a function of cookie hardness.

Snap development in the granular sucrose cookie was studied using a different cookie flour. Instron curves produced from these cookies indicated that snap development occurred within one day postbake. The area under the curve did not change for cookies measured at one, two, and three days postbake. This indicates that flour also influences snap development.

A change in snapping characteristics over time also occurs in cookies containing high fructose corn syrup; however, the development of the snap does not appear to coincide with a decrease in the area of the Instron curves over time (Table IV). When measured on the Instron, the HFCS cookies produce compression curves with larger areas than those for granular sucrose cookies. As the level of HFCS solids was increased, the area of the compression curves also increased. Instron curves for cookies with 0%, 10%, 30%, and 50% replacement of sucrose solids by HFCS solids are shown in Figure 11.

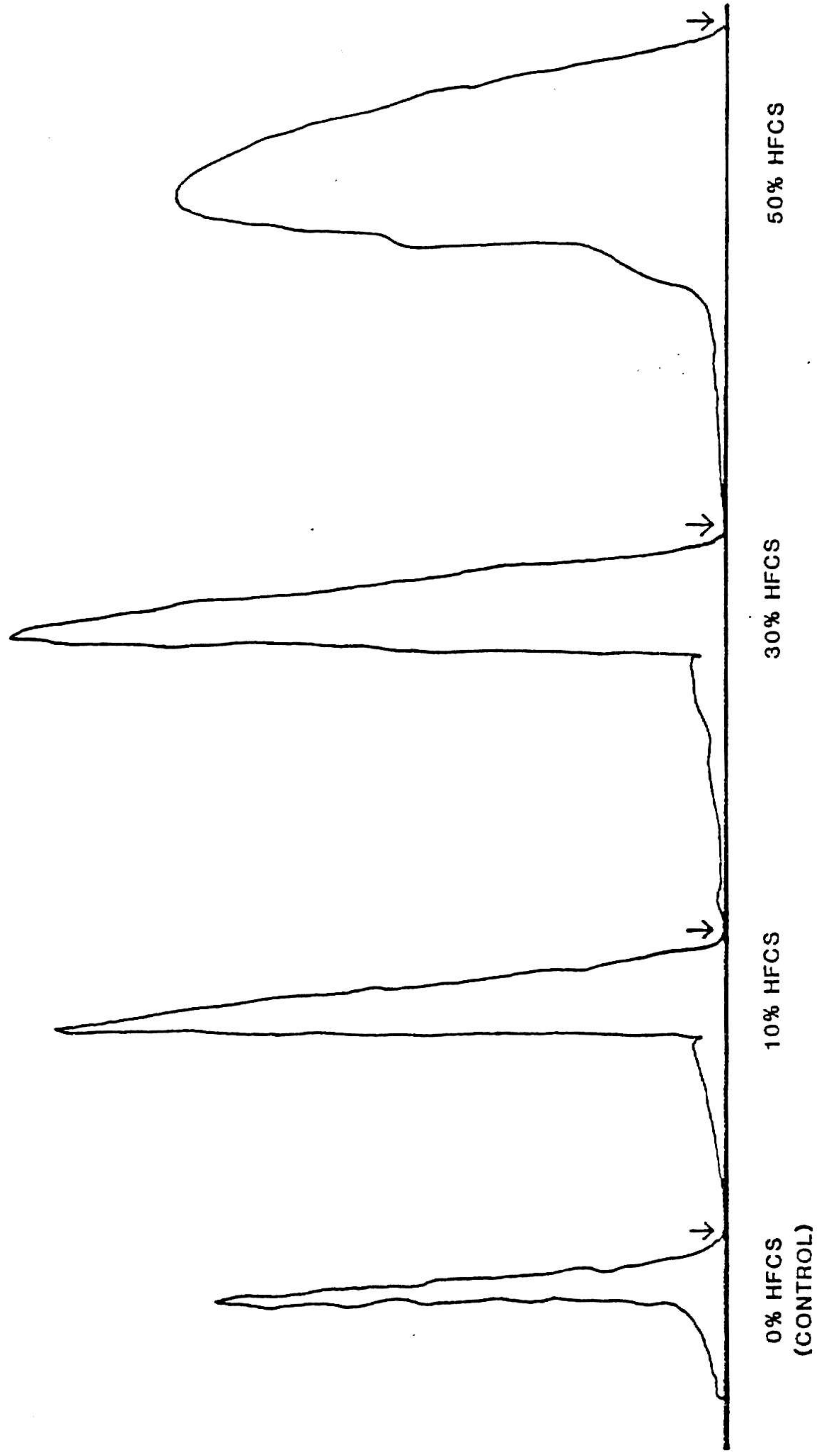
The increase in the area of curves coincides with an increase in the width of the curves; the height of the curve changed but relatively little in relation to the change in width. This suggests that cookie hardness is not lost at these lower substitution levels of HFCS solids. The cookie's ability to bend does, however, increase with an increase in high fructose corn syrup solids.

The increase in the width of the curves, resulting from the addition of high fructose corn syrup, may interfere with the sensitivity of the curve to measure snap development. At higher levels of HFCS substitution, the area

Table IV. Effect of HFCS Levels and Time on the Area of the Instron Compression Curve

Sucrose Replaced by HFCS %	Area Compression Curve, cm^2					
	1 day postbake		3 days postbake		5 days postbake	
	Mean	S.D.	Mean	S.D.	Mean	S.D.
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

Figure 11. Instron curves for compression of sugar snap cookies containing 0%, 10%, 30%, and 50% HFCS.


0% HFCS
(CONTROL)
10% HFCS
30% HFCS
50% HFCS

of the compression curves increased with time. This change may relate to the movement of free water within the cookie.

A plot of percent high fructose corn syrup solids against area of the compression curve shows a positive linear relationship at both one day (Fig. 12) and five days (Fig. 13) postbake. The increase in the area of the compression curve is a function of the amount of high fructose corn syrup present in the cookie system. Based on the work of Youngquist and Brabbs (1982), a hypothesis to explain the change in snapping characteristics has been developed. Upon removal from the oven, the sugar in a cookie is in a super-satuarated solution. Upon cooling and with time, the sucrose will begin to crystallize. The change from dissolved sugar (syrup) to crystalline sugar occurs over time and coincides with the "snap" development. As a result of crystallization, the sugar gives up water which is rapidly absorbed by the other dry cookie components (starch).

In an effort to support the above we measured water activity of baked cookies over time. Cookies were baked, cooled, and measurement of the a_w of the cookie was continuously taken over 3 days. The results showed an increase in a_w from 0.305 at 1.5 hrs postbake, to 0.335 at 64 hrs postbake. This increase in a_w coincides with snap development. The a_w data appears to support the hypothesis of Youngquist and Brabbs (1982).

When HFCS is used we increase the concentration of fructose and glucose, both of which inhibit sucrose crystallization. As a consequence of less sugar crystallization the cookie has different snapping characteristics. The presence of syrup within the cookie makes it softer and allows it to bend under compression.

Figure 12. Effect of HFCS on the area of the Instron compression curves for cookies one day postbake.

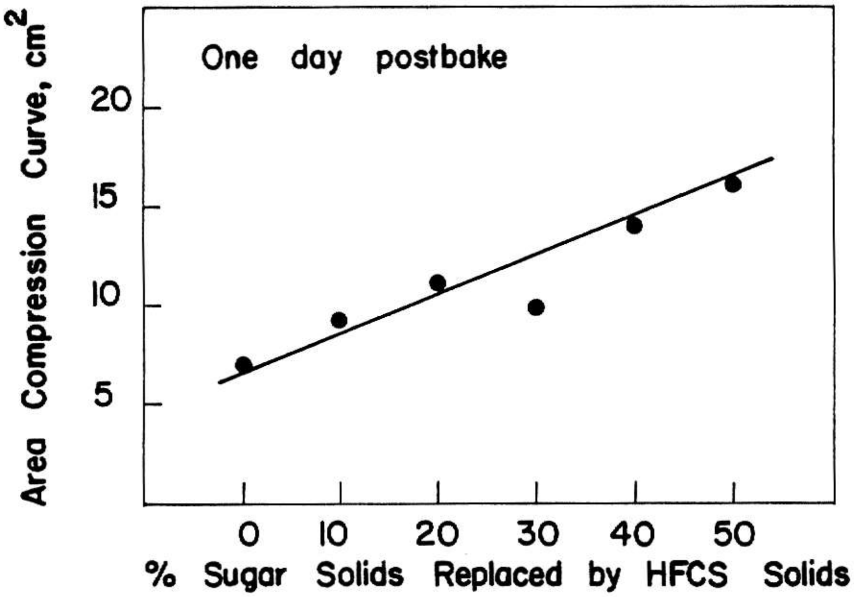
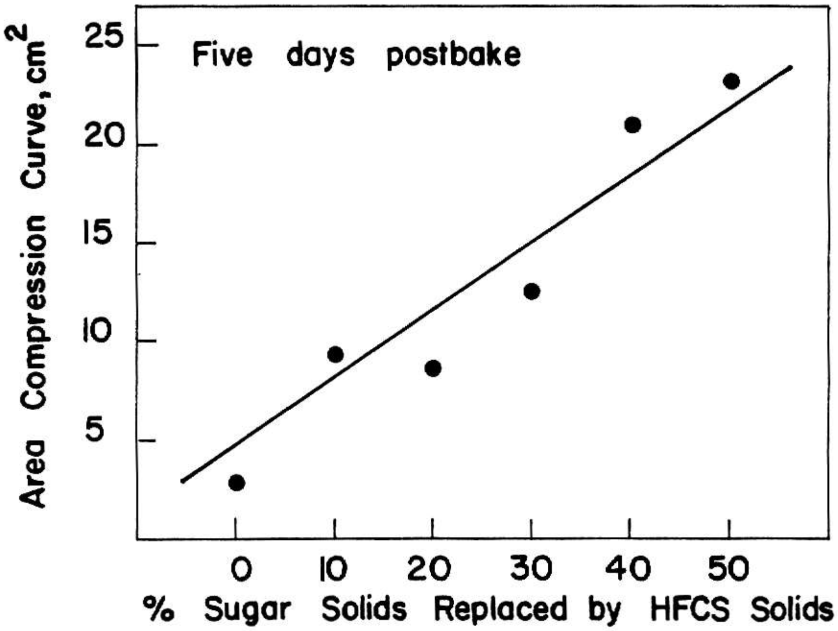

One day postbake
Area Compression Curve, cm^2
20
15
10
5
0
10
20
30
40
50
% Sugar Solids Replaced by HFCS Solids

Figure 13. Effect of HFCS on the area of the Instron compression curves for cookies five days postbake.


Five days postbake
Area Compression Curve, cm^2
25
20
15
10
5
0
10
20
30
40
50
% Sugar Solids Replaced by HFCS Solids

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THE EFFECT OF CORN SWEETENERS ON COOKIE QUALITY

by

LYNN PATRICIA CURLEY

B. S., Rugters University, 1981

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the
requirements for the degree

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KANSAS STATE UNIVERSITY
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1983

ABSTRACT

The replacement of granular sucrose with high fructose corn syrup 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 high fructose corn syrup; the significance of this change is dependent on the amount of corn syrup substitution. If small amounts of sucrose are replaced with corn syrup, the typical cracked surface of the baked cookie is lost and a porous surface results. Measurement of the rate of water loss during baking showed no differences between cookies baked with 100% sucrose and 50% sucrose plus 50% high fructose corn syrup. A complementary hypothesis suggests that the rate of internal water diffusion causes the change 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 increased with increasing levels of corn syrup. This delay in snap development appears to coincide with sugar recrystallization.