AN INVESTIGATION OF INFLUENCE OF SUGAR AGENTS ON BAKING QUALITY

by

HAROLD NATHAN BARHAM, JR.

B. S., Kansas State College
of Agriculture and Applied Science, 1949

---

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Milling Industry

KANSAS STATE COLLEGE
OF AGRICULTURE AND APPLIED SCIENCE

1950

TABLE OF CONTENTS

INTRODUCTION

During the war, many bakers used glucose as a supplementary source of sugar in place of (or in addition to) sucrose. Both sucrose and glucose sugars were very difficult to acquire and many times the commercial bakers were forced to reduce their sugar supplement far below the meager war-time standards (four per cent). There were, occasionally, a few complaints from various bakers on defects of glucose in relation to the quality of the product.

Few investigators have compared directly sucrose and glucose for baking purposes although both are used in commercial bread production. Most of the work with these sugars has been concerned with alcoholic fermentation rather than with the effects of the two sugars on bread quality. Weiss (49) and Rice (41) reported that since glucose is more readily and completely fermented into alcohol and carbon dioxide, insufficient residual sugar remained at the end of fermentation to produce the rich brown crust color, the pleasant flavor of the loaf, and the moisture retaining quality which prevents it from rapid staling. Sucrose, being inverted, provided readily fermentable glucose and sufficient levulose remained to enhance the moisture retention of the crumb. Weiss (48) also stated that glucose showed undesirable characteristics in the fermentation and baking processes.

Sandstedt and Blish (43) reported that aside from crust color, the effect on loaf properties produced by added sucrose over a range of two and one-half to five per cent was surprisingly unimportant in the absence of shortening, but in the presence of shortening changes were noted.

Whitcomb (50), and Blish, Sandstedt and Platenius (12) stated that the abundance of sugar in the dough at the time of baking is indicated by shade of brown color on the crust. Whitcomb stated that this was not reflected in the high oven spring. Blish et al (12), Dadswell and Gardner (18), and Blish, Sandstedt and Astleford (11) further showed that the crust color was affected not only by the added sugars but also by the relative diastatic activity of the flour. Since sucrose possesses more natural sweetness than glucose it is conceivable that residual sucrose might affect the sweetness of the final bread to a greater extent than residual glucose.

Two very important criteria in determining flour and bread quality are gas production and gas retention in the dough stage. Gas production depends not only upon the carbohydrate and enzymic content (23) but also upon the formula employed (47). Gas production is related to loaf volume (37). Gas retention, while related to gas production (45, 47) is, on the other hand, an inherent property of the flour and depends upon the protein content and physical properties of the dough (23). Simpson (44) concluded that gas retention and gas production were profoundly influenced by yeast growth since lower yeast concentration favored greater gas production efficiency.

The smaller the quantity of yeast in a dough the greater the percentage multiplication of cells in the dough (31). No growth occurs, however, beyond the two per cent yeast concentration (26).

Gas production studies carried out with no-sugar doughs by Blish, Sandstedt and Astleford (11) suggested that these factors may be correlated with the naturally occurring sucrose content, but probably not to reducing sugars because of their low and constant concentration in sound flours. It was found that reducing sugar content was only about 0.1 to 0.2 per cent in all flours, while naturally occurring sucrose was present in quantities from 1.0 to 1.74 per cent depending upon the wheat variety.

Lanning (36), using the straight dough procedure, reported that five per cent maltose, five per cent sucrose and no-sugar doughs gave the same gas production values (using standard yeast supplementation) until the four hour period. At the end of that time the no-sugar doughs produced little additional gas while doughs containing maltose and sucrose continued to produce gas at an equivalent rate for an additional three hour period. Blish and Hughes (10), employing the straight dough formula, showed that the period of active fermentation for no-sugar doughs lasted for two hours, whereas doughs containing two and one-half and ten per cent sugar continued to produce gas for four and 10 hours respectively.

Gassing determinations are widely used by many flour mills.

Due to the importance of these measurements many different methods have been devised. According to the available literature, gas measuring devices for doughs were constructed over 50 years ago and most equipment used today is of similar design.

For gas production measurements, Blish, Sandstedt and Astleford (10) used an Erlenmeyer flask fitted with a manometer. Two years later, the device, as well as the technique, was improved by these workers (Sandstedt and Blish, 42). This is now an A.A.C.C. method for gassing power determinations (3). The principles of the mechanism allowed for constant volume with varying pressure. In 1942, Glabe (28) described the Fermentometer, a device very similar to the pressuremeter of Sandstedt and Blish. The apparatus was designed to measure gas production and gas retention.

Bailey (7) developed a method of measuring gas production by use of apparatus involving a constant pressure and changing volume. Eisenberg (19) compared Bailey's method with that of Sandstedt and Blish, with special emphasis on yeast standardization. Eisenberg (20) concluded that the method of Bailey's involved more error, due to the effects of barometric pressure and temperature, than did the manometric method. However, Eisenberg (20) maintained that the manometric method incurred error in production; i.e., the greater the pressure the less the gas produced due to the mechanics of the equilibrium.

Eva, Geddes and Frisell (24) studied several gassing power procedures. The main methods tested were the improved manometric, volumetric, and the Brabender Fermentograph. The order of experimental error was manometric > volumetric > Fermentograph. The Blish, Sandstedt and Astleford (11) method, as improved by Blish and Sandstedt, and the Fermentograph seemed to be the most widely used methods. Other methods tested were the Bailey and Johnson, Markley and Bailey (38), Heald (29), Schultz and Kirby (24), Landis and Frey (35) and Elion (21, 22). These methods are very similar to the three main procedures mentioned by Eva et al.

Working and Swanson (46, 52) described an automatic gasometer which compared favorably with the A.A.C.C. method of gas production and gas retention measurement. The gas retained within the dough could be measured by pressure of dough expansion and by absorption in alkali of the gas escaping from the dough.

The relative merits of proofing to a constant height or to constant time have frequently been discussed. Each method has both advantages and disadvantages. Aitken, Fisher and Geddes (1) showed that the two proofing methods are statistically different and concluded that proofing to a constant height tended to minimize the differences in gluten quality and fermentation development. These factors are the very ones which should be reflected in the final loaf. In spite of these facts, many experimental bakers proof to a constant height.

Within the last few years many experimental bakers have shifted from the straight dough to the sponge procedure in order to assimilate more closely the conditions found in the commercial plant. Since practically all the available literature contains information obtained by the straight dough method it is desirable for comparison purposes to have comparative information using both procedures.

Bread staling is still one of the bakers' most difficult problems involving large financial losses annually. For many years investigators concerned with this field have reported on the addition of different agents, baking methods, flours, and various other ingredients which aid in controlling the rate of staling.

Cathcart (15), in a broad literature review, summarized the effects of various factors and agents on the rate of practical staling and the rate of change of the starch.

Kuhlman and Golossowa (34) have shown that the use of maltose with either the sponge or straight dough procedure resulted in increased water-holding capacity, thereby slightly decreasing the rate of staling. Glucose, dextrinized starch, sucrose, and invert sugar, the latter both in commercial crystalline form and in honey, showed only small effects in retaining freshness in bread as determined by a compressibility test (Bailey, 6). Bailey (6) also reported that malt extract showed a slight tendency in retarding staling rate. Numerous dairy products, also containing sugar(s) were tested and found to possess few anti-staling properties. Hutchinson, according to Whymper (51), reported that glucose showed slight retarding of bread staling. Platt and Powers (40) stated that high sugar concentration (six per cent) increased softness of bread crumb to a very small extent. Kuhlman and Balasheva (33) considered the anti-staling value of carbohydrates in the following order: maltose syrup, glucose syrup, dextrin, sucrose, maltose, dextrose and soluble starch. Because of the tenacious water-holding capacity of fructose it might be expected that it would retard staling. There is no evidence in the literature, however, to bear this out.

Cathcart (15) presented an excellent review of various methods for determining the rate of staling. Cathcart and Luber (14) revised the "swelling power" method originated by Lehman and Katz. This method involved the principle that starch decreased in swelling power as staling took place. A more complex method involved measuring the amount of soluble starch; this decreased as bread staled.

By means of a photoelectric cell, Glabau and Goldman (27) showed that opaqueness of starch gel prepared from bread increased as the bread aged. In later stages, the loss of water could also be measured by common laboratory methods. Still another method for determining rate of staling was by crumbliness of the crumb, which increased as the bread became stale. This method, however, was carried out by use of the hands and was therefore regarded as inferior because of the inherent experimental error.

More recently, the method frequently employed for following bread staling has been crumb compressibility (Bailey, 5). Platt and Powers (40) described an improved method involving a balance with a plunger attached to the bottom of one of the pans. This method was reported to be capable of considerable precision.

Katz (1928) contended that the compressibility method was not capable of good reproducibility. However, since that time the method has been altered several times and is considered to be quite reliable. Freilich (25) reported very small error when using the Platt and Powers apparatus (39, 40) which is also an A.A.C.C. method (3).

A recent modification of the Platt and Powers compressibility apparatus is the Bloom gelometer. This instrument is capable of rapid and accurate measurements.

Perhaps the most important variable property of a food stuff is the flavor and taste appeal to the consumer, yet this is the property which is by far the most difficult to measure. Chemical and physical tests, while affording valuable information, are mainly quantitative precision methods and involve a certain degree of accuracy. Taste, however, cannot be measured quantitatively and is subjective, rather than objective. Because of the numerous difficulties encountered in taste testing little has been accomplished within the food industry to solve the problem of procedure. Often times these tests are of little value or are misleading.

Numerous articles and papers have appeared in the literature on the subject of organoleptic tests but they are rather minor in scope. Nevertheless, some papers have been carefully written and contain much valuable information. Such are the reviews of Bengtsson and Helm (9), Crocker and Platt (16), and Helm and Berger (30) and the methods of statistical analysis shown by Kendall (32) and Bliss et al. (13).

Because of the very complexity of these tests it is necessary that the procedure be carefully controlled since it is subject to gross human errors. Bengtsson and Helm (9) outlined several rules of taste testing and explained them carefully with full reasoning behind each. Samples must be stored and selected carefully in order that they be precisely what they are intended to represent. Generally speaking, the number of different samples should not exceed six in any given test. The subject to be analyzed should largely determine the number of samples tested. The gustatory and olfactory nerves become exhausted rapidly and cease to react under prolonged stimuli. Sometimes rests of an hour or so are needed between samples.

A large number of testers can be trained only by preliminary tests which usually require considerable time. The most suitable method of consumption depends mainly upon the subject at hand. An atmosphere of quiet and concentration is necessary to eliminate possible errors which may be caused by distraction. The times of day when the taster is best able to detect any existing differences has been disputed. Some investigators claim that the morning hours are the best while others say that the afternoon hours are better. However, the best time of day is the time the tasters themselves feel best and this time varies with the individual. The fewer the variables the more accurate the data from the experiment.

The samples should look alike as much as possible in order to counteract further any bias. Written answers are desired before the judges know what the variables are. Each worker should do his work independently. Announcement of the object of the test is desirable, in order to give the judges a better chance to differentiate the variables which are present. This is especially true if the variables are presumed to be difficult to detect.

In a test to determine what substances were the most effective to rid the mouth of a certain taste, Baten (8) served salty tomato juice to a 23-member tasting panel. Between tastes of this juice, the workers tasted water, crackers and water, carrots and water, apples and water, and bread and water. In this case crackers and water were the most effective agents in removing these tastes. However, with some foods, some other agents might have served the purpose to a greater advantage.

A taste tester should be in good health since very slight infections may seriously impair the reactions of the gustatory and olfactory nerves. Further, individuals vary greatly in sensitivity of their taste organs. Smoking seems to reduce the efficiency of these nerves. If the tester does not smoke within an hour or two before testing the best results are attained.

Since few data are available which compare directly the properties of glucose and sucrose in baking, it became the object of this investigation to study the effects of these two sugars on dough and bread characteristics using the rye, hearth, sweet, sponge and straight dough procedures. Study was made of the relationship of sugar type and concentration to toasting quality, crumb compressibility, and consumer preference, as well as the relationships of sugar type and concentration to gas production and gas retention.

MATERIALS AND METHODS

Seven flours were selected for study, 3 of which were milled from hard red winter wheat and 2 from hard red spring wheat. The other 2 were milled from composites of approximately 150 varieties of the 1946 and 1947 hard red winter wheat crops. The characteristics of the flours are shown in Table 1. Moisture, ash and protein were determined in the customary manner. The Brabender Farinograph and Amylograph (4) were used to determine the physical dough properties and malted characteristics of the flours. These flours were also analyzed for maltose value, reducing sugar content and non-reducing sugar content by the A.A.C.C. methods (3). Maltose values as affected by the addition of 1 per cent malted wheat flour were also determined.

Four sugars including glucose, sucrose, fructose and invert

Table 1. Summary of flour characteristics.

Flour No. and type	Per cent Protein[1]	Per cent Ash[1]	Mixing time	Per cent Absorption	Amylograph viscosity[2]	Maltose[1,2]	Maltose[1,2,3]	Reducing sugar[1]	Non reducing sugar[1]	Total sugars[1]
			min.		B.U.	mg/10 g	mg/10 g	mg/10 g	mg/10 g	mg/10 g
Spring wheat flours										
I Patent	12.20	0.41	6.0	66.7	170	329	546	9.0	19.0	28.0
II High protein	13.25	.47	7.0	68.3	205	317	595	6.1	19.5	25.6
Winter wheat flours										
III High protein	12.90	.44	7.5	69.0	180	297	441	11.0	17.8	29.2
IV Patent	11.68	.45	6.0	68.7	190	327	421	5.5	19.0	24.5
V 1947 Composite	11.34	.46	4.0	67.5	880	220	387	9.5	27.0	36.5
VI 1946 Composite	11.50	.47	5.0	67.4	600	-	-	-	-	-
VII All-purpose	11.05	.43	6.0	66.3	180	317	530	10.5	23.0	33.5

[1]14% moisture basis.

[2]Determined on flour as received from mill.

[3]Determined on flour with addition of 1 per cent malted wheat flour.

sugar were used. The invert sugar consisted of equal portions of glucose and fructose.

Sponge Dough Procedure

The following sponge dough procedure was used:

Ingredient	Sponge stage[1] per cent	Dough stage[1] per cent
Flour	70.0	30.0
Water	30.0	30.0
Yeast food (Arkady)	0.5	--
Yeast	2.0	--
Malted wheat flour	0.5	--
Sugar	--	Sucrose and glucose 0 to 10
Dried milk solids	--	2.0
Salt	--	2.0
Shortening	--	3.0

Sponges were mixed for 2 minutes at second speed on a Hobart A-200 mixer. After being mixed at 80°F., the doughs were fermented for four hours at 84° to 86°F. and 90 to 92 per cent relative humidity and then were remixed with the balance of the dough ingredients to optimum consistency. The remixed doughs were allowed a 30-minute floor time, scaled to

[1]All figures are per cents based on the total flour weight (14 per cent moisture basis).

20 ounces, rounded, and after a 20-minute proof time, moulded and proofed for 55 minutes at 90° to 92°F. and 90 per cent relative humidity. The loaves were baked for 35 minutes at 425°F. Loaf volumes and weights were determined immediately after removal from the oven.

Straight Dough Procedure

The following straight dough procedure was used:

Ingredient	Amount[1] per cent
Flour	100
Water	60.0 to 67.0
Yeast food (Arkady)	0.5
Yeast	2.0
Malted wheat flour	0.5
Sugar	0 to 10% of sucrose or glucose
Dried milk solids	2.0
Salt	2.0
Shortening	3.0

Fermentation temperatures and humidities for the straight dough procedure were the same as used in the sponge dough procedure. The straight doughs were mixed to optimum consistency, fermented for 110 minutes, punched, fermented an additional

[1]All figures are per cents based on total flour weight (14 per cent moisture basis).

55 minutes, and repunched. After a 15-minute rest period the remainder of the procedure was the same as used in the sponge dough method.

The Sweet Dough Formula and Procedure

The sweet dough formula used corresponds to that used by the average commercial baker. Only one flour was used. The formula and procedure are as follows:

Procedure	Ingredient	Amount[1] (per cent)
Blend together	Sugar	3,5,7,9,11,13
	Salt	8.0
	Malted wheat flour	0.5
	Shortening	8.5
Mix into above blend	Egg (1)	-
Mix with above	Water	40.0
Mix with the blend	Milk	6.0
	Flour	78% of all flour used
	Arkady	0.5
Add, dissolved in 100 ml water	Yeast	3.0 plus 20% water
	Flour	22% of all flour used

The doughs were mixed to optimum consistency, fermented

[1]All weights were based on the total flour weight (14 per cent moisture basis).

for 2 hours, punched and allowed a 20-minute rest period. The doughs were then moulded and proofed for 55 minutes. All products were subjected to the same temperatures and humidities as those described for the sponge and straight dough procedures.

The dinner rolls were moulded by hand and placed in an 8 inch by 8 inch roll pan. The dough for cinnamon rolls was rolled out, sprinkled with a sugar-cinnamon mixture, rolled up again and cut to the desired size. The sugar-cinnamon mixture was made up in a ratio of 10 parts of sugar to 1 of cinnamon, 15 g. of which were sprinkled out on each rolled out dough. The buns were scaled at 25 g. each, and placed 16 to the pan. The cinnamon rolls were scaled at 15 g. and placed 12 to the pan.

Plain Rye and Hearth Bread Procedures

Glucose and sucrose concentrations of 1/2, 1, 1 1/2, 3 and 5 per cent were used for bread baked by the plain rye and hearth sponge dough methods. Flour IV (Table 1) was used for both bread types and a light rye flour was used for the rye bread. These formulae, representing average commercial bakers' formulae, are as follows:

Hearth bread, sponge method.

Ingredient	Sponge stage[1]	Dough stage[1]	
Flour	60	40	
Water	40	20	
Yeast	1.75	--	
Salt	--	1.6	
Sugar	--	Glucose ½ - 5	Sucrose ½ - 5
Malted wheat flour	0.30	--	
Shortening	--	2.0	

Plain rye bread, sponge method.

Ingredient	Sponge stage[1]	Dough stage[1]	
Flour	50	30	
Rye flour	20	--	
Water	42	20	
Yeast	1.75	--	
Arkady	0.5	--	
Malted wheat flour	0.3	--	
Salt	--	2.0	
Shortening	--	2.0	
Sugar	--	Glucose ½ - 5	Sucrose ½ - 5

The sponge time was 180 minutes for the plain rye bread and 200 minutes for the hearth bread. The remainder of the procedure was identical for both types of bread.

[1]All figures are per cents based on total flour weights (14 per cent moisture basis).

The doughs were mixed on a Hobart A-200 mixer for 2 minutes, and allowed to ferment (sponge time) at 84° to 86°F. and 90 to 92 per cent relative humidity. The doughs were remixed to optimum consistency and allowed a 30-minute floor time. The rested doughs were scaled to 17 ounces, proofed 20 minutes, moulded by a Century moulder and finished by hand. After the moulded doughs had been proofed for 45 minutes at 90°F. and 90 per cent relative humidity, they were cut slightly on the tops and washed with an egg-wash to provide a glazed crust. The doughs were then baked for 25 minutes at 425°F. The gas oven used afforded sufficient moisture for this type of bread and closely duplicated commercial practices.

Crumb Compressibility Measurements

Compressibility of bread crumb, defined as weight required to depress a 1-inch plunger 4 mm into a slice of bread 1 inch thick, was determined with a Bloom gelometer after 24 and 72 hours of storage in sealed plastic bags. Two readings were taken on each of 3 slices.

Constant Height Proofing

In experiments employing constant height proofing, all doughs with sugar concentrations of from 1 to 10 per cent were proofed to an arbitrarily set height. Doughs containing no sugar were proofed for 70 minutes.

Toasting Comparisons

Comparisons for toasting quality were made by toasting slices of bread containing zero, 2, 4, 6, 8, and 10 per cent concentrations of various sugars. A cafeteria-size continual band toaster was used which had a capacity of 18 slices per loading.

Gas Production and Gas Retention Measurements

Gas production and gas retention measurements were made by using a modified A.A.C.C. method (1). Eight-gram pieces of the doughs used in baking were placed in Sandstedt-Blish pressuremeters over a 23 per cent NaCl solution for gas production measurements and over a 23 per cent KOH solution for gas retention measurements. Paraffin was used to coat the pressuremeter cups to protect them from the strong alkali. Readings were taken at 20, 40, 60, 120 and 180-minute intervals with the sponge dough procedure and at 20, 40, 60, 120, 180 and 240-minute intervals with the straight dough procedure. The time limits of 180 and 240 minutes, for the sponge and straight dough procedures respectively, were chosen to include the fermentation period from the time the sugars were added until fermentation was inactivated by the heat of the oven.

The per cent of total gas retained within the doughs was calculated by dividing the gas retention by the total gas production multiplied by 100. The gassing determinations were carried out at 30°C.

Organoleptic Testing Procedure

Bread containing sucrose and glucose in 3 and 5 per cent concentrations was selected for the organoleptic study, and tested at the end of the second and fourth days. A total of 6 taste testers was employed. All bread was baked by the sponge procedure with a composite winter wheat flour and stored in plastic bags until used.

Each of the testers was given a preliminary test in an effort to determine taste testing ability. This test consisted of tasting 4 samples of bread containing no sugar, 3 per cent glucose, 6 per cent fructose and 10 per cent sucrose respectively. The samples were tested at the end of the second and fourth days. These samples were first judged by grading each sample according to the following key: 1, undesirable; 2, slightly undesirable; 3, acceptable; 4, desirable; and 5, very desirable. Flavor, texture and crust flavor were graded separately. These grades were taken in order to aid the judges in ranking the samples according to their preference. The form used by the judges is shown on Form I. The procedure used for the preliminary test was also used for the regular

Form I

Form used by judges to rank bread according to preference.

ORGANOLEPTIC FLAVOR AND TEXTURE TEST

Date ________________ Name ________________

Sample #

	A	B	C	D
Flavor: Delicate flavor; no objectionable strong, bitter or off-flavors. Not too sweet; pleasant aroma.				
Texture: Tender, smooth and soft; not gummy or tough				
Crust flavor				

KEY

5 - Very desirable
4 - Desirable
3 - Acceptable
2 - Slightly undesirable
1 - Undesirable

Ranking, judged on overall eating qualities:
(Rank any ties as such)

First ______
Second ______
Third ______
Fourth ______

tests.

All samples, including both the regular and preliminary test samples, were coded in a random fashion, a new code being used for each day. Tap water was used by the testers to remove the taste of the previous sample before tasting the subsequent sample. All samples of bread and bread crusts were cut into small cubes and placed in separate beakers. Each tester worked by himself and recorded his results on a special form (Form I). It was not possible at all times to obtain all selected testers on the same day.

EXPERIMENTAL RESULTS

Baking Comparisons of Glucose, Sucrose, Fructose and Invert Sugar

Five hard red winter wheat flours were used in baking tests for comparing the effects of glucose, sucrose, fructose, and invert sugar. The specific volumes of loaves made by the sponge procedure were plotted against the sugar concentrations. While the different flours caused different specific volumes, the effects of the various sugars were the same. These results are shown graphically in Fig. 1. The optimum specific volumes were observed with loaves containing 3 to 4 per cent of all sugars tested. The differences in the optimum specific volumes

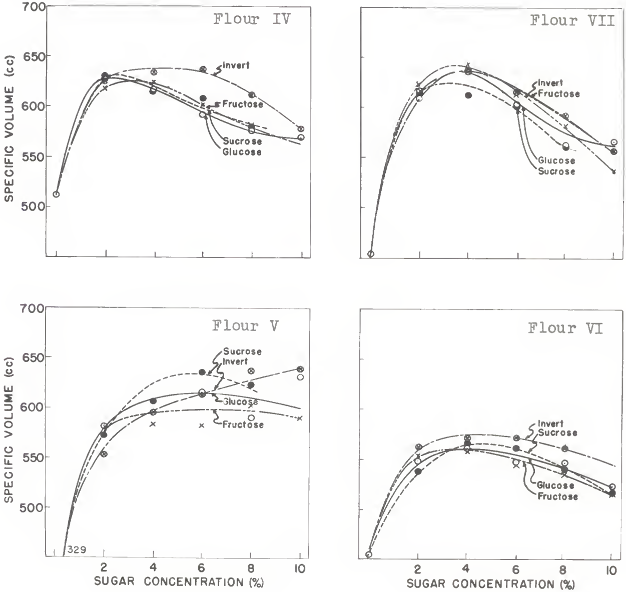

Fig. 1. The effect of sugar concentration on specific volume.

of loaves containing these different sugars were not significant. The order of darkness of crust colors was sucrose > fructose = invert > glucose. With concentrations greater than 3 per cent these differences were insignificant and thus would be irrelevant to the commercial baker.

The optimum grain and texture of the loaves baked with various sugars at different concentrations were found to be optimum for all sugars in a concentration range of 6 to 8 per cent. While the different flours exhibited different grain and texture at a given concentration, the effect of the various sugars on the different flours was essentially the same (Table 2).

Since sucrose and glucose are virtually the only sugars used commercially, further studies with these materials were made employing the sponge dough procedure. Optimum specific loaf volume was obtained with four and 3 per cent of either sugar with hard red winter wheat flour and hard red spring wheat flour respectively (Fig. 2). The hard red spring wheat flour exhibited greater specific volume with no-sugar doughs than did hard red winter wheat flour.

The average weights of loaves baked with these flours were plotted against the sugar concentration (Fig. 3). The minimum weights were observed when 3 to 5 per cent of either sugar was used. These data were inversely related to those of specific volume.

The relationship between specific volume and sugar type

Table 2. Grain and texture scores for sucrose-glucose-fructose invert comparisons.

Flour	Per cent sugar conc.	Glucose		Sucrose		Fructose		Invert	
		Grain	Texture	Grain	Texture	Grain	Texture	Grain	Texture
III	0	75	70	75	70	75	70	75	70
	2	85	80	84	90	85	82	80	80
	4	82	82	82	92	83	88	80	85
	6	82	85	82	90	85	92	85	88
	8	83	85	84	90	83	90	88	90
	10	84	84	83	90	88	90	90	92
IV	0	80	75	80	75	80	75	80	75
	2	78	80	85	80	82	78	85	83
	4	85	85	83	83	82	80	90	90
	6	88	90	85	86	83	83	92	90
	8	88	90	90	87	89	88	86	85
	10	88	92	88	88	87	85	88	86
V	0	70	65	70	65	70	65	70	65
	2	80	80	85	80	82	80	87	75
	4	85	83	80	85	82	82	82	85
	6	80	90	88	88	85	85	85	92
	8	90	90	88	85	85	88	88	92
	10	86	90	86	86	85	88	85	90
VI	0	75	70	75	70	75	70	75	70
	2	82	82	82	80	83	80	78	80
	4	85	84	84	90	82	82	80	85
	6	84	85	80	88	80	87	87	88
	8	92	85	92	93	78	85	90	90
	10	90	85	90	88	88	88	88	88
VII	0	70	65	70	65	70	65	70	65
	2	83	85	80	78	85	88	85	88
	4	95	93	83	65	88	90	88	90
	6	92	95	85	68	92	93	92	93
	8	90	90	90	88	92	92	93	92
	10	90	90	90	90	90	88	90	87

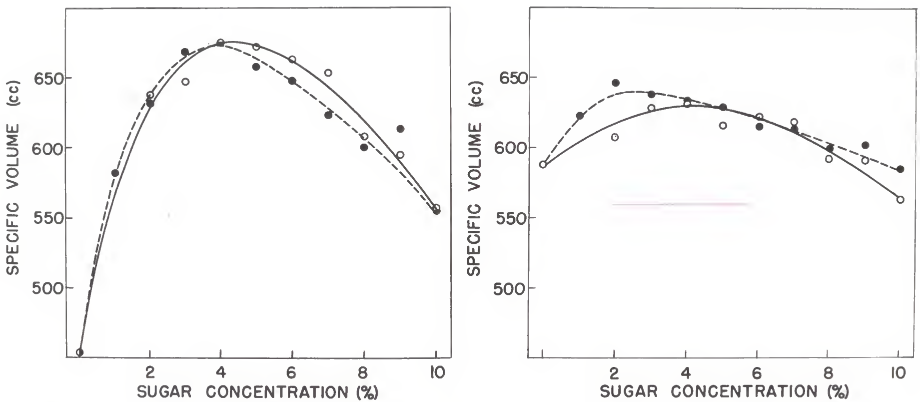

Fig. 2. The effect of sugar concentration on specific volume with the sponge dough procedure. The data were obtained with a hard red winter wheat flour (left) and a hard red spring wheat flour (right). Solid line represents glucose and the dashed line represents sucrose.

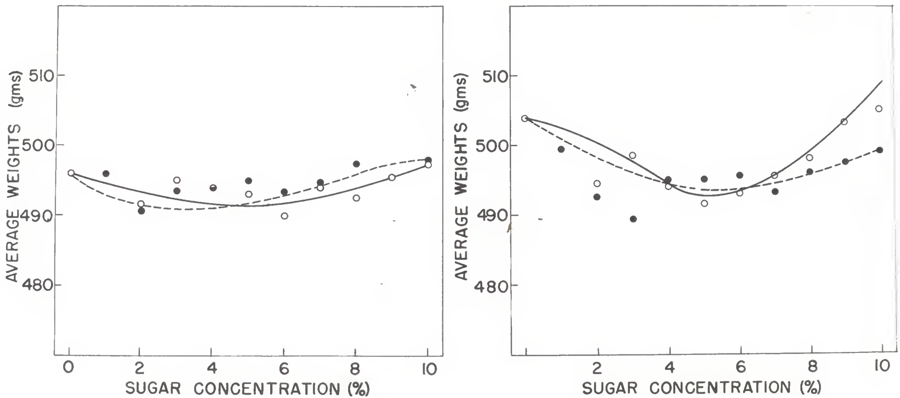

Fig. 3. The effect of sugar concentration on average loaf weight. The data represent hard red spring wheat flour (left) and hard red winter wheat flour (right). The solid line represents glucose and the dashed line represents sucrose.

and concentration for loaves made by the straight dough procedure were not plotted because of the inherent variations encountered (Table 3). The optimum quantity of either sugar agent was found to be between 5 and 9 per cent.

Grain and texture scores were not sufficiently consistent to be shown graphically; however, optimum conditions may be determined from Table 4. Optimum loaf interiors were observed with 7 to 8 per cent of either sugar employed, but higher concentrations were not seriously degrading. Sugar concentrations of 4 per cent or less produced bread with unsatisfactory loaf volume, grain and textures.

A series of bakes employing sucrose-glucose combinations at 4 and 6 per cent levels were made. At each of the 2 levels glucose was varied by 1 per cent increments and supplemented by sucrose to make up the remainder of the level. These particular concentrations were chosen because the range includes the sugar levels used by the majority of the commercial bakers, and these combinations were studied because of the wartime complaints from some bakers using glucose alone or with sucrose. Flours I, II, and III were used.

The specific volume and internal characteristics data are shown in Table 5. From these results it may be observed that glucose or sucrose, or any combination of the two, at a given concentration are equivalent in grain, texture and specific volume. For all practical purposes the crust colors were also equivalent even though slight differences were noted.

Table 3. Specific volumes for the straight dough procedure.

Flour	Per cent sugar conc.	Specific volume		Flour	Per cent sugar conc.	Specific volume	
		Sucrose	Glucose			Sucrose	Glucose
III	0	587	587	V	0	542	542
	1	606	621		1	548	575
	2	618	626		2	555	556
	3	610	594		3	563	537
	4	616	597		4	592	563
	5	650	615		5	594	587
	6	643	644		6	589	598
	7	629	631		7	598	611
	8	625	630		8	582	600
	9	613	612		9	545	574
	10	602	599		10	543	578
Average		619	615			568	575
IV	0	557	557	VI	0	492	492
	1	589	---		1	---	495
	2	571	561		2	510	492
	3	587	559		3	503	496
	4	593	556		4	528	519
	5	623	597		5	540	543
	6	609	593		6	547	555
	7	618	575		7	554	561
	8	606	589		8	557	544
	9	583	616		9	537	562
	10	571	579		10	516	562
Average		592	578			528	529
VII	0	550	550				
	1	557	581				
	2	576	597				
	3	582	567				
	4	584	599				
	5	596	611				
	6	600	622				
	7	580	635				
	8	584	630				
	9	539	597				
	10	539	597				
Average		573	599				

Table 4. Grains and textures for various sugar concentrations (Straight dough procedure).

Flour	Per cent sugar	Sucrose		Glucose		Flour	Per cent sugar	Sucrose		Glucose	
		Grain	Texture	Grain	Texture			Grain	Texture	Grain	Texture
III	0	75	83	75	83	V	0	71	79	71	79
	1	79	80	76	80		1	75	80	80	80
	2	80	84	78	80		2	76	83	79	78
	3	82	85	79	82		3	80	85	84	84
	4	89	88	83	83		4	83	86	83	81
	5	86	93	88	93		5	85	88	87	88
	6	88	93	88	92		6	84	87	88	90
	7	87	93	90	88		7	90	93	90	89
	8	88	92	91	92		8	93	97	90	94
	9	85	--	90	90		9	92	94	91	92
	10	86	89	85	90		10	91	90	91	91
IV	0	78	80	78	80	VI	0	78	80	78	80
	1	78	80	--	--		1	--	--	78	80
	2	84	84	78	79		2	80	80	79	83
	3	85	80	86	85		3	84	84	77	83
	4	83	87	84	82		4	82	83	79	82
	5	88	90	83	88		5	82	87	81	83
	6	93	92	88	90		6	83	87	83	85
	7	93	93	88	90		7	86	90	86	90
	8	91	92	91	92		8	89	92	87	89
	9	93	93	90	93		9	89	94	90	91
	10	89	90	93	92		10	90	91	84	87
VII	0	79	78	79	78						
	1	85	80	76	85						
	2	83	82	76	83						
	3	86	84	82	84						
	4	85	83	81	84						
	5	89	88	85	86						
	6	87	85	86	88						
	7	90	89	89	89						
	8	90	89	90	90						
	9	88	89	88	88						
	10	89	89	88	88						

Table 5. Effect of glucose-sucrose combinations on loaf interior.

Flour	Sugar concentration (per cent) Glucose	Sucrose	Grain	Texture	Specific volume
I	0	6	88	92	624
	1	5	84	90	610
	2	4	85	89	597
	3	3	87	91	588
	4	2	91	92	608
	5	1	92	95	609
	6	0	84	87	609
	0	4	77	85	617
	1	3	90	93	643
	2	2	87	90	649
	3	1	91	90	643
	4	0	91	93	623
II	0	6	83	90	689
	1	5	78	93	702
	2	4	83	88	669
	3	3	83	85	700
	4	2	85	88	672
	5	1	80	85	708
	6	0	90	88	683
	0	4	73	83	688
	1	3	90	95	734
	2	2	93	93	697
	3	1	83	85	734
	4	0	85	88	633
III	0	6	89	89	645
	1	5	94	90	632
	2	4	93	90	641
	3	3	88	90	650
	4	2	90	88	630
	5	1	94	91	637
	6	0	90	90	626
	0	4	85	82	660
	1	3	90	91	657
	2	2	90	94	647
	3	1	92	91	651
	4	0	89	91	654

Comparison of Effects of Sucrose and Glucose on Gas Production and Gas Retention

Glucose and sucrose concentrations of from zero to 8 per cent, in 2 per cent increments, were used. The relationships of gas production, gas retention, and (per cent) gas retention to sugar concentration in the sponge dough procedure, as shown by 3-hour readings, are shown in Fig. 4, for 2 flours. The various doughs exhibited maximum gas production and retention when supplemented with 4 per cent of either glucose or sucrose. The maximum gas retention, however, varied slightly with the flour used. Greater gas production and retention were noted with spring wheat flour than with winter wheat flour when no sugar was employed in the formula. With added sugars, the maximum gas production and retention for the 2 flour types, regardless of the sugar used, were nearly the same. The per cent gas retention increased at a steady rate up to 6 per cent sugar concentration, but at higher sugar levels, i.e., 6 to 8 per cent, increased at the same rate, leveled off, or decreased, depending upon the flour.

Gas production and retention data with the straight dough procedure are shown in Fig. 5. The gas retention remained essentially constant until 6 per cent sugar concentration was used. Beyond the 6 per cent sugar concentration both gas production and gas retention were markedly reduced. Maximum gas retention was observed with sucrose or glucose concentrations 2 per cent higher than that required for maximum gas production.

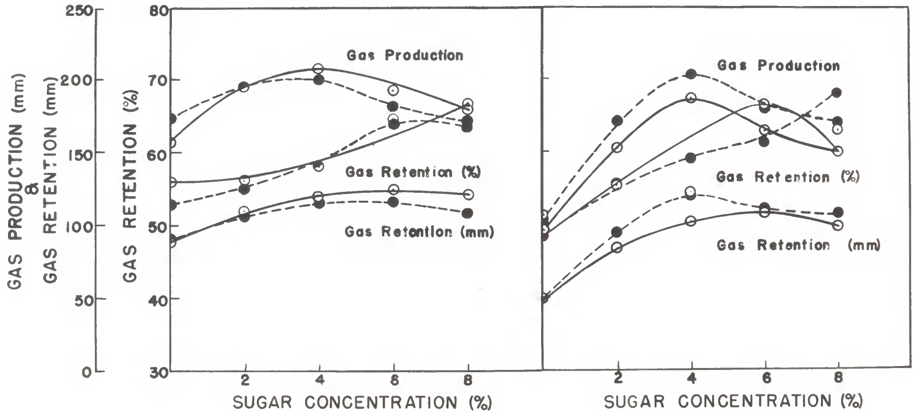

Fig. 4. The effect of sugar concentration on gas production and gas retention with hard red spring wheat flour (left) and hard red winter wheat flour (right). The sponge dough procedure was used. The solid line represents glucose and the dashed line represents sucrose.

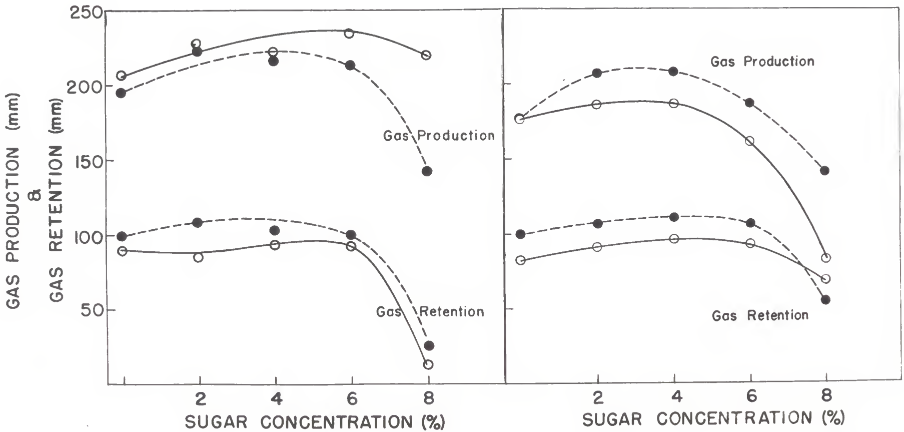

Fig. 5. The effect of sugar concentration on gas production and gas retention with two hard red winter wheat flours. The straight dough procedure was used. The solid line represents glucose and the dashed line represents sucrose.

The per cent retention was omitted from the graph because no well defined trends were observed.

The relationships of gas production and gas retention to time, with the straight dough procedure are shown in Fig. 6. These plots show the effects of glucose and sucrose concentrations on total gas production and retention. Four per cent of either sugar caused the highest total gas production and retention values, while doughs containing no sugar were intermediate and doughs containing 8 per cent the lowest. In certain instances the 8 per cent gas production value was actually lower than the 4 per cent gas retention value. Only in the case of Flour VII, a flour of inferior baking quality, did the gas retention for the 8 per cent concentration decrease after reaching a maximum. The gas retention for any given concentration of sugar was substantially lower than gas production. Eight per cent of either sugar was practically a straight line function of time in all cases; variation from this after the 60-minute period was attributed to error.

The rates of gas production (mm Hg/min.) of a sponge dough as affected by time and sugar concentration for typical hard red winter wheat and hard red spring wheat flours are shown in Fig. 7. The initial variation within the first 40 to 60 minutes, as reported by Eisenberg (19), was noted when either sugar was used. The general trends for all concentrations of both sugars were similar. When no sugar was used the rate of gas production for the first 20 minutes was greater than with

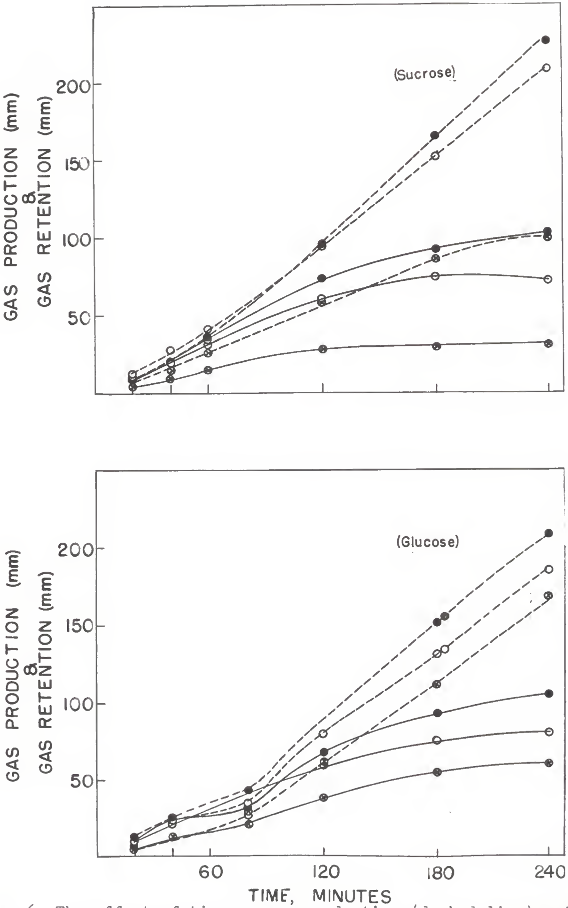

Fig. 6. The effect of time on gas production (dashed line) and gas retention (solid lines) with two hard red winter wheat flours. The straight dough procedure was used. Empty solid, and crossed dots represent the zero, 4, and 8 per cent sugar concentrations respectively.

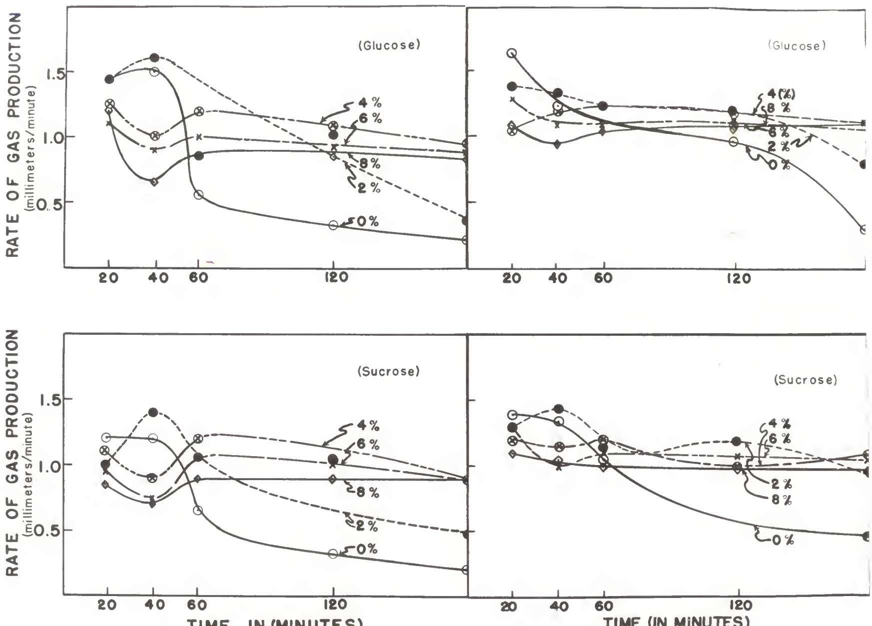

Fig. 7. Effect of sugar concentration on rate of gas production using a hard red spring wheat flour (left) and a hard red winter wheat flour (right). The sponge dough procedure was used. The solid lines represent glucose and the dashed lines represent sucrose.

higher sugar concentrations but the rate rapidly declined after the 40-minute interval. A higher rate of gas production was maintained with no-sugar doughs for a longer period of time with spring wheat flours than hard red winter wheat flours. Two per cent sugar concentrations resulted in a slightly lower initial rate but caused gas to be produced for a longer period of time. In general, as the sugar concentration was increased, the initial rate was lowered and the rate of gas production became more nearly constant as time of fermentation increased. Doughs containing 8 per cent sugar concentration resulted in practically a straight line function in all cases; variation from this after the 60-minute interval was attributed to experimental error.

The rates of gas production with glucose and sucrose for the straight dough procedure, as affected by time and sugar concentration, are shown in Fig. 8. Similar fluctuations within the first 60 minutes, as noted with the sponge doughs, were also observed. Four per cent of either sugar caused the optimum rate of gas production while 8 per cent sugar concentration resulted in a minimum rate of gas production up to 180 minutes of fermentation. Beyond 180 minutes the rate of gas production for the 8 per cent sugar concentration steadily increased.

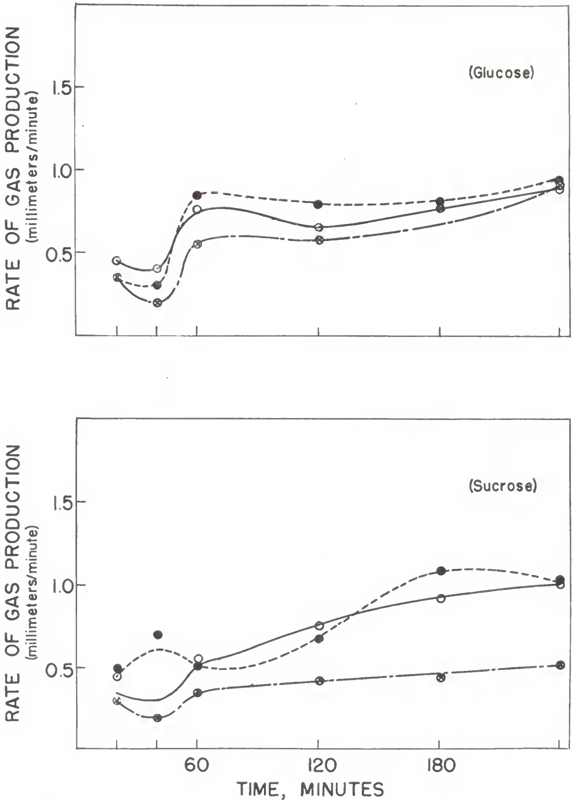

Fig. 8. The effect of sugar concentration on rate of gas production with a hard red winter wheat flour. The straight dough procedure was used. The solid, dashed and broken lines represent the zero, 4, and 8 per cent sugar concentrations respectively.

Proofing to a Constant Height

Four winter wheat flours were baked by the sponge procedure. All doughs with sugar concentrations of from 1 to 10 per cent were proofed to an arbitrarily set proofing height. These data are shown graphically in Fig. 9. The shortest proofing times were obtained with doughs containing 2 per cent of either sucrose or glucose. The 1 per cent concentration was equivalent to between 3 and 5 per cent of either sugar as measured by the time required to attain the proper height. Loaves with higher or lower concentration than 2 per cent required longer proofing times. Differences between sugar types were negligible. Converse to the results obtained by the constant time proofing procedure, the specific volumes (Fig. 10) were nearly constant after a maximum was reached with increasing sugar concentrations. Generally, 3 to 7 per cent of either sugar caused the optimum specific volume.

Crumb Compressibility Studies

Crumb compressibilities were measured at the end of 24 and 72-hour intervals using bread baked with 4 different flours and 4 sugars at 5 different concentrations. All flours showed virtually identical tendencies. The results and statistical analysis for a typical flour are shown in Table 6. In all cases the sugar x day x concentration interaction was significant

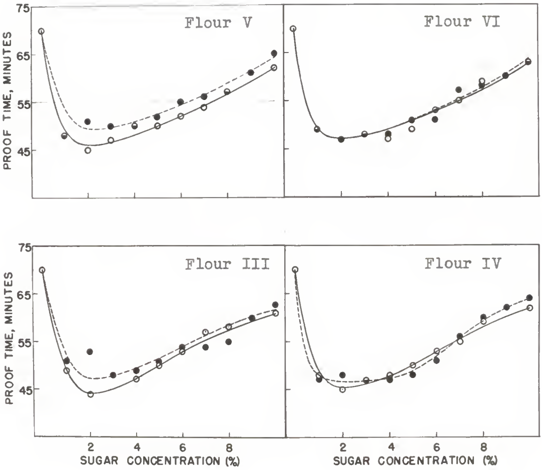

Fig. 9. The effect of sugar concentration on proofing time. Dashed line represents sucrose and solid line represents glucose.

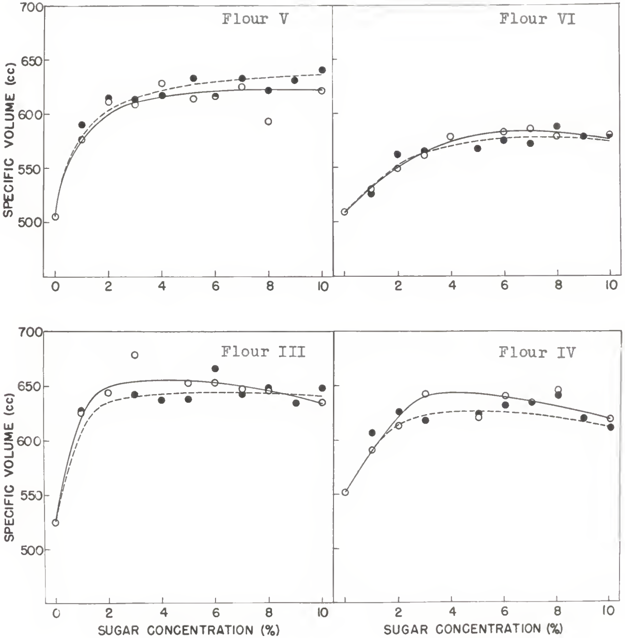

Fig. 10. The effect of sugar concentration on specific volume. Dashed line represents sucrose and solid line represents glucose.

Table 6. Tables of compressibility means and analysis of variance of compressibility measurements for bread baked with various sugars.

A. Table of means.

Sugar used	Day	Concentration 2	4	6	8	10	Average means
Glucose	1	7.23	6.18	7.15	6.43	6.72	6.74
	3	9.70	9.05	9.12	9.50	10.17	9.51
Sucrose	1	7.10	6.57	7.18	7.93	7.95	7.35
	3	11.35	10.50	11.35	10.57	13.70	11.49
Fructose	1	7.65	6.17	6.72	7.45	7.92	7.18
	3	12.88	11.30	11.68	12.03	14.12	12.40
Invert	1	7.40	6.47	8.42	6.80	7.73	7.36
	3	12.67	10.82	12.28	12.60	13.15	12.10
Average means		9.498	8.381	9.113	9.163	10.181	9.267

B. Analysis of variance.

Source of variation	Degrees of freedom	Mean squares
Sugar	3	3,648.3***
Concentration	4	2,050.2***
Day	1	106,810.0***
Sugars x days	3	1,697.3**
Sugars x concentrations	12	151.69
Concentrations x days	4	469.93
Sugars x days x concentrations	12	172.94**
Error	200	46.61
Totals	239	

* - significant to the 5% interval.
** - significant to the 1% interval.
*** - significant to the 0.1% interval.

when tested by the error term, and was used as a test of significance for other factors. The analysis of variance showed that the difference in compressibility between the first and third days was highly significant. Variation due to sugars was also highly significant with all flours tested. Loaves baked with glucose and stored for 3 days showed greatest compressibility. For purposes of demonstration the 72-hour compressibility measurements on bread made with Flour V were plotted against sugar concentration (Fig. 11). The order of compressibility as influenced by other sugars was sucrose $>$ invert $>$ fructose. It was concluded that while loaves containing glucose exhibited the greatest compressibility, no sugar retarded rate of staling to any great extent. The loaves containing 10 per cent of any sugar revealed the least compressibility while loaves containing 4 per cent possessed the greatest compressibility. These differences were significant.

Effect of Sugars on Toasting Quality

A photograph of slices of bread baked with 2, 4, 6, 8, and 10 per cent of all 4 sugars is shown in Plate I. The characteristic brown color of the toast was definitely intensified as the sugar concentration was increased, but no sugar revealed a significantly greater browning effect than any other sugar at a given concentration.

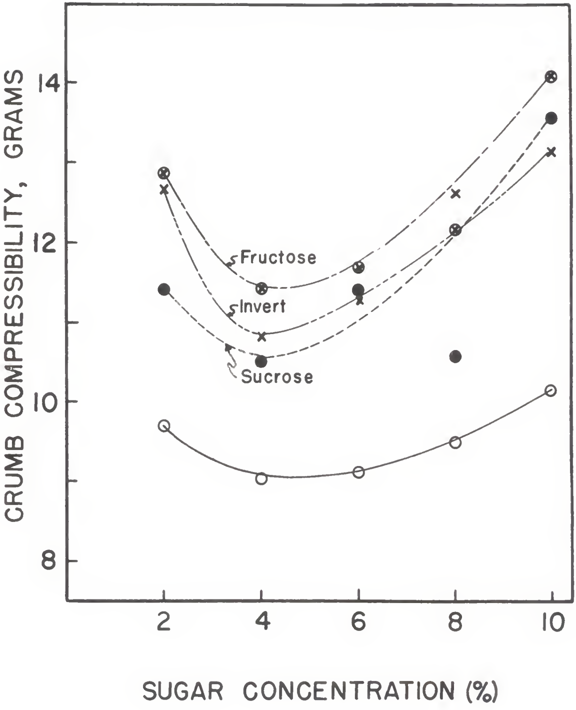

Fig. 11. The effect of sugar type and concentration on the crumb compressibility.

EXPLANATION OF PLATE I

Effect of sugar type and concentration on toasting quality

Sugar type	Concentration					
Glucose	2	4	6	8	10	0
Sucrose	2	4	6	8	10	
Fructose	2	4	6	8	10	
Invert	2	4	6	8	10	

PLATE I

The Sweet Dough Procedure

One bake using a standard sweet dough procedure and Flour III were considered adequate for the testing of sucrose and glucose for dinner and cinnamon rolls. Sugar concentrations equal to 3, 5, 7, 9, 11, and 13 per cent of both sucrose and glucose were used for both types of rolls.

The grading and measurements taken were all subjective in nature and are shown in Table 7. The grains and textures of the dinner rolls baked with 3 and 5 per cent glucose and sucrose were tough and harsh. Nine to 11 per cent sugar was optimum when glucose was used and 9 to 13 per cent for sucrose. Sucrose was more advantageously utilized than glucose in dinner rolls because of the greater natural sweetness. The crust color of the dinner rolls was satisfactory for 9 per cent or more glucose and 7 per cent or more sucrose.

Subjective scores for the cinnamon rolls indicates that 9 per cent of either sugar produced satisfactory tenderness. Based on flavor, the sugars cannot be considered as equal. The flavor was satisfactory only at the 13 per cent level of glucose while 11 per cent showed fair flavor and lesser concentrations were unsatisfactory. Seven per cent or more sucrose produced good flavor, 5 per cent was fair, and 3 per cent was unacceptable. The external color was satisfactory when 7 per cent of either sugar was used.

It was concluded that 9 to 11 per cent sucrose was optimum

Table 7. Characteristics of products baked by the sweet dough procedure.

Part A: Grain, texture, sweetness, and crust color scores for dinner rolls baked by the sweet dough procedure.

Sugar concentration	(per cent)	Grain and texture	Relative sweetness	Crust color
Glucose	3	75	-	Unsatisfactory
"	5	78	-	"
"	7	84	-	"
"	9	90	+	Satisfactory
"	11	92	+	"
"	13	85	++	"
Sucrose	3	75	-	Unsatisfactory
"	5	85	-	"
"	7	85	+	Satisfactory
"	9	90	+++	"
"	11	85	++++	"
"	13	90	++++	"

Part B: Tenderness, flavor (inc. sweetness), and crust color scores for cinnamon rolls baked by the sweet dough procedure.

Sugar concentration	(per cent)	Tenderness	Flavor (inc. sweetness)	External color
Glucose	3	70	-	Unsatisfactory
"	5	75	-	"
"	7	75	-	Satisfactory
"	9	90	-	"
"	11	90	+	"
"	13	95	+++	"
Sucrose	3	75-80	-	Unsatisfactory
"	5	80	+	"
"	7	85	+++	Satisfactory
"	9	95	++++	"
"	11	98	++++	"
"	13	90	++++	"

for either dinner or cinnamon rolls.

Effect of Sugar and Concentration on Hearth and Rye Bread

Glucose and sucrose concentrations of zero, 1/2, 1, 1 1/2, 3, and 5 per cent were chosen in order to bracket the range of sugar usually employed by most commercial bakers of rye and hearth bread. Grain and texture, external appearance, and crust color scores are recorded in Table 8. It was shown that as the glucose or sucrose concentration in hearth bread was increased from zero to 5 per cent the loaf interior was not improved. The crust color of loaves made with either sugar were progressively darkened with increasing concentrations.

Rye bread, on the other hand, showed superior crumb characteristics when the glucose or sucrose concentration was 1 1/2 per cent; lower or higher concentrations were equally nonbeneficial. The crust color was satisfactory with 1 to 3 per cent glucose and from 1 to 1 1/2 per cent sucrose. The crust color differences were not pronounced, however, the external appearances of the loaves at all concentrations were virtually the same.

Organoleptic Testing

The results of the initial qualifying test are shown in

Table 8. Internal and external characteristics of loaves baked by the hearth and rye procedures.

Part A. Grain, texture, external appearance, and crust color scores for hearth bread.

Sugar	Per cent concentration	Grain & texture	External appearance	Crust color	Sugar	Per cent concentration	Grain & texture	External appearance	Crust color
Glucose	0.0	90	Good	L.B.	Sucrose	0.0	90	Good	L.B.
	0.5	89	"	"		0.5	89	"	"
	1.0	87	Very good	M.B.		1.0	86	"	"
	1.5	87	Fair	"		1.5	88	Fair	"
	3.0	84	"	"		3.0	86	"	M.B.
	5.0	85	"	D.B.		5.0	87	Good	D.B.

Part B. Grain, texture, external appearance and crust color scores for rye bread.

Sugar	Per cent concentration	Grain & texture	External appearance	Crust color	Sugar	Per cent concentration	Grain & texture	External appearance	Crust color
Glucose	0.0	85	Good	L.B.	Sucrose	0.0	85	Good	L.B.
	0.5	85	"	"		0.5	83	"	M.B.
	1.0	88	"	M.B.		1.0	84	"	D.B.
	1.5	89	Very good	"		1.5	88	Very good	"
	3.0	87	" "	"		3.0	86	Good	"
	5.0	84	Good	D.B.		5.0	85	Very good	"

L.B. - Light brown
M.B. - Medium brown
D.B. - Dark brown

Table 9. Of the 8 testers who participated, only 1 was rejected. That the other 7 judges could differentiate between the sweet loaves (6 per cent fructose and 10 per cent sucrose) and the relatively unsweetened loaves (no sugar and 3 per cent glucose) is evidenced by the fact that each judged bracketed bread containing these sugars the same way on the fourth day. The judges, however, could not detect differences between the loaves containing 6 per cent fructose and 10 per cent sucrose or between the no-sugar and 3 per cent glucose loaves. Judge V did not prefer the sweet bread as did the other judges, but was consistent in his choice. Since it was assumed that the differences between the sweetened and relatively unsweetened loaves were sufficiently small that they could not be detected organoleptically, all judges, except III, were accepted.

These tests were conducted 4 times, only once in a given week. In Test I (Table 10) each judge, without exception, was able to differentiate between the loaves containing sucrose and those containing glucose on both the second and fourth days. The various rankings, which were analyzed statistically, showed a high degree of concordance. Each tester preferred loaves containing sucrose regardless of the concentration.

The data resulting from the second test (Table 11) not only showed that the judges did not consistently prefer bread containing 1 sugar to another but that the judges did not rank them the same on the fourth day. The degree of concordance was nonsignificant on both days.

Table 9. Special taste test: organoleptic flavor, texture and crust flavor test.

Criterion	Loaf numbers								Rank								Judge
	2nd Day				4th Day				2nd Day				4th Day				
	A	B	C	D	A	B	C	D	1st	2nd	3rd	4th	1st	2nd	3rd	4th	
Flavor	3	3	4	4	3	3	4	4	C	D	A	B	C	D	B	A	I
Texture	3	3	4	4	4	4	5	4									
Crust flavor	3	3	4	5	4	4	4	5									
Flavor	3	2	2	4	4	3	4	3	D	A	C	B	C	A	B	D	II
Texture	3	2	3	5	4	3	5	3									
Crust flavor	3	4	3	4	4	4	4	3									
Flavor	4	3	4	5	4	4	5	5	D	A&C	B		D&C	A	B		III
Texture	4	4	4	4	4	4	4	4									
Crust flavor	3	4	3	4	3	4	3	3									
Flavor	3	2	2	2	2	3	3	3	A	B	C&D		B	A	D&C		IV
Texture	3	3	2	3	2	3	3	3									
Crust flavor	3	3	3	2	3	2	2	2									
Flavor	1	1	3	3	1	1	3	3	D&C		A&B		D&C		A&B		V
Texture	2	2	3	3	2	2	3	3									
Crust flavor	1	2	3	3	2	2	3	3									
Flavor	4	4	5	5	4	4	4	5	D	ABC			D	ABC			VI
Texture	4	4	4	5	3	3	3	4									
Crust flavor	3	3	3	2	3	3	3	4									
Flavor	2	2	4	4	2	2	4	4	D	C	A	B	C	D	B	A	VII
Texture	2	4	2	4	2	2	4	4									
Crust flavor	3	3	3	3	2	2	2	4									

Key: A - No sugar
B - 3% glucose
C - 6% fructose
D -10% sucrose

Table 10. Tables of ranks and statistical analyses.

A. Table of ranks by judges in the first test.

Judge	Rank							
	2nd day				4th day			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th
I	C	D	B	A	D	C	A	B
II	D	C	B	A	D	C	A	B
IV	D	C	B	A	A	D	B	C
V	C	D	B	A	C	A	B	D
VI	C	D	B	A	D	C	A	B
VII	C	D	A	B	D	A	C	B

Key: A - 3% glucose
B - 5% glucose
C - 3% sucrose
D - 5% sucrose

B. Statistical analysis of the first test.

Judge	Rank							
	A		B		C		D	
Day:	2nd	4th	2nd	4th	2nd	4th	2nd	4th
I	4	3	3	4	1	2	2	1
II	4	3	3	4	2	2	1	1
IV	4	1	3	3	2	4	1	2
V	4	2	3	3	1	1	2	4
VI	4	3	3	4	1	2	2	1
VII	3	2	4	4	1	3	2	1

$m = 6$ (rankings), and
$n = 4$ (objects)
For 2nd day:

W = coefficient of concordance $= \dfrac{S}{\dfrac{m^2(n^3 - n)}{12} - m \; \Sigma T'} = 0.855^{**}$

For 4th day:
$W = 0.478^{*}$

* - significant to 5% interval
** - significant to 1% interval
(n.s.)- nonsignificant

Table 11. Tables of ranks and statistical analyses.

A. Table of ranks by judges in the second test.

Judge	Rank: 2nd day 1st	2nd	3rd	4th	Rank: 4th day 1st	2nd	3rd	4th
II	D	B&C	A		D	C	B&A	
IV	C	A	B	D	C	A	B	D
V	A	C	B	D	A	B	D	C
VI	D	C	B&A		A	C&D	B	
VII	C&D		B&A		D&A	B	C	
VIII	B	C	A	D	B	D	A	C

Key: A - 3% glucose
B - 5% glucose
C - 3% sucrose
D - 5% sucrose

B. Statistical analysis of the second test.

Judge	Rank: A, Day: 2nd	A, 4th	B, 2nd	B, 4th	C, 2nd	C, 4th	D, 2nd	D, 4th
II	4	3.5	2.5	3.5	2.5	2	1	1
IV	2	2	3	3	1	1	4	4
V	1	1	3	2	2	4	4	3
VI	3.5	1	3.5	4	2	2.5	1	2.5
VII	3.5	1.5	3.5	3	1.5	4	1.5	1.5
VIII	3	3	1	1	2	4	4	2

$m = 6$, and $n = 4$

For 2nd day:

$$W = \text{coefficient of concordance} = \frac{S}{\frac{m^2(n^3 - n)}{12} - m\ \Sigma T'} = 0.134 \text{ (n.s.)}$$

For 4th day:
$W = 0.108$ (n.s.)

* - significant to 5% interval
** - significant to 1% interval
(n.s.)- nonsignificant

Only 3 judges were available on both days for the third test (Table 12). Two judges succumbed to severe colds and thereby rendered themselves useless for the subject at hand. The data showed that the judges could not reproduce their second day results on the fourth day. There was no consistent preference for sugar type or concentration.

The ranking data in the fourth test (Table 13), statistically analyzed, had a lower degree of concordance than any of the other 4 tests. Second day preferences were not duplicated on the fourth day, and there was no order of preference shown for the 2 sugar types or 2 concentrations.

The pooled rankings of <u>each</u> of the 3 judges which was present for all 4 of the tests are shown on Table 14. In each case, and on both days, the coefficient of concordance was nonsignificant. This tendency corresponds to the results of the individual tests.

Statistically treated pooled data for rankings of the 3 judges present on both days for all 4 tests are shown on Table 15. The coefficient of concordance was nonsignificant and showed that these judges' preferences were not the same on both days. It was also shown (Table 16) that the judges shifted preference slightly from the sweeter loaves to the unsweetened loaves from the second to the fourth days. The shift was again shown to be nonsignificant.

All tests taken into consideration, it was concluded that: (1) there was no preference for one sugar concentration

Table 12. Tables of ranks and statistical analyses.

A. Tables of ranks by judges in the third test.

Judge	Rank							
	2nd day				4th day			
	1st	2nd	3rd	4th	1st	2nd	3rd	4th
IV	D	C&A	B		C	D	B	A
VI	C	A	B	D	D	C	B	A
VII	ABCD				A	DBC		

Key: A - 3% glucose
B - 5% glucose
C - 3% sucrose
D - 5% sucrose

B. Statistical analysis of the third test.

Judge	Rank							
	A		B		C		D	
Day:	2nd	4th	2nd	4th	2nd	4th	2nd	4th
IV	2.5	4	4	3	2.5	1	1	2
VI	2	4	3	3	1	2	4	1
VII	2.5	1	2.5	3	2.5	3	2.5	3

$m = 3$, and $n = 4$

For 2nd day:

$$W = \text{coefficient of concordance} = \frac{S}{\frac{m^2(n^3 - n)}{12} - m\ \Sigma T'} = 0.228 \text{ (n.s.)}$$

For 4th day:

$W = 0.231$ (n.s.)

* - significant to 5% interval
** - significant to 1% interval
(n.s.)- nonsignificant

Table 13. Tables of ranks and statistical analyses.

A. Table of ranks by judges in the fourth test.

Judge	Rank: 2nd day 1st	2nd	3rd	4th	4th day 1st	2nd	3rd	4th
IV	C	B	D&A		A	B	C&D	
V	A	D	C	B	D	A	C	B
VI	B&D	C	A		C&B	D	A	
VII	D&A	C	B		D&B		C&A	
VIII	A	B	D	C	D	C	A	B

Key: A - 3% glucose
B - 5% glucose
C - 3% sucrose
D - 5% sucrose

B. Statistical analysis of the fourth test.

Judge	Rank: A Day: 2nd	A 4th	B 2nd	B 4th	C 2nd	C 4th	D 2nd	D 4th
IV	3.5	1	2	2	1	3.5	3.5	3.5
V	1	2	4	4	3	3	2	1
VI	4	4	1.5	1.5	3	1.5	1.5	3
VII	1.5	3.5	4	1.5	3	3.5	1.5	1.5
VIII	1	3	2	4	4	2	3	1

$m = 5$, and $n = 4$

For 2nd day:

W = coefficient of concordance $= \dfrac{S}{\dfrac{m^2(n^3 - n)}{12} - m\ \Sigma T'} = 0.055$ (n.s.)

For 4th day:

W = 0.074 (n.s.)

* - significant to 5% interval
** - significant to 1% interval
(n.s.)-nonsignificant

Table 14. Tables of ranks and statistical analyses of the judges considered individually.

A. Table of rank and statistical analysis of Judge IV.

	Rank							
	A		B		C		D	
Test	2nd	4th	2nd	4th	2nd	4th	2nd	4th
I	4	1	3	3	4	2	1	2
II	2	2	3	3	1	1	4	4
III	2.5	4	4	3	2.5	1	1	2
IV	3.5	1	2	2	1	3.5	3.5	3.5

B. Statistical analysis of Judge IV.
For 2nd day: W = coefficient of concordance = 0.300 (n.s.)
For 4th day: W = 0.100 (n.s.)

C. Table of rank of Judge VI

	Rank							
	A		B		C		D	
Test	2nd	4th	2nd	4th	2nd	4th	2nd	4th
I	4	3	3	4	1	2	2	1
II	3.5	1	3.5	4	2	2.5	1	2.5
III	2	4	3	3	1	2	4	1
IV	4	4	1.5	1.5	3	1.5	1.5	3

D. Statistical analysis of Judge VI.
For 2nd day: W = coefficient of concordance = 0.295 (n.s.)
For 4th day: W = 0.200 (n.s.)

E. Table of ranks of Judge VII.

	Rank							
	A		B		C		D	
Test	2nd	4th	2nd	4th	2nd	4th	2nd	4th
I	3	2	4	4	1	3	2	1
II	3.5	1.5	3.5	3	1.5	4	1.5	1.5
III	2.5	1	2.5	3	2.5	3	2.5	3
IV	1.5	3.5	4	1.5	3	3.5	1.5	1.5

F. Statistical analysis of Judge VII.
For 2nd day: W = coefficient of concordance = 0.5 (n.s.)
For 4th day: W = 0.400 (n.s.)

Table 15. Tables of ranks and statistical analyses for the three judges present for all four tests.

A. Table of ranks

Test	A 2nd	A 4th	B 2nd	B 4th	C 2nd	C 4th	D 2nd	D 4th
I	23	14	19	22	8	14	10	10
II	17	12	16.5	16.5	11	17.5	15.5	14
III	7	9	9.5	9	6	6	7.5	6
IV	11	13.5	13.5	13	14	13.5	11.5	10

B. The same data ranked

Test	A 2nd	A 4th	B 2nd	B 4th	C 2nd	C 4th	D 2nd	D 4th
I	2.5	3	4	4	2.5	1	1	2
II	1	2	3	4	4	1	2	3
III	3.5	2	3.5	4	1.5	1	1.5	3
IV	3.5	3.5	2	2	3.5	3.5	1	1

C. Statistical analysis of the above data:

For 2nd day:
W = coefficient of concordance = 0.400 (n.s.)

For 4th day:
W = coefficient of concordance = 0.400 (n.s.)

Table 16. Tables of analyses of all possible pairs of loaves with the number of times picked first.

Test	Day	A	C	Tie	Test	Day	A	B	Tie	Test	Day	A	D	Tie
1	2nd	0	6	0	1	2nd	1	5	0	1	2nd	0	6	0
	4th	2	4	0		4th	6	0	0		4th	2	4	0
2	2nd	1	5	0	2	2nd	2	2	2	2	2nd	3	3	0
	4th	4	2	0		4th	4	1	1		4th	3	2	1
3	2nd	0	1	2	3	2nd	2	0	1	3	2nd	1	1	1
	4th	1	2	0		4th	1	2	0		4th	1	2	0
4	2nd	3	2	0	4	2nd	3	2	0	4	2nd	2	1	2
	4th	2	2	1		4th	3	2	0		4th	1	4	0
Test	Day	B	C	Tie	Test	Day	B	D	Tie	Test	Day	C	D	Tie
1	2nd	0	6	0	1	2nd	0	6	0	1	2nd	4	2	0
	4th	1	5	0		4th	1	5	0		4th	1	5	0
2	2nd	1	4	1	2	2nd	3	3	0	2	2nd	3	2	1
	4th	3	3	0		4th	3	3	0		4th	1	4	1
3	2nd	0	2	1	3	2nd	1	1	1	3	2nd	1	1	1
	4th	0	2	1		4th	0	2	1		4th	1	1	1
4	2nd	2	3	0	4	2nd	2	2	1	4	2nd	1	4	0
	4th	2	2	1		4th	2	2	1		4th	1	3	1

	A		B		C		D		Total	
	2nd	4th	2nd	4th	2nd	4th	2nd	4th	2nd	4th
A	-	-	0.5	1	0	0.5	0	0	0.5	1.5
B	0.5	0	-	-	0	0	0	0	.5	0
C	1	1.5	1	1	-	-	0.5	0	2.5	1.5
D	1	1	1	1	0.5	1	-	-	2.5	3

Pooled ranks

Day:	1st	2nd	3rd	4th
2nd	C&D		B	A
4th	D	C	A	B

to another concentration; (2) the judges did not prefer one sugar type to another in the bread; (3) although there was no significant sugar type preference shown when analyzed statistically (at the 5 per cent confidence interval) there was a "trend" which suggested sucrose preference; (4) in most cases the judges' order of preference changed from the second to the fourth day.

DISCUSSION

No significant differences in total gas production and gas retention in bread doughs containing sucrose and glucose were observed. This fact does not lend support to the widely accepted belief that glucose is fermented more rapidly than sucrose in bread doughs (41, 48, 49). It is known that results of determinations of glucose and sucrose utilization with liquid yeast cultures might differ somewhat from the baking results because of the differences in composition of the media. The data (Figs. 7 and 8) do not show that the rate of dough fermentation was affected by one sugar more than another, but rather that these sugars, in their subjected circumstances, affected the rate of dough fermentation similarly. Geddes and Winkler (26) showed that yeast provided sufficient invertase to provide adequate glucose from sucrose inversion in a dough for maximum fermentation rate. Thus, in a fermenting dough, provided the necessary yeast nutritional requirements are present, it is not surprising to find that glucose and sucrose affect a dough fermentation similarly.

The concentration of either sugar that provided optimum total gas production, with both the sponge and straight dough procedures, was found to be 4 per cent. With either procedure the rate of gas production was optimum with either sugar at the 4 per cent level. The rate of gas production decreased after a short lapse of time with doughs containing zero to 2 per cent sugar.

Slator, according to Aitkin et al (2), showed that the concentration of sugar did not significantly affect the rate of fermentation in concentrations ranging from 0.5 to 10 per cent, although Hopkins and Roberts pointed out that this was somewhat dependent upon the choice of conditions employed. The latter workers concluded that the kinetics of alcoholic fermentation were very similar to the ordinary enzyme reaction and that fermentation of glucose conforms to the theory of Michaelis and Menten. If an enzymic reaction follows the Michaelis and Menten equation, 3 cases may arise: 1, the substrate concentration remains so high that the enzyme is fully saturated and consequently the observed rate of reaction is nearly constant; 2, the substrate concentration is so low that the reaction behaves in a unimolecular manner; and 3, the fermentation rate may rise to a maximum, remain stationary for a period, and then drop as the substrate is exhausted.

In the present study, however, it was noted that at high sugar concentrations the rate steadily increased as the sugar was further utilized by fermentation. The preservative action of high sugar concentration may be due to the osmotic effect. Atkin, Schultz and Frey (2) stated that as the concentration of sugar in a dough is increased much above 10 per cent the rate of fermentation is progressively retarded. Other substances, such as salt, soluble solids of flour, and soluble milk solids, usually present in the dough, also have an osmotic effect. The rate of gas production thus appears to be related to the sugar concentration in a dough at any given time. The gas retention was optimum when using 4 per cent of either sugar with the sponge dough procedure and 6 per cent with the straight dough procedure.

Gas production and gas retention in doughs appear to be closely related to specific loaf volumes and weights of loaves (Figs. 1, 2 and 3). Four per cent of either sugar provided optimum specific volumes and loaf weights. Studies of proofing to a constant height also provided results which were closely related to those of gas production and gas retention studies. Doughs containing 2 per cent of either sugar proofed to the set height in the shortest time while high concentrations of sugar required increasingly longer proof time.

Toasting studies did not evolve a maximum or optimum concentration since the relationship of toast color to sugar concentration appeared to be linear. Crust color, however, involving the same principle, was most satisfactory for loaves containing 5 to 7 per cent of all sugars tested.

Dadswell and Gardner (17) and Sandstedt and Blish (42) have shown that sugars originally present in the flour were important <u>only</u> in the early stages of gas production. The analysis for reducing and nonreducing sugar contents (Table 1) supported results of earlier workers (17, 32) and indicated that sugars originally present in the flour were not responsible to any degree for the prolonged gas production in no-sugar doughs with hard red spring as compared to the hard red winter wheat flours. Alpha-amylase content was responsible for variations in gas production as was the susceptibility of starch to amylase attack (12, 17). The addition of 1 per cent malted wheat flour, in the present study, resulted in greater maltose value in the spring wheat flours (Table 1). These results appear to corroborate those of Dadswell and Gardner (17) and Blish, Sandstedt and Platenius (12) and may explain why greater <u>total</u> and increased <u>rate</u> of gas production, from doughs prepared from these flours, resulted when no sugar was employed.

The sugar concentration affording greatest compressibility at the end of 3 days of staling was 4 per cent, regardless of sugar type. Since compressibility differences due to sugar type were small, although significant, it is possible that the 4 per cent level was optimum because of the greater volume accompanying this sugar level.

Although no sugar agent tested showed any important differences on compressibility, glucose was superior to sucrose, fructose and invert sugar. It may be that glucose, possessing lesser bonding strength, did not bind the various ingredients as tenaciously as did other sugars. This also may be due to lesser amounts of glucose being present, granting that glucose is more completely fermented than the other sugars.

The organoleptic tests showed that the testers tended to prefer loaves containing sucrose to those of glucose but when the bread was older the preference trend shifted in favor of the loaves containing glucose. There may be a correlation between this phenomena and the tendency for glucose to enhance compressibility. Glucose allowed greater compressibility at the end of the third day, in relation to the other sugars tested, but after only 1 day these differences were shown to be negligible.

SUMMARY AND CONCLUSIONS

1. An investigation was conducted on the use of sucrose, glucose, fructose and invert sugar on various dough and bread properties. Flour type, sugar concentration and methods of treatment were also variables.

2. Optimum specific volumes were observed with loaves containing 3 to 4 per cent of all sugars tested. Specific volumes for loaves containing sucrose or glucose were optimum at 4 per cent sugar with hard red winter wheat flour and approximately 3 per cent with hard red spring wheat flour. The specific volumes of no-sugar loaves were considerably greater when hard red spring wheat flour was used. Average loaf weights were inversely related to specific volumes. These phenomena were noted when using either the sponge or straight dough procedure.

3. The order of darkness of loaf crust colors containing these sugars was sucrose $>$ fructose $=$ invert $>$ glucose at any given concentration. These differences were not important above the 3 per cent sugar level.

4. Loaf interior scores were optimum between 6 and 8 per cent of either sucrose or glucose. Any differences in effect of either sugar on grain and texture were unimportant.

5. No significant differences in gas production and gas retention due to sucrose and glucose were observed. The concentration of either sugar causing optimum gas production

was 4 per cent with either the sponge or straight dough procedure. The optimum gas retention in the sponge dough procedure was noted with 4 per cent of either sugar; 6 per cent of either sugar afforded optimum gas retention with the straight dough procedure.

6. The rate of gas production was the same for both sucrose and glucose at any given concentration, and the optimum sugar concentration was 4 per cent. In general, as the concentration of either sugar was increased from zero to 8 per cent, the initial rate of gas production was lowered progressively. In later stages of fermentation gas production rate became progressively more constant but was lower.

7. Gas production and retention values for low (zero to 2 per cent) sugar concentrations remained high for a longer period of time with hard red spring wheat flours than with hard red winter wheat flours. Variation in maltose values for the flours as received and with 1 per cent added malted wheat flour suggested that differences in starch susceptibility to amylase attack were responsible for these characteristics. These differences were correlated with specific volume and weight.

8. Proofing to a constant height showed that doughs containing 2 per cent of either sugar were fermented more rapidly than those containing lower or higher concentrations.

9. Compressibility measurements revealed that bread stored for 72 hours was less compressible than that stored

for 24 hours. The order of compressibility with bread stored 72 hours as influenced by sugar was glucose $>$ sucrose $>$ invert = fructose. Four per cent sugar concentration showed greatest compressibility and 10 per cent the least.

10. Increase of sugar concentration from zero to 10 per cent, in 2 per cent increments, caused toast color to become progressively darker, independent of sugar type.

11. Cinnamon and dinner rolls were baked by the sweet dough procedure employing sugar concentrations of 3 to 13 per cent in 2 per cent increments. Grain and texture scores for the dinner rolls were optimum with concentrations of 9 per cent or more of either sugar. The crust colors were satisfactory for 9 per cent or more of glucose and 7 per cent or more of sucrose. Sucrose was more advantageously utilized in the dinner rolls because of the greater natural sweetness. Based on the subjective flavor scores the sugars were not considered as equals. Seven per cent or more of sucrose produced satisfactory flavor while 13 per cent of glucose was required. The external color was satisfactory for 7 per cent of either sugar.

12. It was shown that very low concentrations of either glucose or sucrose was most beneficial to loaf interior when used in hearth bread. Neither sugar was found to be superior to the other in so far as crust color, external appearance, and loaf interior were concerned.

13. The best loaf interior in rye bread was noted when

supplemented with 1 1/2 per cent of either sucrose or glucose and the best crust color with 1 to 3 per cent glucose or 1/2 to 1 1/2 per cent sucrose. No significant differences were found to exist between the sugars when used for rye bread.

14. Each of 4 organoleptic tests consisted of tasting 4 bread samples which contained 3 and 5 per cent glucose and 3 and 5 per cent sucrose at the end of the second and fourth days of storage. From these studies, the following conclusions were made: 1, there was no preference for bread containing one sugar concentration to another concentration; 2, the judges did not prefer bread containing one sugar type to another; 3, although there was no significant sugar type preference shown when analyzed statistically, there was a "trend" which suggested sucrose preference; 4, in most cases the judges' order of preference changed from the second to the fourth day.

ACKNOWLEDGMENTS

Indebtedness is acknowledged to Mr. John A. Johnson, major instructor and Associate Professor in Milling Industry, for directing this investigation and for counsel in the preparation of this manuscript; to Dr. J. A. Shellenberger, Head, Department of Milling Industry, for providing research facilities and for his interest in the work; to Dr. H. C. Fryer, Professor of Mathematics and to Mr. Jack I. Northam, Assistant Professor of Mathematics, for their assistance with the statistical treatment of the data.

The assistance of the following persons is also greatly appreciated: Mr. Boyce W. Dougherty, Mr. William B. Caldwell, Mr. David P. Taylor, and Mrs. Marjorie Abbott for technical assistance; to the members of the taste testing panel: Dr. J. A. Shellenberger, Dr. Byron S. Miller, Miss Katherine Morris, Mrs. Maxine Potter, Mrs. Marjorie Abbott, Mrs. Arlene Davis, Mr. Gerald D. Miller, and Mr. Donald C. Abbott; and to members of the Department of Milling Industry and Department of Chemistry who in various ways aided in this investigation.

Acknowledgment is given to Corn Products Incorporated for their cooperation in making this project possible.

LITERATURE CITED

(1) Aitken, T. R., M. H. Fisher and W. F. Geddes.
The effect on loaf volume, of proofing doughs to a definite height as compared with that for a fixed time. Cereal Chem. 14:233-238. 1937.

(2) Aitken, Lawrence, Alfred S. Schultz and Charles N. Frey.
Enzymes and Their Role in Wheat Technology. New York: Interscience Publishers, Inc. 1946.

(3) American Association of Cereal Chemists.
Cereal Laboratory Methods, 5th ed. American Association of Cereal Chemists. St. Paul, Minnesota. 32, 33, 100 p. 1947.

(4) Anker, C. A. and W. F. Geddes.
Gelatinization studies upon wheat and other starches with the amylograph. Cereal Chem. 21:335-360. 1944.

(5) Bailey, L. H.
A simple apparatus for measuring the compressibility of baked products. Cereal Chem. 7:340-341. 1930.

(6) Bailey, L. H.
The use of certain constituents in breadmaking with particular reference to the problem of staling. Cereal Chem. 9:65-70. 1932.

(7) Bailey, L. H.
Fermentation and gas losses in dough. Cereal Chem. 16:665-671. 1939.

(8) Baten, W. D.
Materials for removing taste effects in organoleptic tests. Jour. Home Econ. 39:30. 1947.

(9) Bengtsson, Kjell and Eric Helm.
Principles of taste testing. Wallerstein Laboratories Communications. 9:171-180. 1946.

(10) Blish, M. J. and R. C. Hughes.
Some effects of varying sugar concentrations in bread dough, on fermentation by-products, and fermentation tolerance. Cereal Chem. 9:331-335. 1932.

(11) Blish, M. J., R. M. Sandstedt and G. R. Astleford.
Sugars, diastatic activity and "gassing power" in flour. Cereal Chem. 9:378-392. 1932.

(12) Blish, M. J., R. M. Sandstedt and H. Platenius.
Correlation between diastatic power of flour and crust color in the test loaf. Cereal Chem. 6:121-127. 1929.

(13) Bliss, C. I., E. O. Anderson and R. E. Marland.
A technique for testing consumer preferences, with special reference to the constituent of ice cream. Storrs Agr. Expt. Sta. Bul. 252. 20 p. 1943.

(14) Cathcart, William H. and Steven B. Luber.
Modification of the "swelling power" test for stability of bread. Cereal Chem. 16:430-440. 1939.

(15) Cathcart, William H.
Review of progress in research on bread staling. Cereal Chem. 17:100-121. 1940.

(16) Crocker, E. C. and Washington Platt.
Food flavors - a critical review of the literature. Food Research 2:183-196. 1937.

(17) Dadswell, Inez W. and Joan F. Gardner.
The relation of alpha-amylase and susceptible starch to diastatic activity. Cereal Chem. 24:79-99. 1947.

(18) Dadswell, Inez W. and Joan F. Gardner.
Relationship of susceptible starch, alpha-amylase and sugars originally present in the flour to flour gassing power. Cereal Chem. 24:415-435. 1947.

(19) Eisenberg, Sylvan.
Gas production in yeast fermentation and its application. I. Volumetric versus manometric methods for the determination of gas production. Cereal Chem. 17:417-430. 1940.

(20) Eisenberg, Sylvan.
Gas production in yeast fermentation and its application. II. A volumetric method for the determination of gas production. Cereal Chem. 17:430-447. 1940.

(21) Elion, E.
A simple volumetric method for measuring gas production during dough fermentation. Cereal Chem. 10:245-249. 1933.

(22) Elion, E.
Some remarks on the varying influence of compressed yeast of different industrial origin on the gas retention of the dough, as recorded by a new instrument, the Chefaro balance. Cereal Chem. 16:598-609. 1939.

(23) Elion, E.
The importance of gas production and gas retention measurements during the fermentation of dough. Cereal Chem. 17:573-583. 1940.

(24) Eva, W. J., W. F. Geddes and B. Frisell.
A comparative study of the various methods of measuring flour gassing power. Cereal Chem. 14:458-480. 1937.

(25) Freilich, J.
Studies on bread staling. III. Influence of fermentation variables on bread staling and measured by compressibility and Farinograph procedures. Cereal Chem. 25:87-98. 1948.

(26) Geddes, W. F. and C. A. Winkler.
A study of the relative value of honey and sucrose in bread manufacture. Can. Jour. Research 3:543. 1930.

(27) Glabau, Charles A. and Pauline F. Goldman.
A study of certain physical properties of bread through the staling process with the use of the electronic cell. Cereal Chem. 15:541. 1938.

(28) Glabe, Elmer F.
The fermentometer, a gas production measuring device. Cereal Chem. 19:230-234. 1942.

(29) Heald, W. L.
Some factors which affect gas production during fermentation. Cereal Chem. 9:603-616. 1932.

(30) Helm, Erik and Trolle Berger.
Selection of a taste panel. Wallerstein Laboratories Communications. 9:181-194. 1946.

(31) Hoffman, Charles, T. R. Schweitzer and Gaston Dalby.
Factors affecting the growth of yeast in fermenting doughs. Cereal Chem. 18:342-349. 1941.

(32) Kendall, M. G.
Rank Correlation Methods. London: Charles Griffin and Co. 1948.

(33) Kuhlman, A. G. and E. P. Balasheva.
Staling of bread; influence of added ingredients on the process. Tekhnol. Protessy i Kontrol Pishchevoi. Ind. 175. 1938.

(34) Kuhlman, A. G. and O. N. Golossowa.
Bound water in breadmaking. Cereal Chem. 13:202-217. 1936.

(35) Landis, Quick and C. N. Frey.
Diastatic supplements for the A.A.C.C. baking test. Cereal Chem. 10:588-591. 1933.

(36) Lanning, J. H.
The effect of sucrose and maltose upon acid and gas production in doughs. Cereal Chem. 13:690-697. 1936.

(37) Larmour, R. K. and S. F. Brockington.
Studies on experimental baking tests. I. Effect of variation in baking formulas on gas production and loaf volume. Cereal Chem. 11:451-469. 1934.

(38) Markley, M. C. and C. H. Bailey.
An automatic method for measuring gas production and expansion in doughs. Cereal Chem. 9:591-594. 1932.

(39) Platt, Washington.
Staling of bread. Cereal Chem. 7:1-34. 1930.

(40) Platt, Washington and Raymond Powers.
Compressibility of bread crumb. Cereal Chem. 17:601-621. 1940.

(41) Rice, Whitman.
Sugars in bread. Cereal Chem. 15:672-677. 1938.

(42) Sandstedt, R. M. and M. J. Blish.
Yeast variability and its control in flour gassing power tests. Cereal Chem. 11:368-383. 1934.

(43) Sandstedt, R. M. and M. J. Blish.
The question of sugar levels in laboratory baking. Cereal Chem. 16:36-42. 1939.

(44) Simpson, A. G.
The mechanism of gas production in dough fermentation. Cereal Chem. 13:140-152. 1936.

(45) Swanson, E. C. and C. O. Swanson.
Gas production and gas retention as affected by type of flour, baking formula and amount of mixing. Cereal Chem. 23:432-440. 1946.

(46) Swanson, E. C. and C. O. Swanson.
Modification of gas production and gas retention properties of a dough by some surface-active reducing and oxidizing agents. Cereal Chem. 23:590-600. 1946.

(47) Waldon, C. C. and R. K. Larmour.
Studies on experimental baking tests. IV. Combined effects of yeast, salt and sugar on gassing rates. Cereal Chem. 25:30-40. 1948.

(48) Weiss, Francis Joseph.
Sugar in the baking industry. Bakers' Digest 21(6): 13-20. 1948.

(49) Weiss, Francis Joseph.
Sugar in the baking industry. II. Bakers' Digest 22(1):24-27. 1949.

(50) Whitcomb, W. O.
Oven spring of dough as influenced by sugar, salt and yeast. Cereal Chem. 13:698-702. 1936.

(51) Whymper, Robert.
The use of lecithin in bread. Baker's Helper 81(1014): 66, 82. 1945.

(52) Working, Earl B. and Swanson, E. C.
An automatic device for the measurement of gas production and gas retention in doughs. Cereal Chem. 23:210-216. 1946.