THE USE OF A NEW CORN BASED SWEETENER IN BAKERY PRODUCTS

by

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TABLE OF CONTENTS

LISTING OF TABLES

LISTING OF FIGURES

LISTING OF PLATES

INTRODUCTION

Sweetening agents in varying amounts are added to almost all bread formulas. Their functions include improving grain and texture, increasing volume, and promoting fermentation. There are many classes and types of sweetening agents varying in granulation from fine to coarse and in color from clear to a very dark brown.

The bread for this research was baked by the sponge-dough method. The bread formulation was based on 700 grams of flour. Four sweetening agents at three levels of concentration were employed. The sweetening agents used were sucrose, dextrose, corn syrup, and Pendex.

The Penick and Ford sugar product (Pendex) was a specially prepared and processed corn based sweetener developed for commercial use in bakery products.

This investigation was undertaken to relate the effects of Pendex at the various levels of concentration employed upon the final bread characteristics as compared with the other sweetening agents.

LITERATURE REVIEW

Sweeteners in Bread

Several sweetening agents or sugars are available for the baking industry today. The sugars most widely used are cane and beet sugars, both known to the chemist as sucrose. Sucrose must be broken down to dextrose (glucose) and fructose by the enzyme invertase before being metabolized by the yeast during normal bread dough fermentation. Another sugar which is used extensively by the baking industry is dextrose. This sugar is manufactured from cornstarch by hydrolysis with mineral acids and/or enzymes followed by a purification procedure. By this method almost pure dextrose (glucose) is produced (42).

While both sucrose and dextrose are widely used industrially, few investigations have compared directly their use as sweetening agents in baking. Weiss (93) and Rice (71) have reported that dextrose is much more readily fermentable than sucrose, and that after normal fermentation insufficient sugar remains to produce a loaf having a brown crust color and pleasant flavor. Work by Koch et al. (50) has demonstrated that sucrose is completely hydrolyzed at the end of the mixing period. The same workers also found dextrose to be fermented slightly faster than fructose until the concentration of fructose became greater than the concentration of dextrose. Then dextrose and fructose were fermented at equal rates.

Corn syrups are commercial sweetening agents used by the baking industry for production of bread and various confections. They provide a readily fermentable source of carbohydrates for the yeast (72). Corn syrups are produced by acid and/or enzyme conversion of corn starch. While they consist mainly of glucose, maltose, and water they usually contain varying amounts

of higher oligosaccharides depending on the degree of conversion and reversion (87). Cost of production and ease of handling may make corn syrup more economical to use than crystalline sugars for production of bakery products.

Honey is also used by the baking industry. This sweetening agent contains a mixture of dextrose and fructose. The ratio of these two sugars may vary but generally is close to one. Since honey is a natural product its chemical composition, flavor, aroma, and color tend to show great variations Johnson, et al.(44). These variations are largely due to differences in floral sources that are dependent upon area of production and weather conditions. Only during sugar shortages, such as in time of war, has the baking industry used large quantities of honey (81, 82).

Malt sugar (maltose) is present in malt syrup used in bakery products, and adds sweetness to the product. Most of the maltose is used in hard bread and roll production (87).

Lactose or milk sugar is found in both whole and skimmed milk. Lactose is not used as a separate ingredient but is present in milk and milk products. It is one of the sugars non-fermentable by bakers' yeast but can be broken down if malt flour containing the enzyme lactase is present in the dough.

Brown sugars are those which contain impurities due to mineral matter and moisture. Light brown sugar has been refined to the point where nearly all the impurities have been removed. The darker sugars still contain a greater per cent of mineral material and moisture. The main uses for these sugars are in products where flavor and color are desired (87).

The baker classifies sugars into two principal types: (1) simple sugars (monosaccharides) such as glucose, dextrose, fructose, etc. which are directly fermentable by yeast, i.e., they do not have to be converted by enzymes before they can serve as food for yeast. (2) The second type of sugars fall into the complex sugar (disaccharide) class. This class is made up of sucrose, maltose, etc. These sugars must be converted to simple sugars by enzymatic action before they can serve as food for yeast. Sultan (87) stated that the main functions of sugar in breadmaking are: (1) it serves as a form of food for the yeast during fermentation; (2) it provides good grain and texture; (3) it aids in moisture retention and prolongs freshness; (4) it promotes crust color; (5) and also adds nutritional value to the product.

Bread Staling

Bread staling during aging is of considerable interest from both theoretical and practical viewpoints. It is a complex phenomenon on which a great deal of research has already been performed but the mechanism and nature of changes are still not clearly understood. The literature indicates that staling is accompanied by certain changes in bread such as loss of taste and aroma, changes in softness of crust, changes in hardness and dryness of crumb, the loss of crumb swelling power, and a decrease in the amount of soluble starch in the crumb. Excellent reviews on staling have been reported by Alsberg (1), Platt (66), Cathcart (22), Schoch and French (76), and Geddes and Bice (28). An approximate chemical analysis shows little difference between fresh and stale bread (22). Karacsonyi (47) found that the acidity either remains constant or shows some decrease on bread staling.

The first ideas of bread crumb staling were that it was due entirely to the loss of moisture. However, as early as 1853, Boussingault (19) distinguished between the hardening of bread due to the evaporation of water and crumb firming due to starch retrogradation. He also recognized that heating of bread at 60°C or higher reversed the crumb firming. Von Bibra (91) confirmed Boussingault's findings. He showed that bread containing less than 35% moisture could not be refreshened by heating unless moistened first. Alsberg (1) found it significant that native starch granules when fully hydrated contain about 30% water. Horsford (37) was the first one to suggest that staling of bread was due to changes in the distribution of water between gluten and starch, explaining that gluten was dehydrated during baking while the starch retained most of the water He predicated that during aging gluten took up water from the starch.

Lindet (59) suggested that the non-soluble form of starch in aged bread crumb was aggregated starch. This change was called retrogradation of starch and was thought to be accompanied by the setting free of moisture to other components. This process was considered to be more rapid than the development of crumbliness of the crumb. Katz (48) explained the delay in crumbliness in terms of the time it takes for water to diffuse from the starch to the protein. This was verified later microscopically by Verschaffelt and Van Teutem (90). They observed that in fresh bread the starch granules were surrounded with a continuous thin gluten matrix. As the bread aged, the matrix separated from the starch forming air cells. This occurred without a change in the moisture content. Katz (48) believed that the moisture was shifted from the starch to other components of the crumb as the starch retrogradated. Ostwald (65) thought that the transfer of moisture was not a matter of retrogradation but rather one of syneresis. Both views are in agreement since syneresis does not exclude the possibility of retrogradation. Alsberg (1) believed that the separation of moisture during retrogradation was a special case of syneresis. Katz (48) established a means of following changes in bread crumb with time of storage. He followed the increase in crumbliness, hardness by feel, decrease of crumb swelling in water, and decrease in amount of soluble starch that could be extracted from the crumb at 30°C. He found that at temperatures lower than 50°C., bread staled and the rate of staling increased until a maximum was reached at 3°C. If the temperature was lowered below 3°C. the rate of staling decreased due to the immobilization of water and starch molecules by freezing. In fresh bread the starch was considered to exist as a mixture of amorphous and crystalline forms while in stale bread it was thought to be in a totally crystalline form (49). Hellman, et al. (33) showed by x-ray

diffraction pattern that the rate of development of crystallinity at different moisture contents differed with age but in all cases it was complete in 8 days. Reheating stale bread did not cause the x-ray diffraction patterns to revert completely to those of fresh bread. Kuhlmann and Golessowa (53) determined that the water binding capacity of bread crumb gradually decreases during staling.

It was suggested by Fuller (27) that during staling, gelatinized starch undergoes a reduction in its hydration capacity and therefore becomes less susceptible to alpha- and beta-amylase action. Freezing or the addition of sugars altered the dydration capacity but did not effect the susceptibility to amylase action. Moderate heating restored the susceptibility of the starch to alpha- and beta-amylase.

Hixon (35) concluded that since waxy maize starch was unable to retrograde rapidly due to its branched molecular structure, that bread staling was due to the amylose portion of the starch. Noznich, et al. (64) found that by increasing the percentage of waxy maize starch in bread it caused the crumb rigidity to decrease, whereas in substituting wheat starch with waxy maize starch, crumb compressibility increased but upon storage the compressibility of loaves decreased at about the same rate. This work suggested that bread staling was associated with the branched (amylopectin) portion of the wheat starch. Bread from synthetic flour became increasingly stale as the proportion of cross-linked starch increased (12). Bread with increasing levels of bacterial alpha-amylose was less firm. Zobel and Senti (94) showed by x-ray patterns that bread made with 40% cross bonded starch and a heat-stable enzyme changed less with storage than conventional bread. Changes in x-ray patterns, however, were not paralled by the changes in crumb firming. Gilles et al. (30) analyzed

the soluble starch in both fresh and stale bread and showed differences in the percentage of water-soluble pentosans and related this factor to the retrogradation of amylose.

Jackel, et al. (40) reported an increase in soluble crumb polysaccharides on storage that was most predominant at 8°C. The same workers also found significant increases in the soluble polysaccharides in bread when bacterial alpha-amylase was used. Jackel and his co-worders (39, 41) found that the soluble starch fraction of bread was not capable of appreciable retrogradation as evaluated by decreased susceptibility to beta-amylase and that the phenomena of staling of crumb starch was confined to the insoluble part of the crumb. With alpha-amylase, a high rate of digestibility was maintained over a prolonged storage period while the digestibility of starch by pancreatic amylase decreased during aging of the crumb.

Bechtel and Meisner (14, 15, 16) dealt with the staling problem by using flour fractions. If the moisture content of the bread remained constant, even though the flour fractions were varied, the staling rate of the crumb was essentially constant. The bread remained fresh longer if the moisture content of the bread was increased through the effect of the flour fraction. The amount of tailing fraction added directly affected the water absorption.

It has long been known that reheating will freshen bread provided it contains sufficient moisture. Katz (48) reported that bread stored at 60° to 90°C. in properly controlled humidity did not stale, but Fuller (27) reported that at even these temperatures bread may stale at a slow rate. Bacterial growth is a serious problem when bread is stored at such temperatures.

Bailey (9) found that bread stored for three days at -9°C. retained the characteristics of fresh bread after thawing. Cathcart and Luber (23)

and Cathcart (22) reported that bread stored at a temperature of -22°C. was somewhat stale, after being thawed, when judged by the crumb swelling power test. At a temperature of -35°C. the bread retained its organoleptic freshness for seventy days. The results found by Bechtel and Meisner (14, 15, 16) suggested that staling of bread crumb was most directly related to the starch during the first three days of storage but that gluten had its main effects after 3 days. Prentice, et al. (68) used a synthetic flour consisting of gluten, starch, starch tailings and the water solubles of rye flour to reveal the effect of the individual fractions on the crumb firmness. They found that increasing the protein content in synthetic flour, maintaining a constant ratio of gluten to water solubles, decreased the average crumb firmness and crumb firming rate. By using soft flour gluten, the average crumb firmness increased but the firming rate was not affected. Starch tailings decreased the average crumb firmness but not the rate.

Numerous substances have been reported by many workers as retarders of bread staling. Substances such as volatile and water-soluble aldehydes and strongly basic substances show a strong retarding effect. Since these materials are toxic the search for staleness retarders has concentrated upon naturally occurring food substances. There was no change in firmness of fresh bread crumb when oligo-saccharides appeared to accelerate staling. This contrasts with the effect of alpha-amylase on wheat starch degradation, which retards crumb firming. This may be explained by assuming that the oligo-saccharides served as an aggregating agent, while alpha-amylase split the starch to dextrins that tended to firm less readily (45). By reviewing these results it can be concluded that corn syrups of a relatively high dextrose equivalent appear to be preferable for bread. Steller and Bailey

(86) determined that bread baked from a high-protein flour staled more slowly than bread from a low-protein flour. The addition of a small percentage of rye flour was found by Alsberg (1) to improve keeping quality slightly. Alsberg also recommended the conservative use of yeast. Platt and Powers (67), Alsberg (1), and Hutchinson (38) found that milk in the formula has only a slight effect on retarding staleness.

Kuhlmann and Balasheva (52) reported that carbohydrates served as anti-staling agents in the following order of their effectiveness: maltose syrup, glucose syrup, dextrin, beet sugar, maltose, glucose, soluble starch, and potato starch. Barham and Johnson (10) stated that crumb firmness was affected by sugar concentration, with the minimum crumb firmness occurring at 2-4% concentration of any sugar but that the rate of firming was not affected. Hester, et al. (34) reported that a decrease in the hydration of starch granules occurred in the presence of sucrose. Thomas (88) found that sugar in amounts of 2-4% produced a slight retarding effect on the staling rate. Bailey (9) did not confirm the retarding effect of invert sugar and dextrinized starch on staling of the bread. He found that malt extract exerted an improving effect which was later attributed by Sandstedt and co-workers (74) to amylase action on the starch, while Brooks (20) thought the hygroscopic nature of malt sugar accounted for its moisture retaining effect.

Shortenings have been shown to enhance the keeping quality of bread. Carlin (21) has reported that the influence of fats on the keeping quality is a progressive effect. Loaves containing 6% shortening were found to possess superior keeping quality when compared to loaves of lower shortening content. Alsberg (1), Platt and Powers (67), and Hutchinson (38) reported

on the favorable effect of shortening on the tenderness of crumb. Two of the main anti-staling or bread softening agents that have been studied are the mono- and diglycerides and the polyoxyethylene monostearates (21, 26).

Hutchinson (38) recommended the use of a slack dough for prolonging freshness. Alsberg (1) reported the superiority of the sponge-dough method over the straight-dough method as a means of decreasing crumb firming. He also reported that the optimum fermentation temperature (71-79°F.) increased the keeping quality of the bread. Slow baking at relatively low temperatures prevented excessive moisture loss.

Wrapping of bread was introduced for the purposes of sanitation and reducing moisture loss. Wrapping does not retard chemical staling but does prolong the bread's shelf life. Cathcart (22) found that the moisture loss from sliced, wrapped bread from the time of wrapping until 72 hours was only about 2%. The moisture loss from unwrapped loaves occurred from the outer one-half inch of the bread crumb within 24 hours. Berg (17) determined that bread wrapped under warm conditions had the best keeping quality.

Staling is accompanied by a number of measurable physical changes that can be used as a measure of the degree of staleness. The methods used universally to determine crumb changes are those which measure the compressibility of the crumb.

Sugar Fermentation

The directly fermentable materials in a bread dough are some simple sugars which are either directly utilized by the yeast, such as glucose and fructose, or readily hydrolyzable, such as maltose and sucrose, through the action of the enzymes present in yeast. The latter yields glucose and/or fructose upon hydrolysis. Some of the indirectly fermentable sugars in dough include malto-oligosaccharides, dextrins, and starch. These substances are hydrolyzed by the amylases to eventually yield maltose. Some trisaccharides, such as raffinose and glucodifructose, are hydrolyzed by the enzyme invertase in yeast to yield fermentable sugars (63). Raffinose was found not to be completely hydrolyzed and the melibiose produced was not utilized by yeast (60). Glucofructans have also been reported to be partially hydrolyzed to fructose upon the action of invertase (13, 63).

Lactose which composes about 50% of the total weight of non-fat dry milk solids, was reported to be not hydrolyzed by the enzymes present in yeast and was completely unfermentable (8).

Although flour contains a very limited amount of directly fermentable sugars, a large percentage of the fermentable sugars present in dough are produced indirectly by the hydrolysis of flour. The combined action of alpha- and beta-amylases, as cited in American Association of Cereal Chemists, Method No. 22-16, (3), plays an important role in the production of maltose during fermentation. The glucofructan content varies considerably from one wheat to another (13, 63) as do the other indirectly fermentable sugars.

Atkin, et al. (8) conducted extensive studies on the fermentability of different sugars and their fermentation rates, the adaptation of bakers' yeast to maltose fermentation, and other factors that influence the rate of fermentation. There have been only limited studies of the fermentation of different sugars in dough, because of the need for analytical methods to study such a complex system.

Hopkins and Roberts (36) confirmed that glucose was fermented at slightly faster rate than fructose when both were present at a concentration of 2 to 8% and much faster at lower concentrations. Geddes and Winkler (29) reported that sucrose was hydrolyzed faster than it was fermented. The rate of sucrose fermentation was equivalent to that of an equimolecular mixture of glucose and fructose. The fermentation of glucose, fructose, and sucrose was almost instantaneous but the fermentation of maltose was found to require a much longer induction period than for the other sugars (70). Glucose and maltase (77) sucrose and oxygen (78) were found to be activators for the fermentation of maltose. Without the presence of all of these activators the induction period for maltose was extremely long. This observation (54, 62) was supported by gas production curves which measured the fermentation rate of the different sugars during sponge fermentation. The transference from sucrose fermentation to maltose fermentation was quite well marked by two maximum points.

Koch et al. (51) used a paper chromatography-elution method to study the change in concentrations of different sugars in dough. These workers found that sucrose was completely inverted within a short time and that the concentration of glucose decreased at a uniform rate throughout fermentation. The concentration of fructose was found to decline only when the glucose

concentration became quite low. When fructose was the only fermentable sugar present it also was fermented at a constant and uniform rate. These findings were confirmed by Griffith and Johnson (31). The maltose concentration in straight dough was found to increase as long as there were sufficient hexoses to support the fermentation; but in the doughs which contained no added sugar the maltose level began to decrease when the glucose and fructose levels became depleted. In a study of sponge doughs (56) reported that once the yeast became adapted to rapid maltose fermentation, the glucose and fructose concentrations had no effect on the rate of maltose fermentation. During the first forty minutes after remixing, the dough containing maltose produced more gas than those containing glucose or sucrose. Johnson et al. (43) studied brews without flour that contained 6% sucrose and found that 50% of the sugars were fermented within 1 1/2 hours, and only 10% of the sugar remained after 5 hours of fermentation.

The growth and activity of yeast is influenced by environmental conditions. Slator (80) found that the temperature affected the rate of fermentation of each sugar differently. He reported that bakers' yeast produces more CO_2 at 34°C than at 18°C. The optimum temperature is thought to lie between 25° and 35°C (69, 87). The retardation of yeast activity at high concentrations of sugar, due to the osmotic effect, has been studied by Hopkins and Roberts (36), Larmour and Brokington (55), and Matz (61). Different strains of yeasts were found by Thorn and Reed (89) to have different tolerance to variable sugar levels under high osmotic pressure. The osmotic effect of salt on the fermentation rate is much higher than that of sugars because salt is a completely ionized electrolyte (89, 92). The optimum pH range for yeast fermentation is in the acidic region near pH 5.0. According to Atkin et al. (8), and Leibowitz and Hestrin (58) this also

coincides with the optimum pH range for alpha- and beta-amylase activities. Pyler (69) found that in an unbuffered dough, the pH decreased during fermentation from pH 6.0 to about 5.0. When non-fat milk solids are added to a dough or brew the rate of decline in pH is slowed or sometimes stopped (43). It may become necessary to add certain acid salts to lower the pH in order to maintain an active fermentation and insure a good quality product (11).

No study of residual sugars in bread was reported by early workers. Rice (71) using a modified copper reduction technique found a higher fructose than glucose content in bread made from a formula containing sucrose. He also reported a lower maltose content in bread made by the sponge-dough method than in that made by the straight-dough method. Bohn (18) used special strains of yeasts which fermented glucose, fructose and sucrose but not maltose. He found no hexoses in breads made from no-sugar or 1% sucrose straight-doughs. With the use of 2% or more sucrose, the hexose content of the bread increased as the sugar level in the formula was increased. The analysis of eighteen commercial breads showed wide variations in the total and specific sugar contents. The hexose content varied from 0 to 3.54%, maltose from 0.15 to 2.85% and the total sugar content from 2.36 to 5.56% based on the crumb moisture.

Methods of Sugar Determination

Cold or hot boiling water can be used to extract sugars from biological materials (75). Craig (24) stated that pure water frequently extracts interfering substances such as acids, salts, and colloidal substances. For the extraction of sugars from flour or dough, pure water is undesirable because the amylases present will change the original sugar content upon wetting, while hot water will rapidly gelatinize the starch (57).

Seventy per cent (w/v) hot aqueous ethanol is generally used for extraction of sugar because of its rapid inactivating effect on enzymes present (24, 46).

To eliminate the substances that may interfere with quantitative determinations, the crude extracts can be subjected to one or more of the following treatments: filtration, centrifugation, decolorization, dialysis, ion-exchange and clarification by treatment with precipitating agents as stated in the Methods of the Association of Official Agriculture Chemists (7).

Many methods have been used for the quantitative determination of sugars. Most of the quantitative methods are based upon the oxidation of sugars containing a reducing keto or aldehyde group. The commonly used oxidizing agents are cupric and silver or ferricyanide ions. The reaction takes place at high temperatures under basic conditions (6, 85). The cupric ions are reduced to Cu_2O and can be determined gravimetrically, electrolytically, or by reoxidation. Oxidation-reduction titrations using methylene blue as the indicator are also used frequently. According to Halliwell (32) and Somogyi (84) ferricyanide is reduced to ferrocyanide and determined by iodometric titration or a spectrophotometric method. Stanek et al. (85) stated that both the cupric and ferricyanide oxidation of reducing sugars do not proceed

stoichiometrically. By carefully selecting and standardizing the method, controlling the conditions, and adjusting the concentration of the sugars in solution so that it falls within the optimum range; highly accurate and reproducible results can however be obtained.

A method based on the reaction with furfural or its derivatives has also been used. Heating with strong acids causes all the aldoses and ketoses with five carbon atoms or more to give rise to furfural or its derivatives. These products will readily undergo color reactions with phenols and amines. The reaction is specific for reducing sugars (25, 85).

Salomon and Johnson (73) reported that the enzymatic determination of glucose by the use of glucose-oxidase was very accurate and sensitive. Different strains of bakers' yeast have been used to determine individual sugars in the presence of other sugars (79, 83).

MATERIALS AND METHODS

Flour and Sugar Data

A good conventional bread flour milled from a blend of hard red winter wheats was obtained from the Rodney Milling Company. A chemical analysis of the flour is shown in Table I. The physical dough properties of the flour are included in Figures 1 and 2.

The objective of this study was to determine the acceptability of Pendex for use in bakery products. The Pendex product was compared with sucrose, dextrose, and corn gyrup for use in commercial bread production by the sponge-dough method. The bread formulation was standardized so that the only variable ingredient was the sweetening agent. Each sweetener was used on a total solids basis at 4, 6, and 8% level (Table II and III). The sucrose was a high grade commercial sugar. The dextrose was "cerelose" brand supplied by Corn Products Company. The corn syrup was of a high conversion fermentable type (44° Baume/64 D.E.) supplied by Corn Products Company. The Pendex was a corn sugar specially prepared and processed by Penick and Ford Company. The microscopic characteristics of the three sugars are shown in Plate I (P. 67). The manufacture's description of Pendex is given in Table IV.

TABLE I. FLOUR PROPERTIES

Flour Analysis *

Ash %	Protein %	Moisture %	Oxidation Requirement mg	Absorption %	Mixing Time Min.
0.45	12.4	12.8	none	62.4	5.5

* Air-dry Moisture basis

TABLE II. SUGAR MOISTURE AND SOLIDS DETERMINATION

Sugar Analysis		
	Moisture, %*	Solids, %
Sucrose	0.0	100.0
Pendex	9.0	91.0
Dextrose	9.0	91.0
Corn Syrup	16.6	83.4

* Determined after 18 hours at 80°F.

TABLE III. THE PERCENTAGE AND GRAMS OF SUGAR USED IN DOUGHS

	Sugar Level, (%) *		
	4	6	8
	Sugar Grams		
Sucrose	28	42	56
Pendex	31	46	62
Dextrose	31	46	62
Corn Syrup	34	50	67

* Based on Total Solids.

TABLE IV. MANUFACTURER'S DESCRIPTION OF PENDEX

Analysis			
Moisture	Ash	pH	D.E.
10.5 Max.	0.06 Max.	4.5-6.5	95 Min.

Sugars Present		
Dextrose	Maltose	Higher Sugars
92% Min.	5% Max.	3% Max.

PENDEX -- is a free flowing dry product composed of spherical porous granules which are aggreates of dextrose micro-crystals intermixed and coherred with a small proportion of higher molecular weight sugars. It is a result of complete enzymatic hydrolysis of starch.

Physical Dough Testing

The farinograph measures and records the resistance of a dough to mixing. It is used to evaluate absorption of flours and to determine stability and other characteristics of doughs during mixing. Approved Method No. 54-21 of the American Association of Cereal Chemists (4) was used. From the farinogram (Figure 1) the absorption and peak time were taken as the basis for the flour mixing study. To determine the optimum absorption several doughs were mixed using the farinograph absorption, plus 3%, and minus 3% absorption from the farinograph curve. The mixing time was also varied from the peak time by plus two, plus four, and minus two minutes (Table V).

The amylograph value, or malt index, provides information on the probable effect of malt alpha-amylase during the baking process. By use of the standard amylograph method (22-10) of the American Association of Cereal Chemists (5), for measurement of diastatic activity of flour, it was found that the amylograph curve peaked very near the 500 Brabender Unit line indicating that the addition of malt was not necessary (Figure 2).

Variable oxidation levels were used in combination with the flour mixing study (Table V). The doughs contained potassium bromate ($KBRO_3$) at either 10, 20, or 30 parts per million (ppm) level. By carefully studying the external and internal characteristics of the baked bread it was determined that the best product resulted from less than 10 ppm of oxidant. The main external characteristics observed were volume, conformation, and crust characteristics. Internally the bread was scored for grain and texture.

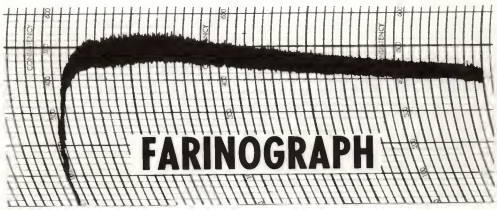
By evaluating this study objectively on the basis of specific volume and total score (Table V), the following optimum conditions were determined: (1) mixing time, 5.5 min.; (2) absorption, 62.5%; (3) oxidant level, 0 ppm.

Extensiograph: Using the official American Association of Cereal Chemists method (54-10) the values for the following extensiograph measurements are recorded in (Table VI).

1) Resistance to extension: obtained as height of curve in Brabender Units at 5 cm. on kymograph chart.
2) Extensibility: total length of curve in cm.
3) Evaluation of area under curve with a planimeter: value reported in sq. cm.

HRW BLEND

PROTEIN 12.4%



ABSORPTION	62.4%
PEAK TIME	6.5 MIN.
STABILITY	10.0 MIN.
TOLERANCE INDEX MTI	40 B.U.
VALORIMETER	55 UNITS
ARRIVAL TIME	2.0 MIN.
DEPARTURE TIME	12.0 MIN.
TIME TO BREAKDOWN	12.5 MIN.

Figure 1. Farinograph Curve and Data From Standard Flour.

HRW BLEND

PROTEIN 12.4%

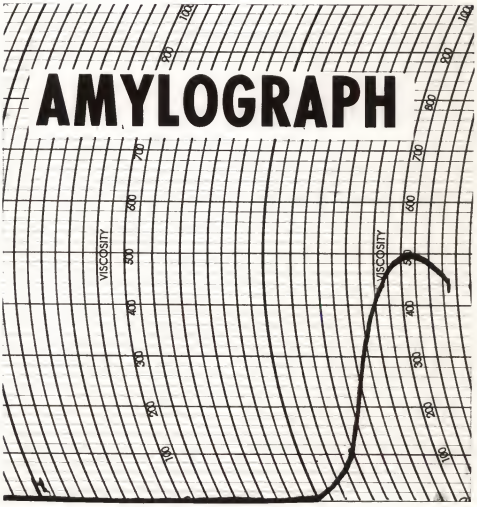


Figure 2. Amylograph Curve of Standard Flour.

TABLE V. TEST BAKING RESULTS USING STANDARD FLOUR

	Oxidation Levels (ppm)					
	10	20	30	10	20	30
Mixing and Absorption	Specific Volume			Total Score		
Mixing Time (Peak Time)						
+3% - - - - - - - - -	6.5	6.6	6.7	74.5	74.0	71.0
Farinograph Absorption - - -	6.9	6.8	6.9	77.0	75.5	72.0
-3% - - - - - - - - -	7.1	7.0	7.0	78.0	77.0	74.0
Mixing Time (+2 min.) - - - - - -						
+3% - - - - - - - - -	5.7	5.8	5.8	63.5	62.5	62.0
Farinograph Absorption - - -	5.9	5.9	6.0	65.0	64.5	63.0
-3% - - - - - - - - -	6.1	6.2	6.1	68.0	67.0	63.0
Mixing Time (+4 min.) - - - - - -						
+3% - - - - - - - - -	5.6	5.6	5.8	54.5	53.0	53.0
Farinograph Absorption - - -	5.5	5.5	5.5	56.0	55.5	54.0
-3% - - - - - - - - -	5.3	5.4	5.5	59.5	58.0	58.5
Mixing Time (-2 min.) - - - - - -						
+3% - - - - - - - - -	6.6	6.7	6.7	74.5	72.0	70.0
Farinograph Absorption - - -	6.4	6.6	6.5	68.0	65.0	64.5
-3% - - - - - - - - -	6.2	6.2	6.2	66.5	66.0	63.5

TABLE VI. PHYSICAL DOUGH TESTS BY EXTENSIOGRAPH METHOD

	Extensiograph Values		
	Resistance At 5 cm. B.U.	Extensibility cm.	Area sq. cm.
45 min.	270	25.7	150.22
	255	24.5	148.93
	250	24.3	144.54
	235	23.6	143.19
90 min.	335	23.1	182.54
	330	23.1	175.50
	320	22.4	160.28
	310	20.0	152.93
135 min.	360	21.4	151.83
	345	20.5	145.51
	320	18.6	135.64
	300	17.4	128.36

Baking Method

The bread was made by a sponge-dough formulation (Table VII). The sponge was mixed with 70% of the total water for two minutes. The mixture was then placed into a fermentation pan and put into the fermentation cabinet at 86°F and 86% humidity for a period of four hours. After the fermentation period the sponge and dough with the remaining water were remixed at medium speed for 5.5 minutes on a Hobart A-200 mixer with a MacDuffy bowl. After twenty minutes in the fermentation cabinet each dough was divided and scaled at 18 ounces (511 gms). The two scaled dough pieces were rounded by hand and given a twenty minute rest period before being moulded on a drum type moulder. The moulded doughs were panned in single pre-glazed pans. The pans containing the doughs were then placed into the proof box for 55 minutes at 98% humidity and 110°F. The bread was baked at 425°F for 25 min. in a gas, reel oven. The finished baked product was allowed to cool for several hours before the volume (seed displacement) and weights were recorded. The loaves were bagged in individual type plastic bags, tied, and stored in an open door storage cabinet at room temperature.

Eight doughs were mixed per day. Each dough was divided into two loaves so a total of sixteen loaves were baked per day. Four loaves of bread contained sucrose, four Pendex, four dextrose, and four corn syrup all at a given concentration based on total solids. One day following baking, four loaves of bread each containing a different one of the four sugars were placed in the freezer (-10°F) for storage. A duplicate of these loaves was evaluated for total score, crust and crumb reflectance, pH and titratable acidity (T.A.), penetrometer readings, and the bread sugar was extracted from a ten-gram

sample. The remaining loaves of bread were stored in plastic bags at room temperature for determination of penetrometer readings after three and six days of storage respectively.

Five baking replications were made at the 4, 6 and 8% levels of each sweetening agent.

TABLE VII. THE CONTROL BREAD FORMULA

Sponge Ingredients

	Percentage **	Grams
Flour	70.0	483.0
Yeast Food *	0.5	3.5
Yeast	2.5	17.5
Water	70.0 of total	306 ml.

Dough Ingredients

	Percentage **	Grams
Flour	30.0	207.0
Sugar ***	4,6,8	(Table III)
Salt	2.0	14.0
Shortening	3.0	21.0
Milk	1.5	10.5
Calcium Propionate	0.15	1.0
Water	30.0 of total	131 ml. base (variable with moisture of sugar)

* Fermaloid
** All ingredients based on flour 100% (700 gm) at 14% moisture
*** Sugar based on total solids

Objective Scoring Methods

Bread Scoring Procedure: A standard scoring system was designed and used throughout the entire project (Table VIII). The maximum score possible with this system was 100. The volume score was allotted in relationship to specific loaf volume (cc/gm). The conversion values for specific volume score are shown in (Table IX). A specific volume of 7.1 to 7.5 was considered optimum and given the maximum score of 20 points. The other characteristics scored included a maximum of 10 points each for crust color, symmetry, break and shread, and crumb color; and a maximum of 20 points each for crumb grain and crumb texture.

Penetrometer Determinations: A storage study was carried out using a Precision Penetrometer to measure the compressability of bread after it had been bagged and stored 1, 3, or 6 days at room temperature. The penetrometer was calibrated into one-tenth millimeter divisions. Three slices of bread were placed together beneath the steel, cone-shaped disc. The disc and a connecting rod weighing a total of 270 grams were lowered until the point of the disc came into contact with the product. The rod was then released allowing the disc to drop onto the product. The compressability was recorded in tenths of a millimeter in triplicate from each loaf of bread.

Crumb and Crust Color Determinations: Crumb and crust colors were measured with a Photovolt Reflectometer Model 610, equipped with a green filter. The higher the reading the less color was present. Results for the crust color were reported as averages of three measurements per loaf. The results of the crumb color were reported as averages of fifteen measurements for each loaf of bread.

TABLE VIII. BREAD EVALUATION

Scoring Procedure (Max.)							
Specific Volume	Crust Color	Symmetry	Break & Shread	Grain	Texture	Crumb Color	Total Score
20	10	10	10	20	20	10	100

Sugar Extraction: Extraction of sugar from either dough or bread was carried out by placing 10 grams of the material into a Waring Blender (steel cup) with 50 ml. of boiling 75% (v/v) ethyl alcohol solution. The product was homogenized for three min. at medium speed, rinsed into a 100 ml. volumetric flask and diluted to volume with 75% ethanol.

The dough samples were obtained and extracted during the scaling stage of the baking process. The extraction from bread samples were made the day following the baking of the bread.

The extracts were centrifuged in a refrigerated centrifuge at 6°C. and 3600 R.P.M. for twenty minutes. The supernatant was then removed, placed in labeled sample bottles and stored at -10°F. until reducing sugar tests could be determined.

The purpose of the hot alcohol solution was three fold; first to stop the activity of yeast enzymes and other enzymes rapidly and to precipitate macromolecules. The final reason was as a preservative in the storage of the solutions to prevent bacterial growth and enzymatic changes.

pH and Titratable Acidity: The hydrogen-ion activity (pH) and the titratable acidity (T.A.) were determined on the dough as it came out of the fermentation and on the baked product. Ten grams of dough or bread was placed in a Waring Blender with 90 ml. of distilled water and homogenized for one minute at high speed. The pH was then read directly off an Expandomatic pH meter and recorded. The titratable acidity was then determined by slowly adding 0.1 N. sodium hydroxide solution until a pH of 8.5 was reached, which is very close to the phenophthalein end point.

The pH meter was checked and standardized every day by using two known buffers. The standard buffer solutions used were pH 4.01 and 9.18 and readings were corrected to room temperature.

TABLE IX. SPECIFIC VOLUME LOAF SCORE CONVERSION FOR BREAD

Specific Volume (cc/gm)	Loaf Score (pts.)	Specific Volume (cc/gm)	Loaf Score (pts.)
8.0		5.5	
7.9		5.4	
7.8	19	5.3	16
7.7		5.2	
7.6		5.1	
7.5		5.0	
7.4		4.9	
7.3	20	4.8	15
7.2		4.7	
7.1		4.6	
7.0		4.5	
6.9		4.4	
6.8	19	4.3	14
6.7		4.2	
6.6		4.1	
6.5		4.0	
6.4		3.9	
6.3	18	3.8	13
6.2		3.7	
6.1		3.6	
6.0		3.5	
5.9		3.4	
5.8	17	3.3	12
5.7		3.2	
5.6		3.1	

Measurement of Reducing Sugars

It has been general practice for cereal chemists to measure the reducing power of a solution of sugar extracts by one of the various methods described in the Literature Review Section. The results are usually expressed as the equivalent of either maltose or glucose. However, there is usually more than one sugar present in the extract and the reducing powers of the different sugars may be greatly different from one another. Therefore, such a result may be ambiguous and misleading, and should always be carefully interpretated.

In this experiment, the total reducing sugar values of the extracts were reported as glucose equivalents, because in this particular case, these values are quite reliable indexes of the readily fermentable sugars present in the dough. Since 1.5% milk was included in the formula, some reduction due to lactose would have occured. The reducing power was however mainly attributed to fructose, glucose, and maltose---three principal sugars fermentable by baker's yeast.

The Folin-Wu blood sugar determination method was chosen for the following reasons: (1) excellent reproducibility with linear relationship between sugar concentration and absorbance when sugar concentration is under 0.03%; (2) highly sensitive, suitable for micro-analysis; (3) reagents are relatively easy to prepare and stable, frequent caliberation of standard curve was unnecessary; (4) nearly stoichiometric oxidation of sugar under the optimum conditions. The reducing power of glucose was found to be very close to that of fructose and twice that of maltose if a longer reaction time was used.

Reagents:

Alkaline Copper Solution-- Forty grams of anhydrous Na_2CO_3 was dissolved in 400 ml. of water, 7.5 grams tartaric acid was added. After it dissolved,

4.5 grams $CuSO_4 \cdot 5H_2O$ was added, and the solution was made up to a volume of one liter.

Phosphomolybdic Acid Solution-- To 35 grams of molybdic acid and 5 grams $Na_2WO_4 \cdot 2H_2O$, 200 ml. of 10% NaOH and 200 ml. water were added and the solution was boiled vigorously for 20-40 min. It was then cooled and diluted to about 350 ml., 125 ml. of concentrated 85% H_3PO_4 was added and the solution diluted to 500 ml.

Procedure: Two milliliters of standard sugar solution or sugar solution to be determined was transferred to a Folin-Wu tube. Two milliliters of alkaline copper solution was added. The tube was placed in a boiling water bath for 20 min. After boiling, the tubes were cooled in running water without shaking. Then 2 ml. phosphomolybdic acid reagent was added and the solution was diluted to the mark (25 ml.) after 1 min., and mixed thoroughly. Absorbance was measured on the spectrophometer at 420 mμ with reference to a reagent blank set at zero.

Calculation of The Results: The total reducing sugars in doughs and bread crumb extracts were calculated by use of the following formula, (the results were all reported in glucose equivalents):

$$\frac{\text{Absorbance of the Standard (conc: 0.1 mg./ml.) x Times of Dilution}}{\text{Absorbance of the Unknown}}$$

The Folin-Wu method for the determination of reducing sugars appeared to be highly accurate and reproducible. With standard glucose solutions, it was found that the color reaction between 0.0 and 0.4 mg/ml. followed Beer's Law. The standard curve for glucose using the Folin-Wu method is presented in Figure 3.

The boiling time suggested in the literature was 8 min., but it was found that 20 min. boiling was required to oxidize maltose stoichiometrically. The absorbance values of glucose and fructose were not affected by the longer boiling time.

For accurate measurement, it was essential to dilute the extracts properly so that the final sugar concentration would give an absorbance within the optimum range, that corresponds to 0.005 to 0.30 mg. of glucose per ml.

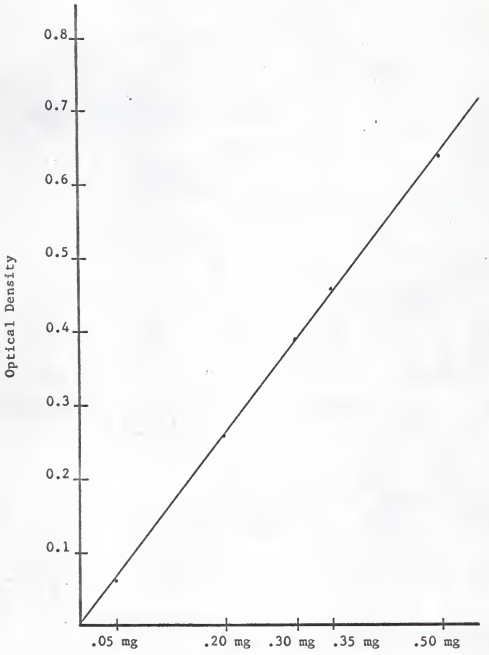


Figure 3. Standard Glucose Curve

RESULTS AND DISCUSSION

Statistical Analysis of Results

A general computer program was developed to calculate all statistical analyses. The program was written in Fortran IV language for an IBM 360 computer.

Significant differences were reported at either the 1 or 5% probability level.

pH: Statistical analysis for dough pH (Table X) of the four sweeteners showed that dextrose produces a product with a significantly higher pH than that of the dough containing sucrose (1% level) and also higher than that of the dough containing Pendex (5% level). There were, however, no significant differences caused by any of the other sweeteners. It was also found that 6% sweetener solids in dough gave a significantly higher pH in dough than 4% sweetener solids (1% level) and that 8% solids gave a significantly higher pH (5% level) than that of the dough with 4% sweetener solids.

The corn syrup product was found to give a significantly higher bread pH (5% level) than the bread made from dextrose. No other significant differences due to sweetener type or level were found from the analysis of bread pH (Table XI).

Titratable Acidity: When examining the data for titratable acidity of both the dough and bread no significant differences were determined between sweetener types or levels (Tables XII, XIII).

Penetrometer: The penetrometer readings measured the bread compressability and gave an indication of the amount of retrogradation or staling that had occurred (Tables XIV, XV, XVI). Statistical analysis of penetrometer readings after the bread had been stored for one day indicated that the corn syrup product gave a significantly higher reading (5% level) than did the dextrose

TABLE X. DOUGH pH

LSD of Sweetener Types 0.0393 5% and 0.0524 1%

LSD Table

Treatment	Means	X-1	X-2	X-4	X-3
Dextrose (3)	5.4500	0.0533**	0.0433*	0.0300	0.0000
Corn Syrup (4)	5.4200	0.0233	0.0133	0.0000	
Pendex (2)	5.4067	0.0100	0.0000		
Sucrose (1)	5.3967	0.0000			

LSD of Sweetener Levels 0.0340 5% and 0.0454 1%

LSD Table

Treatment	Means	X-1	X-3	X-2
6 % (2)	5.4375	0.0475**	0.0100	0.0000
8 % (3)	5.4275	0.0375*	0.0000	
4 % (1)	5.3900	0.0000		

* 5% Level Significance

** 1% Level Significance

TABLE XI. BREAD pH

LSD of Sweetener Types 0.0685 5% and 0.0914 1%

LSD Tables

Treatment	Means	X-3	X-1	X-2	X-4
Corn Syrup (4)	5.3033	0.0733*	0.0333	0.0167	0.0000
Pendex (2)	5.2867	0.0567	0.0167	0.0000	
Sucrose (1)	5.2700	0.0400	0.0000		
Dextrose (3)	5.2300	0.0000			

LSD of Sweetener Levels 0.0593 5% and 0.0791 1%

LSD Table

Treatment	Means	X-1	X-2	X-3
8% (3)	5.2925	0.0375	0.0225	0.0000
6% (2)	5.2700	0.0150	0.0000	
4% (1)	5.2550	0.0000		

* 5% Level of Significance

** 1% Level of Significance

TABLE XII. TITRATABLE ACIDITY OF DOUGH

LSD of Sweetener Types 4.6416 5% and 6.1904 1%

LSD Table

Treatment	Means	X-1	X-4	X-2	X-3
Dextrose (3)	53.9333	1.9333	1.8000	0.8667	0.0000
Pendex (2)	53.0667	1.0667	0.9333	0.0000	
Corn Syrup (4)	52.1333	0.1333	0.0000		
Sucrose (1)	52.0000	0.0000			

LSD of Sweetener Levels 4.0198 5% and 5.3610 1%

LSD Table

Treatment	Means	X-3	X-2	X-1
4% (1)	54.1500	2.8000	1.3000	0.0000
6% (2)	52.8500	1.5000	0.0000	
8% (3)	51.3500	0.0000		

* 5% Level of Significance

** 1% Level of Significance

TABLE XIII. TITRATABLE ACIDITY OF BREAD

LSD of Sweetener Types 2.6538 5% and 3.5393%

LSD Table

Treatment	Means	X-2	X-4	X-3	X-1
Sucrose (1)	51.3333	0.8667	0.4000	0.0667	0.0000
Dextrose (3)	51.2667	0.8000	0.3333	0.0000	
Corn Syrup (4)	50.9333	0.4667	0.0000		
Pendex (2)	50.4667	0.0000			

LSD of Sweetener Levels 2.2983 5% and 3.0651 1%

LSD Table

Treatment	Means	X-2	X-1	X-3
8% (3)	51.8500	1.5500	1.0000	0.0000
4% (1)	50.8500	0.5500	0.0000	
6% (2)	50.3000	0.0000		

* 5% Level of Significance

** 1% Level of Significance

TABLE XIV. PENETROMETER, DAY 1

LSD of Sweetener Types 10.8441 5% and 14.2523 1%

LSD Table

Treatment	Means	X-3	X-1	X-2	X-4
Corn Syrup (4)	140.3778	13.0000*	10.5111	2.6667	0.0000
Pendex (2)	137.7111	10.3333	7.8444	0.0000	
Sucrose (1)	129.8667	2.4889	0.0000		
Dextrose (3)	127.3778	0.0000			

LSD of Sweetener Levels 9.3913 5% and 12.3428 1%

LSD Table

Treatment	Means	X-3	X-2	X-1
4% (1)	136.3167	4.9833	2.4667	0.0000
6% (2)	133.8500	2.5167	0.0000	
8% (3)	131.3333	0.0000		

* 5% Level of Significance

** 1% Level of Significance

TABLE XV. PENETROMETER, DAY 3

LSD of Sweetener Types 4.0243 5% and 5.2890 1%

LSD Table

Treatment	Means	X-3	X-1	X-4	X-2
Pendex (2)	62.5111	7.5111**	1.4444	0.8444	0.0000
Corn Syrup (4)	61.6667	6.6667**	0.6000	0.0000	
Sucrose (1)	61.0667	6.0667**	0.0000		
Dextrose (3)	55.0000	0.0000			

LSD of Sweetner Levels 3.4851 5% and 4.5804 1%

LSD Table

Treatment	Means	X-3	X-2	X-1
4% (1)	64.8000	8.1500**	6.0667**	0.0000
6% (2)	58.7333	2.0833	0.0000	
8% (3)	56.6500	0.0000		

* 5% Level of Significance

** 1% Level of Significance

TABLE XVI. PENETROMETER, DAY 6

LSD of Sweetener Types 2.0441 5% and 2.6866 1%

LSD Table

Treatment	Means	X-2	X-3	X-1	X-4
Corn Syrup (4)	48.2889	4.8889**	4.8444**	2.9333**	0.0000
Sucrose (1)	45.3556	1.9556	1.9111	0.0000	
Dextrose (3)	43.4444	0.0444	0.0000		
Pendex (2)	43.4000	0.0000			

LSD of Sweetener Levels 1.7703 5% and 2.3266 1%

LSD Table

Treatment	Means	X-3	X-1	X-2
6% (2)	46.0000	1.7333	0.9000	0.0000
4% (1)	45.1000	0.8333	0.0000	
8% (3)	44.2667	0.0000		

* 5% Level of Significance

** 1% Level of Significance

product. There were no measured significant differences between the readings on breads made with different sweetening levels after one day of storage.

Penetrometer readings taken after the third day of storage indicated that different rates of staling had occurred in breads made with different types of sweetener. Breads made with Pendex, sucrose, and corn syrup all gave significantly larger penetrometer readings than that made with dextrose (1% level). Four per cent sweetener solids produced less evidence of staling (1% level) than 6 and 8% sweetener solids.

After six days of storage a considerable amount of staling was evident. The product maintaining the greatest amount of compressability was determined to be the bread containing corn syrup. It was significantly less stale (1% level) than the bread containing any one of the three other sweeteners. Sweetener level had no significant effect upon penetrometer measurements of staling after the bread had been stored for six days.

Crust Reflectance: Reflectance of the bread crust and crumb (Tables XVII, XVIII) was measured by a reflectometer. The larger reading indicated that less color was present than when a smaller reading was observed. The results indicated that the greatest amount of residual sugar present in dough after fermentation and available for browning of crust was in doughs containing the sweeteners in the following order: Sucrose, dextrose, Pendex, and corn syrup; although no significant differences were observed between doughs containing dextrose and Pendex. As was expected bread baked with 4% sweetener solids was significantly lighter in crust color than bread containing 6% solids, which in turn was significantly lighter than bread containing 8% sweetener solids each at the 1% level.

TABLE XVII. CRUST REFLECTANCE

LSD of Sweetener Types 0.7798 5% and 1.0249 1%

LSD Table

Treatment	Means	X-1	X-3	X-2	X-4
Corn Syrup (4)	18.0000	4.8889**	3.6889**	3.6667**	0.0000
Pendex (2)	14.3333	1.2222**	0.0222	0.0000	
Dextrose (3)	14.3111	1.2000**	0.0000		
Sucrose (1)	13.1111	0.0000			

LSD of Sweetener Levels 0.6754 5% and 0.8876 1%

LSD Table

Treatment	Means	X-3	X-2	X-1
4% (1)	18.6167	6.5333**	4.5000**	0.0000
6% (2)	14.1167	2.0333**	0.0000	
8% (3)	12.0833	0.0000		

* 5% Level of Significance

** 1% Level of Significance

TABLE XVIII. CRUMB REFLECTANCE

LSD of Sweetener Types 14.6164 5% and 19.2102 1%

LSD Table

Treatment	Means	X-4	X-2	X-1	X-3
Dextrose (3)	67.1156	10.8844	10.6356	10.3356	0.0000
Sucrose (1)	56.7800	0.5489	0.3000	0.0000	
Pendex (2)	56.4800	0.2489	0.0000		
Corn Syrup (4)	56.2311	0.0000			

LSD of Sweetener Levels 12.6582 5% and 16.6365 1%

LSD Table

Treatment	Means	X-2	X-3	X-1
4% (1)	63.2983	6.3350	6.1050	0.0000
8% (3)	57.1933	0.2300	0.0000	
6% (2)	56.9633	0.0000		

* 5% Level of Significance

** 1% Level of Significance

Crumb Reflectance: There were no significant differences observed due to sweetener types or levels of concentration in the bread when measuring the crumb reflectance.

Bread Yield: The dough containing the 8% sweetener solids gave a significantly larger bread yield than did the product containing 4% sweetener solids (5% level). No differences were found due to sweetening types (Table XIX).

Specific Volume: The specific volume was obtained by dividing loaf volume by the loaf weight. The statistical analysis for specific volume of bread indicated no significant differences between sweetener type or level (Table XX).

Crust Color: The scores reported for bread crust and crumb color were a visual determination (Table XXI, XXII). Significant differences were found due to sweetening type. The crust color produced by Pendex had a significantly higher score than the corn syrup and dextrose (1 and 5% level). Products containing sucrose and dextrose were also significantly darker in crust color than the corn syrup product (1% level). Bread with 6 and 8% sweetener solids gave a significantly darker crust color than did that with the 4% sweetener solids (1% level).

Symmetry: No significant differences were found by the statistical analysis of the bread symmetry for either sweetener type or level (Table XXIII).

Break and Shread: Sucrose produced a loaf of bread with a significantly better break and shread than that in which dextrose was used. There were, however, no significant differences between breads baked with the other sugars. The three sweetener levels produced no significant differences in the final baked product (Table XXIV).

Grain: It was evident that sucrose produced bread with a significantly better grain than was obtained by the use of dextrose or corn syrup (1% level). Bread

TABLE XIX. BREAD YIELD

LSD of Sweetener Types 9.9656 5% and 13.0976 1%

LSD Table

Treatment	Means	X-4	X-2	X-1	X-3
Dextrose (3)	429.4167	9.9000	3.0500	0.6333	0.0000
Sucrose (1)	428.7833	9.2667	2.4167	0.0000	
Pendex (2)	426.3667	6.8500	0.0000		
Corn Syrup (4)	419.5167	0.0000			

LSD of Sweetener Levels 8.6304 5% and 11.3429 1%

LSD Table

Treatment	Means	X-1	X-2	X-3
8% (3)	429.1875	9.0250*	0.4750	0.0000
6% (2)	428.7125	8.5500	0.0000	
4% (1)	420.1625	0.0000		

* 5% Level of Significance

** 1% Level of Significance

TABLE XX. SPECIFIC VOLUME

LSD of Sweetener Types 0.7332 5% and 0.9779 1%

LSD Table

Treatment	Means	X-3	X-4	X-1	X-2
Pendex (2)	19.1333	0.5333	0.2000	0.2000	0.0000
Sucrose (1)	18.9333	0.3333	0.0000	0.0000	
Corn Syrup (4)	18.9333	0.3333	0.0000		
Dextrose (3)	18.6000	0.0000			

LSD of Sweetener Levels 0.6350 5% and 0.8469 1%

LSD Table

Treatment	Means	X-3	X-2	X-1
4% (1)	19.1500	0.5000	0.2500	0.0000
6% (2)	18.9000	0.2500	0.0000	
8% (3)	18.6500	0.0000		

* 5% Level of Significance

** 1% Level of Significance

TABLE XXI. CRUST COLOR

LSD of Sweetener Type 0.4180 5% and 0.5575 1%

LSD Table

Treatment	Means	X-4	X-3	X-1	X-2
Pendex (2)	7.3667	1.5000**	0.5000*	0.1000	0.0000
Sucrose (1)	7.2667	1.4000**	0.4000	0.0000	
Dextrose (3)	6.8667	1.0000**	0.0000		
Corn Syrup (4)	5.8667	0.0000			

LSD of Sweetener Levels 0.3620 5% and 0.4828 1%

LSD Table

Treatment	Means	X-1	X-3	X-2
6% (2)	7.0750	0.7000**	0.0000	0.0000
8% (3)	7.0750	0.7000**	0.0000	
4% (1)	6.3750	0.0000		

* 5% Level of Significance

** 1% Level of Significance

TABLE XXII. CRUMB COLOR

LSD of Sweetener Type 0.4180 5% and 0.5575 1%

LSD Table

Treatment	Means	X-3	X-2	X-1	X-4
Corn Syrup (4)	7.7000	0.1667	0.0667	0.0333	0.0000
Sucrose (1)	7.6667	0.1333	0.0333	0.0000	
Pendex (2)	7.6333	0.1000	0.0000		
Dextrose (3)	7.5333	0.0000			

LSD of Sweetener Levels 0.3620 5% and 0.4828 1%

LSD Table

Treatment	Means	X-1	X-3	X-2
6% (2)	7.7500	0.3500	0.0000	0.0000
8% (3)	7.7500	0.3500	0.0000	
4% (1)	7.4000	0.0000		

* 5% Level of Significance

** 1% Level of Significance

TABLE XXIII. SYMMETRY

LSD of Sweetener Type 0.5334 5% and 0.7113 1%

LSD Table

Treatment	Means	X-3	X-2	X-1	X-4
Corn Syrup (4)	6.8333	0.3667	0.2000	0.1667	0.0000
Sucrose (1)	6.6667	0.2000	0.0333	0.0000	
Pendex (2)	6.6333	0.1667	0.0000		
Dextrose (3)	6.4667	0.0000			

LSD of Sweetener Levels 0.4619 5% and 0.6160 1%

LSD Table

Treatment	Means	X-1	X-2	X-3
8% (3)	6.7750	0.2250	0.1500	0.0000
6% (2)	6.6250	0.0750	0.0000	
4% (1)	6.5500	0.0000		

* 5% Level of Significance

** 1% Level of Significance

TABLE XXIV. BREAK AND SHREAD

LSD of Sweetener Type 0.6455 5% and 0.8609 1%

LSD Table

Treatment	Means	X-3	X-4	X-2	X-1
Sucrose (1)	7.2667	0.8333*	0.5000	0.3333	0.0000
Pendex (2)	6.9333	0.5000	0.1667	0.0000	
Corn Syrup (4)	6.7667	0.3333	0.0000		
Dextrose (3)	6.4333	0.0000			

LSD of Sweetener Levels 0.5590 5% and 0.7455 1%

LSD Table

Treatment	Means	X-1	X-3	X-2
6% (2)	7.1000	0.4250	0.3250	0.0000
8% (3)	6.7750	0.1000	0.0000	
4% (1)	6.6750	0.0000		

* 5% Level of Significance

** 1% Level of Significance

containing Pendex had a grain that was significantly better than the bread containing dextrose or corn syrup (1 and 5% levels). Breads made with the four sweeteners did not show a significant difference due to sweetener level (Table XXV).

Texture: Bread containing sucrose was significantly better than that containing dextrose, corn syrup, or Pendex at the 1% level (Table XXVI). However, there were no significant differences between the last three sweetener types. Also, no significance was found due to sweetener level.

Crumb Color: The statistical analysis of crumb color showed no significant differences for sweetener type or sweetener level.

Total Score: The total score was a combination of the seven other individual scores. The maximum total score was based on 100 points. By analysis of the total scores (Table XXVII) it was found that breads containing sucrose or Pendex were significantly superior in total score (1% level) than the products containing dextrose or corn syrup. Although sucrose and Pendex produced significantly superior bread scores than the other sweetener types no differences were found due to sweetener levels.

Dough Reducing Sugar: The reducing sugars in dough and bread were measured by the Folin-Wu sugar determination method (Table XXVIII, XXIX). The doughs prepared with sucrose gave greater reducing values than, the doughs containing corn syrup, dextrose, or Pendex (1% level). The reducing sugar value of dough containing Pendex was significantly higher (1% level) than that of dough containing corn syrup. The dough containing dextrose gave a reducing sugar value also significantly greater than that for dough containing corn syrup (1% level). As would be expected with sweetener levels the product containing 8% sweetener solids gave a significantly higher reducing sugar value (1% level) than did

those with 4 or 6% sweetener solids. The dough with 6% sweetener solids were, however, significantly higher in dough reducing sugar values than those containing 4% sweetener solids (1% level).

Bread Reducing Sugar: Dextrose produced a significantly larger reducing sugar value in bread than did corn syrup, sucrose, or Pendex (1% level). The reducing sugar values of bread made with either Pendex or sucrose were significantly higher (1% level) than those for bread made with corn syrup. Breads with 8% levels of sweetener solids had significantly higher reducing sugar values (1% level) than those made with 4 or 6% sweetener solids. It was also found that 6% sweetener solids produced bread with reducing sugar values greater than those for bread with 4% sweetener solids (1% level).

TABLE XXV. GRAIN

LSD of Sweetener Type 0.7675 5% and 1.0237 1%

LSD Table

Treatment	Means	X-3	X-4	X-2	X-1
Sucrose (1)	15.2000	1.7000**	1.4333**	0.6000	0.0000
Pendex (2)	14.6000	1.1000**	0.8333*	0.0000	
Corn Syrup (4)	13.7667	0.2667			
Dextrose (3)	13.5000	0.0000			

LSD of Sweetener Levels 0.6647 5% and 0.8865 1%

LSD Table

Treatment	Means	X-3	X-1	X-2
6% (2)	14.3750	0.3000	0.0250	0.0000
4% (1)	14.3500	0.2750	0.0000	
8% (3)	14.0750	0.0000		

* 5% Level of Significance

** 1% Level of Significance

TABLE XXVI. TEXTURE

LSD of Sweetener Type 0.5407 5% and 0.7211 1%

LSD Table

Treatment	Means	X-3	X-4	X-2	X-1
Sucrose (1)	15.4000	1.2333**	1.2000**	0.8000**	0.0000
Pendex (2)	14.6000	0.4333	0.4000	0.0000	
Corn Syrup (4)	14.2000	0.0333	0.0000		
Dextrose (3)	14.1667	0.0000			

LSD of Sweetener Levels 0.4682 5% and 0.6245 1%

LSD Table

Treatment	Means	X-3	X-1	X-2
6% (2)	14.8000	0.4000	0.2250	0.0000
4% (1)	14.5750	0.1750	0.0000	
8% (3)	14.4000	0.0000		

* 5% Level of Significance

** 1% Level of Significance

TABLE XXVII. TOTAL SCORE

LSD of Sweetener Type 2.0999 5% and 2.8005 1%

LSD Table

Treatment	Means	X-3	X-4	X-2	X-1
Sucrose (1)	78.4000	4.7667**	4.3333**	1.5000	0.0000
Pendex (2)	76.9000	3.2667**	2.8333**	0.0000	
Corn Syrup (4)	74.0667	0.4333	0.0000		
Dextrose (3)	73.6333	0.0000			

LSD of Sweetener Levels 1.8186 5% and 2.4253 1%

LSD Table

Treatment	Means	X-1	X-3	X-2
6% (2)	76.6750	1.6000	1.1750	0.0000
8% (3)	75.5000	0.4250	0.0000	
4% (1)	75.0750	0.0000		

* 5% Level of Significance

** 1% Level of Significance

TABLE XXVIII. DOUGH REDUCING SUGAR

LSD of Sweetener Type 8.8900 5% and 11.8563 1%

LSD Table

Treatment	Means	X-4	X-3	X-2	X-1
Sucrose (1)	373.4667	157.9333**	21.1333**	19.0000**	0.0000
Pendex (2)	354.4667	138.9333**	2.1333	0.0000	
Dextrose (3)	352.3333	136.8000**	0.0000		
Corn Syrup (4)	215.5333	0.0000			

LSD of Sweetener Levels 7.6990 5% and 10.2679 1%

LSD Table

Treatment	Means	X-1	X-2	X-3
8% (3)	442.1000	243.7000**	110.7500**	0.0000
6% (2)	331.3500	132.9500**	0.0000	
4% (1)	198.4000	0.0000		

* 5% Level of Significance

** 1% Level of Significance

TABLE XXIX. BREAD REDUCING SUGAR

LSD of Sweetener Type 9.7056 5% and 12.9440 1%

LSD Table

Treatment	Means	X-4	X-1	X-2	X-3
Dextrose (3)	477.0667	129.9333**	25.9333**	19.5333**	0.0000
Pendex (2)	457.5333	110.4000**	6.4000	0.0000	
Sucrose (1)	451.1333	104.0000**	0.0000		
Corn Syrup (4)	347.1333	0.0000			

LSD of Sweetener Levels 8.4053 5% and 11.2098 1%

LSD Table

Treatment	Means	X-1	X-2	X-3
8% (3)	564.9000	241.6000**	153.4500**	0.0000
6% (2)	411.4500	88.1500**	0.0000	
4% (1)	323.3000	0.0000		

* 5% Level of Significance

** 1% Level of Significance

Explanation of Plates

Plate I: An enlargement (50X) of the three solid sweetening agents, Pendex, dextrose, and sucrose used in this project. These photographs show the differences in physiological crystal granulation and structure. Photograph B is an enlarged area taken from A showing enlarged crystalline structure of A.

Plate II: A longitudinal view of the whole loaves comparing the external characteristics of the bread using the four sweetening agents at three sweetener levels. The distinguishing features shown are break and shread, height of loaf, and symmetry.

Plate III: A sectional view showing both internal and external characteristics of the bread. The photograph gives a side and front view of loaf height.

Plate IV: A cross-sectional view of the bread showing the sweetening types at the various levels of concentration. It gives a good indication of such characteristics as grain, texture, and crumb color.

Plate V: An (8 X 10 -in.) color photograph showing crust color differences due to sweetener types and levels.

The label PAF 2011 on the photograph should read "Pendex" the trade name for the new corn based sweetner.

EXPLANATION OF PLATE I

A. Penick and Ford product enlarged fifty times.

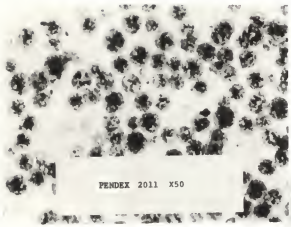
B. Enlarged area of photograph A to show crystal structure.

C. Dextrose monohydrate enlarged fifty times.

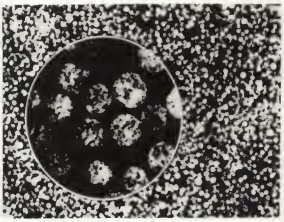
D. Granular sucrose enlarged fifty times.

This plate reproduced courtesy of Penick and Ford Company

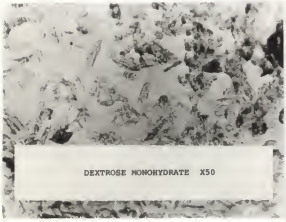
TABLE I


PENDEX 2011 X50

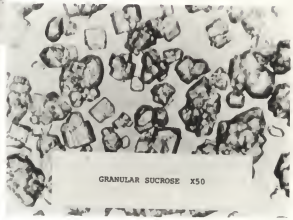
A



B


DEXTROSE MONOHYDRATE X50

C

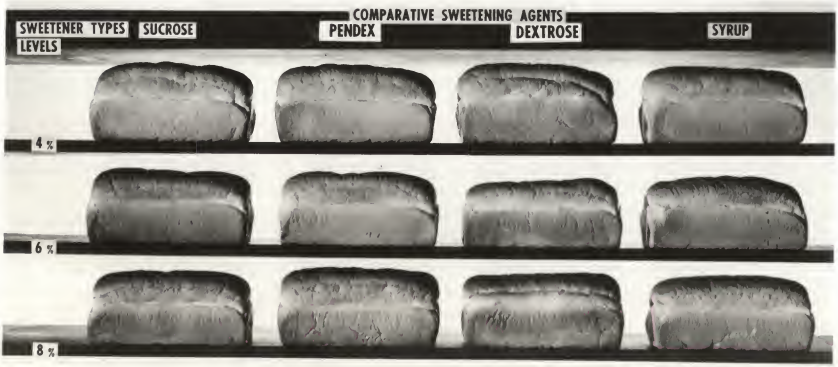

GRANULAR SUCROSE X50

D

EXPLANATION OF PLATE II

Longitudinal view showing
break and shread.

PLATE II


COMPARATIVE SWEETENING AGENTS
SWEETENER TYPES
LEVELS
SUCROSE
PENDEX
DEXTROSE
SYRUP
4 %
6 %
8 %

EXPLANATION OF PLATE III

Sectional view showing
side and front view of
loaf height.

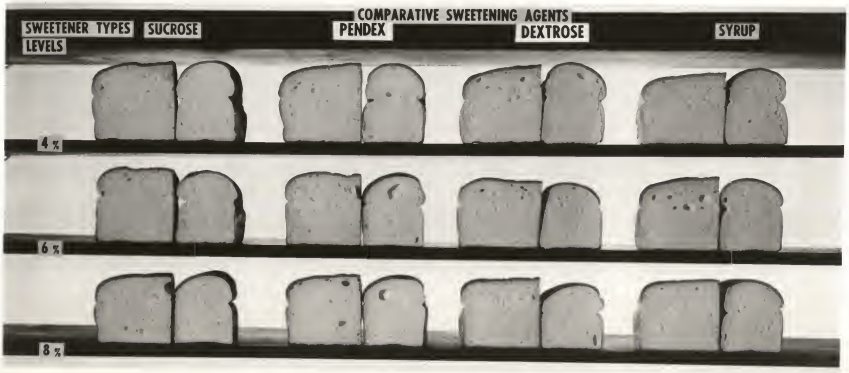
PLATE III


COMPARATIVE SWEETENING AGENTS
SWEETENER TYPES
LEVELS
SUCROSE
PENDEX
DEXTROSE
SYRUP
4 %
6 %
8 %

EXPLANATION OF PLATE IV

Cross-sectional view showing grain and texture.

PLATE IV


COMPARATIVE SWEETENING AGENTS
SWEETENER TYPES
LEVELS
SUCROSE
PENDEX
DEXTROSE
SYRUP
4 %
6 %
8 %

EXPLANATION OF PLATE V

Top view showing color differential.

* Note change, PAF 2011 to "Pendex" the trade name of new corn based sweetener.

PLATE V


COMPARATIVE SWEETENING AGENTS
SWEETENER TYPES
LEVELS
SUCROSE
PAF
CERELOSE
SYRUP
4 %
6 %
8 %

SUMMARY AND CONCLUSIONS

The purpose of this investigation was to study the effect of a new sweetener Pendex, for use as a commercial sweetening agent. Pendex was compared with three usual sweetening agents, sucrose, dextrose, and corn syrup.

Three sweetening levels on a total solids basis at 4, 6, and 8% were used in a sponge-dough formula.

It was found that dextrose gave a significantly higher dough pH than either sucrose or Pendex. Six and 8% sweetener solids gave significantly higher dough pH than 4% sweetener solids. The bread made with corn syrup showed a higher pH than bread made with dextrose.

The corn syrup product gave a significantly higher penetrometer reading after one day of storage than was obtained for bread containing dextrose. Penetrometer readings after three days were significantly higher for bread containing Pendex, corn syrup, and sucrose than dextrose. Bread containing 4% sweetener solids was found to have higher penetrometer readings after three days than that made with either 6 or 8% sweetener solids. Bread containing corn syrup had significantly higher penetrometer readings after six days storage than bread containing Pendex, dextrose, or sucrose stored for the same length of time.

It was found that the corn syrup product had a significantly higher crust reflectance than bread containing sucrose, dextrose, or Pendex and that the crust reflectance for breads containing either Pendex or dextrose was higher than that for the sucrose product. The bread with 4% sweetener solids had a significantly higher crust reflectance than that with 6 or 8% solids, while the reflectance for bread containing 6% sweetener solids was higher than that for bread containing 8% sweetener solids.

Eight per cent sweetener solids in bread were found to give a significantly higher bread yield than 4% solids.

Crust color of bread made with Pendex scored significantly higher than that of bread containing corn syrup or dextrose. Bread containing dextrose or sucrose was also scored higher than that containing corn syrup. Six or 8% sweetener solids produced a bread crust that was scored significantly higher than bread containing 4% sweetener solids.

The sucrose product had a significantly better break and shread than the dextrose product.

It was also found that bread containing sucrose or Pendex had a significantly better grain than bread containing dextrose or corn syrup.

Texture was significantly better for the sucrose product than in bread containing dextrose, Pendex, or corn syrup.

Sucrose and Pendex gave breads with a significantly higher total score than that of bread made with dextrose or corn syrup.

The product containing sucrose had a higher dough reducing sugar value than that made with corn syrup, dextrose, or Pendex; breads made with either dextrose or Pendex had values significantly higher than those for bread made with corn syrup. Sweetener level affected dough reducing sugar values in the following order: 8, 6, and 4%, with 8% leading to the highest values and 4% to the lowest value.

Reducing sugar values for bread showed significant differences, bread made with dextrose having the highest value. It was also found that 8% sweetener solids in bread produced higher reducing values than 6%, while the values for 6% were higher than those for 4% level.

Summary of Tables XXX and XXXI: Penetrometer readings for day one showed that the breads made with Pendex, sucrose, and corn syrup were better than that made with dextrose. The third day's readings were identical to those obtained after one day, but after six days of storage penetrometer readings showed the best product to be one containing corn syrup. When measuring crust reflectance no significant difference was found between bread containing Pendex and that containing dextrose while significant differences were measured between breads made with each of the other sweeteners. No known standard has been set for optimum crust reflectance although, sweetener level was found to have a large influence. The best bread crust color was obtained by use of Pendex or sucrose while Pendex, sucrose, and corn syrup gave products with better break and shread than those obtained by use of dextrose. The best grain in bread occurred when sucrose or Pendex was used as the sweetening agent. Texture was scored highest when bread was sweetened with sucrose. The best overall total scores showed Pendex and sucrose to be the best sweetening agents of the four used in this investigation.

Although, several significant differences were measured for sweetener level no practical significance was evident.

From the results of the work with sweetening agent Pendex it was concluded that a highly acceptable bread can be made by using this new product.

The author would suggest that further investigations might be of interest for finding application of Pendex in such areas as continuous mix operations, sweet goods production, and formulation of various other baked products.

TABLE XXX. SUMMARY OF DIFFERENCES IN EFFECTS OF SWEETENER TYPE

Different Number Indicates Significant Difference

	Pendex	Sucrose	Dextrose	Corn Syrup	(Best)
pH, Dough	1	1	2	1,2	NC
pH, Bread	1,2	1,2	1	2	NC
T.A., Dough	1	1	1	1	ND
T.A., Bread	1	1	1	1	ND
Penetr., 1 Day	1,2	1,2	1	2	2
Penetr., 3 Days	1	1	2	1	1
Penetr., 6 Days	1	1	1	2	2
Reflect., Crumb	1	1	1	1	ND
Reflect, Crust	1	2	1	3	DL
Yield, Bread	1	1	1	1	ND
Spec. Vol.	1	1	1	1	ND
Color Crumb	1	1	1	1	ND
Color, Crust	1	1	2	3	1
Sym.	1	1	1	1	ND
B. & S.	1,2	2	1	1.2	2
Grain	1	1	2	2	1
Texture	1	2	1	1	2
Total Score	1	1	2	2	1
Red. Sug., Dough	2	1	2	3	NC
Red. Sug., Bread	1	1	2	3	NC

NC - no criteria
NC - no difference
DL - depends on level of sweetener used

TABLE XXXI. SUMMARY OF DIFFERENCES
IN EFFECTS OF SWEETENER LEVEL

Different Number Indicates Significant Difference

	4%	6%	8%	(Best)
pH Dough	1	2	2	NC
pH Bread	1	1	1	ND
T.A., Dough	1	1	1	ND
T.A., Bread	1	1	1	ND
Penetr., 1 Day	1	1	1	ND
Penetr., 3 Days	1	2	2	1
Penetr., 6 Days	1	1	1	ND
Reflect., Crumb	1	1	1	ND
Reflect., Crust	1	2	3	NC
Yield, Bread	1	1,2	2	2
Spec. Vol.	1	1	1	ND
Color Crumb	1	1	1	ND
Color Crust	1	2	2	2
Sym.	1	1	1	ND
B & S	1	1	1	ND
Grain	1	1	1	ND
Texture	1	1	1	ND
Total Score	1	1	1	ND
Red. Sug., Dough	1	2	3	NC
Red. Sug., Bread	1	2	3	NC

NC = no criteria
ND = no difference

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THE USE OF A NEW CORN BASED SWEETENER IN BAKERY PRODUCTS

by

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This investigation dealt with the effect of a new sweetener Pendex, in comparison with three usual sweeteners, in a sponge-dough formula. Each of the four sweetening agents, sucrose, Pendex, dextrose, and corn syrup, was used at levels of 4, 6, and 8% on a total solids basis.

The relative amounts of sugars utilized during fermentation were measured by means of the Folin-Wu reducing sugar test. These measurements were taken on the dough after the remixing stage and on the final baked product.

Characteristics including pH, T.A., penetrometer readings, crust and crumb reflectance, bread yield, specific volume, crust and crumb color, symmetry, break and shread, grain, texture, total score, and bread and dough reducing sugar were statistically analyzed for significance.

During the dough stage significant differences in pH were found due to sweetener type and level.

After the bread had been stored for three days, penetrometer readings began to decrease, indicating a lowering of bread quality.

The amount of sugar left available for the browning reaction during baking decreased with use of the different sweeteners in the following order; sucrose, Pendex, dextrose, and corn syrup. The last produced the significantly lightest crust color. The sweetener levels led to increases in crust color formation from 4 to 6% and from 6 to 8%.

Sucrose and Pendex both produced significantly better grain in the final product than did the other two sweetening agents.

Total scores were highest when sucrose or Pendex was used as the sweetening agent.

Sucrose produced the greatest amount of reducing sugars in the dough while use of dextrose led to the largest reducing sugar value in the bread. Reducing

sugar values increased with sweetener levels as would be expected from observing crust color relationships.

On the basis of statistical analyses and observations made during this investigation it appeared that Pendex was very comparable to sucrose in its effect on baking characteristics. Pendex was equal to or better than dextrose and corn syrup as a sweetener on the basis of shelf life, grain, texture and overall baking quality of the bread produced.