# EFFECT OF SUBSTITUTING GLUCOSE FOR SUCROSE IN BAKED, WHEAT-FLOUR BASED DIETS ON GROWTH AND LIVER COMPOSITION OF RATS

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**ABSTRACT**

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Weanling rats were fed diets containing 20% sugar in the form of sucrose or glucose or combinations of the two. The dry ingredients, including wheat flour, soybean flour, nonfat milk solids, oil, minerals, vitamins, baking powder, and sugar were mixed with water and baked. After baking, the diets were lyophilized, ground, and fed ad libitum to the animals. Significant reductions in weight gain and feed efficiency were observed in the animals receiving the diet containing as little as 5% glucose. Further substitution of glucose for sucrose in the diets resulted in decreased size and number of hepatic cells and increased concentration of lipid in the liver. These results indicate that substitution of glucose for sucrose had significant detrimental effects on the nutritional quality of this wheat-flour based diet. It is possible that nutritional quality of some food products may be jeopardized (without organoleptic or functional properties being noticeably affected) by substitution of small quantities of less expensive corn-derived sweeteners for sucrose.

In 1974, the price of refined sucrose rose dramatically, resulting in increased ingredient costs in many processed food items. As a consequence, other sweeteners have been suggested as substitutes for cane sugar, and one of the more frequently mentioned alternates to sucrose is corn syrup. For example, it has been postulated that increased domestic production of corn syrup might serve to reduce the need for imported cane sugar (1). While economic advantages of substituting corn-derived sweeteners for sucrose in processed foods are attractive, the nutritional consequences of this substitution should be explicitly understood by the processor.

Sweeteners derived from corn all contain significant amounts of free glucose which will combine with proteins through a chemical addition known as the Maillard reaction. Briefly, it is the reaction that takes place between carbonyl compounds, such as glucose, and primary amines, such as those occurring in proteins as N-terminal units or those attached to the epsilon carbons of lysine molecules present in the protein. Since Maillard first described this reaction in 1912, it has been studied extensively. A recent review of its nutritional and physiological consequences listed more than 200 references (2).

Occurrence of this reaction during food processing may have both beneficial and detrimental effects. It causes the development of some desirable aromas and results in browning, which may be either an asset or a liability. The effect of the Maillard reaction on the nutritional quality of proteins, however, is decidedly adverse. The addition products of the reaction are not available to man and other animals as a source of amino acids (3,4). Since lysine is the most limiting amino acid in proteins of nearly all cereal grains and their products, the heating of such products in the presence of corn-derived sweeteners could be expected to significantly reduce their nutritive value.

The study reported here was undertaken to assess the nutritional consequences

of substituting glucose for sucrose in a processed food item similar to one that might be prepared for human consumption. Rats were fed a sweetened bread of wheat flour, enriched with soybean flour and nonfat milk solids, and fortified with vitamins and minerals.

## MATERIALS AND METHODS

The basal diet contained the following ingredients as percentage of the total: wheat flour, 52.27%; soybean flour, 10.0%; nonfat dry milk, 10.0%; soybean oil, 5.0%; vitamin mix[1], 1.0%; mineral mix[2], 1.48%; double-action baking powder, 0.25%; and sucrose, 20.0%. According to published values for the first three ingredients, this diet contained approximately 13.8% protein. The mineral mixture was formulated to supply the rats' requirements for inorganic nutrients not provided by the other dietary ingredients. In the test diets, glucose was substituted for sucrose at 5, 10, and 20% of the total diet. The dry ingredients were thoroughly mixed and a batter was prepared by blending in two parts of deionized water. The batter was baked in cake pans (9 × 13 in.) at 177° C for 50 min. After baking, the diets were lyophilized and ground. Sprague-Dawley male rats were housed individually, 10 animals per diet, and provided with food and deionized water ad libitum. They were 4 weeks old (average weight 85 g) at the beginning of the study, and were maintained on the experimental diets for 28 days.

At the end of the experimental feeding period, the animals were sacrificed under pentobarbital anesthesia by heart puncture. Packed-cell volume using heparinized microtubes and total hemoglobin content (5) of the blood were determined. Samples of liver tissue were excised quickly for determination of glycogen (6,7) and nucleic acids. Nucleic acids were extracted as described by Munro and Fleck (8). Ribonucleic acid (RNA) was determined by ultraviolet spectroscopy, and deoxyribonucleic acid (DNA) was determined by the method of Ceriotti (9). An aliquot of the nucleic acid homogenate was used for determining liver protein content by the method of Lowry *et al.* (10). The remaining liver was lyophilized for determination of lipid—as described by Miller (11)—and ash by heating at 450° C for 20 hr in a muffle furnace. The kidneys were removed for weight determination. The method described by Booth (12) was used to measure fluorodinitrobenzene-available lysine in the diets as fed.

The data were subjected to analysis of variance, and differences associated with dietary treatments were determined according to the multiple range tests of Duncan (13).

## RESULTS AND DISCUSSION

The visual appearance of the bread containing 20% glucose was somewhat darker in color and had a heavier texture after baking than the other diets.

[1]The vitamin mixture provided per 100 g of diet: vitamin A, 2000 IU; vitamin D, 220 IU; α-tocopherol, 11 mg; ascorbic acid, 100 mg; inositol, 11 mg; choline chloride, 165 mg; menadione, 5 mg; *p*-amino-benzoic acid, 11 mg; niacin, 10 mg; riboflavin, 2 mg; pyridoxine hydrochloride, 2 mg; thiamine hydrochloride, 2 mg; calcium pantothenate, 6.6 mg; biotin, 44 mcg; folic acid, 200 mcg; and vitamin $B_{12}$, 3 mcg.

[2]The mineral mixture provided per 100 g of diet: calcium phosphate, 750 mg; calcium carbonate, 700 mg; cupric sulfate pentahydrate, 1.3 mg; potassium iodate, 0.3 mg; ferrous sulfate heptahydrate, 5 mg; manganese sulfate monohydrate, 14.5 mg; and zinc carbonate, 1.6 mg.

**TABLE I**
**Effect of Substituting Glucose for Sucrose in the Diet on Growth Performance of Rats**

| Dietary Sugar | | Feed | Weight | | | % of Body Weight | |
|---|---|---|---|---|---|---|---|
| Sucrose % | Glucose % | Efficiency[a] | Animal g | Liver g | Kidneys g | Liver | Kidneys |
| 20 | 0 | 0.311a[b] | 249a | 9.76a | 1.89a | 3.92a | 0.76b |
| 15 | 5 | 0.255b | 223b | 8.24b | 1.64b | 3.70ab | 0.74b |
| 10 | 10 | 0.218c | 193c | 6.74c | 1.50c | 3.48bc | 0.78ab |
| 0 | 20 | 0.183d | 166d | 5.37d | 1.38d | 3.22c | 0.83a |

[a]Feed efficiency: weight gained per gram of feed consumed.
[b]Values in a column not followed by the same letter are significantly different at $P \leq 0.05$ according to Duncan's multiple range test.

However, when the diets were dried and ground, they were very similar in appearance.

The animals adapted well to the experimental diets with no obvious ill effects. There were no significant differences due to dietary treatment in hemoglobin (13.6%) or packed-cell volume (46.4%) of the blood.

Growth performance of the rats was adversely affected by addition of as little as 5% glucose in their diets (Table I). In fact, successive significant decreases in final body, liver, and kidney weights and feed efficiency were observed with each increment of glucose substitution in the diet. The reduction in feed efficiency indicates that the failure of animals to thrive on the diets containing glucose was not due entirely to lack of palatability associated with decreased sucrose content. The reduced conversion of feed to body tissues indicates that the nutritional quality of the diets was damaged by substitution of glucose for sucrose and the extent of the damage was proportional to the concentration of glucose in the food.

Weights of the liver and kidneys as a function of body weight may be further evidence of physiological changes associated with dietary treatments. Livers of the animals receiving 10 and 20% glucose in the diet were smaller in proportion to body size than those of the controls. On the other hand, kidneys of the animals receiving 20% dietary glucose were proportionately heavier than those of the control animals.

Composition of the livers of the rats in this study also showed differences due to substitution of glucose for sucrose in the diet. Although livers of animals receiving the diet containing 20% glucose were smaller in relation to body weight than those of control animals, they contained a significantly ($P < 0.05$) higher concentration of lipid.

| *Dietary Glucose (%)* | *Liver Lipid (%)* |
|---|---|
| 0 | 4.65b |
| 5 | 4.77b |
| 10 | 4.92ab |
| 20 | 5.35a |

**TABLE II**
**Effect of Substituting Glucose for Sucrose in the Diet on Weight and Composition of Liver Cells of Rats**

| Dietary Sugar | | | | | | |
|---|---|---|---|---|---|---|
| Sucrose % | Glucose % | Weight μg | RNA | Protein | Ash | Glycogen |
| | | | pg/cell | | | |
| 20 | 0 | 1.78a[a] | 14.3a | 383a | 23.7a | 99a |
| 15 | 5 | 1.68a | 13.4a | 362a | 22.0a | 108a |
| 10 | 10 | 1.38b | 11.5b | 302b | 18.0b | 77ab |
| 0 | 20 | 1.36b | 11.5b | 303b | 17.8b | 60b |

[a]Values in a column not having a common letter are significantly different at $P \leq 0.05$ according to Duncan's multiple range test.

The number of hepatic cells as determined by DNA content of the liver was decreased by addition of glucose to the diets and animals on the highest level of glucose were found to have significantly ($P < 0.05$) fewer hepatic cells than the control animals.

| *Dietary Glucose (%)* | *Cells (Billions)* |
|---|---|
| 0 | 5.6a |
| 5 | 5.0a |
| 10 | 4.9a |
| 20 | 4.0b |

These values for number of cells per liver were used to calculate weight and composition of the cells. Size of the cells was significantly reduced when half or more of the dietary sucrose was replaced by glucose (Table II). Cellular content of RNA, protein, and ash was significantly reduced when glucose was added at 10 and 20% of the diet, when compared to controls, and glycogen reduction was significant when glucose was added at 20%. Both reduction in hepatic cell proliferation and size (14) and accumulation of lipid in the liver (15) have been reported as consequences of protein malnutrition due to unbalanced amino acid composition.

The data reported in this study indicate that substitution of glucose for sucrose had a detrimental effect on nutritional quality of this wheat-flour based diet, even when present at only 5% of the total diet. Part of the adverse effect was attributed to the Maillard reaction between glucose and lysine. The amount of lysine in the cooked diets that was free to react with fluorodinitrobenzene decreased from 0.57% of the diet in the recipe containing sucrose as the only sugar to 0.52, 0.49, and 0.46% in those containing 5, 10, and 20% glucose, respectively. Therefore, it appears that nutritional quality of some food products may be jeopardized (without organoleptic or functional properties being noticeably affected) by substitution of small quantities of less expensive corn-derived sweeteners for sucrose.

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