

CURRENT TOPICS in review

Changing food habits and our need for evaluations of the cariogenic potential of foods and confections^{*}, †

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Abstract

Dietary habits have changed dramatically over the past 60 years and especially in the past generation. Notable decreases in total carbohydrate consumption have occurred with compensatory increases in fat consumption. Within the carbohydrate category, almost a 50% decrease in starch consumption has occurred with a 25% increase in sugars. The frequency of eating away from home has increased in striking fashion with an increasing dependence in recent years on fast-food places. The tendency for dependence on a decreasing number of food items appears to be increasing with the likelihood of a decreased amount of planning for the adequacy of food intake. The pedodontist is faced with an increasing need to provide wise and convincing dietary counseling to his or her patients. The need for estimates of the caries-producing potential of many foods and confections is obvious. Assays with experimental animals offer promise of being able to provide very helpful data on this subject.

Food changes in the past generation

A generation ago, nutritionists believed and taught that individual dietary habits were very difficult, if not impossible, to change. No one then dreamed of the widespread, dramatic changes that would occur in such a brief period. The best description of these

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changes is probably in a recent issue of *Advertising Age*.¹ Obviously, this article was written for advertisers, but the following quotations from the food industry's perspective can be very instructive to us:

"In one generation, we have gone from a traditional food producing society to a food grazing society—one where we eat wherever we happen to be."

"Instead of the traditional three square meals, we have as many as 20 'food contacts' a day—and spend as little as 20 minutes eating together."

"We spend about 35¢ of each food dollar away from home. Most of this is spent in restaurants and cafeterias (60%) or fast-food places (25%)."

"During 1978, consumers have spent at the annual rate of \$53 billion in eating out; \$17 billion in fast-food places. Growing at a compound annual rate of over 10%, fast foods look to have an eventual 50% to 60% share of the entire purchased meal industry."

"Ice milk grew from 1.2 lbs. per capita nationally in 1950 to 7.4 lbs. in 1976. Frozen potatoes (the kind used in french fries) grew from 6.6 lbs. per capita to 36.8. Soft drink consumption went from 192 8-oz. servings in 1960 to an astonishing 493 per capita in 1976."

My concern does not center entirely on whether the individual foods and confections that have become readily available and frequently used are nutritious or not. Obviously, some are nutritious and desirable if eaten in reasonable amounts. Others are not nutri-

tious, and their increased usage is to be deplored. Clearly, if half or two-thirds of the numerous "food contacts" are with potentially cariogenic foods or confections, the current high levels of dental caries are to be expected regardless of whether other preventive procedures are being followed.

I am especially concerned that during the past generation, there has been an increasing tendency for the diet of many individuals to be based on a restricted number of food items instead of the great variety that nature provides so abundantly. In addition, the recent trends have certainly reduced greatly the amount of planning by the "gatekeeper" of the household who bought the food, planned the menus, prepared the food, and supervised that each family member received and consumed a reasonable portion. Good nutrition does not occur by chance but has to be planned.

The above information described from an industrial viewpoint the recent changes in food habits and consumption of specific foods. Data are available since early in this century on the average availability of food components per capita in contradistinction to foods themselves. In Fig. 1, information is shown on the changes in food energy, fat, protein, and carbohydrate from 1910 to 1970.² About 500 g of carbohydrate were available for consumption per person in the United States in 1910. The decrease to 380 g per person in 1970 was due largely to decreased use of flour and cereal products. This change automatically resulted in reduced intake of starches and dietary fiber.

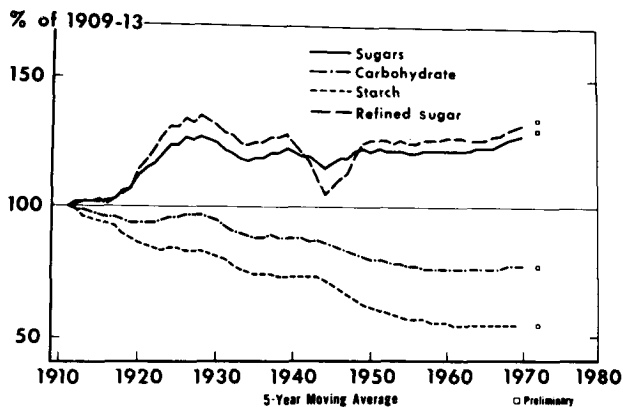


Fig. 1. Per capita civilian consumption of food energy (calories), protein, fat, and carbohydrate, 1909-1913 to 1972.⁹ (Reproduced with permission from Page and Friend.²)

Simultaneously, fat consumption increased proportionately. One g of fat provides 9 kcal of energy in contrast to 1 g of carbohydrate providing only 4 kcal of energy. Thus, the trading of dietary carbohydrates for fats leads to a major increase in the caloric density of the overall diet. Hence, a substantially lesser weight

or volume of food is necessary to provide the appropriate caloric intake.

After decreases and considerable fluctuation, protein availability in 1970 regained approximately the record high in 1910 and by now may have exceeded that record. Certainly, on the average, protein consumption in the United States exceeds the Recommended Daily Allowance. Food energy availability per capita in 1970 was not appreciably less than in 1910 despite the introduction of the automobile and so many labor-saving devices. The latter statement speaks for itself as a major reason why a high percentage of the American population weighs substantially more than their ideal weights.

The change in distribution in carbohydrate intake between starches and sugars is shown in Fig. 2.² In the interval of 1909-1913, slightly over two-thirds of the available carbohydrate was as starches with the sugars less than one-third. The available amounts of starches and sugars averaged 340 and 160 g daily, respectively. By 1972, the starches provided less than one-half of the carbohydrates or approximately 180 g per day in comparison with approximately 200 g of sugars. This change represents a decrease in starch consumption of about 47% over this 60-year interval. Simultaneously, the sugars increased from about 160 to 200 g per day, a 25% increase.

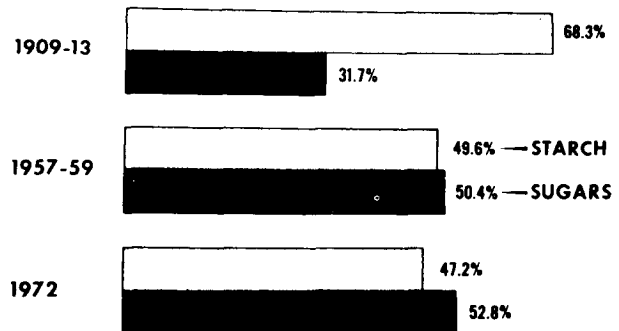


Fig. 2. Proportion of carbohydrate in the national food supply provided by starch and sugars, selected periods.^a (Reproduced with permission from Page and Friend.²)

Fig. 3 provides especially important information about the changes in patterns of usage of sugars over the same interval.² In 1909-1913, 19.3 lb of the 76.4 lb of the refined sugars per capita were used in industrial preparation of food products and beverages. Thus, 52.1 lb were used in the home and were thereby under the direct control of the homemaker. By 1971, 70.2 lb of the annually available 101.5 lb of refined sugars per capita were used industrially, and only 24.7 lb were used in the home. In other words, between 1909-1913 and 1971, industrial use increased 3.6-fold per person while home use decreased in 1971 by one-half. It is

reasonable to assume that these trends have continued in the ensuing eight years. From an oral health standpoint, this increased use of sugars by industry may have more serious implications for oral health than the absolute increase of available sugars.

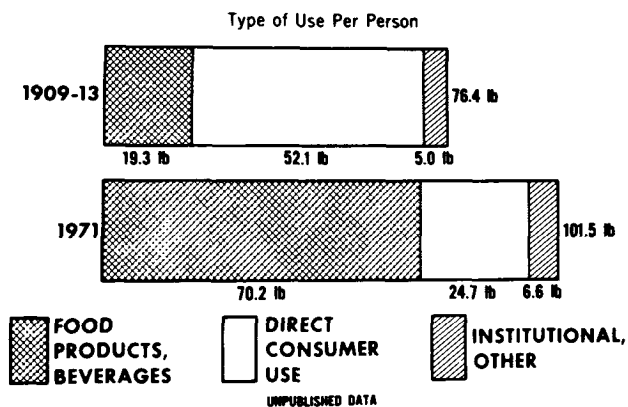


Fig. 3. Per capita per year use of refined sugar in industrially prepared food products and beverages, direct consumer use, and use by institutional and other users, selected periods. (Reproduced with permission from Page and Friend.²)

As shown in Table 1, the principal sugar used in commerce is the disaccharide, sucrose, with about a 20% increase from 1910-1913 to 1974.³ Milk sugar (lactose) consumption has not changed to any important degree. The increase in corn sweetener usage from 6.4 to 26.6 lb per year represents the most dramatic change in the same interval. The corn sweeteners are mixtures of glucose and fructose produced by the hydrolysis of corn starch. In the first corn sweeteners, primarily glucose was present which is only one-half as sweet as sucrose. With the introduc-

tion of the isomerase process during manufacture to convert glucose to fructose, corn sweeteners now contain up to 70% fructose which is substantially sweeter than sucrose. Glucose and fructose are the most common monosaccharides occurring naturally in food, one or both being present particularly in fruits, vegetables, and honey. The actual consumption of glucose and fructose is higher than the figures shown in Table 1 because of the amounts of these monosaccharides in the corn sweeteners. In addition, the strongly acidic nature of soft drinks results in an almost complete hydrolysis of the sucrose used in their manufacture to equal amounts of glucose and fructose. Increasingly, evidence indicates that glucose and fructose have caries-producing potentials similar to those of sucrose. Therefore, neither the increasing use of corn sweeteners nor the hydrolysis of sucrose to glucose and fructose in soft drinks provides any hope that their use will reduce cariogenic potentials of human foods and confections.

The ability to guide and direct food consumption still exists to some extent in the home where there is the parental desire to do so. However, by reason of the sweeping changes shown in the above figures, the choices for the family with the desire to maintain low sugar-containing diets or to reduce sugar intake below the current levels and frequency of usage are becoming more limited and more difficult. The industrial addition of sugars to many products is widespread, even to foods that traditionally did not have sugars added. Usually, industry assures us that such additions were made only after taste panels determined that the products with added sugar were more palatable and, therefore, more saleable. Unfortunately, food labeling does not yet require the amount of added sugar to be specified by the manufacturer so that the purchaser

Table 1. Calculated average consumption of various carbohydrates in grams per day and in pounds per year*

Year	1910 to 1913		1960		1974	
	Daily cons. (g)	Annual cons. (lb)	Daily cons. (g)	Annual cons. (lb)	Daily cons. (g)	Annual cons. (lb)
Starch	342	275.5	188	151.5	179	144.2
Sugars						
Sucrose	101	81.3	121	97.5	123	99.1
Corn sweeteners	8	6.4	19	15.3	33	26.6
Lactose	21	16.9	25	20.1	23	18.5
Glucose	6	4.8	11	8.9	12	9.7
Fructose	6	4.8	4	3.2	3	2.4
Maltose	2	1.6	4	3.2	4	3.2
Others	12	9.7	5	4.0	3	2.4
Total sugars	156	125.5	189	152.2	200	161.9
Total carbohydrate	498	401.0	377	303.7	379	306.1
Percentage of sugars		31.5		50.0		52.6

* Compiled from USDA/ARS 1972 data and sugar statistics (USDA) by Cantor.³

often can be quite unaware of the amount of sugar present in the product.

Carbohydrates in nutrition

The human race has always depended and, no doubt, always will depend heavily upon carbohydrates for a substantial portion of its caloric needs as well as for nutrients that are carried by the carbohydrate sources. The amounts of carbohydrate consumed varied from relatively low amounts in those tribal situations with a heavy dependence on domestic or hunted animals to very high amounts in developing countries where limited food choices, primarily cereal grains such as rice and corn, are available. Especially where dependence is on a single food source, the carbohydrates of corn, rice, wheat, millet, or manioc supply 80% or more of the caloric needs often simultaneously in the context of severe malnutrition due to the inadequacy of calories and/or other nutrients. Thus, from a nutritional standpoint, the human body has the ability to survive with a widely varied level of carbohydrate consumption.

Far more carbohydrate calories can be produced per unit of land area than calories from fats and proteins with sugar cane probably being the highest carbohydrate producer of all plants. In addition, plant foods can be produced far more efficiently with respect to land area than foods of animal origin such as dairy products, eggs, and meat. As the world population continues to increase, greater dependence has to be placed on plants and their carbohydrates with a lesser dependence on animal foods. The inefficient use of 10 lb or more of cereal grains to produce one lb of meat will become increasingly uneconomical and more difficult to justify morally as the need for direct human consumption of these grains increases.

Further decreases in carbohydrate consumption with compensatory increases in fat consumption in continuation of the trends described above from 1909 to 1970 are not desirable for numerous reasons. A reverse in this trend is needed with this reverse being accomplished in ways that will enable improved oral health rather than further deterioration. Intelligent application of available information is vitally important. No further validation is necessary to the following generalizations: the frequency of consuming foods and confections containing sugars and the length of time that these materials are retained on tooth surfaces and in the mouth are intimately related in the causation of carious lesions. No one should question that variables in natural constituents may exist in the composition of foods and confections as commonly produced that may alter the potential cariogenicity of the item. However, no variable with the exceptions of the sugars has been demonstrated yet to have the

ability in man to change an item of potential high cariogenicity to one of noncariogenic potential.

Animal studies of dental caries

In order to counsel patients wisely and convincingly, the clinician has a great need for estimates of the potential cariogenicity of specific foods and confections. When such estimates become available, he or she can describe to the patient more accurately the items that should be used as infrequently as possible and those that can be consumed safely as replacements.

Human experimentation is always expensive, difficult to conduct with adequate guarantees that the variable being studied is the only variable between the experimental and control groups, and fraught with ethical concerns about the well-being of the subjects. Hence, the kinds of clinical trials that resulted in the premises that consumption, frequency of use, and duration of sugar retention in the mouth are causatively related to dental caries can no longer be conducted for ethical reasons. In addition, in a society where many daily food contacts with potentially cariogenic items are commonplace, one more contact with either an item with highly cariogenic potential or an item with a potentially low cariogenicity is not likely to be detectable in the overall cariogenic milieu. Furthermore, suppose a clinical investigator wished to estimate the potential cariogenicity of a confection as one of the hundreds that could be tested and could assure his supporters that the clinical system was sufficiently sensitive to detect one or two uses of it daily. How does the investigator guarantee that each of the large number of subjects will not only use product X as specified daily for the two or three years of the trial but also will not delete other items to compensate?

Obviously, human experimentation in this area has gross limitations that necessitate the use of less expensive procedures of which experimental animals are likely to be the most suitable. The most commonly used animals in caries research have been the white rat, hamster, and cotton rat. Their easy availability, low cost, short assay periods, large litter size, ability for close genetic control, and ease of handling made experiments possible with large numbers under reasonably controlled conditions and with quick turnover.

Subhuman primates have been used in limited fashion for caries assays of etiologic parameters. The monkey has the advantages of larger teeth that are more similar anatomically to man than those of rodents, permitting the collection of plaque for various analyses as well as careful interim oral examinations. In addition, the permanent teeth of monkeys develop over long periods after birth which makes possible the imposition of various nutritional and other metabolic

variations to evaluate their influences on tooth structure and composition and on caries proneness.

The use of the monkey will probably always be limited because of the expense to obtain and maintain them, the small number that can be included in a group, the increasing scarcity of some species for experimental purposes, and the greater genetic variability within an experiment. However, in view of the increasing difficulty in conducting suitable clinical trials, it may become necessary despite the difficulties and costs of subhuman primate experimentation to turn increasingly to monkeys to find necessary answers.

Much of what is known about the complex etiology of dental caries has come from animal studies for no other reason than the fact that many of these studies could not have been conducted in man. From the large number of animal studies on dental caries that have been conducted with a cariogenic diet and a caries-producing oral flora, the following generalizations can be made about food components and experimental caries. These generalizations could be called consensus views that most knowledgeable investigators in experimental dental caries would accept.

1. Food introduced into the body without passage through the mouth is not capable of producing carious lesions.

2. Food must be available numerous times per day and consumed for at least a total of 60 to 100 minutes per day for carious lesions to occur.

3. Carious lesions do not occur in the absence of carbohydrate in the diet even when such severe penalties as surgical removal of the salivary glands are imposed.

4. The carbohydrates have differing abilities to produce carious lesions. Raw starch under most circumstances has a low ability to produce caries; dextrin and partially cooked starch have higher caries-producing abilities; the common mono- and disaccharides all have high caries-producing abilities.

5. The type of cariogenic flora, the experimental species, and possibly the site of the carious lesion influence the relative caries-producing ability of the mono- and disaccharides. In the hamster, sucrose tends to be somewhat more cariogenic than other mono- and disaccharides, probably because *Streptococcus mutans* may be of greater importance than in the white rat and the cotton rat due to different cuspal configurations; in the rat, superinfection with *S. mutans* also appears to increase the caries-producing ability of sucrose beyond that of other mono- and disaccharides, especially on buccal and lingual surfaces. However, under many situations, the caries-producing ability of the mono- and disaccharides does not differ from one to another sugar.

6. The composition of the non-carbohydrate part

of the diet is tremendously important in determining how cariogenic a given amount of sugar will be. For example, in relatively high fat diets with relatively low carbohydrate, more sugar is required to reach the minimal threshold for producing caries than in a low fat, high carbohydrate diet. As little as 2 to 5% sugar is adequate to reach the threshold for caries production in the presence of 50 to 70% starch, whereas five times as much sugar or more is necessary when only sugar is present in a high fat diet with just adequate protein, vitamins, and minerals.

7. Introduction of water into a cariogenic diet tends to reduce its cariogenicity. On a gram-for-gram basis, sugars in solution are less cariogenic than sugar by itself or in a powdered diet.

8. The sugar alcohols, xylitol, sorbitol, and mannitol, tend to have no ability to initiate or support the caries process in most experiments.

9. The addition postdevelopmentally of many phosphates to cariogenic diets at levels well above the nutritionally required level results in major reductions in dental caries. If the high levels of phosphates necessary to reduce caries in rodents are equally necessary for comparable benefits in man, the daily level of phosphate ingestion may be substantially in excess of physiologically appropriate intake and may lower the calcium:phosphorus ratio inappropriately. If sodium phosphates are used, excessive sodium may be introduced into the diet for human well-being.

10. The addition of adequate amounts of fluorides to the diet or drinking water, either during tooth development or postdevelopmentally, results in major reductions in proneness to dental caries.

11. Studies on the effects of a variety of trace elements provided during and after tooth development on dental caries have led to equivocal and controversial results.

Anyone with an open mind who compares the above generalizations to what is known about caries in man will immediately recognize many points of agreement between the two and no points of disagreement. The same is true for many other areas of human biology and pathology where the contributions from animal research have been invaluable. With judicious use, animal models can play a very important role in the estimation of the potential caries-producing ability of many foods and confections.

Estimation of potential caries-producing ability of foods and confections

Only limited time and energy have been expended on efforts to estimate the potential cariogenicity or cariogenic potential of human foods and confectionery items in animal model systems. Rodent studies conducted to estimate the caries-producing ability of human foods under reasonably standardized conditions

can be divided into four general categories.

1. In the first category, investigators sought to determine whether human diets as a whole were cariogenic. Instead of using the typical semipurified cariogenic diet, human foods were mixed in an approximation of the combination that an average person might eat, based on a survey of food consumption. Zeppelin *et al.*⁴ studied with cotton rats a "human" diet that contained 17.3% sucrose. This diet was as cariogenic as their laboratory's high-sucrose caries-producing control diet. However, this study does not remotely resemble the typical use of the same foods by people; the foods selected as typical of a human diet were thoroughly mixed together and fed in dry particulate or puréed form to be consumed repetitiously by the rodents throughout the entire experimental period. This situation is in striking contrast to the daily consumption by people of several foods or confections singly or in different combinations as snacks or meals. The consumption of this diet in three meals per day with no between-meal snacks might have been relatively innocuous with respect to causing caries in caries-prone children. However, this diet might have been relatively or highly cariogenic for children if consumed on the repetitious basis that is becoming increasingly typical with as many as 20 food contacts per day. In addition to being an inadequate measure of the potential caries-producing ability of the human diet as a whole, the caries-producing ability of each food item is lost by reason of its being merged with all the other components.

2. In a second category of experiments, the individual food is fed as the sole source of nutrients throughout the experimental period. This procedure has the substantial advantage of only one food being in the mouth of the animals at any time, and the food has the ability to express itself with regard to its ability to initiate carious lesions in caries-susceptible areas. This procedure has the great disadvantage that practically no individual food used by man is able to sustain life with animals with a rapid growth potential for the length of a caries assay. As soon as the experimental animals have been depleted of one or more limiting nutrients during this single-food regimen, complicating factors systemically and orally enter to confuse any interpretation of the relation of this food item to caries production.

A good example of the problems in this approach is in the comparison of corn flakes, Cap'n Crunch, and Life as the individual sources of nutrients for three groups of rats where 46% of the rats fed corn flakes and 33% of those fed Cap'n Crunch died during a 28-day experiment.⁵ The remaining rats grew very slowly. The oft-quoted conclusion from this experiment that the caries-producing potential of a food is unrelated to its sugar content is meaningless in view of the inability

of two of the products to support health and well-being and the complicating factors that this inability precipitated.

3. In the third category are those trials where a food is mixed in known proportions with a cariogenic diet. The typical cariogenic diet as used in a standard caries assay has a very high capability to produce caries in a model system where the oral flora and the experimental subjects are all favorable to the development of caries. Thus, the cariogenic diet has the potential to obscure the true cariogenicity of any food incorporated into it even in relatively large amounts. For example, the expectation is high that the chemical composition of ground shredded wheat makes it highly unlikely to be cariogenic. However, when a mixture of 1 g of shredded wheat per g of cariogenic diet was fed, the mixture was not less cariogenic than the cariogenic diet itself.⁶ Thus, a food that theoretically should be incapable of producing a high-caries activity appeared to be as cariogenic as the cariogenic diet. In contrast, the addition of foods that are theoretically highly cariogenic to a standard highly cariogenic diet is not likely to cause any further increase in its caries-producing ability.

4. The fourth category probably has received the least attention, but it may have the greatest potential, namely, to make the test item available alone for part of the time to otherwise well-nourished experimental subjects. Possibly the first investigator to use this procedure was Stephan,⁷ who provided experimental rats with a relatively nutritious diet for two one-hour feedings per day each day. In addition, the rats in one of each of the 53 experimental groups had free access at all times to one of the 53 foods that were being tested for their caries-producing potential. Widely different abilities to cause caries were observed for the various products tested.

In addition, using a programmed feeder, König⁸ alternated feedings of a cariogenic diet with feedings of a food such as bread and found that the level of caries activity was reduced, suggesting that bread was much less cariogenic than the caries-producing diet. Another variant of this type of procedure has been proposed by Bowen *et al.*⁹ The essential nutrients were provided by gastric intubation twice daily. Then, the item being tested for its potential cariogenicity was provided 17 times daily in a programmed feeder. In this study, four items were evaluated for their cariogenic potentials: starch, sucrose, a presweetened cereal, and a regular cereal. The groups of rats provided with sucrose or a presweetened cereal had significantly higher caries scores in the sulci and on the smooth surfaces than did those fed either starch or a regular cereal. In this study, a very high amount of technical time is necessary for intubation and use of the programmed feeder.

Similar studies have been conducted in this laboratory with a simpler, less labor-intensive procedure that involves an alternation once daily of (1) a highly nutritious, low caries-producing diet to provide adequate protein, minerals, and vitamins, and (2) a test food or confection. The composition of the highly nutritious diet is such that it has a relatively low ability to cause caries and is sufficiently nutritious to be able to support excellent growth and well-being when it provides one-half of the food intake. The other half of the food consumed may be sucrose or any test food or confection that rats will eat. In any experiment, one control group (low caries) receives only the nutritious diet while a second control group (high caries) receives the nutritious diet for part of each day and granulated sugar (sucrose) for the remainder of the day. The increase in caries attributable to sucrose ingestion is the standard increase for that experiment against which each test item is compared. Each rat in an experimental group receives the nutritious diet alternating with a test food or confection that may be a commercially available breakfast cereal, cracker, cookie, candy, or a component of candy. A ratio of the caries increase attributable to the test item to the increase attributable to sucrose is determined. In the following figures, sucrose routinely has a value of 1.0 while the ratios for the other items express the increases in caries that they caused under these experimental conditions.

In Table 2 are shown the estimated values for the potential caries-producing abilities of several breakfast cereals and peanuts as determined in this type of assay. Peanuts, in contrast to sucrose, had only one-fifth of the potential ability to cause caries when consumed by rats under these conditions. However, under the same circumstances, Wheat Chex, corn flakes, and Frosted Flakes caused high levels of caries with the average of seven comparisons for Frosted Flakes being the same as for sucrose.

Table 2. Comparison of the caries-producing potentials of breakfast cereals and peanuts with the caries-producing potential of sucrose as determined in a rat assay

Food	Caries-producing potential
Sucrose	1.0
Frosted Flakes (7)*	1.0
Wheaties (2)	0.6
Cheerios (1)	0.5
Life (1)	0.4
Corn Flakes (3)	0.8
Ralston, dry (2)	0.6
Wheat Chex (2)	0.7
Quaker Oats (1)	0.3
Peanuts (1)	0.2

* Numbers in parentheses, number of trials in which the item was compared to sucrose.

The statement is often heard that the milk consumed with a presweetened cereal is capable of nullifying any cariogenic potential that the cereal might have. The buffering power of milk proteins, the high-phosphate content of milk, and the fact that the mixture is consumed wet are all invoked as possible caries-protective factors. As shown in Table 3, three tests with the above assay, the addition of the same volume of milk as the cereal weighed, did not cause any major reduction in the caries-producing potential of Frosted Flakes in this test.

Table 3. Comparison of the caries-producing potential of a presweetened cereal when fed without or with milk with the caries-producing potential of sucrose as determined in a rat assay

Sucrose, cereal ± milk	Caries-producing potential
Sucrose	1.0
Frosted Flakes (3)*	0.7
Frosted Flakes + fresh milk (3)	0.6

* Numbers in parentheses, number of trials in which the item was compared to sucrose.

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