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The Chemistry and Metabolism of the Starch Based Sweeteners

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ABSTRACT

Starch hydrolysates (glucose syrups), widely used in the food industry, have recently been modified by hydrogenation on a commercial scale, making available a new range of carbohydrate compounds with distinctive physico-chemical and physiological properties.

Hydrogenated glucose syrups may be used in foods to control non-enzymic browning reactions, moisture absorption, sweetness and fermentability. The degree of control is directly related to the degree of hydrogenation and to the extent of initial hydrolysis of the starch. Furthermore, good complexing power toward mineral components of foods allows the control of cation-catalysed oxidation processes such as vitamin C destruction.

Physiologically, hydrogenated syrups may offer certain advantages in foods for the diabetic market. Blood glucose and serum insulin levels after ingestion may remain lower than after conventional carbohydrates.

INTRODUCTION

Sweet foods and drinks are consumed by mankind far in excess of their value for relieving hunger and thirst. Western peoples like the sweet sensation and, whilst sugars are primarily consumed for their sweet function, they also possess many useful physico-chemical and physiological properties which may be utilised by the food manufacturer for the

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benefit of the consumer. Increased consumption of refined sugars, mainly in the form of sucrose, has been associated with increased incidence of diseases such as tooth decay, obesity, heart disease and diabetes mellitus (Yudkin, 1979). Very few foods contain no sugar or carbohydrate and the carbohydrate may be present as a simple mono- or di-saccharide or as a more complex polymer such as starch, although potato starch in its raw form is not without problems and has been shown to cause death in rats (El-Harith *et al.*, 1982). A particular group of sugars of growing interest and importance to the food manufacturer are the partial hydrolysates of starch, the glucose syrups. It has been known for over 150 years that if starch is boiled with acid, a sweet liquor is produced, and this crude process formed the basis of a glucose syrup industry which has now progressed to a highly complex, biotechnologically based concern. The majority of syrups are now, however, produced enzymically although acid hydrolysis, being a relatively simple process, still finds applications, especially in developing countries. Enzymic hydrolysis enables production of syrups with closely controlled composition and properties, whereas acid hydrolysis produces a more limited range of syrups (Howling, 1979). Glucose syrups, in their various forms, are likely to be widely used in the future since they possess certain technological and metabolic advantages compared with other carbohydrates.

Chemically, glucose syrups consist of the reducing sugar glucose and its oligomers (short polymers) and the components of the syrups range in molecular weight from 180 (glucose) to about 3000. Each syrup contains varying proportions of each component and, since the latter have different properties, the glucose syrups themselves also have different properties depending on their composition. Glucose syrups are characterised by their carbohydrate composition and dextrose equivalent, or DE, which is a measure of the total reducing sugars in the syrup, expressed as dextrose and calculated on a dry weight basis. Carbohydrate composition is most usually determined by high performance liquid chromatography (HPLC) and DE by simple reducing sugar determinations or by physical means (Lane & Eynon, 1923; Kearsley, 1978*a*). Many of the properties of the syrups are related to DE, as will be illustrated later. The dual characterisation is necessary since it is possible to have two syrups of the same DE but of different composition. In addition to the more traditional types of glucose syrup, which have been produced for over a century, the industry has seen some recent developments in the form of high maltose syrups in the early 1960s, of

high fructose glucose syrups in the late 1960s and of hydrogenated glucose syrups in the early 1970s. The early 1970s also saw the technique of reverse osmosis applied to the fractionation of glucose syrups, to produce a range of syrups from 15–78 DE using a 43 DE syrup as starting material (Birch & Kearsley, 1974; Kearsley, 1976). High fructose syrups are widely used in soft drinks, owing to their high sweetness, whilst hydrogenated syrups have only recently been permitted in foods and are thus in their infancy as food components. Oxidised glucose syrups are still at the development stage, but may find future use in foods as the manufacturing process is developed (Gallali, 1981). It is the purpose of this paper to describe some of the more useful physico-chemical and physiological properties of glucose syrups, comparing the more traditional syrups with the more recently developed compounds.

GLUCOSE SYRUP PRODUCTION

In the UK the majority of glucose syrups are now produced by enzymic hydrolysis of the starch polymers, amylose and amylopectin; amylose being an essentially linear molecule composed of glucose units joined by α(1–4) linkages, and amylopectin a branched molecule with α(1–4) linkages in the linear parts of the molecule and α(1–6) linkages forming the branches. The amylase enzymes which are used commercially to catalyse the hydrolysis of starch, and their methods of action, are given below.

α Amylase will catalyse the hydrolysis of (1–4) links in the starch polymer, and in its partially hydrolysed breakdown products, by a random endo technique. The products of hydrolysis have the α configuration. The α amylases originate from either bacterial or fungal sources and some are stable at temperatures in excess of 100 °C. The (1–6) linkages are hydrolysed only slowly or not at all.

β Amylase will catalyse the hydrolysis of (1–4) links in starch but, in contrast to α amylase, the hydrolysis is by an exo technique. Maltose units, with the β configuration, are cleaved from the non-reducing ends of the molecules. The (1–6) linkages are not hydrolysed or by-passed and thus whilst amylose is completely hydrolysed to maltose, amylopectin is not, and a limit dextrin is produced. Higher plants, e.g. barley, are the usual source of β amylase.

Amyloglucosidase catalyses the removal of glucose units from the non-reducing ends of the starch chains by the hydrolysis of (1–4) and (1–6) linkages. It will almost totally convert starch into glucose.

Pullulanase is not an amylase enzyme in the true sense, but will selectively hydrolyse (1–6) linkages in amylopectin. It is used in conjunction with β amylase to convert starch almost completely into maltose.

These enzymes, used singly and in combination, can be used to produce a range of glucose syrups from about 20–90 DE and to produce pure glucose by crystallisation from the highest DE syrups.

SPECIALITY GLUCOSE SYRUPS

Although many speciality glucose syrups have been produced by the industry and in research laboratories in the last twenty years, the examples described below are those which are of most importance to the food industry and are permitted in foods in the UK.

(1) High maltose syrups

The availability of amylase enzymes, and in this case β amylase, in commercial quantities enabled the production of glucose syrups containing high concentrations of specific components, particularly maltose. Syrups containing maltose in excess of one third of the total sugars present are now commonplace. These possess many useful physico-chemical properties, such as high fermentability, a stabilising effect with regard to sugar crystallisation in confectionery and a low hygroscopicity, which can be utilised by the food industry (Takasaki & Yamanobe, 1981; Fullbrook, 1982). High maltose syrups were originally produced by an acid/enzyme process, in which the starch was first subjected to an acid hydrolysis followed by treatment with β amylase. Such syrups contained appreciable quantities of glucose in addition to the maltose. The syrups are now produced using either a single or dual enzyme hydrolysis. In the single process the starch is treated with an α amylase (as opposed to a β amylase as might be expected) and is hydrolysed to mainly maltose and maltotriose with small amounts of glucose (Allen & Spraldin, 1974). In the dual process the starch is first hydrolysed to oligomers containing about 10 glucose units, using a heat

stable α amylase (Fullbrook *et al.*, 1977), and this is followed by treatment with β amylase to give syrups containing little glucose (4–8 %) but up to 60 % maltose. Detailed descriptions of these processes are given in the literature (Fullbrook, 1982). Whilst high maltose syrups are very useful food ingredients in their own right, they may also be an ideal substrate for hydrogenation, as will be described below.

(2) High fructose glucose syrups

Glucose and its oligomers were originally the only components of glucose syrups. In the late 1960s, enzymes capable of converting between 15 and 42 % of the glucose fraction of glucose syrups into fructose became commercially available. These enzymes were in liquid form and very expensive, but were later immobilised to reduce processing costs. The process is more fully described in the literature (Seidman, 1977; Palmer, 1982). Syrups containing up to 90 % fructose are now produced and these form the main commercial source of fructose. Fructose syrups are very sweet and used, for example, to reduce the calorie levels in soft drinks since less carbohydrate is required to maintain the same sweetness compared with conventional syrups.

(3) Hydrogenated glucose syrups

These are one of the most recent commercial developments from the glucose syrup industry. The raw material for the process can be any glucose syrup, although the differences between conventional and hydrogenated syrups are predictably greater when high DE syrups are used, since these contain potentially more aldehyde groups for hydrogenation. Typically, the glucose syrup is placed in a pressure vessel and heated to 100 °C in the presence of a nickel catalyst. Hydrogen is admitted to a pressure of 100 atm. and the reaction completed in 5–6 h. During the reaction, free aldehyde groups are converted to alcohol groups and sugar alcohols formed. Glucose is converted to sorbitol, maltose to maltitol, etc. (Akher *et al.*, 1974*a*, *b*, *c*, *d*, 1975; Kearsley & Birch, 1977*a*, 1979; Kearsley *et al.*, 1980*a*). Hydrogenated glucose syrups possess no free reducing groups and therefore physico-chemical and physiological reactions involving this group are eliminated or changed. When the syrups are hydrogenated, only the terminal glucose residue is reduced and is then unable to form a ring structure. This may be

responsible in part for many of the different properties of hydrogenated glucose syrups, compared with conventional syrups. Examples of the properties are given below.

PROPERTIES OF GLUCOSE SYRUPS

Glucose syrups have many physico-chemical and physiological properties of use to the food manufacturer, and these properties are in some cases related to DE. It is not the purpose of this paper to discuss all these properties (such discussions may be found in the literature (Pancoast & Junk, 1980)) but to indicate how the more recently developed syrups have changed some of these properties.

Sweetness

The relative sweetness of glucose syrups, calculated from their threshold concentration values and on a scale where sucrose = 100, are given in Fig. 1 (Kearsley *et al.*, 1978). Predictably, there is an increase in sweetness as DE increases, but there is little difference in relative sweetness between glucose syrups of 64 DE and above, and glucose itself. Table 1 shows the carbohydrate content of these syrups and, as expected, there is a wide variation in composition. It has previously been reported that whilst glucose and maltose are sweet, maltotriose is only trace sweet (Birch, 1976). It may thus appear that sweetness in glucose syrups is related only to their glucose and maltose contents. There are, however, wide variations in the concentrations of these components in the higher DE syrups and the equisweet properties are not so easily explained. Synergistic interactions

TABLE 1
Carbohydrate Content of Glucose Syrups

DE	*Carbohydrate content* (%)			
	Glucose	*Maltose*	*Maltotriose*	*Higher saccharides*
64	48	23	12	17
78	62	25	10	3
86	82	2	1	5
100	100	0	0	0

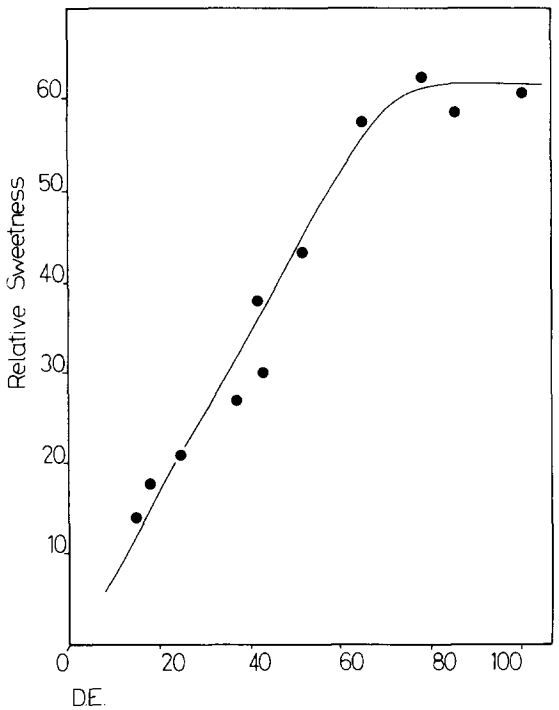

Fig. 1. Relative sweetness versus DE.

between sugars are known to cause increased sweetness in sugar mixtures (Dahlberg & Penczec, 1941; Stone & Oliver, 1969; Fruin & Scallet, 1975) above the additive sweetness of the individual sugars and must occur in these examples. Fructose syrup has approximately the same sweetness as sucrose, although the syrups with 90% fructose have been reported as being 160 on the same scale (Pancoast & Junk, 1980). The effect of hydrogenation on mono- and disaccharides has been shown to cause an increase in sweetness, except in the case of cellobiose (Kearsley *et al.*, 1980*b*). When glucose syrups are hydrogenated a similar effect occurs. At threshold levels the effect is limited, but is more pronounced at 10 and 20% concentration. The two main components of glucose syrups are glucose and maltose. The relative sweetness of these compounds and their hydrogenated derivatives are given in Table 2.

On the same scale, sucrose is 100. As previously reported, maltose is less sweet than glucose and hydrogenation of glucose causes a slight increase in sweetness. Maltose, however, becomes almost 50% sweeter on

TABLE 2
Sweetness of Glucose and Maltose and their Hydrogenated Derivatives

Carbohydrate	*Relative sweetness*
Glucose	61
Sorbitol	63
Maltose	43
Maltitol	68

hydrogenation and about 10% sweeter than glucose or sorbitol. The increased sweetness has been attributed to intramolecular H-bonding between the aglycone and the 4-hydroxyl group on the glucose residue. It was previously stated that high maltose syrups may be an ideal substrate for hydrogenation, the reason now being clear. Such a high maltose content should give a very sweet hydrogenated product.

Previously, high fructose glucose syrups have been described and high DE syrups are used commercially as the substrate for isomerisation, since these syrups are the greatest potential source of fructose. A range of glucose syrups, from 21 to 100 DE, have been subject to treatment with glucose isomerase and their sweetness determined (Dziedzic, 1981). In all examples, sweetness increased and the effect was most pronounced at low DE. For example, with the 21 DE syrup a twofold increase was observed.

Hygroscopicity

Hygroscopicity is a property of glucose syrups, and involves moisture absorption from the surroundings, usually the atmosphere. Very hygroscopic sugars absorb the moisture rapidly and change from the solid state to form a solution in a matter of a few hours. The water sorption properties of carbohydrates are important with regard to drying out or wetting of foods by moisture absorption. For example, cakes lose moisture and dry out but, if hygroscopic sugar is included in the cake formulation, the tendency is reduced. Conversely, boiled sweets manufactured from hygroscopic sugars become sticky and unacceptable. Hygroscopicity of glucose syrups increases with increase in DE as shown in Fig. 2 (Kearsley & Birch, 1975).

Whilst hygroscopicity can be controlled by using low DE glucose syrups in foods, the functional properties of these compounds may not be

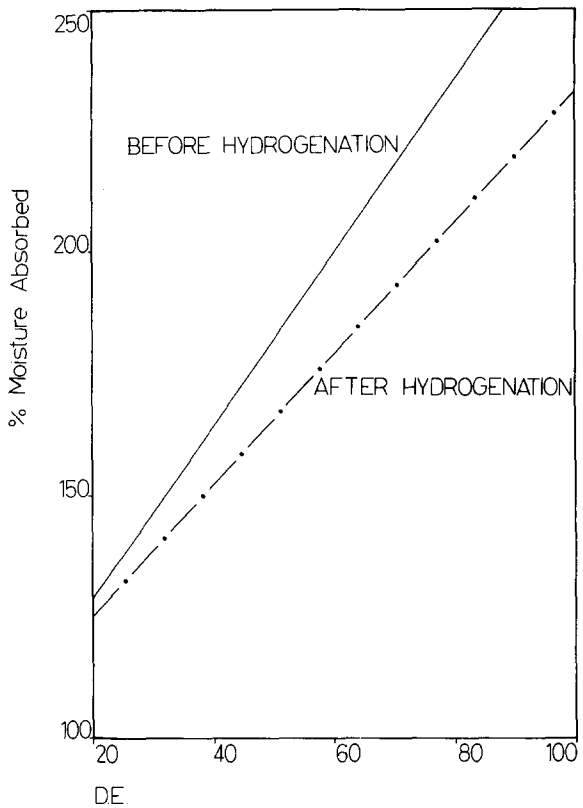

Fig. 2. Moisture absorption versus DE.

desirable for the particular product. Sorbitol is reported to be less hygroscopic than glucose above 79% relative humidity (RH), although we have not been able to confirm these findings. Whilst our results indicate sorbitol to be slightly more hygroscopic at 100% RH, the general trend for glucose syrups is that hydrogenation reduces the hygroscopic tendencies of the carbohydrates, as shown also in Fig. 2 (Kearsley, 1978*b*).

Fermentability

Highly fermentable glucose syrups (above 95 DE) are desirable for the brewing industry in order to produce alcohol, using yeast. Syrups containing only about 70% fermentable sugars are also useful, however,

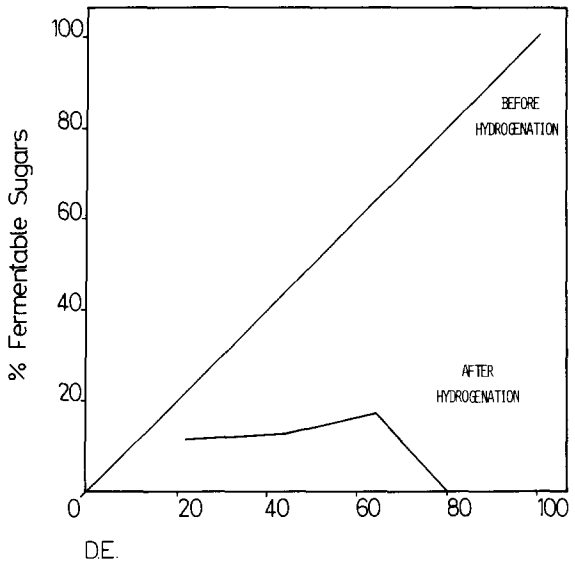

Fig. 3. Fermentable sugars versus DE.

as are the remaining carbohydrates, which are of molecular weight greater than maltotriose (MW 504) and, for example, provide 'body' in beers. Syrups containing high concentrations of glucose, fructose and maltose are most rapidly fermented and in glucose syrups the percentage of fermentable sugars is directly related to DE, as shown in Fig. 3. Unfortunately, fermentation may be a spoilage reaction in some foods and is most definitely undesirable. Breakdown of glucose syrups by bacteria in the mouth may lead to increased incidence of dental caries. Sorbitol is known to be unfermentable by brewing yeasts, and the relationship between fermentability and hydrogenation of glucose syrups is also shown in Fig. 3 (Kearsley, 1978*b*). This shows that, whilst the higher DE syrups are not fermented after hydrogenation, the 21, 43 and 65 DE syrups are fermented, but to a much reduced extent after hydrogenation. This effect is not easily explained. However, if the yeast possessed some α amylase activity, then some hydrolysis of the oligomers might have occurred to produce fermentable glucose or maltose. The activity of some α amylases is inhibited by low molecular weight carbohydrates, as found in high DE syrups, and this may explain the lack of fermentation in the 84 DE syrup hydrogenation. The overall trend, however, is that fermentability is reduced by hydrogenation.

Browning

The interactions of reducing sugars and amino compounds is well documented but, nevertheless, a very complex series of reactions is involved to produce the final brown colour. These brown colours may be desirable, as in the case of brown crusty loaves of bread, but generally are indicative of poor manufacturing technique as in brown boiled sweets or jam. The initial stages of the browning, or Maillard reaction, involve carbonyl and amino groups, and the greater the concentration of these structures the more browning will take place. An obvious solution to the problem is, therefore, to use a low DE glucose syrup in the food product, since this, by definition, contains few carbonyl (reducing) groups. Unfortunately, the properties of the low DE syrup may not be desirable in the product; it may be too viscous or not sweet enough, and thus may create more problems than it solves. Hydrogenation offers a convenient alternative means of controlling browning by converting the carbonyl groups to primary alcohol groups which play no part in the reaction. The desirable properties of sweetness and viscosity are not adversely affected.

These are the main properties of glucose syrups which can be controlled or modified by simple means, but it is not a comprehensive list of the physico-chemical properties of these commodities. Other properties such as viscosity, osmotic pressure and bodying effect remain relatively unchanged, for example, after hydrogenation.

Glucose syrups are used primarily in foods for the physico-chemical properties they confer on the food. Few foods or drinks are sold primarily as a source of energy or of carbohydrate, that is, sold for dietetic reasons, although certain preserves for diabetics contain the non-insulin requiring sugar alcohol, sorbitol. It is likely, in the future, that 'purpose made' foods and drinks will be available for dietetic purposes and an understanding of the physiological properties of glucose syrups is, therefore, important.

PHYSIOLOGICAL PROPERTIES OF GLUCOSE SYRUPS

Carbohydrates in the diet are used as a source of energy and must, at some stage in their metabolism, be converted to glucose to be assimilated in the body. A convenient method of assessing the response of the body and its capability of dealing with carbohydrates is by the glucose tolerance test.

This involves a subject ingesting a solution containing a test carbohydrate and measuring the blood glucose response induced by the carbohydrate. The observed blood glucose elevation after ingesting different carbohydrates depends not only on the carbohydrate, but also on the gastric emptying rate, digestion and absorption rates, insulin response and metabolic conversion of non-glucose compounds into glucose itself.

It has been shown that when 50 g doses of different glucose syrups or their fractions, produced by reverse osmosis, are ingested, there is no significant difference in the blood glucose profiles induced by each compared with glucose alone (Etheridge, 1975; Kearsley *et al.*, 1975). This indicates that hydrolysis of the oligomers in the syrups is not a limiting factor in their metabolism, but that gastric emptying and absorption from the gut are the main limiting factors.

Chemical modification of glucose syrups might be expected to influence the shape of the blood glucose profile. Thus, isomerised glucose syrups may be expected to produce a lowered blood glucose peak as a result of the fructose they contain (about 40%). When this theory was put into practice, no significant differences were found between isomerised syrups and glucose (Kearsley & Birch, 1976). Subjects given 50 g of fructose produced a wide variation in response in blood glucose elevation, ranging from no increase in blood glucose to a normal shaped curve (Birch & Kearsley, 1977). The lack of difference between the isomerised syrups and glucose must therefore be due to the high glucose content of the isomerised syrups, and to establish any difference between the compounds, a lower dose must be given. Further studies showed that 50 g and 25 g of glucose gave the same blood glucose profiles, and only when 10 g of glucose was ingested was a lowered peak value obtained. When 20 g of isomerised syrup (containing 10 g of glucose) was ingested, the blood glucose profile was the same as for 50 g and 25 g of glucose, indicating perhaps that fructose, in the presence of glucose, is rapidly converted to glucose (Kearsley & Birch, 1976).

Whilst isomerised syrups represent a modification of glucose syrups, more severe modification is obtained by hydrogenation of the parent syrup. Sorbitol (hydrogenated glucose) is known not to elevate blood glucose after ingestion or to require insulin for its metabolism. Hydrogenated glucose syrups should behave in a similar manner, although predictably to a lesser extent. When subjects ingested hydrogenated glucose syrups it became apparent that only syrups of high DE induced lower peak values for blood glucose. In the study carried out,

hydrogenated 21 and 43 DE syrups and hydrogenated high maltose syrup induced the same peak values as glucose, whilst the hydrogenated 65 DE syrup and maltitol (hydrogenated maltose) gave significantly lower values. Subjects consuming the hydrogenated 65 and 43 DE samples experienced some discomfort in the way of flatulence and diarrhoea, whilst the remaining samples caused no problems (Kearsley & Birch, 1978; Kearsley & Lian-Loh, 1982).

It was evident from this study that hydrogenated glucose syrups may cause some abdominal problems when consumed, and it was considered important to identify what quantity the body could tolerate each day without discomfort, since this would govern how widely the modified syrups could be used in foods or taken in the diet.

A study was carried out involving 35 subjects, male and female, in three groups (Kearsley *et al.*, 1982). None of the subjects had, to their knowledge, ever consumed hydrogenated glucose syrup previously. This was considered important, to eliminate any adaptation to these compounds thus affecting the results. Each group was required to ingest, over a period of 12 h, a predetermined quantity of a commercial hydrogenated glucose syrup, Lycasin which corresponded in composition to a hydrogenated high maltose syrup. Group 1 ingested 50 g; group 2, 85 g; group 3, 120 g. Subjects were asked to note any intenstinal discomfort, flatulence or diarrhoea. In groups 1, 2 and 3 the results were 2/12, 3/12 and 6/11, respectively, with no difference between male and female subjects. This indicated that about 85 g of the syrup could be tolerated per day, by most subjects, without too much discomfort. Discomfort increased in severity with dose.

Further studies with hydrogenated syrups

In addition to the blood glucose response to different carbohyrates, insulin demand is also an important factor, especially with hydrogenated syrups and their possible inclusion in foods designed for diabetic subjects. Studies have been carried out to measure blood glucose and serum insulin after ingestion of hydrogenated sugars, to compare these values with those obtained from glucose (the standard) (Kearsley *et al.*, 1982; Lian-Loh, 1982).

Five carbohydrates were used in the work: glucose; a commercial hydrogenated syrup; maltitol; and two combinations of glucose and sorbitol in which the glucose/sorbitol ratios were identical to those in the

hydrogenated syrup and maltitol, respectively. The combined glucose/sorbitol samples were included in the study to establish if the hydrogenated syrup and maltitol were metabolised to the same extent as their component sugar residues. Samples were given at levels of 0·5 g kg^{-1} body weight, and blood samples taken for analysis for glucose and insulin. Both male and female subjects were used in the study and slight differences were found between them. Overall, glucose induced significantly elevated blood and serum insulin profiles compared with the maltitol and hydrogenated glucose syrup, whilst there was no significant difference between the glucose and the glucose/sorbitol mixtures. The maltitol and hydrogenated glucose syrup tended, however, to induce sustained blood glucose and serum responses after 60 and 90 min compared with the other test samples. This indicates that hydrogenated sugars are hydrolysed only slowly in the gut and hence metabolised more slowly compared with their component monosaccharides. This feature would make these hydrogenated carbohydrates eminently suitable for inclusion in foods for diabetics, where rapid and large increases in blood glucose cannot be tolerated.

Long-term studies

Ten-day studies were carried out in which subjects ingested as their only carbohydrate source glucose, hydrogenated glucose syrup, maltitol or a conventional glucose syrup at a ratio of 40:60 with protein (Kearsley *et al.*, 1982; Lian-Loh, 1982). Glucose tolerance tests were carried out initially and after 4 and 10 days, using the same carbohydrate as involved in the test: blood glucose and serum insulin were determined. Initially, the hydrogenated sugars induced lower blood glucose peak values than either glucose or the glucose syrup, although there was no significant difference in overall blood glucose profiles. After 4 days however, there was no significant difference between any of the carbohydrates with respect to blood glucose. For serum insulin, the hydrogenated samples induced lower peak values and lower overall insulin profiles throughout the test period, although towards the end slightly elevated values were found indicating some adaption, perhaps, to the sugar alcohols. Intestinal discomfort, flatulence and diarrhoea gradually disappeared after consuming the hydrogenated samples for about 4 days. No glucose was excreted in the faeces or urine when glucose or glucose syrup was ingested, and with maltitol and hydrogenated glucose syrup over 99% of the samples were utilised by the body.

The results indicate that maltitol and hydrogenated glucose syrup are hydrolysed in the body to their component monosaccharides, albeit slowly, and almost all the monosaccharides are retained by the body. Whilst initial problems may occur on ingestion of hydrogenated carbohydrates, adaption to them by the body is a relatively rapid process.

CARBOHYDRATE/IRON COMPLEX FORMATION

It has been shown that all common carbohydrates, including glucose syrups, have the ability to form complexes with iron and particularly with ferric iron (Kearsley & Birch, 1977*b*; Kearsley *et al.*, 1979). It is likely that this chelation of inorganic species is not restricted solely to iron but that all metal ions will be complexed to a greater or lesser extent. This complex formation could be of both physico-chemical and physiological importance. In foods, inorganic ions can cause discoloration; for example, iron can form a complex with rutin, a flavanol, to give black/brown discoloration in cauliflower, and chromium can lead to grey discoloration in sweetcorn; copper ions are known to catalyse oxidation reactions in fats and oils. Complexing of the metal ions with carbohydrate may reduce these effects, although the pH of the system may be an important factor, as will be indicated. Physiologically, trace metals are vital in the diet. Iron, for example, is required for the respiratory pigment haemoglobin. Shortage of iron leads to anaemia, a condition which is very difficult to treat since iron absorption by the body is very poor. Simultaneous ingestion of iron with carbohydrate is known to cause increased absorption of iron from the gut, and a refined form of this interaction may find use in the treatment of anaemia (Charley *et al.*, 1963; Bates *et al.*, 1972). A problem associated with producing foods fortified with iron is that the iron produces an unpleasant, metallic taste in the food, and in high concentrations makes the food unpalatable. Isolated iron/carbohydrate complexes do not, however, possess this metallic taste (Kearsley *et al.*, 1979). It was thus envisaged that addition of iron to a high-sugar product such as a soft drink may provide a method of fortifying foods whilst eliminating the metallic taste. This theory was evaluated using glucose and fructose solutions at the typical low pH of a soft drink, but the sugars in fact enhanced rather than reduced the metallic taste. Only when the pH was raised above 4·5–5·0 did masking

occur (Cross & Kearsley, 1984), indicating that complex formation is very much dependent on pH.

Addition of carbohydrate will also inhibit the copper catalysed oxidation of ascorbic acid (vitamin C), hydrogenated glucose being particularly useful in the respect (Cross *et al.*, 1984).

CONCLUSION

Maize starch is a relatively inexpensive substrate, from which it is possible to derive simple hydrolysis products by acid or enzyme means. These products are used widely in the food industry both in their native form and after modification, either by isomerisation or by hydrogenation. From a single raw material a wide range of products may therefore be produced with distinct physico-chemical and physiological properties, useful for both the food manufacturer and the consumer.

REFERENCES

Akher, M. A., Ghali, J., Raouf, M. S. & Roushdi, M. (1974*a*). *Starke*, **26**, 307; (1974*b*). **26**, 352; (1974*c*). **26**, 383; (1974*d*). **26**, 436; (1975). **27**, 128.

Allen, W. G. & Spraldin, J. E. (1974). *Brewers Digest* (July), **48**, 65.

Bates, G. W., Boyer, G., Hegenaur, J. C. & Saltman, P. (1972). *Am. J. clin. Nutr.*, **25**, 983.

Birch, G. G. (1976). *Crit. Revs. Fd Sci. Nutr.*, **9**, 57.

Birch, G. G. & Kearsley, M. W. (1974). *Starke*, **26**, 220.

Birch, G. G. & Kearsley, M. W. (1977). *Starke*, **29**, 348.

Charley, P. J., Stitt, C., Shore, E. & Saltman, P. (1963). *J. Lab. clin. Med.*, **61**, 397.

Cross, H. L. & Kearsley, M. W. (1984). *Lebensm. Wiss. u. Technol.*, **17**, 11.

Cross, H. L., Pepper, T., Kearsley, M. W. & Birch, G. G. (1984). *Starke* (in press).

Dahlberg, A. C. & Penczec, E. S. (1941). New York State Agric. Exp. Sta. Bull., 696, p. 1.

Dziedzic, S. Z. (1981). *Starke*, **33**, 369.

El-Harith, A. E., Walker, R., Birch, G. G. & Sukan, G. (1982). In: *Nutritive Sweeteners* (Birch, G. G. & Parker, K. J. (Eds)). London, Elsevier Applied Science Publishers.

Etheridge, I. (1975). PhD Thesis, University of Reading.

Fruin, J. C. & Scallett, B. L. (1975). *Fd Technol.*, **11**, 40.

Fullbrook, P. D. (1982). In: *Nutritive Sweeteners* (Birch, G. G. & Parker, K. J. (Eds)). London, Elsevier Applied Science Publishers.

Fullbrook, P. D., Vabo, B. & Ostegaard, J. (1977). *Ind. Chem. Eng.* Symposium No. 51, London.
Gallali. Y. (1981). PhD Thesis, University of Reading.
Howling, D. (1979). In: *Sugar: Science and Technology* (Birch, G. G. & Parker, K. J. (Eds)). London, Elsevier Applied Science Publishers.
Kearsley, M. W. (1976). *Starke*, **28**, 138.
Kearsley, M. W. (1978*a*). *J. Assoc. Publ. Analysts*, **16**, 85.
Kearsley, M. W. (1978*b*). *J. Fd Technol.*, **13**, 339.
Kearsley, M. W. & Birch, G. G. (1975). *J. Fd Technol.*, **10**, 625.
Kearsley, M. W. & Birch, G. G. (1976). *Proc. Nutr. Soc.*, **36**, 45A.
Kearsley, M. W. & Birch, G. G. (1977*a*). *Starke*, **29**, 425.
Kearsley, M. W. & Birch, G. G. (1977*b*). *Food Chem.*, **2**, 209.
Kearsley, M. W. & Birch, G. G. (1978). *IRCS Med. Sci.*, **6**, 82.
Kearsley, M. W. & Birch, G. G. (1979). In: *Sugar: Science and Technology* (Birch, G. G. & Parker, K. J. (Eds)). London, Elsevier Applied Science Publishers.
Kearsley, M. W. & Lian-Loh, R. H. P. (1982). In: *Nutritive Sweeteners* (Birch, G. G. & Parker, K. J. (Eds)). London, Elsevier Applied Science Publishers.
Kearsley, M. W., Fairhurst, E. & Green, L. F. (1975). *Proc. Nutr. Soc.*, **34**, 60A.
Kearsley, M. W., Birch, G. G. & Dziedzic, S. Z. (1978). *Lebensm. Wiss. u. Technol.*, **11**, 23.
Kearsley, M. W., Birch, G. G. & Foyle, R. A. J. (1979). *Acta Alimentaria*, **8**, 69.
Kearsley, M. W., Satti, S. H. & Tregaskis, I. (1980*a*). *Starke*, **32**, 169.
Kearsley, M. W., Dziedzic, S. Z., Birch, G. G. & Smith, P. D. (1980*b*). *Starke*, **32**, 244.
Kearsley, M. W., Birch, G. G. & Lian-Loh, R. H. P. (1982). *Starke*, **34**, 279.
Lane, J. H. & Eynon, L. (1923). *J. Soc. Chem. Ind., Lond.*, **42**, 32T.
Lian-Loh, R. H. P. (1982). PhD Thesis, University of Reading.
Palmer, T. (1982). In: *Nutritive Sweeteners* (Birch, G. G. & Parker, K. J. (Eds)). London, Elsevier Applied Science Publishers.
Pancoast, H. M. & Junk, W. R. (1980). Handbook of Sugars, 2nd edn, Westport, Connecticut, Avi Publishing Co. Inc.
Seidman, M. (1977). In: *Developments in Food Carbohydrate* (Birch, G, G. & Shallenberger, R. S. (Eds)). London, Elsevier Applied Science Publishers.
Stone, H. & Oliver, S. M. (1969). *J. Fd Sci.*, **34**, 215.
Takasaki, Y. & Yamanobe, T. (1981). In: *Enzymes and Food Processing* (Birch, G. G., Blakebrough, N. & Parker, K. J. (Eds)). London, Elsevier Applied Science Publishers.
Yudkin, J. (1979). In: *Sugar: Science and Technology* (Birch, G. G. & Parker, K. J. (Eds)). London, Elsevier Applied Science Publishers.