



Nordic Sugar
Member of Nordzucker Group

The functional properties of sugar

– on a technical level



Dear Reader,

In this brochure, we have gathered some of our deeper knowledge regarding the functional properties of sugar.

Besides sweetening, sugar has many functional roles in food.

Without sugar, jam would soon go off, ice cream would crystallise, and bread would lose its freshness and dry out. In addition, the taste of foods would be disappointing without the ability of sugar to round off and enhance natural taste components. Sugar has one or more unique, quality enhancing properties to offer almost all types of food production involving both solid and liquid foods.

All these functional properties are not always well known and sometimes even forgotten, despite of the importance sugar actually do play in the different applications.

You can also find information about the functional properties of sugar on our web site www.nordicsugar.com

Nordic Sugar

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Schematic Overview

	SWEETNESS	FLAVOUR	VOLUME	TEXTURE	SHELF LIFE	FERMENTATION	FREEZING POINT DEPRESSION	COLOUR	MOISTURE RETENTION
Sweetness	•								
Interaction with other tastes and flavours		•							
Bulking			•						
Solubility			•	•			•		•
Crystallisation				•					
Effect of sugar and sweeteners on pectin gel formation				•					
Particle size				•					
Viscosity				•					
Sucrose hydrolysis					•	•	•	•	•
Water activity and its implications in sugar-rich foods					•				
Fermentation feedstocks						•			
Browning reaction								•	

Sweetness

Sucrose is the standard sweetener to which all other sweeteners are compared. The relative sweetness of sucrose is set to 1 or 100%. The only way to measure the sweetness of a substance is to taste it. When a substance is placed on the tongue, the taste buds decipher the chemical configuration of the substance and a signal of the taste is sent to the brain.

A growing number of alternative sweeteners exist on the market; all with somewhat different sweetness compared to sucrose. The literature offers figures for the sweetness of the various sweeteners but in most cases these figures are related to just one application.

It is necessary to know in what medium the product was tested because the sweetness of many sweeteners

depends on concentration, pH, temperature and the use of other ingredients, for example other sweeteners or flavours. In some cases, psychological effects also influence the taste sensation: green jelly is perceived as less sweet than red jelly although they contain exactly the same amount of sweetener.

Figure 1 shows some of the sweeteners available today and their approximate level of sweetness.

Sweeteners are divided into two main groups: bulk sweeteners, with a relative sweetness lower or slightly higher than sucrose, and high intensity sweeteners (HIS) with a relative sweetness considerably above 1.

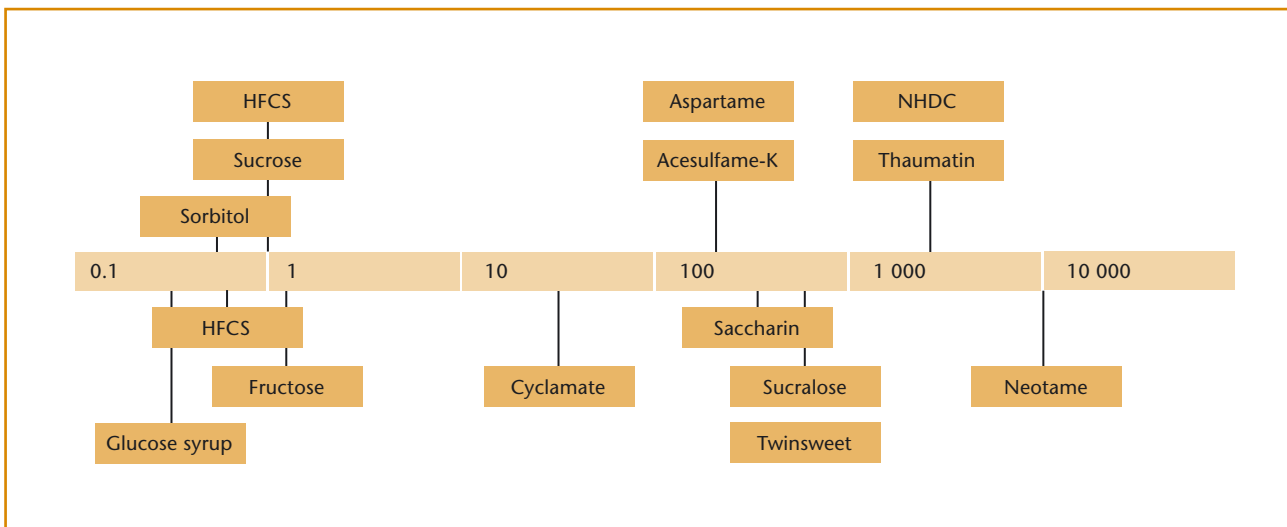


Figure 1. Approximate sweetness of selected sweeteners.

NATURAL SWEETENERS

Sucrose, glucose and fructose are the most common sweeteners in nature. Glucose is always less sweet than sucrose, whereas the sweetness of fructose is highly dependent on temperature. Figure 2 shows that fructose is sweeter than sucrose at low temperatures, whereas the sweetening effect decreases as the temperature rises.

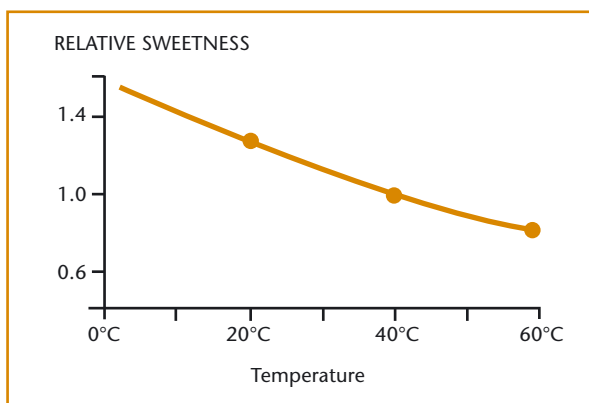


Figure 2. Effect of temperature on the relative sweetness of fructose. Source: Shallenberger RS, Taste Chemistry, 1993

Nordic Sugar has investigated beverages sweetened with sucrose, glucose and fructose alone and in different combinations. Table 1 shows the relative sweetness determined from these tests. Invert sugar is a 50:50 mix of fructose and glucose derived from inversion of sucrose.

The ratios 30:70, 90:10, 80:20 and 50:50 in the table indicate the weight percentages of the sweeteners as dry substances. The amount of sweeteners added to the beverages corresponds to 6-10% sucrose.

SWEETENER	RELATIVE SWEETNESS
Sucrose	1.0
Invert sugar	0.8
Sucrose: Invert sugar 30:70	0.9
Glucose	0.5-0.6
Fructose	0.9-1.2
Sucrose: Fructose 90:10	1.0
Sucrose: Fructose 80:20	1.1-1.2
Sucrose: Fructose 50:50	1.1-1.2

Table 1. Relative sweetness of raspberry-blackcurrant soft drinks.

GLUCOSE SYRUPS

Glucose syrup exists in many different versions depending on the degree of starch hydrolysis. There are also some variants with different levels of fructose due to isomerisation of the glucose molecule. Glucose syrups without fructose are less sweet than sucrose. Glucose syrups are given a DE number (glucose equivalents) based on the degree of breakdown. The higher the number, the more starch has been hydrolysed, see figure 3.

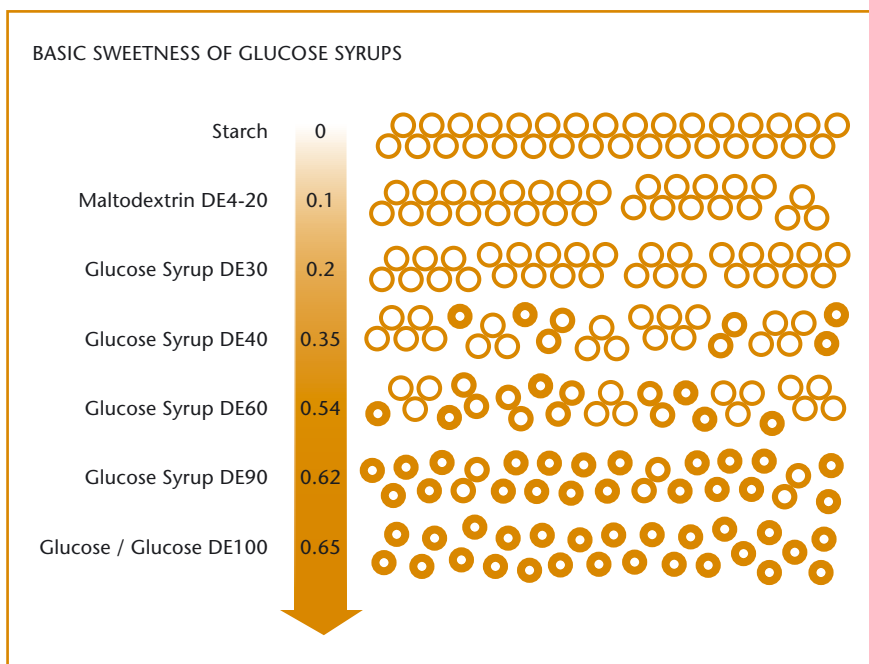


Figure 3. Sweetness related to the DE equivalent of glucose syrup.

The literature uses many different values for the relative sweetness of glucose syrups. Danisco therefore made tests with different mixes of sucrose and glucose syrup to evaluate the perception of sweetness. In the following example we compared non-carbonated raspberry and wild strawberry soft drinks and a carbonated soft drink called fruit soda (same type as Sprite) sweetened with either sucrose only (S 100) or a 50:50 mix of sucrose and a glucose syrup with 9% fructose at two different levels: S:F9 123 and S:F9 111 (123 and 111 indicate the amount of sweetener, counted as a dry substance compared to the amount of sucrose).

A taste panel ranked the sweetness of the samples on a scale from 1-9, where 1 was least sweet and 9 was sweetest. Some samples were tested both fresh from production and after four months of storage. Figure 4 illustrates the relation between the sweetness of the three samples and shows that for the fresh samples S:F9 123 is closest to the sucrose-sweetened sample in two applications, while S:F9 111 comes closer in the application. After four months' storage a dose of S:F9 123 is also necessary in this application. This is probably due to inversion of sucrose during storage, which increases the sweetness. The tests demonstrate that dosage tests must be made for each application to make sure that the product is sweetened optimally.

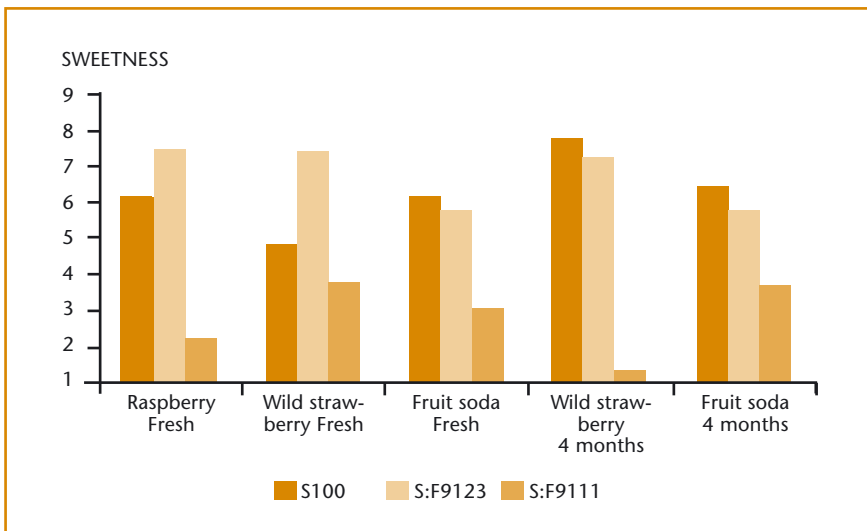


Figure 4. Sweetness in fresh and stored soft drinks.

POLYOLS

There are many different polyols available today, but all except one is less sweet than sucrose. The relative sweetness of the polyols appears from figure 5. All polyols have a more or less pronounced cooling effect due to negative heat solubility, which may add value to some products but cause problems in others.

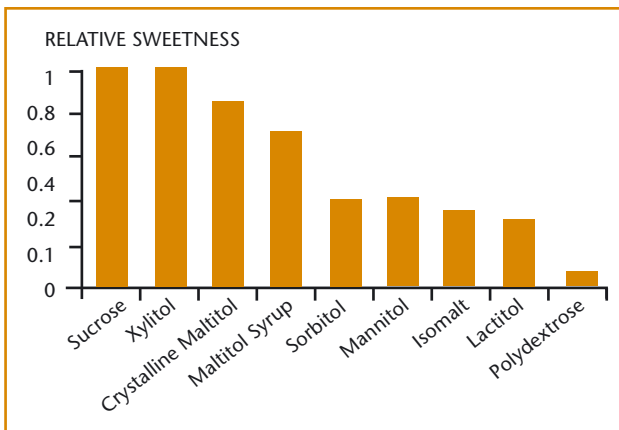


Figure 5. Relative sweetness of selected sugar alcohols (polyols).

HIGH INTENSITY SWEETENERS (HIS)

There are many different HIS products on the market. Table 2 lists the ones allowed in the EU. Restrictions for use in various applications apply to all of them, see the EU's sweetener directive (http://europa.eu.int/comm/food/food/chemicalsafety/additives/comm_legisl_en.htm) for more information on restrictions.

E NUMBER	SWEETENERS ALLOWED IN THE EU
E 950	Acesulfame K
E 951	Aspartame
E 952	Cyclamic acid, Na-Cyclamate, Ca-Cyclamate
E 954	Saccharin and its Na-, K- and Ca-salts
E 955	Sucralose
E 957	Thaumatococcus
E 959	Neohesperidin DC
E 962	Twinsweet (salt of aspartame and acesulfame)

Table 2. Sweeteners allowed in all EU countries.

The relative sweetness of all HIS products is highly dependent on concentration and pH, as exemplified in figures 6 and 7.

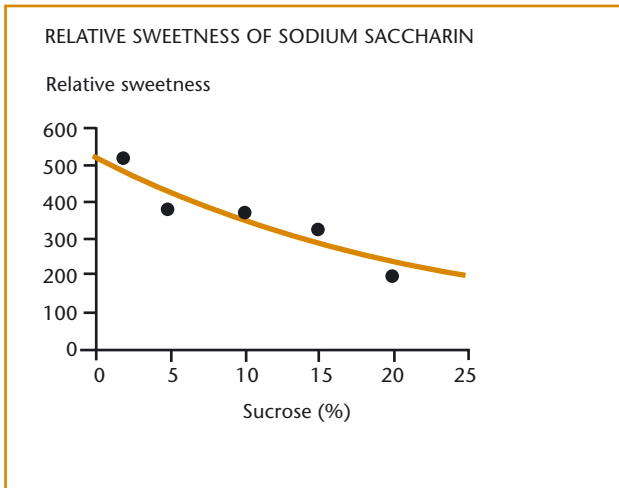


Figure 6. Dependence on concentration.
Source: ABC International Consultants

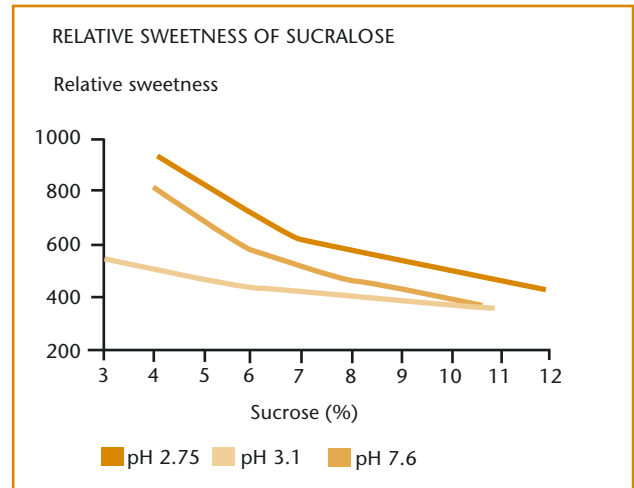


Figure 7. Dependence on pH and concentration.
Source: Zannoni Low Calorie Foods 1993

Mixing different HIS products often creates synergy effects resulting in higher sweetness than when used separately. Figure 8 illustrates the effect of mixing aspartame and acesulfame K.

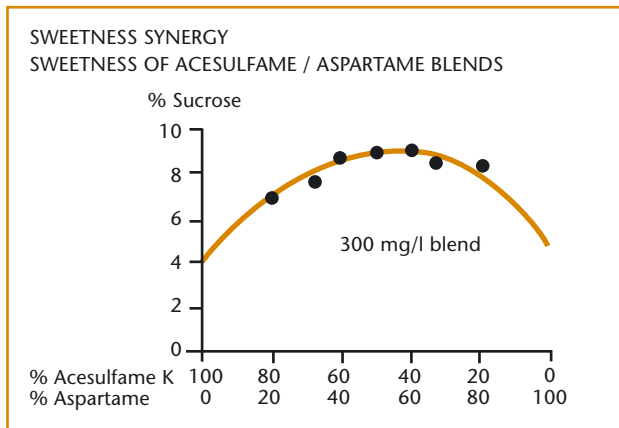


Figure 8. Example of synergy in HIS mixes.
Source: von Rymon Lipinsky 1991

Other mixes of sweeteners also generate synergies. Table 3 lists a number of mixes and their synergistic ability.

SWEETENER MIX	SYNERGY
Aspartame + Acesulfame K	Yes
Aspartame + Saccharin	Yes
Saccharin + Cyclamate	Yes
Acesulfame K + Saccharin	No
Sucralose + Aspartame	No
Sucralose + Acesulfame K	Yes
Sucralose + Saccharin	Yes

Table 3. Synergistic ability of selected HIS mixes.

Flavour

INTERACTION WITH OTHER TASTES AND FLAVOURS

Besides sweetness there are three other basic tastes: salt, sour and bitter. Sometimes umami is included as a fifth basic taste. In many food systems we use sweetness to balance the basic tastes and to enhance and modify flavours.

Sour applications

Beverages, jams and marmalades are all mixes of sweet and sour components. It is important to create a good balance between sourness and sweetness, which is often achieved by adding a mix of sugar and citric acid. This is a good mix because the time-intensity curves for both components are almost identical, i.e. the sweet and sour tastes reach their maximum almost simultaneously.

The time-intensity curves for the natural sugars, sucrose, glucose and fructose, are illustrated in figure 1.

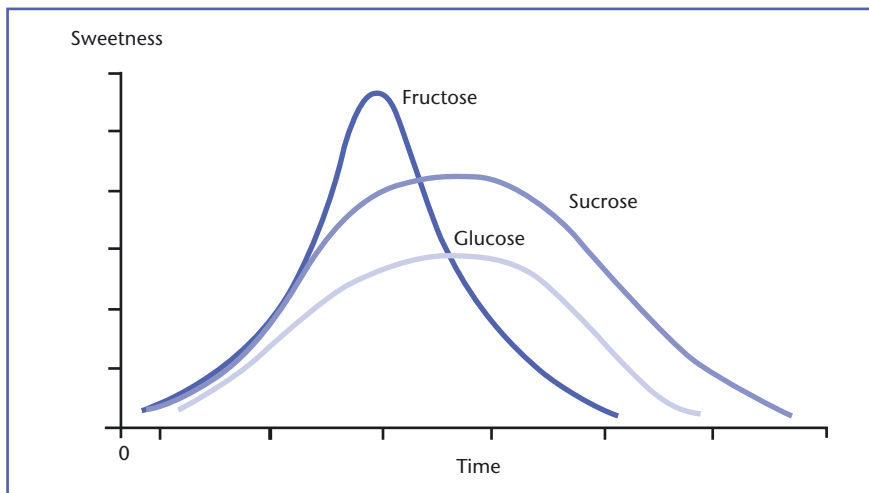


Figure 1. Time-intensity curves of fructose, glucose and sucrose.
Source: Shallenberger RS, *Taste Chemistry*, 1993

The time-intensity curves of different sweeteners vary greatly. The sweetness of, for instance, aspartame and sucralose lasts longer than that of natural sugars. It also outlasts the sourness of citric acid to the effect that the sweet taste lasts for too long. Using another acid, e.g. malic acid, can to some extent compensate for this, as its sour taste lasts longer. The time-intensity

curves of some sweeteners, for instance Thaumatin and Neohesperidin DC, are so different from all acids that they cannot be used in sour applications because the sourness disappears even before the sweetness is perceived. The sweetness is also very long-lasting, see figure 2.

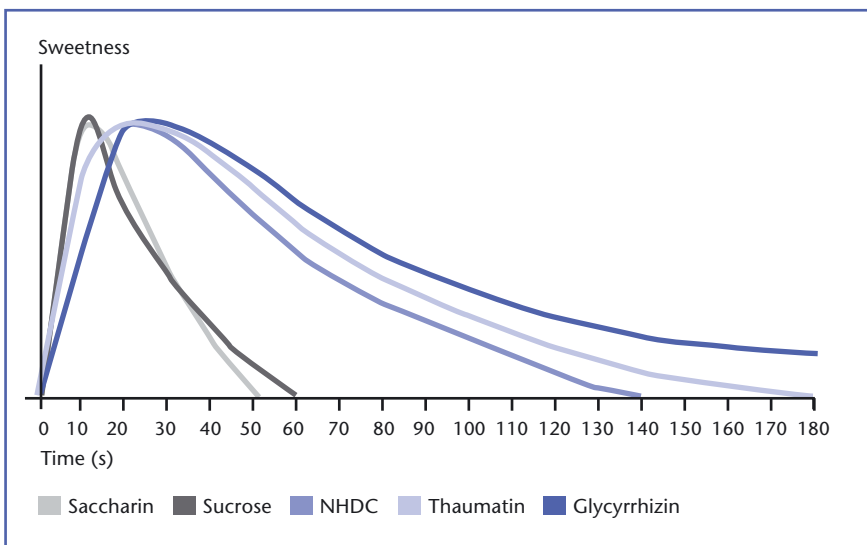


Figure 2. Time-intensity curves of selected sweeteners.
Source: Leatherhead Food RA Ingredients Handbook Sweeteners

Sucrose is often used in fruit preparations because of its ability to enhance the flavours of the fruit. This ability varies for different types of sweeteners. To find the optimal sweetener mix it is necessary to perform tests for every application. However, some mixes are preferred in most applications.

Figure 3 shows the results of tests made to rank the preference of selected sweetener mixes in two applications: non-carbonated raspberry and wild strawberry soft drinks. All mixes with sugar or glucose syrup reduced the energy by 40% compared to the drink sweetened with sugar only.

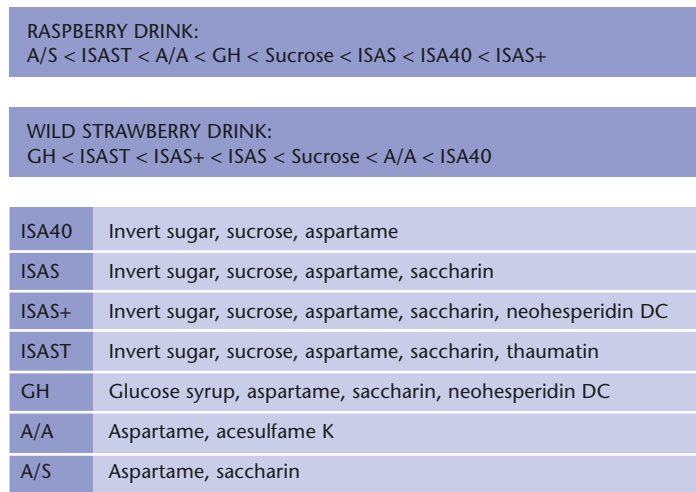


Figure 3. Preference ranking for non-carbonated soft drinks with total (A/A and A/S) or 40% (ISA40, ISAS, ISAS+, ISAST, GH) energy reduction compared to the sugar-sweetened drink.

Bitter applications

In bitter applications such as chocolate and coffee, sugar is often used to moderate or disguise the bitterness. Using taste panels, Galvino examined the effect of sugar on coffee and vice versa. Varying amounts of sugar were added to a standard coffee (100% coffee) prepared from 100 grams of coffee made with 1 litre

of water. It appears from figure 4 that sugar does have a strong influence on the perception of the coffee flavour and that the effect increases with increasing amounts of sugar, although not linearly. Likewise, the bitterness of coffee has a significant influence on the sweetness perceived, as illustrated in figure 5.

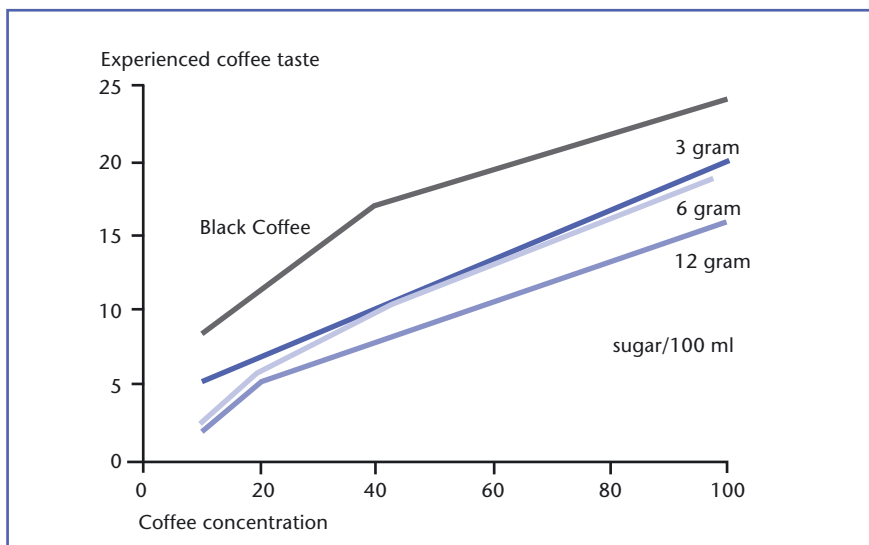


Figure 4. Effect of sugar on perceived coffee taste.
Data from Galvino et al, *Chemical Senses*, 1990.

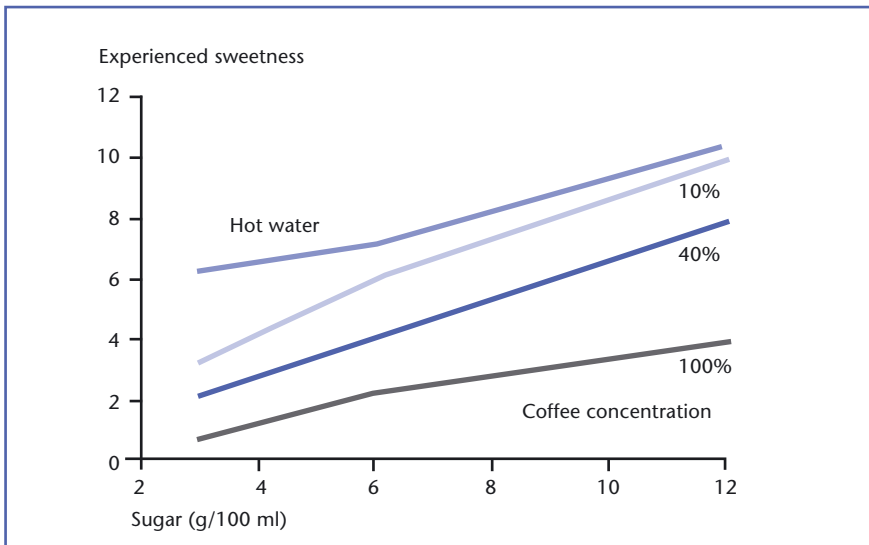


Figure 5. Effect of coffee bitterness on perceived sweetness.
Data from Galvino et al, *Chemical Senses*, 1990.

Volume

BULKING

There are two main groups of sweeteners: bulk sweeteners and high intensity sweeteners (HIS). Bulk sweeteners not only add weight and volume to the product, they also have a big impact on mouthfeel and texture. High intensity sweeteners are used in such small amounts that they affect neither the volume nor the mouthfeel of the product. Natural sugars, glucose syrups and sugar alcohols are all bulk sweeteners.

Weight/Volume

Bulk sweeteners always add some weight to the product. At low concentrations, the volume is only slightly

affected, whereas they contribute a substantial part of the volume in products with a high sweetener content, e.g. jam and marmalade. Bulk sweetener solutions have slightly different specific density (kg/m^3). Density also depends on concentration and temperature, as illustrated in tables 1-2 and figures 1-2. Table 3 and figure 3 show the volume achieved at different concentrations of sugar or glucose syrup.

In dry applications, the weight/volume relation depends on particle size and particle size distribution. For ordinary caster sugar, the density is approximately 880 kg/m^3 . The value may vary depending on handling.

DENSITY OF AQUEOUS SUGAR AND GLUCOSE SYRUP SOLUTIONS AT 20°C						
W %	Sucrose	Invert	Fructose	Glucose	Glucose syrup DE42	Glucose syrup DE63
0	998.20	998.20	998.20	998.20	998.20	998.20
10	1038.10	1038.10	1038.50	1037.70	1039.07	1038.57
20	1080.97	1080.74	1081.74	1079.85	1083.17	1081.90
30	1127.03	1126.30	1127.76	1124.81	1130.68	1128.36
40	1176.51	1174.95	1177.07	1172.74	1181.73	1178.11
50	1229.64	1226.82	1229.65	1223.79	1236.48	1231.35
60	1286.61	1282.00	1285.55	1278.05	1295.01	1288.26
70	1347.49	1340.49	1344.67	1335.57	1357.34	1349.00
80	1412.2	1402.20	1406.78	1396.30	1423.43	1413.76

Table 1. Density (kg/m^3) of aqueous sugar and glucose syrup solutions at 20°C.
Source of data: Leatherhead Food RA Scientific & Technical Surveys.

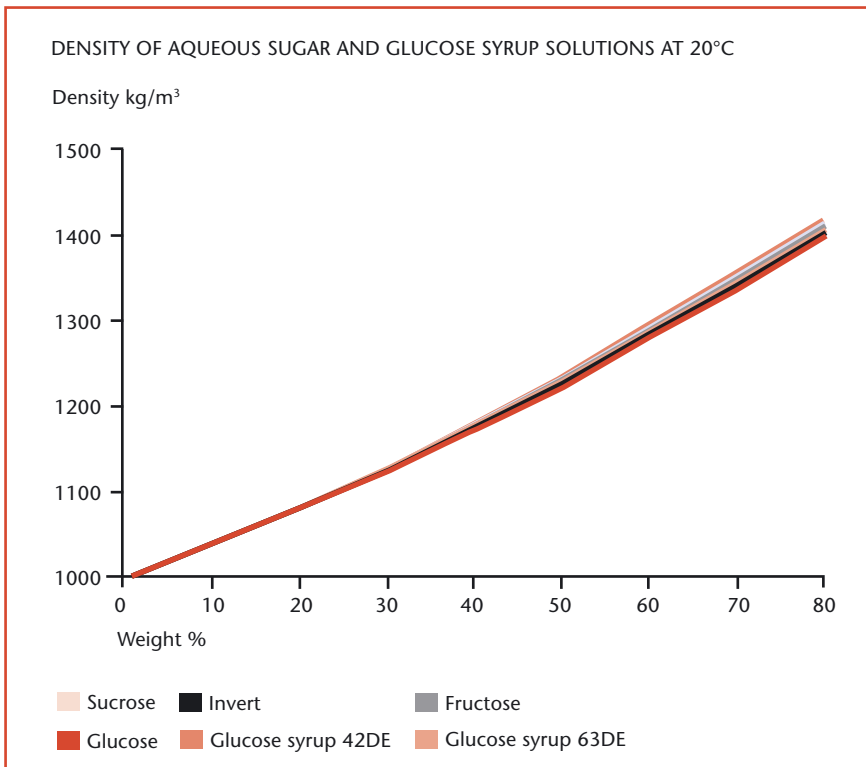


Figure 1. Density of aqueous sugar and glucose syrup solutions at 20°C.

DENSITY (kg/m ³) OF AQUEOUS SUCROSE SOLUTIONS				
Temperature °C	10% sucrose	20% sucrose	40% sucrose	65% sucrose
10	1040.15	1083.58	1180.22	1321.46
20	1038.10	1080.97	1176.51	1316.56
30	1035.13	1077.58	1172.25	1311.38
40	1031.38	1073.50	1167.52	1305.93
50	1026.96	1068.83	1162.33	1300.21
60	1021.93	1063.60	1156.71	1294.21
70	1016.34	1057.85	1150.68	1287.96
80	1010.23	1051.63	1144.27	1281.52

Table 2. Density of aqueous sucrose solutions.

Source of data: Leatherhead Food RA Scientific & Technical Surveys.

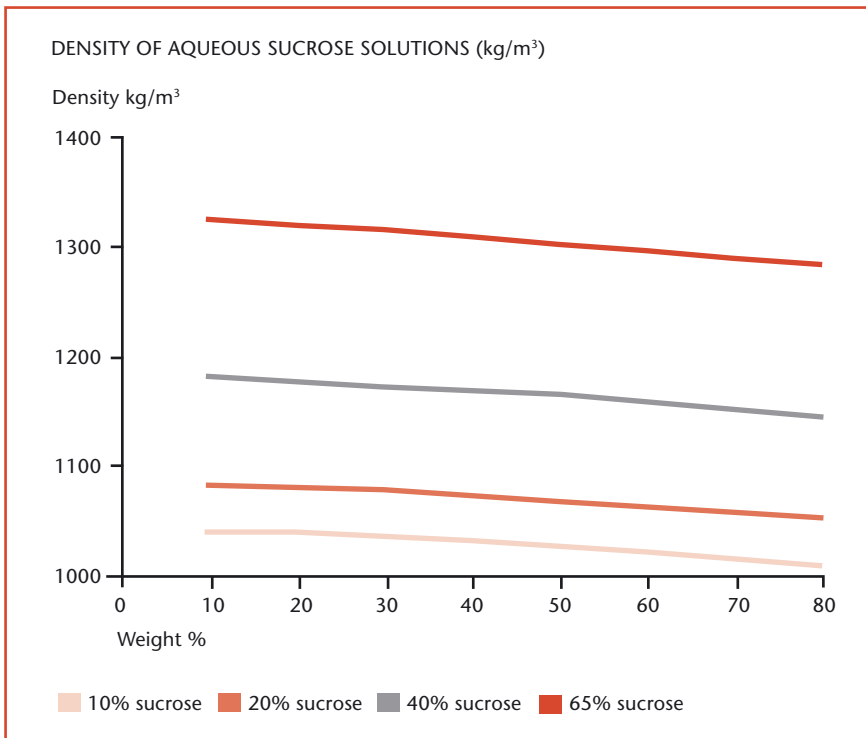


Figure 2. Density of aqueous sucrose solutions.

VOLUME/WEIGHT (l/kg) FOR SUGARS AND GLUCOSE SYRUPS AT 20°C						
W %	Sucrose	Invert	Fructose	Glucose	Glucose syrup DE42	Glucose syrup DE63
0	1.002	1.002	1.002	1.002	1.002	1.002
10	0.963	0.963	0.963	0.964	0.962	0.963
20	0.925	0.925	0.924	0.926	0.923	0.924
30	0.887	0.888	0.887	0.889	0.884	0.886
40	0.850	0.851	0.850	0.853	0.846	0.849
50	0.813	0.815	0.813	0.817	0.809	0.812
60	0.777	0.780	0.778	0.782	0.772	0.776
70	0.742	0.746	0.744	0.749	0.737	0.741
80	0.708	0.713	0.711	0.716	0.703	0.707

Table 3. Volume/weight (l/kg) for sugars and glucose syrups at 20°C.
Source data: Table 1; 1/X * 1000.

Mouthfeel

At as low dosages as 7-10%, bulk sweeteners provide a different mouthfeel in beverages or yoghurt than high intensity sweeteners. In products that require even higher amounts of sweeteners, e.g. mustard and ketchup, a texturiser is needed to obtain the same texture with a high intensity sweetener as when using a

bulk sweetener. In jams and marmalades, where the sugar content normally is 35-60%, bulk sweeteners not only add weight, volume and mouthfeel, they also influence the gelation process and, consequently, have a big effect on texture. Different bulk sweeteners have a slightly different effect on gelation and texture.

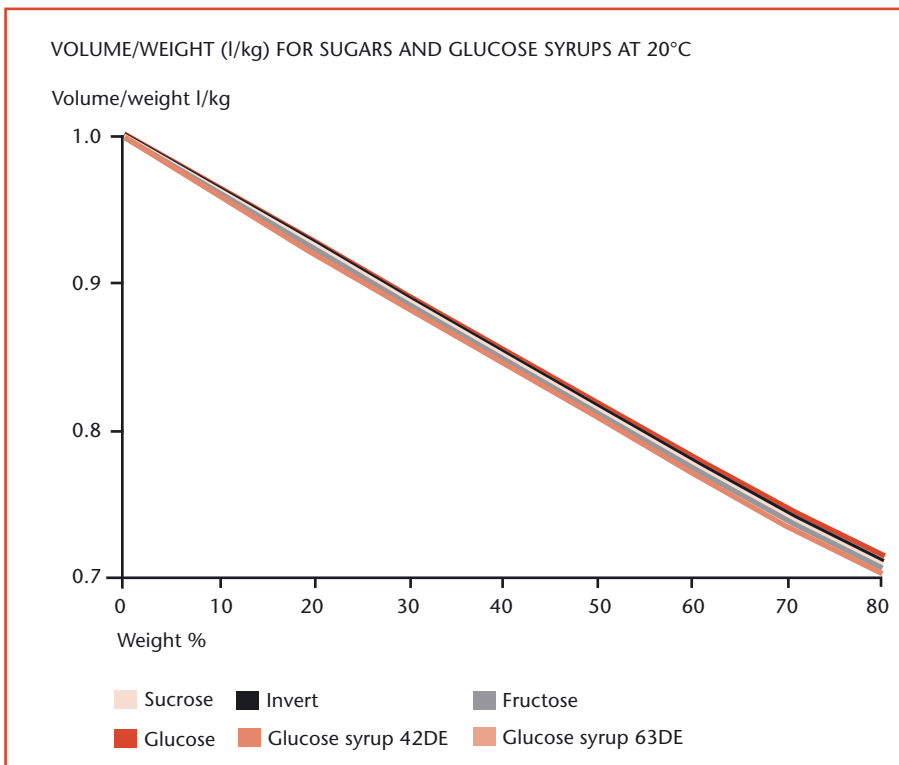


Figure 3. Volume/weight (l/kg) for sugars and glucose syrups at 20°C.

SOLUBILITY

Basically, temperature and the chemical interaction between a given component and the water molecule determine the component's solubility in water. Figure 1 shows how much sucrose can be kept in solution in pure water at temperatures between 0 and 140°C. At temperatures above 100°C, pressurisation is necessary to achieve the solubility shown.

The relatively high solubility of sucrose is an important parameter for its bulking effect in many foods and beverages. The dissolved sugar increases the viscosity of water-based solutions or mixtures, resulting in enhanced mouthfeel.

Dissolved sugar lowers the freezing point of ice cream by preventing the water molecules from combining to form ice crystals, which slows down the freezing process. The frozen water crystals no longer in solution increase the sugar concentration in the remaining solution and lower the freezing point even further.

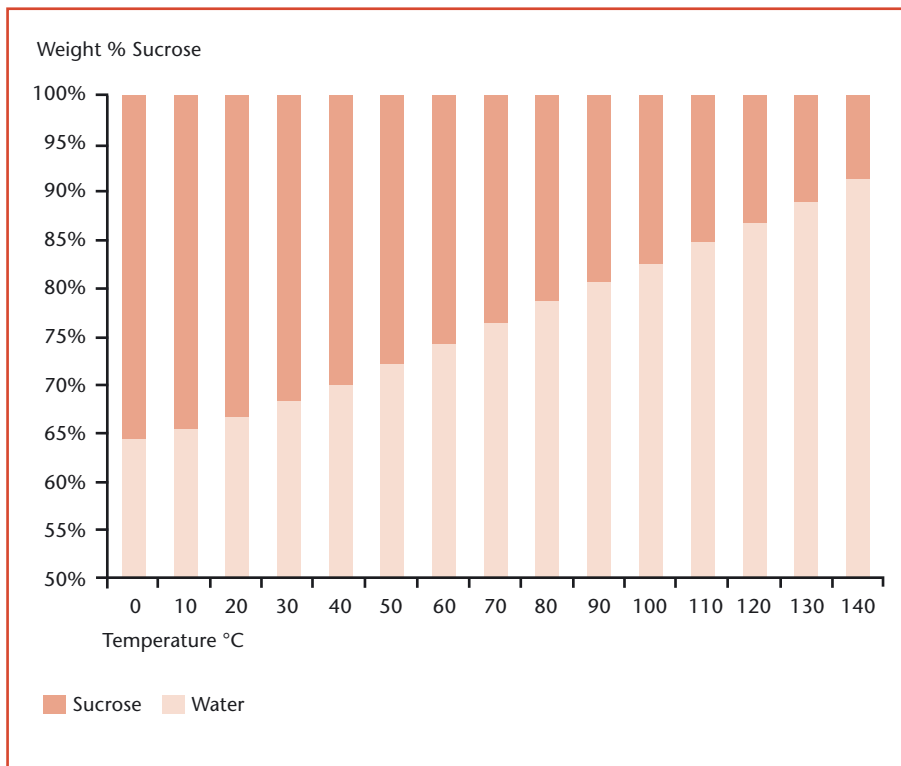


Figure 1. Solubility of sucrose in pure water.

In bakery products, the solubility, or hygroscopicity, of sugar makes it compete with flour proteins and starch granules for the available water, which minimises gluten formation and decreases gelatinisation of the starch. This makes the final product more moist and tender, and the hygroscopicity of the sugar ensures that it remains that way longer.

The solubility of sucrose is lower than fructose but higher than glucose, as shown in figure 2.

The presence of other ingredients in the solution or product affects the solubility and the potential crystallisation. Glucose syrups and invert sugar are typically used to avoid crystallisation of sucrose, but other ingredients such as proteins, texturisers and stabilisers also influence crystallisation.

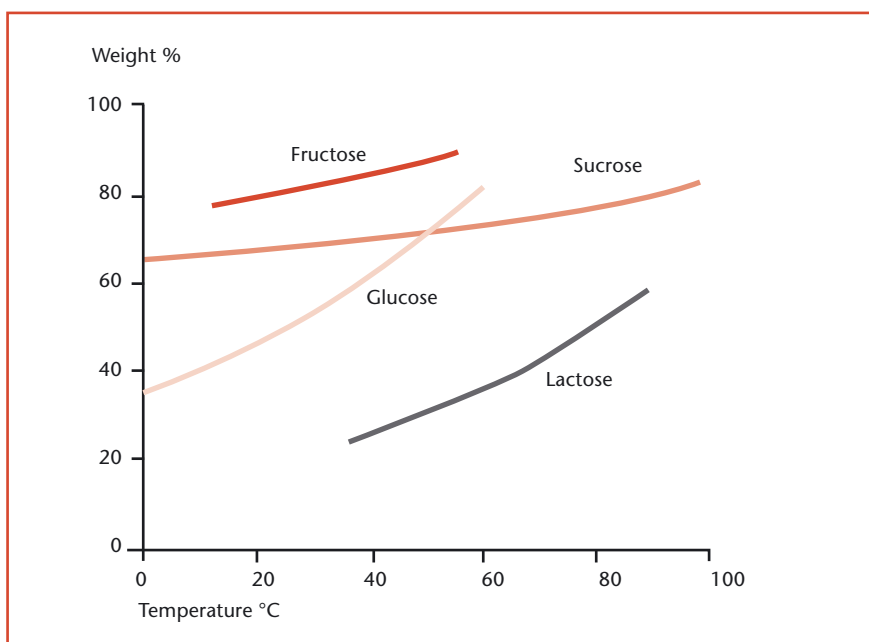


Figure 2. Solubility of selected sugars.

Figure 3 shows the solubility of glucose, sucrose and mixes of sucrose and glucose, and figure 4 shows the solubility of sucrose, invert sugar and mixes of the two sugars. Mixing glucose or invert sugar with sucrose increases the solubility of the combined sugar matrix and allows for production of products with higher total sugar solids than when using single components.

The solubility curves also show that glucose crystallisation is likely to occur in high glucose/low sucrose systems with high total solids. Since the most commonly used glucose syrups contain only a limited amount of glucose, glucose crystallisation is most likely to occur in systems with high amounts of invert sugar or isoglucose, or in products where large amounts of sucrose are converted into invert sugar due to low pH.

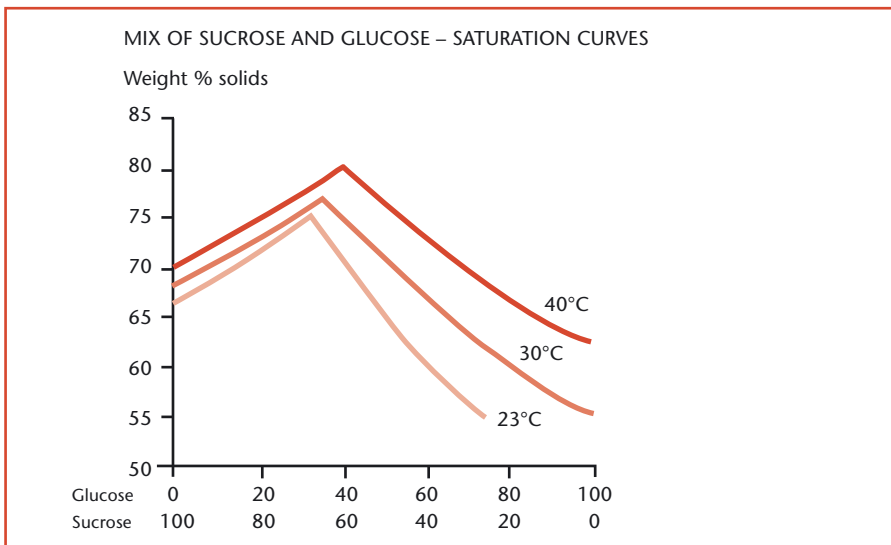


Figure 3. Solubility of selected sugars.

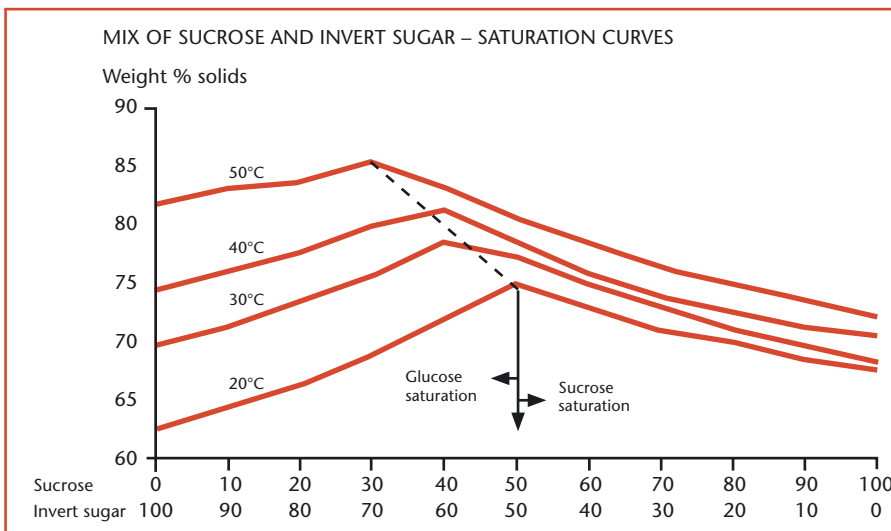


Figure 4. Solubility of mixtures of sucrose and invert sugar. Data from Keyzers, H. *Zucker und Süßwaren Wirtschaft*. (1982); 35:147.

Mixing sucrose with glucose syrup produces even higher weight % solids in solution at lower temperatures, as shown in figure 5. Here 84 weight % solids in solution is reached at 20°C by mixing 23.7% sucrose with 76.3% glucose syrup DE42.

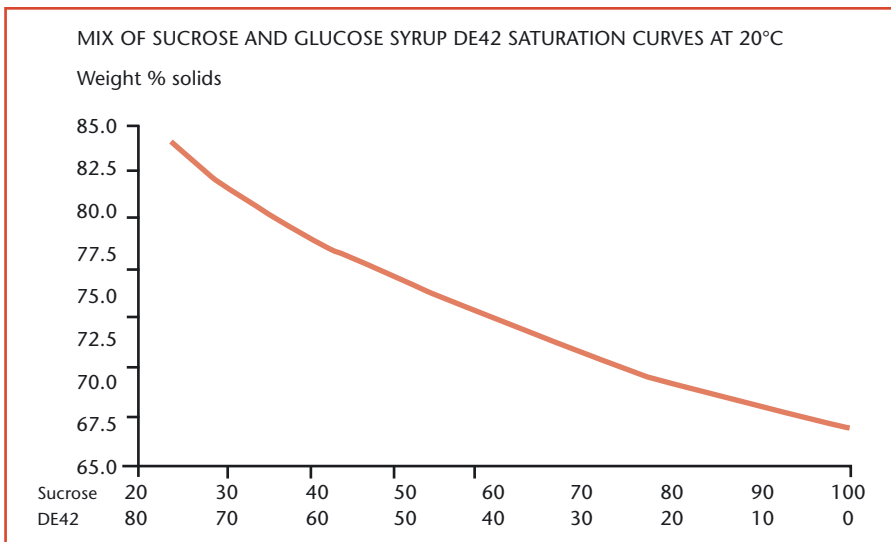


Figure 5. Solubility of mixtures of sucrose and glucose syrup DE42.
Data from Birch, G.G., Green, L.F., Coulson, C.B., 'Glucose Syrups and Related Carbohydrates', London, 1970.

Reference:

Harold McGee, 'On Food and Cooking – The Science and Lore of the Kitchen', Scribner, 1984.

Texture

CRYSTALLISATION

Crystallisation of sugars is desirable in products such as fondant, dragees, fudge etc., but not in many other products like jam and jellies. Crystallisation occurs when the solubility limit of the sugar, typically sucrose or glucose, has been exceeded and a supersaturated environment has been created, as shown for sucrose in figure 1.

The term 'supersaturated' refers to the situation where more sugar than theoretically possible from the solubility data is in solution. As indicated in figure 1, the supersaturated solution has been reached either by lowering the temperature or by increasing the sucrose concentration, or both. A metastable region exists where the solution is in fact supersaturated but in practice no crystallisation is likely to occur.

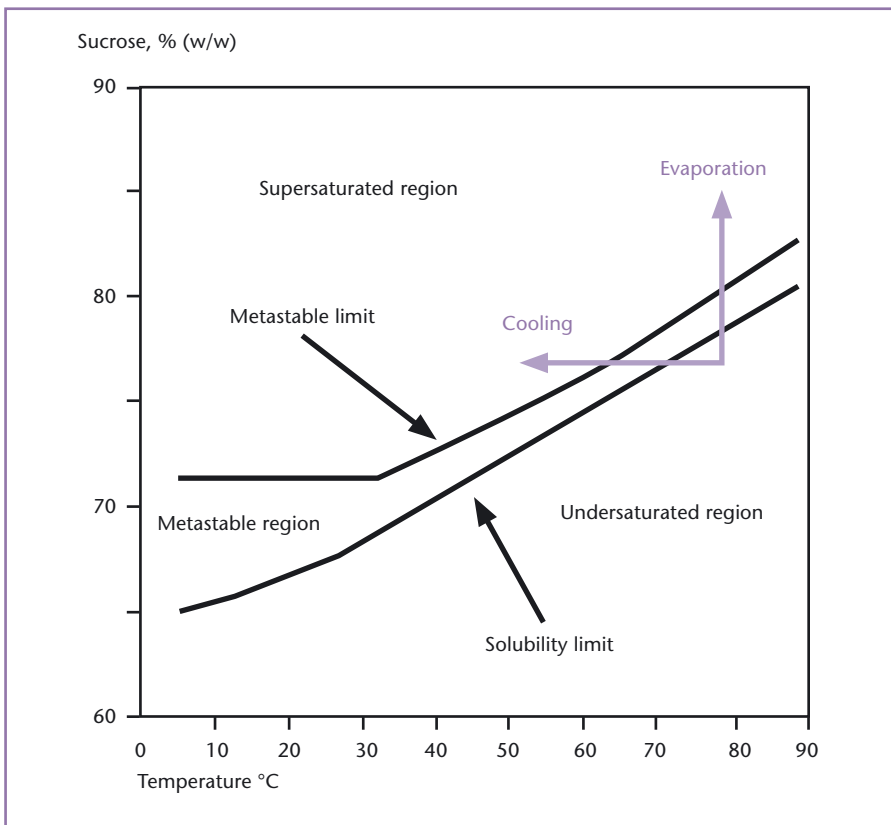


Figure 1. Phase diagram of the crystallisation of sucrose.

In the supersaturated state, above the metastable limit, crystallisation in liquids is catalysed by the presence of small particles, rough edges in the equipment, stirring or shaking. At very high viscosity, and in gels, the onset of crystallisation requires a higher degree of supersaturation, which can occur when a jam is cooled in the refrigerator or the surface of a confectionery gel dries out. Typically high viscosity means slow crystallisation rates. Glucose syrups and invert sugar are typically used to avoid crystallisation of sucrose, but also ingredients like proteins, texturisers and stabilisers influence crystallisation.

Unwanted crystallisation of sugars in products like jams and confectionery jellies may affect the appearance of the products, giving them a grainy look and a greyish colour, and the texture of confectionery products can appear 'short' and crispy. Furthermore, the water activity of the product may increase, as water is 'squeezed out' when the sugar solids are concentrated in crystals. Increased water activity may affect the shelf life of the product.

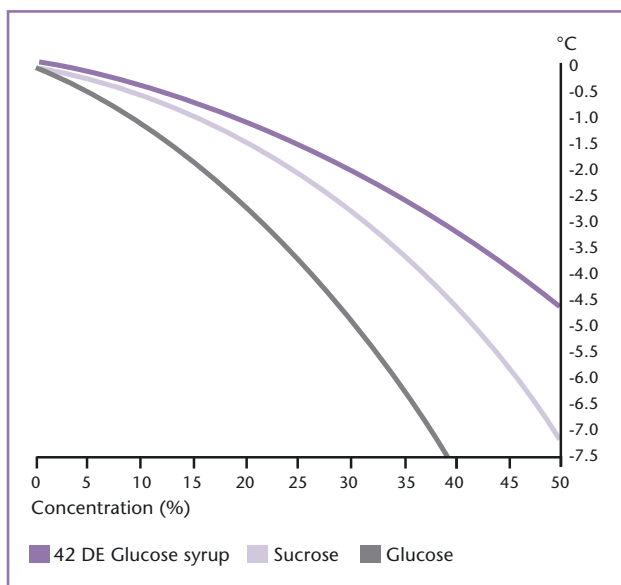


Figure 2: Freezing-point depression of 42 DE glucose syrup, sucrose and glucose

To avoid unwanted crystallisation in jams and jellies the following issues should be considered:

- Sucrose/glucose syrup ratio in the recipe
- Crystallisation of glucose due to increasing invert sugar content
- Too heavy mechanical handling: mixing, kneading and pulling
- Insufficient mixing of ingredients added after cooking
- Recycling of products or intermediaries in the production line
- Not optimal storage conditions of finished products: high temperature and varying humidity

Freezing-point depression

Sugars are effective in lowering the freezing point of a solution. This is important in the manufacture of ice-cream products and frozen desserts. Frozen products containing sugars can be made softer and easier to scoop at a given temperature than the same products without sugars. Sugars are used to control or prevent the formation of ice crystals in these products. The lower the freezing point, the more difficult for the ice crystals to form.

The freezing point is related to the number of molecules in solution. The greater the number of solute molecules present, the greater the depression of the freezing point. Monosaccharides are more effective than sucrose at lowering the freezing point.

EFFECT OF SUGAR AND SWEETENERS ON PECTIN GEL FORMATION

In jams, marmalades and jellies the long, string-like pectin molecules convert liquid into a solid-like structure by bonding and forming a fine-meshed network that holds the liquid in its cavities. Pectin is a polymeric carbohydrate of high molecular weight and is found in all plants. Protopectin and cellulose form the structure of the plant cell walls. Some fruits, typically berries, contain so much pectin that they can form gels on their own, while other fruits need supplementary gelling agents when used for jams and jellies. Commercial pectin for this purpose is derived from the peel of citrus fruits (lemon, lime, orange and grapefruit), or from apple pomace.

Pectin consists primarily of a chain of galacturonic acid units linked by α -1,4 glucosidic bonds. Pectin molecules have a molecular weight of up to 150,000 and a degree of polymerisation of up to 800 units. The galacturonic acid chain is partially esterified as methyl esters. High ester pectins (high degree of esterification of the galacturonic acid chain) can form gels with the presence of sugar at low pH, while low ester pectins (low degree of esterification) typically need calcium ions present for forming gels, but can work at low sugar contents or without any sugar at all.

For making a high ester (HE) pectin gel certain conditions are needed. When dissolved in water the negatively charged pectin molecules first need a low pH to reduce the charge and hereby reduce one

barrier for making the molecule bond to itself. Next, the availability of water molecules must be reduced, as the pectin molecule will otherwise tend to bond to water rather than to itself. Sugar's great hydrophilic properties make it ideal for this application, so by adding sugar in adequate quantities the water is kept away from the pectin molecules, allowing them to interact and form the network, i.e. the gel. Typical conditions for jam making are: pH of 2.8-3.4, pectin concentration of 0.5-1% and sugar content of 60-65%.

The mechanism behind low ester (LE) pectin gelling is as follows: When positively charged calcium ions are present, they form bridges between the negatively charged points of the pectin molecules and a network, or meshwork, is formed.

If sucrose is substituted with glucose syrup, fructose, polyols or bulking agents, the conditions for gelation and the character of the gel differ. The distribution and orientation of the -OH groups appear to be the issue, not their effects on the colligative properties of water. Furthermore, different carbohydrate sweeteners have different abilities to form stable complexes with cations. This interaction can be unfavourable to the formation of pectin gel due to the decrease of calcium ions available to associate with pectin molecules and, therefore, decreasing gel rigidity. In low ester pectin gels, the rigidity essentially depends on the capacity of the carbohydrate sugar to compete with pectin for calcium ions. The interaction between carbohydrates and water is a secondary effect. This behaviour might be of considerable importance in dietary gels.

In high ester pectin gels, simple sugars like glucose, sucrose and maltose tend to give better true gel strengths than high molecular weight oligosaccharides found in glucose syrups. The large molecules tend to give a high deformation gel strength, but with low elasticity and with syneresis. When choosing glucose syrups for high ester pectin gels, high levels of maltose and glucose and low levels of high molecular weight oligosaccharides are important. Table 1 summarises the effect on pectin gel setting temperature when substituting sucrose with other sugars. The subsequent effect on gel strength is shown in table 2.

	HE-PECTIN	LE-PECTIN
Glucose syrup DE40	↑	↑
Glucose syrup DE60	–	–
HFCS 42	–	↓
HFCS 55	↓	↓
Fructose	↓	↓
Invert sugar	↓	↓

Table 1. Effect of sugar composition on pectin gel setting temperature (relative to sucrose).

The higher average molecular weight of the sweetener, the higher the tendency to increased setting temperature.

	HE-PECTIN	LE-PECTIN
Glucose syrup DE40	–	–
Glucose syrup DE60	–	–
HFCS 42	–	↓
HFCS 55	↓	↓
Fructose	↓	↓
Invert sugar	–	↓

Table 2. Effect of sugar composition on pectin gel strength (relative to sucrose).

The effect of various carbohydrate sweeteners on the gel strength of pectin jellies is illustrated in the following case study in which pectin jellies were made according to formula X1, see table 3. One third of the sucrose, on a weight basis, was substituted by a given alternative carbohydrate sweetener, and the gel

strength of the resulting pectin jellies was measured. Figure 1 summarises the results for some of the basic sugars, and figure 2 shows the corresponding results for the glucose and fructose syrups listed in table 4.

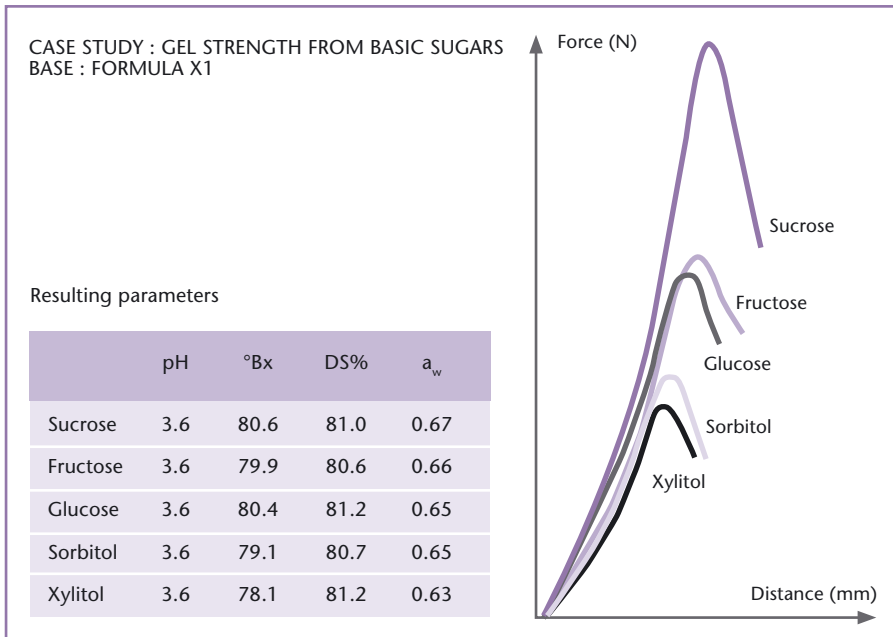


Figure 1. Case study of gel strength – basic sugars.

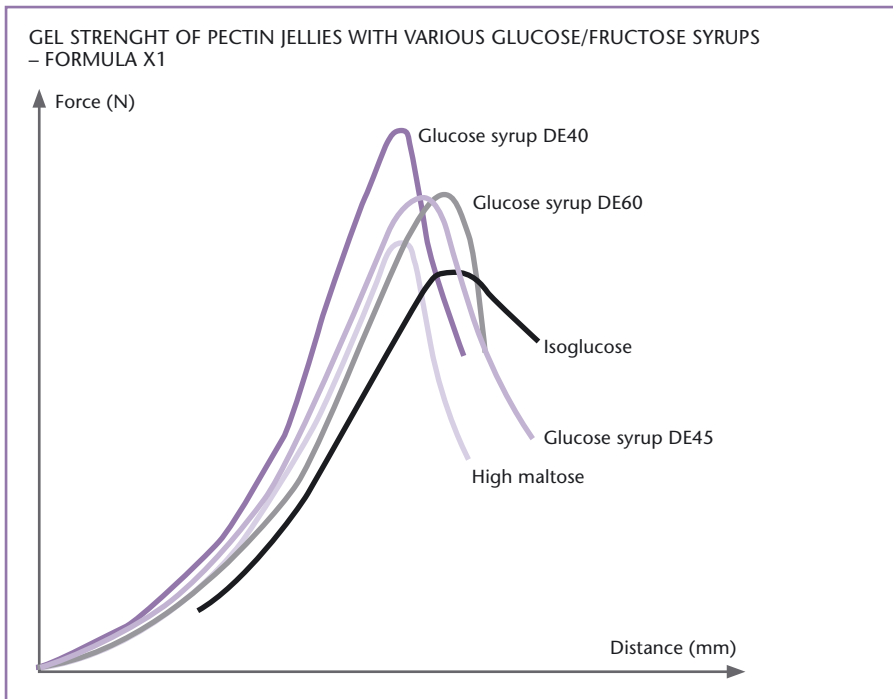


Figure 2. Case study of gel strength – glucose / fructose syrups.

BASIC FORMULA FOR CASE STUDY WITH PECTIN JELLIES WITH VARIOUS GLUCOSE/FRUCTOSE SYRUPS – FORMULA X1		
A.	Water	30.0 kg
	Sodium	0.4 kg
	Citric acid	0.37 kg
B.	Pectin	1.5 kg Grindsted XSS 100
	Sugar	5.0 kg
C.	Sugar	46.0 kg
	Glucose syrup Water evaporated to 100 kg total	24.0 kg (as DS)
D.	Citric acid 50% Starch moulded, 24-25 hours	0.74 kg

Table 3. Basic formula for case study of pectin jellies.

	pH	°Bx	DS%	a _w
DE25	3.5	78.6	78.5	0.73
DE40	3.3	76.5	78.9	0.72
DE60	3.4	78.4	78.9	0.70
HM	3.4	78.0	78.5	0.72
ISO-GL	3.5	78.5	78.9	0.67

Table 4. Parameters for pectin jellies with glucose/fructose syrups. Case study of formula X1. Parameters for pectin jellies with various glucose/fructose syrups.

Reference:

McGee, H., 'On Food and Cooking', Scribner, 2003.

PARTICLE SIZE

Sugar particle size

An important stage in sugar production is the crystallisation of sucrose. During the crystallisation process a specific crystal size and crystal size distribution are obtained by strict control of the nucleation and growth parameters of the sucrose crystals.

Various commercial grades of crystallised sugar with different particle sizes are obtained by screening or milling of the crystalline sugar. By passing sugar through vibrating multi-deck screens, the crystals are separated into different size fractions. Size reduction can be obtained by grinding the sugar crystals.

Sugar particle size is normally determined by way of a sieve analysis in which the particles are sorted by size, and the relations between the amounts of the different 'fractions' are calculated. For crystalline, non-screened sugar it is assumed that the size distribution follows a normal distribution. Based on this

assumption the mean particle size is calculated as the hypothetical mesh aperture of a sieve that allows 50% of the sugar to pass. The standard deviation is used as a measure for the particle size distribution and is normally stated as the coefficient of variance, which is the standard deviation related to the mean particle size.

The mean particle size and the particle distribution determine the physical behaviour of the sugar, e.g. bulk density, flow properties and abrasion. Chemical properties such as purity and dissolution rate are also influenced by the crystal size.

Bulk density primarily depends on the particle size and increases with decreasing particle size, see table 1. A narrow particle size distribution – i.e. the particles are relatively uniform in size – means a lower bulk density than for a wide particle size distribution. In the latter case, the voids between the large particles can be filled by smaller particles, resulting in higher bulk density.

PARTICLE SIZE FOR 90% OF THE SUGAR mm	BULK DENSITY g/l
1.0-2.20	822
0.5-1.25	864
0.2-0.75	887
0.2-0.50	894
0.1-0.35	902
80%<0.1 mm	565

Table 1. Influence of particle size on bulk density (van der Poel et al., 1998).

The bulk density determines the space required for bulk storage of sugar in silos, and it affects volumetric dosing. In combination with the moisture content, the particle size distribution determines the flow properties of the sugar. If crystalline sugar is stored correctly (above 10°C and at 40-65% RH) it will remain free-flowing and can easily be conveyed by means of gravity, vacuum or compressed air.

As regards purity, non-sucrose substances are mainly found in the syrup film covering the crystal surface. Since the specific surface area decreases markedly with increasing crystal sizes, sugar with a coarse crystal size is purer than sugar with a fine crystal size. The purity of icing sugar and other milled products of course depends on the purity of the starting material. In most cases, the purity of commercial sugars is above 99.9% with the major non-sugar present being water.

The dissolution rate of sugar depends on the size of the particles (other conditions remaining constant), as fine particles dissolve more rapidly than coarse particles. However, when particles become very small they are difficult to moisten and disperse and tend to lump. In practice this is observed when more than 5% of the particles are less than 200 micron. Temperature also affects the dissolution rate, since increasing temperature increases dissolution rates, see figures 1-2. Instant Sugar is made from finely milled sugar spray-dried onto water droplets. This process produces agglomerates with a porous structure that makes the product rapid dissolving. The average particle size of Instant Sugar is 200-400 micron. The average particle size of Icing Sugar and Standard Granulated Sugar is 20 micron and 500-600 micron, respectively.

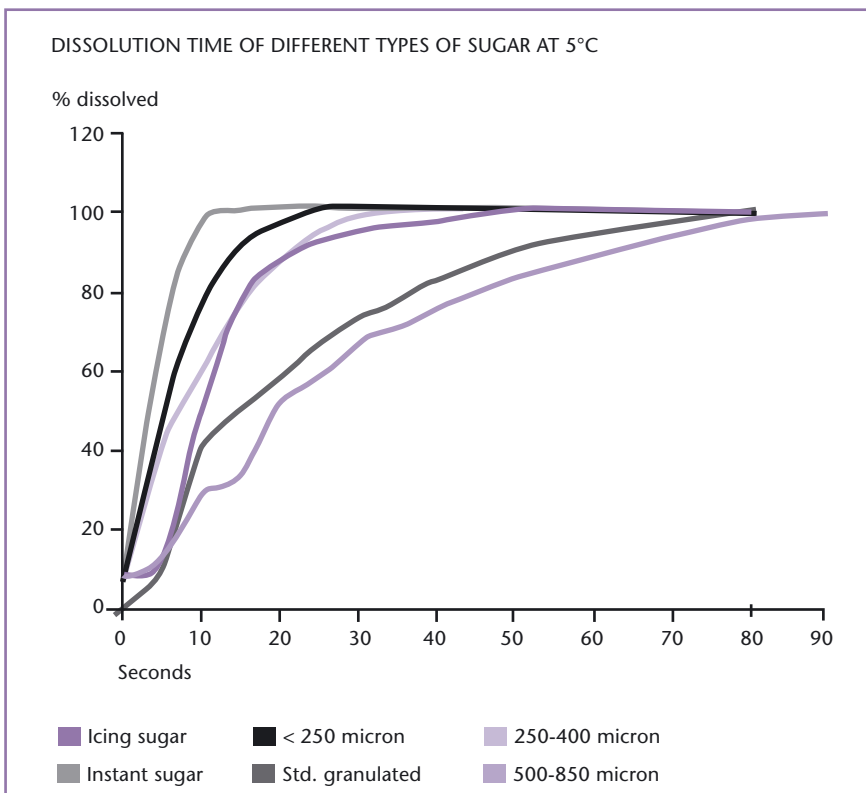


Figure 1: Dissolution time of different sugars at 5°C.

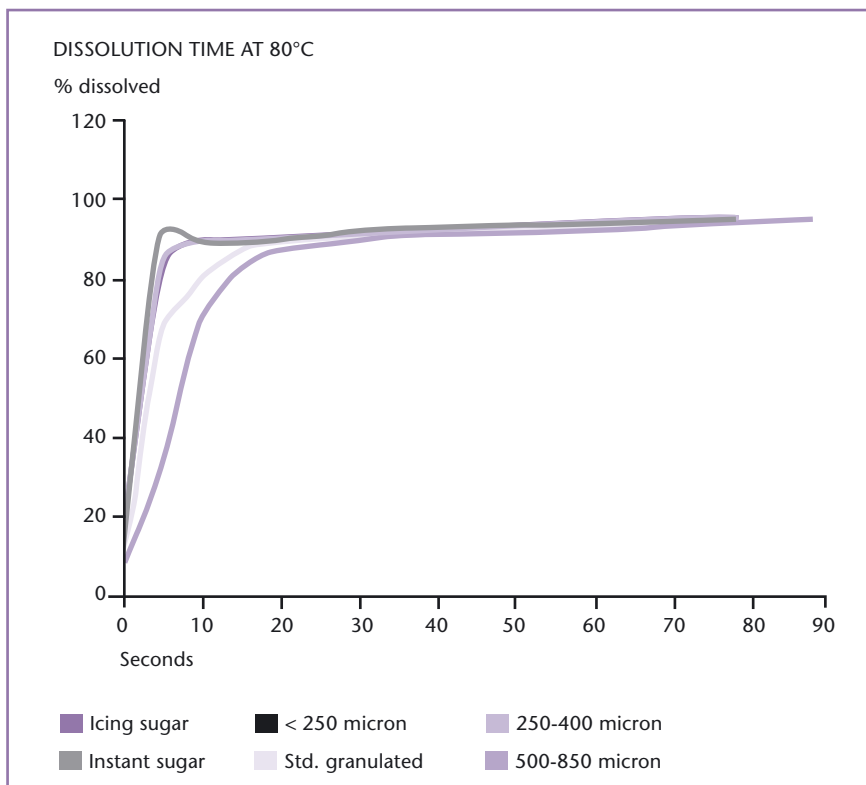


Figure 2. Dissolution time of different sugars at 80°C.

Sugar particle size and applications

The crystal size distribution affects the quality of the foods in which sugar is only partially dissolved and it is the main contributor to the structure or consistency of the product. Fine particles give a smooth texture and, as a rule-of-thumb, the mouthfeel is smooth and no particles are sensed when less than 5% of the particles are bigger than 30 micron.

In moulded chocolate, sugar is found mainly in the crystalline state, although some amorphous sugar is formed during the preceding sugar milling and chocolate mass refining. Most of the amorphous sucrose, however, recrystallises during the conching process.

The main purpose of the refining process is to reduce the particle size to avoid a sandy-gritty mouthfeel in the final product. Particle size also influences the flow and solid formation of chocolate.

In cookies and sweet biscuits, where most of the sugar is dispersed in the fat phase, the particle size affects the dough spread during baking and as such the diameter and height of the final product. The finer the sugar, the more spread. Sugar particle size also affects the texture of the cookie or sweet biscuit and thus the mouthfeel. A coarser sugar produces a crisper cookie.

The texture and mouthfeel of fat/sugar-based biscuit fillings, toffee/fudge and marzipan are other examples of how sugar particle size influences the functional properties of food.

Sugar particle size is also essential for the texture and mouthfeel of icings, frostings and fondants. In classical fondant manufacture the size of the crystals precipitated from the supersaturated solution affects the mouthfeel. Some of the factors affecting the grain size are the presence or introduction of undissolved sugar crystals, the temperature at which the agitation starts during cooling, and the presence of invert sugar. The fondant colour is also influenced

by the sugar particle size, as small particles give a whiter icing or fondant due to a different reflection of light. A high quality fondant has a particle size of about 10 micron.

In dry blends, where sucrose is used as a carrier for other ingredients, including colours and flavours, crystal size is an important property. The risk of segregation of ingredients can be minimised by using screened sugar with a particle size close to that of the other ingredients or by using Instant Sugar, where the porous structure of the agglomerates ensures good binding of other ingredients.

References:

- P.W. van der Poel, H. Schiweck, T. Schwartz (1998): Sugar Technology, Beet and Cane Sugar Manufacture (Bartens).
M. Mathlouthi, P. Reiser (1995): Sucrose, properties and applications (Blackie Academic & Professional).

VISCOSITY

The viscosity of sucrose solutions and other bulk sweeteners is highly dependent on the dry substance and temperature.

Pure sucrose, fructose and glucose solutions, and mixes of them, are all Newtonian, meaning that the viscosity is independent of the shear rate. However,

highly concentrated glucose syrups can be slightly pseudoplastic, i.e. the viscosity decreases when the shear rate increases.

The viscosity has been measured, using flow curves on a Bohlin VOR Rheometer, at different concentrations and temperatures for selected sugars, sugar mixes and glucose syrups. The results are presented in tables 1-2 and illustrated in figures 1-2.

	Rt	65	72	76	78	79	80	81	82	83	84
	temp. °C	Viscosity mPas									
Sucrose	50	31	110	243	500	702	850	1040			
Invert	50	16	69	171	270	330	411	560	709	1100	1480
Glucose	50	20	55								
Fructose	50	17	50	120	180	220	290	446	580		
Sucrose	40	56	200	454	900	1220	1700	2270			
Invert	40	26	125	372	500	780	998	1500	1780	2800	4230
Glucose	40	32	110								
Fructose	40	27	90	240	390	510	700	1050	1700		
Sucrose	30	97	415	1040	2300	3220	4800	6660			
Invert	30	46	269	904	1700	2100	2880	4000	5650	9500	15400
Glucose	30	56	220								
Fructose	30	48	190	580	1000	1500	2100	3240	5000		
Sucrose	20	176	1020	2840	7000	10300	15000	21200			
Invert	20	87	664	2588	5000	7400	10400	21000	42800	59000	72600
Glucose	20	105	500								
Fructose	20	92	490	1600	2300	4800	7000	11900	19000		

Table 1. Viscosity of sucrose, invert sugar, glucose and fructose at different Rt and temperatures. 1 mPas = 1 cP.

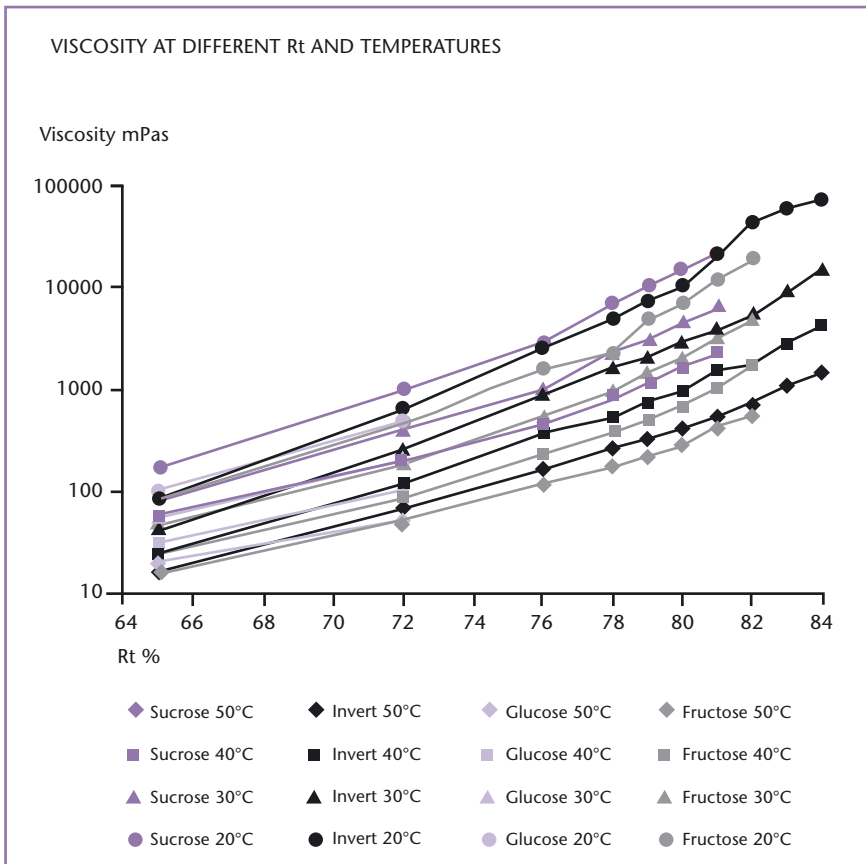


Figure 1. Viscosity of sucrose, invert sugar, glucose and fructose at different Rt and temperatures.

	Rt	65	72	76	78	79	80	81	82	83	84
	temp. °C	Viscosity mPas									
DE40	50	48	238	600	992	1130	1320	2500	3900	5460	
DE60	50	32	99	230	401	516	686	945	1300	1860	2420
DE40	40	102	460	1120	1860	2800	3540	6500	11100	15000	
DE60	40	51	184	370	836	1140	1540	2150	3020	4660	6840
DE40	30	207	987	2900	5080	7500	9590	20000	32000	49800	
DE60	30	91	378	1120	2710	2880	4100	6180	8720	14900	21800
DE40	20	400	2370	8000	15300	24000	30700	70000	114000	219000	
DE60	20	176	894	2800	6180	8870	12800	21100	32800	57900	93800

Table 2. Viscosity of glucose syrup DE40 and DE60 at different Rt and temperatures. 1 mPas = 1 cP.

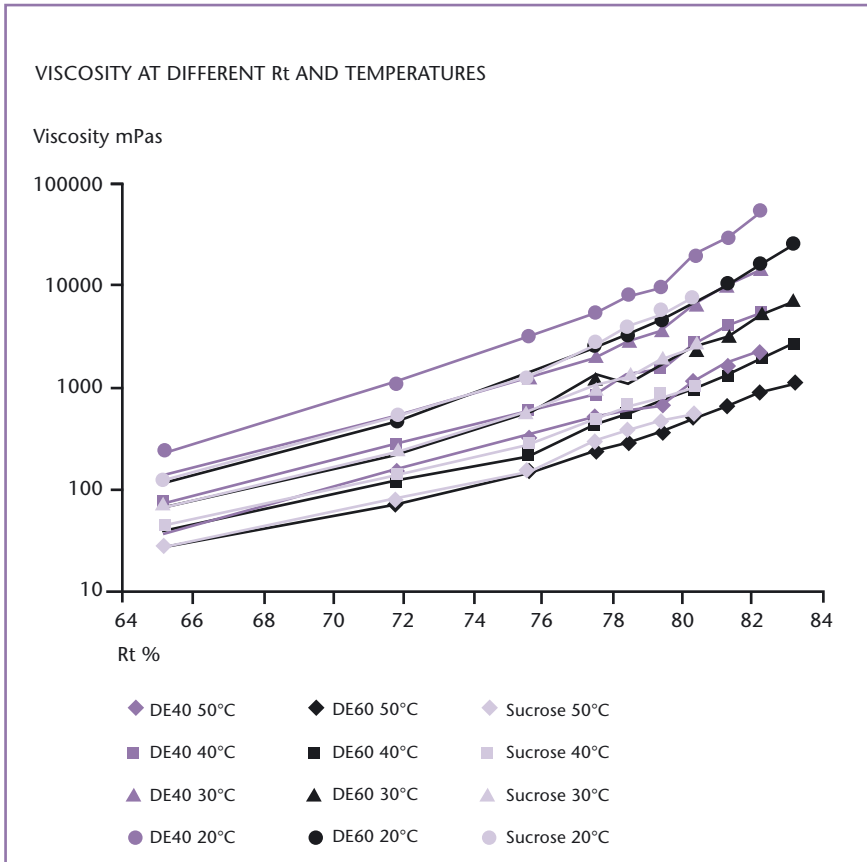


Figure 2. Viscosity of sucrose, glucose syrup DE40 and glucose syrup DE60 at different Rt and temperatures.

Rt stands for refractometric dry substance. Rt is the same as real dry substance (Ds) for sucrose, whereas there is a difference between Rt and Ds for fructose, glucose, invert sugar and some types of glucose syrups. Table 3 shows the difference between Rt and Ds values of selected sugars.

FRUCTOSE	Rt	Ds	DIFFERENCE	DE60	Rt	Ds	DIFFERENCE
	65.4	66.9	1.5		65	65.0	0.0
	75.8	77.7	1.9		76	76.0	0.0
	80.3	82.5	2.2		80	80.0	0.0
	82.4	84.8	2.4		84	84.0	0.0
GLUCOSE	Rt	Ds	DIFFERENCE	DE40	Rt	Ds	DIFFERENCE
	62.4	63.7	1.3		78	76.6	-1.4
	64.5	65.9	1.4		80	78.5	-1.5
	66.4	67.9	1.5		84	82.4	-1.6
	70.7	72.4	1.7				
INVERT	Rt	Ds	DIFFERENCE				
	65	66.3	1.3				
	76	77.9	1.9				
	80	82.1	2.1				
	84	86.3	2.3				

Table 3. Differences between refractometric dry substance (Rt) and true dry substance (Ds).

Figures 1-2 cover highly concentrated sugar solutions and can be used by the food industry to choose the right pump for sugar solutions.

In food, sugars are mostly used in low concentrations. The viscosity of sucrose, glucose and fructose at 20°C and at concentrations between 1% and 70% appears from table 4 and figure 3.

In jams and marmalades, which usually contain high amounts of sugar, the viscosity of the sugar has a big impact on the mouthfeel of the product. Although the viscosity of beverages is quite low (usually around 10%), the viscosity provided by the sugar is quite important for the overall mouthfeel of the beverage.

% WEIGHT	VISCOSITY mPas		
	SUCROSE	GLUCOSE	FRUCTOSE
1	1,028	1,021	1,028
2	1,055	1,052	1,054
5	1,146	1,145	1,134
10	1,336	1,330	1,309
15	1,592	1,566	1,533
20	1,945	1,904	1,837
30	3,188	2,998	2,817
40	6,161	5,491	5,045
50	15,432	11,891	10,823
60	58,479	37,453	32,573
64	120,480		58,140
68	285,710		119,048
70	476,190		178,571

Table 4. Viscosity of sucrose, glucose and fructose at 20°C.
Source of data: Leatherhead Food RA Scientific & Technical Surveys.

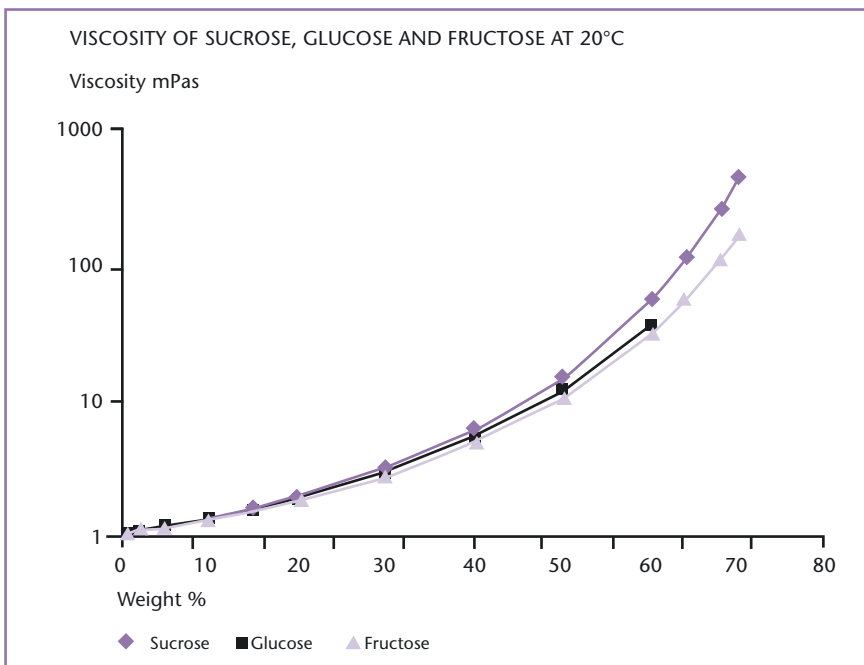


Figure 3. Viscosity of sucrose, glucose and fructose at 20°C.

Shelf Life

SUCROSE HYDROLYSIS

Introduction

Inversion of sugar refers to the hydrolysis of the disaccharide, sucrose, to the monosaccharides, fructose and glucose, in equal proportions (1:1). The inversion is catalysed by hydrogen ions (acids) or enzymes. Fructose and glucose are referred to as invert sugar.

Inversion of sucrose, first order kinetics

After the inversion of sucrose, the rotation angle of polarised light passing through the solution is measured. Sucrose is dextrorotatory (from Latin dexter, right), but the resulting mixture of glucose and fructose is slightly laevorotatory (from Latin laevus, left). As the concentration of sucrose is lower and the glucose-fructose mixture has been formed, the rotation angle is to the left. The rotation of the light is directly proportional to the concentration of sucrose (c) in the solution, and the inversion follows the equation:

$$\ln(c/c_0) = -k t$$

which is of first order kinetics with k as the rate constant.

The measured sucrose concentration is plotted versus time (t) on a semi-log plot giving a straight line with the slope -k.

The degree of inversion, X, can be calculated by the following equation:

$$X = 100(1 - c_t/c_0)$$

k: rate constant (ml . g⁻¹ . min⁻¹)

c: sugar concentration (g . ml⁻¹)

X: degree of inversion (%)

t: time (minutes)

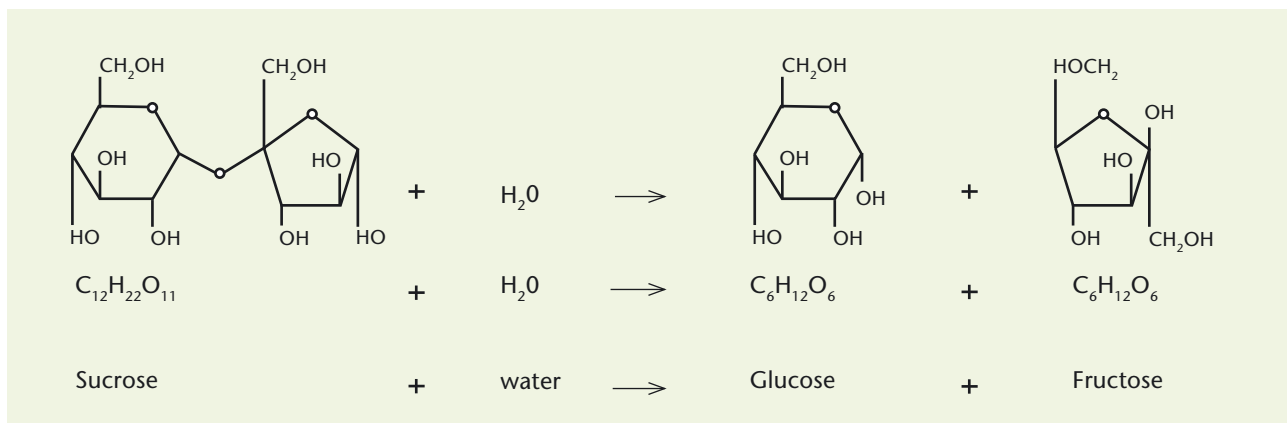


Figure 1. Inversion of sucrose.

Rate of inversion in soft drinks, juice concentrate and marmalades

We have studied the rate of inversion in selected soft drinks, juice concentrates and marmalades and the importance of pH and the concentration of sucrose and invert sugar. Fruit soda and soft drinks contained about 9% sucrose, wild strawberry and raspberry concentrates about 47% and marmalades about 65%. All products were sweetened with either sucrose (S) only or a mix of sucrose and invert sugar (SI) in a 40:60 ratio.

The concentration of sucrose showed a minor impact on the rate of inversion, whereas pH had a very big influence (see figure 2). At pH 2.4 only about 10% of the sucrose was left after 100 days, while at pH 3.1 more than 60% of the sucrose remained after the same period of time. Products with a pH level of 2.9 and 3.0 showed relatively small differences in the rate of inversion. A comparison of figure 2 (the findings of our studies) with figure 3 (time required for a 50% inversion of sucrose at different pH levels and temperatures) shows relatively good agreement between the results.

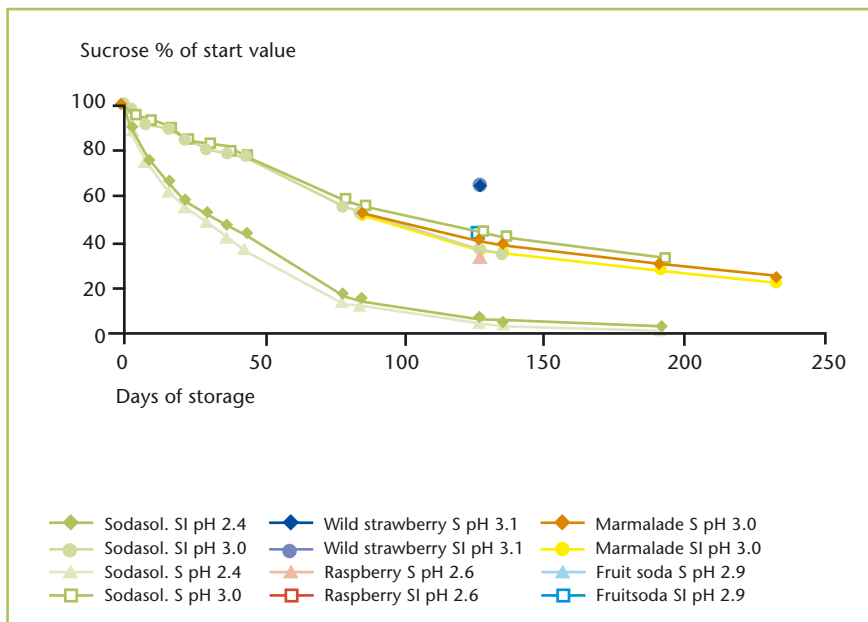


Figure 2. Rate of inversion in soft drinks, juice concentrates and marmalades at different pH.

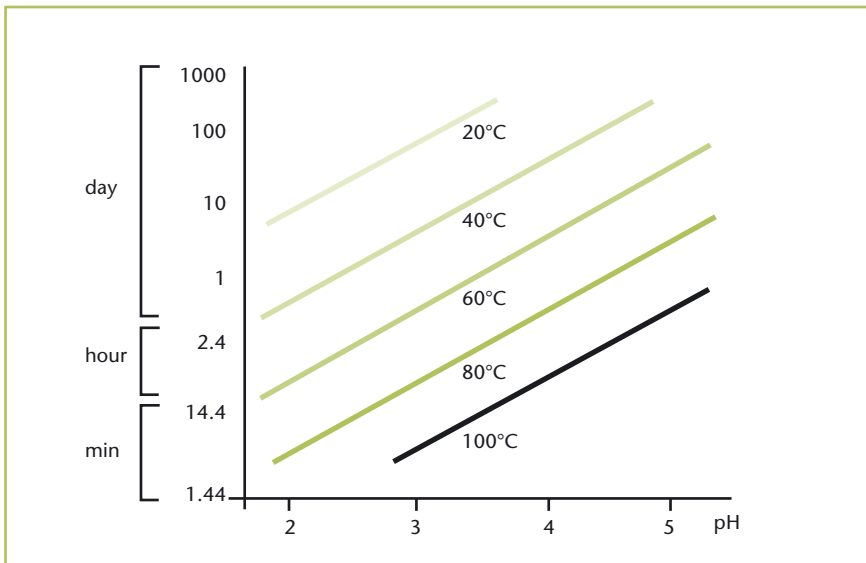


Figure 3. Time required for a 50% inversion of sucrose at different pH and temperature.

Properties of invert sugar

Invert sugar has several properties that play an important role in many food applications.

It has a high affinity for water and is used to make products retain moisture. This is important in, for example, the baking industry where invert sugar helps bakery products retain moisture and prolong shelf life. Since invert sugar has a tendency to absorb moisture from the atmosphere, it keeps bread and cakes fresh for a longer time.

Invert sugar inhibits crystallisation and retains moisture, and it is therefore used in products such as icing, cake filling and confectionery.

Adding invert sugar to a sucrose solution may increase the dry substance content of the solution due to higher solubility of the combined sugar solution compared to a pure sucrose solution. Invert sugar has lower water activity than sucrose. Low water activity has a preservative effect, resulting in longer shelf life.

Glucose and fructose cause a Maillard reaction when heated with protein-rich food ingredients. The Maillard reaction results in browning and flavour development in the product.

Invert sugar also affects the caramelisation process, producing a browning effect.

WATER ACTIVITY AND ITS IMPLICATIONS IN SUGAR-RICH FOODS

Most people know that a bag of sugar can be left in the kitchen cabinet for years without any sign of spoilage while a slice of soft bread normally moulds in a few days. This is to a large extent due to the very low water activity (a_w) of pure granulated sugar as compared to that of bread.

Water is a prerequisite for life on earth, and man has tried for thousands of years to preserve food by reducing the water content of foodstuffs by way of drying, smoking etc. However, the water content is not a very good measure of shelf life. Figure 1 shows that

the water content of foods at a certain water activity varies considerably. Dried fruits, for instance, are microbiologically stable up to a water content of 18-25% while the corresponding limit for nuts can be as low as 4%. As a water activity of 0.7 is often taken as an upper limit for safe shelf life it is very important to know the actual water activity and not only the water content.

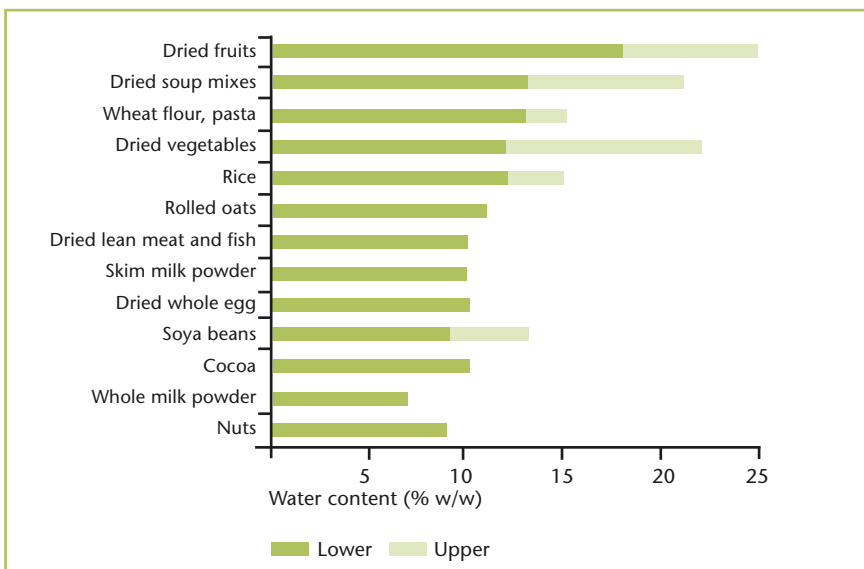


Figure 1. The water content of foods at a_w 0.70, i.e. the upper limit for safe storage. (Data from L. R. Beuchat)

DEFINITIONS AND METHODS OF MEASUREMENT

Water activity is a measure of the amount of water available for microorganism metabolism or other chemical reactions in a food product. It is defined as the ratio of the water vapour pressure of the food (p) to that of pure water (p_0) at the same temperature.

$$a_w = p / p_0$$

As water vapour pressure decreases when a food dries, a_w falls, thus ranging from a maximum value of 1 for pure water to 0. The a_w of gases or air, usually referred to as the equilibrium relative humidity (ERH), is related to a_w as:

$$\%ERH = 100 * a_w$$

The expression RH is used when the air is not in equilibrium with its surroundings. The freezing point, boiling point and osmotic pressure also relate to a_w .

Water activity can be determined by a number of methods: direct measurement of the vapour pressure, gravimetric methods or by way of various electronic devices. However, it is essential that the water activity

of a food is measured when the food is in equilibrium with the air above the food and at a constant temperature. An increase in temperature usually makes a_w go up.

If a foodstuff is allowed to adsorb water and the increase in water content is plotted against the corresponding a_w , the resulting curve is called a water sorption isotherm. If the process is reversed and the foodstuff is dried, the resulting desorption curve will differ from the previous one. This phenomenon is called hysteresis and is shown for sucrose in figure 2. Sucrose, as other soluble crystalline compounds, is in different phases at different a_w values: a crystalline phase, an amorphous phase and a solution. Hysteresis can be of great importance when, for instance, a hygroscopic food is stored under fluctuating humidity/temperature conditions in a warehouse. Table 1 shows the concentration of some sugars at various a_w values.

Computer programs for calculating sorption isotherms for pure foodstuffs and mixtures are commercially available. They are based on mathematical modelling and elaborations of the relationship between concentration and vapour pressure of ideal solutions given by Raoult's law, which expresses $a_w = n_1 / n_1 + n_2$ where n_1 is the moles of solvent and n_2 the moles of solute.

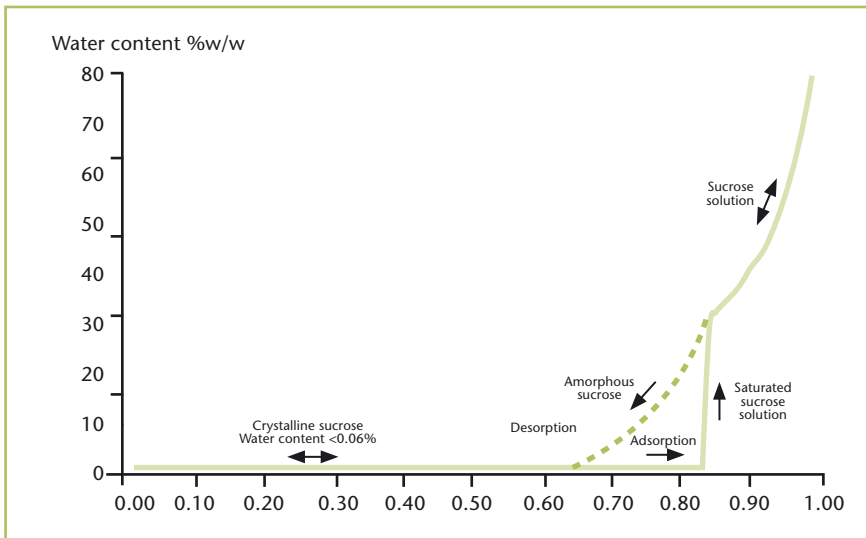


Figure 2. Sorption isotherm of sucrose.
Based on data from Labuza, 1984, Maurandi & Mantovani, 1975, and J. Vindeløv, 2001.

CONCENTRATION OF SUGARS AT VARIOUS VALUES OF WATER ACTIVITY AT 25°C				
	Sucrose ^a	Glucose ^b	Invert sugar ^c	Glucose syrup ^d DE42
a _w	(%, w/w, °Brix)	(%, w/w)	(%, w/w)	(%, w/w)
1.000	0	0	0	0
0.995	8.52	4.45	2.05	1.67
0.990	15.45	8.90	4.11	3.34
0.980	26.07	15.74	8.22	6.68
0.960	39.66	28.51	16.43	13.36
0.940	48.22	37.83	24.65	20.03
0.920	54.36	43.72	32.87	26.71
0.900	58.45	48.54	41.09	33.39
0.880	62.77	53.05	49.30	40.07
0.860	65.63	58.45	57.52	46.75

Table 1: Concentration of sugars at various values of water activity at 25°C
Based on data from: a Robinson and Stokes (1959), b Taylor and Rowlinson (1955), c Grover (1947), and d Cleland and Fetzer (1944).

Shelf life

One of the most significant effects of water activity is its impact on shelf life. As water activity in a foodstuff decreases, the number of microbial species able to grow in that environment also decreases, as do their growth rate. Below the limit of 0.60, no microbial proliferation occurs and the product becomes fully stable in that respect. At least as long as the product is kept dry! Only very few specialised yeasts and moulds are able to grow below a_w 0.70. Therefore, this limit is in practice usually regarded as safe for prolonged storage.

The minimal a_w value for some microorganisms and the corresponding foodstuffs at the specific value is illustrated in figure 3. The water content, and hence the a_w of some of the foodstuffs in the figure, may vary significantly, so it should be regarded as indicative only. Microbial growth is of course also greatly

affected by other factors like temperature, pH and the availability of oxygen and nutrients (e.g. the type of sugars). This is why a pure liquid sugar (e.g. a solution of sucrose at 65% dry matter), due to its lack of other nutrients and the inability of many yeasts to utilise sucrose, is quite stable in spite of an a_w value of about 0.87 where many yeasts are otherwise able to grow. In foodstuffs such as carbonated beverages, pickles and jams, not only the reduced a_w caused by a high sugar concentration, but also the low pH of such products contribute to prolonged shelf life. This is in contrast to many bakery and dairy products, sauces and dressings where preservatives must be added to achieve similar shelf life. The importance of being careful when reducing the sugar content of a foodstuff should be pointed out in order to avoid an increase in a_w above the critical level (0.90) for growth of pathogenic microorganisms.

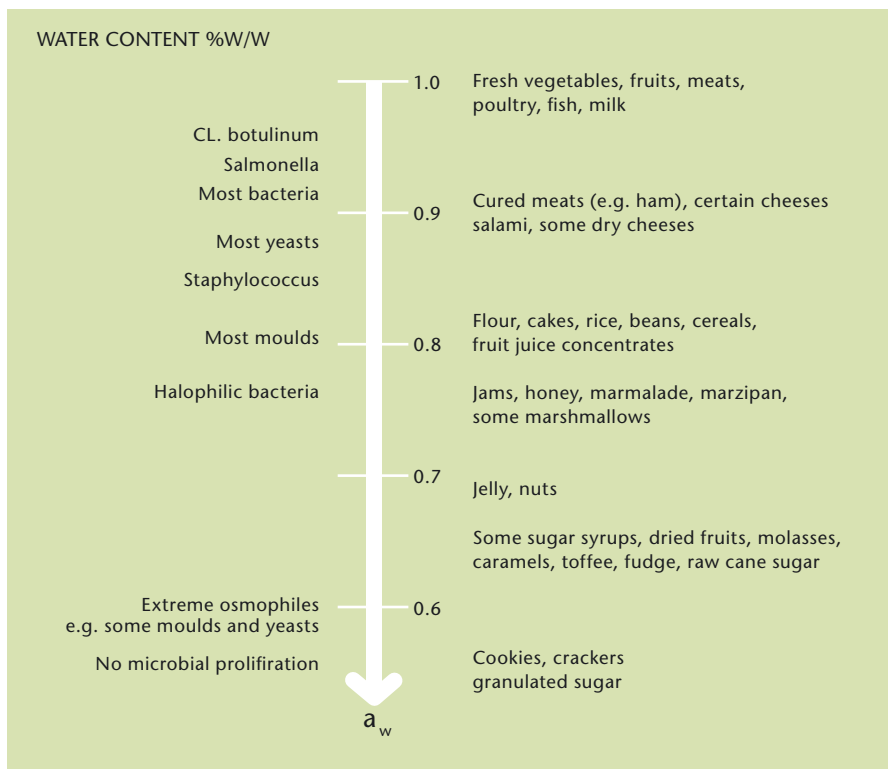


Figure 3. Minimum water activity for the growth of some microorganisms.

Sporulation and toxin production is also affected by aw. Mycotoxin production is usually inhibited at a higher aw value than is growth, and germination of spores usually occurs at a higher aw value than sporulation.

Other effects of water activity

Not only microorganisms are affected by water activity. Also enzymatic activities in general as well as many other chemical reactions are affected, e.g. the rancidification of fat or the nonenzymatic browning of food-

stuffs (Maillard reaction). However, these non-biological reactions cease at a water activity below 0.2.

More practical implications of differences in water activity are of course the moisture migration from areas of food components with a high vapour pressure (high aw or ERH) towards areas with a lower vapour pressure. This is of great importance in, for instance, preserving the crunchiness and crispness of dry cereals or crackers as well as for the well-known moisture migration from warm to cold areas in warehouses and the problems this may create.

Fermentation

FERMENTATION FEEDSTOCKS

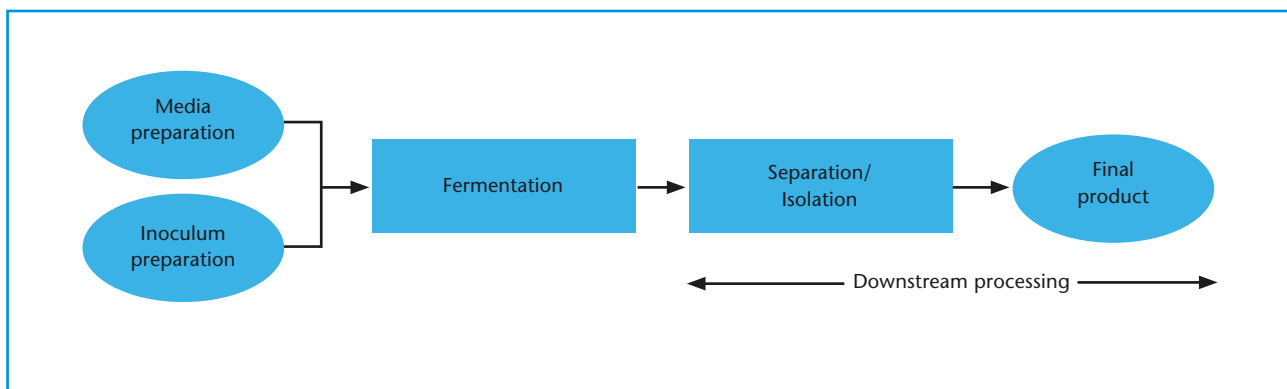
Fermentation technology

Fermentation technology is the oldest of all biotechnological processes. Strictly speaking, fermentation is an *anaerobic* energy-yielding metabolic process in which organic compounds, such as sugar, serve both as electron donors and as electron acceptors. In general, however, fermentation is considered as *any process for the production of a product by means of mass culture of microorganisms*, thus also including the *aerobic* metabolic processes.

Ancient fermented food processes such as the making of wine, bread, cheese, beer etc. are normally excluded from the concept of industrial fermentation, which rather comprises the making of products like antibiotics, organic acids, enzymes, vitamins, amino acids, biopolymers etc.

There are several types of fermentation of which the most common are batch, fed-batch and continuous fermentation. A special type designed for solid media is the Solid State Fermentation (SSF).

The main process steps are:



The feedstocks

The design of the nutrient medium for growth and product formation is a key step. The constituents of the medium must satisfy the elemental requirements for cell biomass, product formation and energy. Nutrients are classified as macronutrients (e.g. a carbon source, nitrogen, phosphorous, sulphur, potassium, magnesium) and micronutrients (trace minerals, vitamins and other growth factors). Usually

the cost of the carbon source determines the production cost, and this is especially pronounced for high volume/low value products (e.g. ethanol, single cell protein, enzymes, organic acids, amino acids) where they may account for the majority of the total production cost. When producing low volume/high value products (e.g. antibiotics, hormones, vaccines), however, the quality of the carbon source becomes more important compared to the price.

Some important considerations in choosing feedstocks for fermentation processes include price, availability, consistency, stability, ease of handling and, of course, the effect on process productivity and downstream processing. The effect on downstream processing and its integration with the fermentation step has become an important area of development to increase efficiency and decrease costs.

The most significant carbon and energy sources for fermentation are renewable sugars found in plant biomass, i.e. sucrose and starch. Structural polysaccharides, e.g. lignocellulose, are still of secondary importance because making the carbohydrates accessible is expensive and time consuming. However, in recent years the utilisation of waste as a source of raw material has gained significance. Such feedstocks can be used in Solid State Fermentations. Generally, the higher the cost of a given chemical, the lower the impact cost of the feedstocks is likely to have on the economics of the process.

Reference:

University of Guelph; <http://www.uoguelph.ca/~hlee/426feedstocks.htm>

Sugar beet derived feedstocks

Sucrose, which fulfils many of the feedstock requirements mentioned above, is one of the most important substrates for fermentation at present. It is available as highly purified granulated or liquid sugar. The latter could be more or less inverted to glucose and fructose and all are especially suitable for defined media. Both glucose and fructose, the building blocks of sucrose, are readily utilised by various microorganisms and therefore can serve as good fermentation substrates.

Another source of sucrose is molasses, the by-product from sugar processing. Molasses is suitable for complex substrates. Apart from easily utilised sugars, about 44%, molasses also contains many valuable micronutrients like trace elements, amino acids and vitamins. Another advantage is the low cost. In some cases though, a pre-treatment may be necessary to remove undesirable impurities.

Sugar beet pulp has been used as a substrate in a number of Solid State Fermentations, e.g. for enzyme and flavourings production.

Colour

BROWNING REACTIONS

Maillard reaction

One of the most important chemical reactions that occur in food is the Maillard reaction. It is critical in the production of the many flavour and colour compounds in processed food products, both desirable and undesirable. The Maillard reaction is a type of non-enzymatic browning which involves the reaction of reducing sugars, mainly D-glucose, and a free amino acid or a free amino group of an amino acid that is part of a protein chain. Other common reducing sugars are fructose, maltose and lactose. Sucrose is not a reducing sugar but yeasts or acids can hydrolyse sucrose to glucose and fructose. The Maillard reaction is named after the chemist who first examined it in detail. It is also called non-enzymatic browning to differentiate it from the enzymecatalysed browning commonly observed in freshly cut fruits and vegetables, such as apples and potatoes.

The Maillard reaction comprises a series of reactions that are far from being clearly elucidated: The classical scheme of the chemical reaction is that of Hodge from 1953. See figure 1. The reaction is generally divided into three stages:

- (1) The first stage involves the sugar-amine condensation and the Amadori rearrangement. The reaction steps have been well-defined and no browning occurs at this stage.
- (2) The second stage involves sugar dehydration and fragmentation, and amino acid degradation via the Strecker reaction especially at high temperatures as used in candy manufacture. At the end of stage two there is a beginning flavour formation.
- (3) The third stage is the formation of heterocyclic nitrogen compounds. Browning occurs at this stage.

The actual reactions are far more complicated than those outlined above, and there are many variations in the pathway. The products of these various pathways range from colourless to intensely coloured and many are volatile aroma compounds.

Increasing temperature, increasing pH and lower water activity all increase the rate of Maillard browning. Water is produced during the Maillard reaction. Thus, as a consequence of the law of mass action, the reaction occurs less readily in foods with a high a_w value. In addition, the reactants are diluted at high a_w values while, at low a_w , the mobility of reactants is limited, despite their presence at increased concentration. In practice, the Maillard reaction occurs most rapidly at intermediate a_w values (0.5-0.8), and a_w is of most significance to the reaction in dried and intermediate-moisture foods, which have a_w values in this range.

While the Maillard reaction is useful in some cases, it also has a negative side. Reaction of reducing sugars with amino acids destroys the amino acid. This is especially important with L-lysine, an essential amino acid, which can react while the amino acid is a unit of a protein molecule.

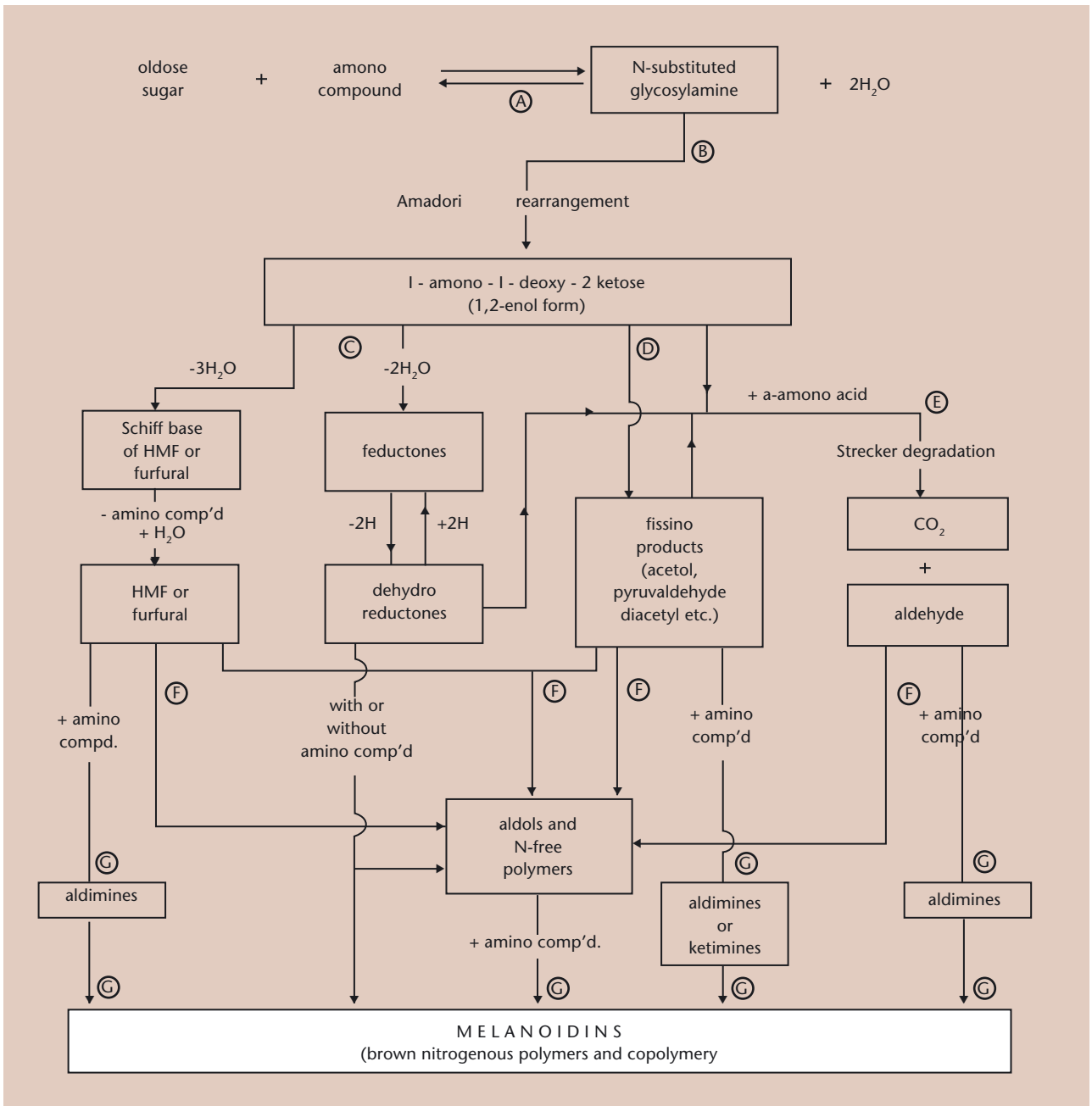


Figure 1. Hodge 1953.

Maillard Browning Pathway

FEATURES OF MAILLARD REACTION

Presence of reducing sugars and amino compounds (proteins, amino acids)

Requires dry heat and high temperature – baking, frying, toasting

Rapid at $\text{pH} > 7.0$, slower at $\text{pH} < 6.0$

Colour: colourless → yellow → brown → dark brown

Benefits: contributes to flavours in bread, crusts, milk chocolates, caramels, fudges and toffees

Drawbacks: loss of amino acids: lysine, histidine, arginine; (production of mutagenic heterocyclic amines)

Melting point

The melting point is the temperature at which the solid crystalline and liquid phases of a substance are in thermodynamic equilibrium at normal pressure. All solids, except the amorphous forms, have a definite melting point. Pure, crystalline solids melt over a narrow range of temperatures, whereas mixtures melt over a broad temperature range. The melting points can be used to identify compounds. Table 1 shows the melting points of some mono-, di- and trisaccharides.

Caramelisation

Caramelisation is defined as the thermal degradation of sugars leading to the formation of caramel aroma and brown-coloured products (caramel colours). The

process is acid or base catalysed and generally requires temperatures $> 120^\circ\text{C}$. Above melting point, melted dry sugar takes on an amber colour and develops an appealing flavour and aroma. This amorphous substance resulting from the breakdown of sugar is known as caramel. Under heat, caramelisation transforms sugars from colourless, sweet compounds into substances ranging in colour from pale yellow to dark brown and in flavour from mild, caramel-type to burnt and bitter. If heating is continued caramelised sugars break down into black carbon. Caramelisation occurs in food, when food surfaces are heated strongly, e.g. the baking and roasting processes, the processing of foods with high sugar content such as jams and certain fruit juices, or in wine production.

MONO- DI- AND TRISACCHARIDES	CHEMICAL FORMULA	MELTING POINT °C
Fructose	$C_6H_{12}O_6$	103-105
Glucose	$C_6H_{12}O_6$	146
Sucrose	$C_{12}H_{22}O_{11}$	186 ± 4
Maltose	$C_{12}H_{22}O_{11}$	160-165
Lactose	$C_{12}H_{22}O_{11}$	223
Ribose	$C_5H_{10}O_5$	86-87
Mannose	$C_6H_{12}O_6$	133
Raffinose	$C_{18}H_{32}O_{16}$	118-120

*Table 1. Melting points for some mono-, di- and trisaccharides.
Source: Sugar Technologists Manual, Z. Bubnik, P. Kadlec, D. Urban, M. Bruhns.*

When sugar is heated the added heat energy can overcome the intermolecular forces and sugar melts to form a liquid. There is no temperature change during the phase change. If the melted sugar is further heated, the sugar is caramelised before it is hot enough to turn to vapour.

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