CHAPTER THREE

Technology of Main Ingredients—Sweeteners and Lipids

3.1 TECHNOLOGY OF SUGARS, SYRUPS, SUGAR REPLACEMENTS AND SWEETENERS

3.1.1 Introduction and Overview

3.1.1.1 Sweeteners

Sweeteners taste sweet and may be of natural or synthetic origin. The main sweeteners are natural sugars from cane and sugar beet and sugar syrups from starch hydrolysis. Sugar alcohols, manufactured from natural sugars, are used as sweeteners for diabetics and in sugar-free bakery and confectionery. For calorie reduction, high-intensity sweeteners (HISs)—artificial or from natural sources—are a further group of sweeteners. Natural sugars and sugar alcohols provide energy, but the HISs provides negligible amounts or none at all.

3.1.1.2 Sugar Definitions

Sugar without additional wording means saccharose (sucrose). Because of the physiological importance of sugar and of strict labelling requirements recently the WHO (2015), in the United Kingdom the SACN (2015), and in the United States the FDA clarified definitions after some discussions and interventions of interest groups.

'*Sugars*' include mono- and disaccharides, the most important of them are the monosaccharides glucose, fructose and galactose, and the disaccharides sucrose, galactose and maltose.

'*Free sugar*' include monosaccharides and disaccharides added to foods by the manufacturer, cook or consumer, and sugars naturally present in honey, syrups, fruit juices and fruit juice concentrates (extrinsic sugars).

'*Intrinsic sugars*', unlike free sugars, are found in whole fresh fruits and vegetables, and they include lactose naturally present in milk and milk products.

'*Added sugars*' (FDA definition 2016) are sugars that are added during the processing of foods, or they are packaged as such; they include sugars (free, mono- and disaccharides), syrups, naturally occurring sugars that are isolated from a whole food and concentrated so that sugar is the primary component (e.g., fruit juice concentrates), and other caloric sweeteners.

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3.1.1.3 The Properties of Sweeteners

Sucrose and other sugars are components in many wafer and waffle baking mass recipes, as well as in most adjuncts such as fillings and enrobings. Not only to impart the characteristic sweetness, there are many more technological effects that will be discussed in detail.

Any requirement to replace a bulk ingredient like sucrose for nutritional, quality or marketing reasons requires some technological adaptations. These have to compensate for differences in the physicochemical as well as in the sensory properties of the substitutes. Table 3.1 provides an overview on technological and physiological properties of sugars, sugar replacements and HISs. The data are compiled from different sources. The columns of the table contain the following:

1. The name of the sugar, syrup, sugar replacement and HIS
2. The legal status
3. The relative sweetness compared to sucrose. The data refer to sweet bakery foods
4. The suitability for diabetics; the sign * indicates that a warning label is required for persons with phenylketonuria (PKU)
5. The cariogenic potential, see Fed. Reg. 21 CFR Part 101.80
6. The energy content in kcal/g. Unfortunately there are still differences between Europe, the United States and Japan on the authorized data
7. The solubility in water at 20°C
8. Information on any cooling effect during the dissolution in the mouth, depending on the heat of the solution of the sugar. Strong: heat of the solution is over −25 kcal/g; medium: heat is from −25 to −15 kcal/g; low: heat is from −15 to −5 kcal/g
9. Information on the hygroscopic properties
10. For solids: the melting point in °C. In case two data are given, the first is for the anhydrous form, and the second for the hydrate form
11. Some brand names

Table 3.2 provides an overview on relevant terms for sweeteners.

3.1.2 Technological Functions of Sugars in Wafers, Waffles and Fillings

The physicochemical properties of sugars influence wafers and waffles in many respects (Table 3.3).

3.1.2.1 Sweetness Regulation

Sweetness is a characteristic element in crisp sugar wafers such as sugar cones, flute wafers (wafer sticks), in waffles and in various adjuncts such as creams, caramel fillings and chocolate enrobings.

Relative Sweetness and Synergy

The taste of sucrose is our familiar basis, the ‘gold standard’ of sweet taste. Its sweetness profile includes a certain rate of sweetness onset, a maximum impression, and a prompt

Table 3.1 Technological and Physiological Properties of Sugars, Sugar Replacements and Sweeteners

Substance	Status	Sweetness Sucrose 100	For Diabetics	Cariogenic	Energy Content (kcal/g)	Water Solubility (%, 20°C)	Cooling Effect	Hygroscopic	Melting Point (°C)	Brand Names
Part 1										
Saccharose	Food	100	No	Highly	4	66	No	–	185	
Fructose	Food	120	+	Highly	4	79	Low	+++	103	
Glucose	Food	70–80	No	Highly	4	47	Medium	–	83/146	
Lactose	Food	30–50	No	Highly	4	17	Low	–	202/253	
Maltose	Food	40–50	No	Highly	4	41	Low	–	102	
Invert sugar	Food	100–120	No	Highly	4	62	–	++	N.A.	
Tagatose	Novel food	90	+	Non	1.5 (United States)	56?	Medium	+	134	
Trehalose	Novel food	45	(–)	Non	4	40.8	?	–	97	
Sorbitol	E 420	50–60	+	Non	2.4 (EU) 2.6 (United States)	69	Strong	+++	95	
Mannitol	E 421	50–60	+	Non	2.4 (EU) 1.6(United States)	16	Strong	–	166	
Glycerol	E 422	60	+	Non	4	Miscible	N.A.	+++	18	
Erythritol	E 968	60	+	Non	0 (EU, JP) 0.2 (United States)	33	Strong	–	126	Zerose
Isomalt	E 953	45–50	+	Non	2.4 (EU) 2.0 (United States)	25	Low	–	145	Palatinit
Isomaltulose	Novel food	40–50	+	Non	4	32	No	+	123	Palatinose Xtend
Xylitol	E 967	90	+	Non	2.4 (EU, United States)	63	Strong	++	92	

Continued

Table 3.1 Technological and Physiological Properties of Sugars, Sugar Replacements and Sweeteners—cont'd

Substance	Status	Sweetness Sucrose 100	For Diabetics	Cariogenic	Energy Content (kcal/g)	Water Solubility (%, 20°C)	Cooling Effect	Hygroscopic	Melting Point (°C)	Brand Names
Part 2										
Lactitol	E 966	30–40	+	Non	2.4 (EU) 2.0 (United States)	58	Low	+	95/149	
Maltitol	E 965	75–90	(+)	Non	2.4 (EU) 2.1 (United States)	58	Low	–	147	
Hydrogenated starch hydrolysate	GRAS	25–50	(+)	Non	2.4 (EU) 3.0 (United States)	Soluble	Low	++	N.A.	Lycasin HBC
Polydextrose	E 1200	<5	+	Non	1 (EU, United States)	44	No	++	125–135	Litesse, Sta-Lite
Inulin	Food	1–14	+	Yes	1 (EU)	1–4	No	+++	N.A.	Frutafit
Acesulfame-K	E 950	Up to 13,000	+	No	0	21.2	No	–	>200 dec	Sunette
Aspartame	E 951	Up to 18,000	*	No		1	No	–	dec	Nutrasweet
Aspartame–Acesulfame-Salt	E 962	Up to 35,000	+	No		2.7	No	–	dec	Twinsweet
Cyclamate Na	E 952	Up to 3,000	+	No		16.6	No	–	169	
Neohesperidine DC	E 959	Up to 100,000				0.05	No	–		
Saccharin Na	E 954	Up to 30,000	+	No	0	54.5	No	–	>300	
Sucralose	E 955	Up to 40,000	+	Non		21.9	No	–	130	Splenda, SucraPlus
Thaumatin	E 957	Up to 200,000	+	No	4	<20	No	–	N.A.	Talin
Neotame	GRAS EU: no	Up to 700,000		No		1.3	No		81	

Table 3.2 Sugars and Sweeteners—Glossary of Substances and Terms

Substance or Term	Comment
Brown sugar	Less refined sugar from sugar cane (muscavado) or white sugar covered with brown cane syrups or caramelized sugar syrup (demerara). Sticky due to a little moisture and minor nonsucrose residues
Caramel	Brown, sweet to bitter flavourful product from heating sugar solutions
Caramel colour	Dark brown food colour from heating sugar, optionally with additives
DE	Dextrose equivalent, measure of the degree of hydrolysis of starch into maltodextrins, glucose (corn) syrups, maltose syrups, or dextrose. Starch has a DE = 0. Dextrose has a DE = 100
Dextrose	Glucose, grape sugar
Fondant	Saturated mass of fine sugar crystals and some percentage of glucose syrup
Fructose	Fruit sugar, laevulose; main component in high fructose corn syrups (HFCS)
Glucose	Grape sugar, dextrose
Glucose, corn, or starch syrup	Made from starch by acid and/or enzyme hydrolysis. Most frequent the DE is 34, 42 or 62
HFCS	High fructose corn syrup is enzymatically prepared from glucose syrup; in Europe isoglucose is syrup with some fructose percentage
High-intensity sweetener	Intensely sweet tasting, food approved chemicals, 30 to over 100,000 times sweeter than sucrose
Instant sugar	Agglomerated powder sugar, nondusting and quickly soluble
Inversion	Cleavage of sucrose into glucose and fructose, catalysed by enzymes and/or acids
Invert syrup	1:1-mixture of fructose and glucose, from sucrose by inversion
Lactose	Milk sugar, a disaccharide, composed of glucose and galactose
Liquid sugar	Concentrated sucrose solution in distilled water
Maltodextrin	Made from starch by acid hydrolysis, the DE is 5–20
Maltose	Malt sugar, a glucose disaccharide
Maltose syrup	Made from starch by acid and enzyme hydrolysis with typically 40–50 DE and 45%–60% maltose. For hard candy as it tends not to crystallize and is comparatively nonhygroscopic
Molasses	Dark, aromatic syrup remaining from cane sugar crystallization
Oligosaccharide	from the polysaccharide starch by cleavage, typically 3 to 10 glucose units
Pearl sugar	Bigger chunks of agglomerated sugar, 5–8 mm, applied in Liège waffles
Polyol	Sugar alcohol; used for sugar replacement such as glycerol, sorbitol, erythritol, maltitol, isomalt, lactitol, or xylitol
Polysaccharide	Starch, cellulose from many (>10) glucose units, no sweet taste
Saccharose	Plain sugar, sucrose, from cane or beets
Sugar replacement	Sometimes synonymous for nonsucrose sugars or polyol sweeteners used in bulk
Sugar substitute	Replaces sugar by other natural or synthetic sweet-tasting substances such as for diabetics or for calorie reduction

Table 3.3 Functions of Sugars in Wafers, Waffles, Fillings and Enrobings

	Technological Effect	Wafer	Waffle	Adjuncts
1	Sweetness regulation	0/+	+	+
2	Sugars provide bulk	0/+	+	+
3	Reduction of flour swelling and water requirement in the baking masses	0/+	0/+	–
4	Nutrient for yeast fermentation in batters and doughs	0/+	0/+	–
5	Foam stabilization in aeration of baking masses and meringue-type fillings	–	–	+
6	Increase of the starch gelatinization temperature in baking	0/+	+	–
7	Substrate for browning reactions: Maillard reaction, caramelization	+	+	–
8	Plasticization for the postbake forming of sugar wafers	0/+	–	–
9	Influence on texture and eating quality	0/+	+	+
10	Taste and flavour improvement, off-taste masking	0/+	+	+
11	Preservation, water activity reduction in waffles	–	+	–
12	Decoration of noncreamed wafers and waffles	+	+	–

fading out, conditions that are not matched perfectly by other sweeteners. We all are conditioned almost from birth on sucrose sweetness and recognize any deviation from that sweetness profile. Sweetness with a delayed onset or with an aftertaste is generally disliked, mainly because it is unfamiliar compared to sucrose.

The only way to compare it to other sweeteners is through sensory comparison, mostly done by tasting in solutions, either 10% of sucrose in water or to some other percentage. In the comparison, sucrose is given the value of either 1 or 100. The tasting procedure is carried out under defined conditions. Factors affecting the sweetness impression, besides the concentration, are the temperature, pH, the presence of other components, the sensitivity of the individual, and if the individual is trained or untrained (Nordic Sugar, 2009). A higher temperature, for example, reduces the sweetness impact of fructose considerably.

Relative sweetness data (Table 3.4) must be considered with care. The sensory impression in solid matrices such as bakery foods may differ considerably from a sugar solution in pure water. In the scientific literature we find different values for relative sweetness due to the subjectivity of sensory methods (Shallenberger, 1993).

- There are sensitivity differences from person to person, based on characteristics such as gender, race, and whether he or she is a smokers or nonsmoker.
- The relative sweetness depends on the total sugar level and increases significantly with a higher concentration. In dilute water solutions, fructose with 117 has a higher relative sweetness than sucrose (relative sweetness=100). In filling creams with high-sugar levels fructose can be recognized as much sweeter, so we find values from 110 to 170.
- There are nonlinear sweetness effects: in the lower concentration range we see mostly synergistic sweetness enhancing effects when combining different sweeteners from

Table 3.4 Relative Sweetness Ranges in Relation to Sucrose = 1

Natural Sugars and Syrups			
Saccharose	1.0	Galactose	0.5–0.7
Fructose	0.8–1.7	Raffinose	0.2
Glucose	0.6–0.75	Starch syrup, DE 60	0.47–0.6
Lactose	0.2–0.4	Starch syrup, DE 40	0.33–0.48
Maltose	0.4–0.5	HFCS (42% fructose)	0.83–0.91
Invert sugar	1.0	Tagatose	0.9
Sugar Alcohols			
Erythritol	0.5–0.6	Xylitol	0.9–1.0
Isomalt	0.5–0.6	Maltitol	0.8
Lactitol	0.3–0.4	Mannitol	0.6–0.7
Sorbitol	0.5–0.6		
High-Intensity Sweeteners, Natural			
Dulcin	150–250	Stevioside	300
Glycyrrhizin	50	Thaumatin	2000–3000
Monellin	2000		
High-Intensity Sweeteners, Synthetic			
Acesulfame K	130–200	Neohesperidin DC	300–2000
Alitame	2000–3000	Saccharin	200–700
Aspartame	120–220	Sucralose	400–800
Cyclamate	20–40		
Others			
Polydextrose	0	Lycasin	0.6–0.8

the groups of sugars, sugar alcohols and HISs. A combination of sucrose and fructose has a sweetness synergy of up to 27% (Tate and Lyle, 2009, 2016). That allows the reduction of the overall dosage. At high total sweetener levels the sweetness effect may not be an additive anymore.

Sweetness Profiles

Sweetness profiles are specific flavour profiles characterizing a sweetener. The main aspects of the sweetness impression that vary from substance to substance (Fig. 3.1) are the following:

1. How fast is the onset, which is quicker with fructose or with the HISs acesulfame K and saccharine, and it is slower with sucralose, aspartame or neotame
2. How intense is the sweetness impression—the maximum is much higher in fructose than in dextrose or maltose
3. How fast the sweetness impression declines, in which is rapidly in sucrose, fructose and dextrose and slow and lingering in sucralose, aspartame or neotame. The time range for the sucrose peak in Fig. 3.1 is about 15 s

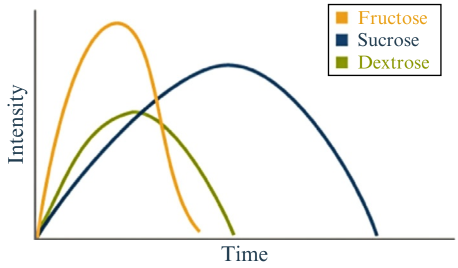

Fig. 3.1 Sweetness profile: onset and intensity. *(Scheme from Tate & Lyle, 2016. Krystar® Crystalline Fructose. Available from http://www.yourbakerysnacksolutions.com/our-ingredients/our-sweeteners/crystalline-fructose/fructose-versatile-and-functional (Retrieved 07-2016)).*

4. Are there any negative side tastes such as astringent, metallic, bitter or burning? Examples are the metallic and bitter side taste of saccharine or the slightly burning note of glycerol

The closer a sweetness profile is to the familiar sucrose, the more likely a sucrose replacer will be accepted well by the consumer.

Low and Excessive Sweetness

In some wafers such as cake cones a little sweetness improves the low flavour. Here a small quantity of sugar additionally improves the crispness, even without imparting a distinct sweetness.

However, more frequently an excessive sweetness is an issue such as in low-cost wafer-filling creams. If the replacement of some sugar by less sweet but more expensive ingredients commercially is not an option, the particle size of sucrose can be one last resort. Finer sugar crystals dissolve in the mouth more quickly and fully when eating a creamed wafer. The cream appears to be sweeter than with coarser sugar particles. In this way, the impression of sweetness declines from fondant sugar > powdered sugar > fine crystal > coarse crystal.

In high-sugar filling creams sometimes this effect is used for an advantage by using a certain part of a more coarse sugar powder at the expense of a less smooth cream texture. Moreover the presence of small quantities of other components with an intensive taste such as traces of salt or fruit acids slightly reduces the sweet top note.

3.1.2.2 Sugars Provide Bulk

Wafers

In low/no sugar wafers such as wafer sheets the sugar level is just a few percent which is no bulk component here.

For moulded sugar wafer cones the level of sugar in the finished product is already from 10% to 18%, in rolled sugar cones sugar makes up from 27.5% to 30.5% of the final cone weight.

In flute wafers (wafer sticks) the sugar makes up about 37% to 47% of the wafers.

Waffles

Sugar in most waffle types is a bulk component. The main products, European fresh egg waffles, contain from 27% to 33% of sugar; Liège waffles contain about 27% to 30% of sugar. Only the frozen waffles in North America and the Brussels waffles are low in sugar and contain only a few percent of sugar.

Filling Creams and Enrobings

In the different adjuncts to wafers and waffles, sugar is a comparatively cost efficient ingredient with clear influences on taste and texture. In the typical filling creams for wafer cookies (biscuits), sugars are the main ingredient, mostly within a range from 30% to 60% of the total cream.

Toffee fillings for wafers contain 70%–75% of carbohydrates from syrups and sucrose, most of them being sugars. The sugar percentage in enrobing chocolates is in the range of 40%–55%, depending on the type and quality. See Chapter 5 of the book for details.

3.1.2.3 Reduction of Flour Swelling and the Water Requirement in Baking Masses

In baking generally as well as in wafers and waffles, sugars used in the preparation of baking masses, batters, pastes or doughs (cf. Chapter 9) have distinct influences on flour/starch systems.

- As a sugar dissolves in the water for batter/dough preparation, the resulting solution has a slightly increased surface tension, which reduces the penetration into the flour particles (wetting of flour)
- Sugars in a solution exhibit an 'antiplasticizing' action. Water plasticizes both the starch granules and the gluten proteins of the flour. With increasing sugar levels that plasticizing is reduced with the consequence that a higher temperature is required to gelatinize the starch and to denature the gluten proteins (Bean and Yamazaki, 1978)
- Whereas in sugar-free batters the starch is gelatinized fully during baking, with increasing sugar levels in sugar batters (rolled cones, flute wafers, waffles) we see increasingly nongelatinized starch granules embedded in the matrix
- For obtaining the same batter viscosity, the water-to-flour ratio in sugar batters is lower than in nonsugar batters. Two effects are responsible for: less wetting and less plasticizing. The swelling of the flour particles is reduced
- That effect also reduces the risk of gluten development during the mixing process
- The same applies to pastes and short doughs. Here the sugar in the recipe can only be dissolved partially, and the mixing times are short. The sugar granulation has to be

tailored to the intended product because important product properties are governed by the dissolved sugar percentage and the granulation of the nondissolved sugar part; these properties include the stickiness of a dough, the flow during wafer cookie development before fixation, and the textural hardness and porosity of the finished wafer cookie

3.1.2.4 Nutrient for Yeast Fermentation in Batters and Doughs

Fermentation processes are applied for flavouring, leavening and preservation of batters and doughs. The fermentation rate is governed by the presence of a low percentage of some sugars, primarily dextrose, which can be utilized fastest by yeasts. Dextrose, high-DE glucose syrups and sugar are applied here as an energy source. The yeasts transform the sugars into alcohol and carbon dioxide mainly. Secondary metabolites are glycerol, succinic acid and acetic acid, which together with the ethanol modify the batter and dough properties (Rezaie et al., 2016).

3.1.2.5 Foam Stabilization in Aeration of Baking Masses and Meringue Fillings

Sugar in combination with water or moist ingredients such as egg whites, butter or margarine forms a viscous syrup phase that stabilizes any air cells formed by mechanical aeration such as in the following:

- Beating egg whites into meringues. There are additional stabilizing factors such as acids and salt
- Creaming sugar and butter. The air can be retained at a low temperature of the fat phase, the maximum being 20°C. An application example are fat pastes in vanilla waffles

3.1.2.6 Increase of the Starch Gelatinization Temperature in Baking

Dissolved sugar significantly increases the temperature at which the starch granules in the flour swell and finally gelatinize (Table 3.5), being a sign of the antiplasticizing action. Water plasticizes the starch granules. With increasing sugar levels that plasticizing is

Table 3.5 Starch Gelatinization Temperature and Concentration of Sugars

	Midpoint Temperature in °C (50% of the Starch Is Gelatinized)		
Sugar Concentration in %	**Sucrose**	**Glucose**	**Fructose**
0	58.5	58.5	58.5
20	63.5	64	63
40	76	73	71
60	94.5	86.5	83

Data from Bean, M.M., Yamazaki, W.T., Donelson, D.H., 1978. Wheat starch gelatinization in sugar solutions II. Fructose, glucose and sucrose: cake performance. Cereal Chem. 55, 945–952.

reduced with the consequence that a higher temperature is required to gelatinize the starch.

Whereas in no/low sugar wafer sheets and cones the percentage of fully gelatinized starch is almost 100%, the higher gelatinization temperatures in sugar batters will reduce that percentage. For sugar wafer batters (rolled sugar cones, flute wafers) in the first baking phase water is quickly lost to the steam generated. In parallel, the sugar concentration rises further and gelatinization is not possible anymore. We see increasingly nongelatinized starch granules embedded in the wafer matrix. The gelatinized starch granules certainly by interlinking and connecting increase the wafers' stability and flexibility. Non-gelatinized starch granules act as fillers, which increase wafer hardness. However their influence on wafer stability in bending, cracking and breaking is difficult to estimate, and at present there is no research available on this.

Table 3.5 provides the interesting point that for sucrose the increase in gelatinization temperature is higher than for glucose and fructose. That offers an explanation for the positive structural effects of combining sucrose with one of the two others as a 'second sugar' in sugar wafer recipes. To compare the data in Table 3.5 to the situation in wafer batters, the typical sugar concentration is the following:

- 35%–40% in rolled sugar cone recipes
- 50%–55% in flute wafer (wafer stick) recipes

3.1.2.7 Substrate for Browning Reactions: Maillard Reaction, Caramelization

The nonenzymatic browning and flavouring in the baking process comes from the following:

(a) Reactions of sugars with proteins (Maillard reaction). The reducing sugars react with amino groups from of the proteins, which create pigments and flavour molecules. That reaction starts at lower temperatures already than the thermal degradation of sugars. An increase in pH value such as by addition of sodium bicarbonate as a leavening agent intensifies the browning

(b) Caramelization, the thermal degradation of sugars and other carbohydrates. The higher the temperature the more that the sweet caramel flavours change to bitter ones. The intensity of browning for the main sugars decreases in the following order: fructose > sucrose, glucose, lactose and maltose. Nondissolved sugar particles in doughs therefore may cause dark spots

Replacing sucrose with other sugars or by sugar replacements might change these browning effects significantly. Then technological adaptations in processing (temperature, pH) or in the recipe will be required.

3.1.2.8 Plasticization for the Postbake Forming of Sugar Wafers

When, after baking, the hot sugar wafer piece of low moisture content cools down, the sugar resolidifies, either due to recrystallization, or in case of sugar mixtures with delayed crystallization due to forming a glass. Any shaping (post forming) operations such as rolling or deep-forming must be done in the still-hot phase.

- At low sugar levels of just a few % sugars, based on flour weight, no post forming is possible. But even the low sugar level imparts a more crunchy (glassy hard) texture to flat wafers, hollow wafers and cake cones
- When increasing the sugar level into a range of 10% sugars (baker's percentage), the molten sugar itself plasticizes (softens) the wafer piece with the consequence that at the demoulding temperature the wafer is still soft and deforms easily, which harms the regularity of shape, such as the flatness of sheets or the regular shape of cones
- A further increase of the sugar content to about 35%–45% sugars, based on flour weight, results in soft, pliable wafer pieces, which immediately after demoulding can be rolled easily into a rolled sugar cone or a sugar wafer reel
- Wafer products formed by deep-drawing operations into bowls or processed further by folding operations require about 50% of sugars (baker's percentage) for a safe forming without crumbling
- Finally for rolling very thin wafer bands into flute wafers (wafer sticks), 60% or more of sugars (based on flour weight) are required
- Mixtures of sugars, sucrose, plus one or more other sugars reduce the 'glass point', the temperature at which the sugars resolidify. That keeps the hot wafer material more pliable and saves a few percent of total sugars in the recipe
- Residues of the molten sugar in contact with the hot baking surface caramelize and later carbonize. That is a main reason for increased baking mould residues in sugar recipes
- Any nondissolved sugar crystals in batters or doughs will result in issues—first in baking because some sticking and burning occurs, resulting a sticky baking mould surface and dark spots on the wafer. Second the nondissolved sugar is missing for the plasticizing effect, which results in crumbling and breaking during the forming operation of rolled cones and flutes

3.1.2.9 Influence on the Texture and Eating Quality

For all types of crisp wafers and wafer cookies an increasing sugar content results in the following:

- A glassier, hard texture. That effect explains the higher quality and mechanical stability of rolled cones for ice cream filling, compared to cake cones. Further this explains the supreme crunchy texture of the thin layers of 'baked sugar glass' in flute wafers (wafer sticks) compared to the more hard-textured wafer reels
- Some retardation of moisture migration into the wafer: However, just the rate of migration is reduced; the final equilibrium moisture content remains unchanged but is just reached later

In soft-textured waffles, higher levels of sugars and syrups reduce the firming by humectancy effects or just reduce the relative percentage of starch in the waffle.

For sugar–fat filling creams the granulation of the sugar has a distinct influence on the eating quality (see Chapter 5 for details).

3.1.2.10 Taste and Flavour Improvement, Off-Taste Masking

Sugars enhance the taste and flavour of foods in concentrations both above and below the sweetness recognition threshold. Even small quantities of added sugars function in masking off-tastes, such as bitter, sour or salty. Bitterness may come from cocoa, caramelization reactions, from HISs, or from the sour taste from fruits. Even tastes from functional ingredients such as vitamins or minerals or first signs of rancidity from lipid oxidation are masked.

3.1.2.11 Preservation, Water Activity Reduction in Waffles

If the concentration of sugars in intermediate moisture foods such as ready-to-eat (RTE) waffles raises, the osmotic pressure increases and most of the water gets bound, which inhibits the growth of microorganisms. Depending on the type of sugar the water activity of saturated sugar solution differs (Table 3.6). By the 'hurdle concept' we create combinations of pH, water activity and temperature being unfavourable for the growth of microorganisms. However, the preservative action decreases whenever any recrystallization of sugars from such concentrated solutions occurs and then the water activity of the remaining solution increases.

3.1.2.12 Decoration of Noncreamed Wafers and Waffles

In noncreamed wafers sugar crystals adhering to the wafer together with some spices and flavours are the principal regulators of the taste and the product appeal.

For RTE waffles sprinkling sugar on top is both for decoration and to reduce the water activity in the package.

Table 3.6 Water Activity of Saturated Sugar Solutions

Type of Sugar	Water Activity (AW)	Solubility (% at 25°C)
Mannitol	0.977	18
Maltose	0.952	46
Lactose monohydrate	0.931	19
Glucose (Dextrose) monohydrate	0.891	51
Glucose syrup, 38 DE	0.89	–
Sucrose	0.844	67
Sucrose/invert sugar 1/1	0.84	–
Invert sugar	0.82	–
Sorbitol	0.725	73
Fructose	0.634	80

Data from Schiweck, H., Clarke, M., Pollach, G. 2007. Sugar. In: Ullmann's Encyclopedia of Industrial Chemistry. doi:10.1002/14356007.a25_345.pub2; Hoffmann, H., Mauch, W., Untze, W., 2002. Zucker und Zuckerwaren, second ed. Behr's Verlag, Hamburg, 364 pp. ISBN: 9783860229378.

3.1.3 Physiological Properties of Sweeteners

3.1.3.1 Calories (Food Energy) of Sugars and Specific Nutrient Content Claims

Sucrose and most other sugars have an energy content of 17 kJ/g (4 kcal/g). Recent WHO recommendations suggest that less than 10% of our total food energy should come from free sugars to counteract the increasing epidemic of obesity. 'Added sugars', making up about 20% of the American caloric intake, have been identified to be related to these issues (Marriott et al, 2010). Recently fructose and high fructose corn syrup (HFCS) came into scrutiny due to the differences in fructose metabolism compared to glucose.

Some of the sugar replacements, discussed later in more detail, offer a lower energy content. All issues of energy reduction currently are not regulated on a worldwide basis but by the local food authorities, which results in some confusion regarding the following:

- The energy content to calculate for the different sugar replacements
- The status of some sugar replacements being either food, novel food or food additive
- The regulation of nutrition claims related to sugars

As much as possible these differences will be addressed when discussing the various substances later in detail. Tables 3.7 and 3.8 offer some information on nutrition claims in the European Union and the United States.

Synonyms for 'free' are 'zero', 'no', 'without', 'trivial Source of', 'negligible source of' and 'dietarily insignificant source of'. Nutrient content claims such as 'no added sugars' and 'without added sugars' are allowed if no sugar or sugar containing ingredient is added

Table 3.7 Specific Nutrient Content Labelling in the United States (Excerpt)

Calories—free	Less than 5 cal per RACC and per labelled serving
Calories—reduced/less	25% less per RACC compared to regular product
Calories—light	50% less fat, 33% less calories
Total fat—reduced	25% less fat and calories per RACC
Total fat—low	Less than 3 g fat in 50 g product, less than 1 g saturated fat, less than 15% of calories from fat
Total fat—free	Less than 0.5 g fat in 50 g product
Saturated fat—reduced	25% less fat and calories per RACC
Saturated fat—low	Less than 1 g saturated fat in 50 g product, less than 10% of calories from saturated fat
Saturated fat—free	Less than 0.5 g saturated fat and less than 0.5 g trans fat in 50 g product
Cholesterol—reduced	25% less per RACC compared to regular product
Cholesterol—free	Less than 2 mg per RACC
Sugars—reduced	25% less fat and calories per RACC
Sugars—free	Less than 0.5 g per RACC and per labelled serving

RACC, Reference Amounts Customarily Consumed.
www.fda.gov/Food/GuidanceRegulation/GuidanceDocumentsRegulatoryInformation/LabelingNutrition/ucm064911.htm (Retrieved 07-2016).

Table 3.8 Specific Nutrient Content Labelling in the EU (Excerpt)

Energy-reduced	30% less calories per kilojoule compared to regular product
Low fat	Less than 3 g fat in 100 g product
Fat free	Less than 0.5 g fat in 100 g product
Low saturated fat	Less than 1.5 g of saturated and trans-fatty acids in 100 g product, providing together less than 10% of the total energy content
Low sugars	Less than 5 g of sugars in 100 g product for solids or 2.5 g of sugars per 100 ml for liquids
Sugars free	Less than 0.5 g of sugars in 100 g or 100 ml product
With no added sugars	No addition of sugars. If sugars are naturally present, the label should say 'Contains naturally occurring sugars'
Source of fibre	At least 3 g fibre in 100 g product or at least 1.5 g fibre per 100 kcal
High fibre	At least 6 g fibre in 100 g product or at least 3 g fibre per 100 kcal
Source of protein	At least 12% of the energy value of the food is provided by protein
High protein	At least 20% of the energy value of the food is provided by protein
Increased nutrient 'X'	The content in one or more nutrients, other than vitamins and minerals, has been increased and (a) the product meets the conditions for the claim 'source of', plus (b) the increase is at least 30% compared to a similar product
Reduced nutrient 'X'	The content in one or more nutrients has been reduced and the reduction is at least 30% compared to a similar product, except for sodium/salt where a 25% apply, and except for micronutrients, where a 10% difference (…) shall be acceptable
Light/lite	The same conditions as term 'reduced' plus an indication what makes the food 'light'/'lite'

http://ec.europa.eu/food/safety/labelling_nutrition/claims/nutrition_claims/index_en.htm (Retrieved 07-2016).

during processing. Terms like 'unsweetened' and 'no Added Sweeteners' remain as factual statements. The claim does not refer to sugar alcohols, which may be present.

3.1.3.2 Sugars Are Cariogenic, the 'Non Cariogenic' Sweetener Claim

There is a well-established relationship between the consumption of fermentable dietary sugars and starches and dental caries (tooth decay), a common disease. Bacteria in the mouth metabolize most dietary carbohydrates, produce acid and form dental plaque. Below a pH-value of 5.5 the tooth enamel surface starts to demineralize. Some sugar replacements are noncariogenic, i.e., are not metabolized by cariogenic microorganisms for a better oral health.

Noncariogenic carbohydrate sweeteners are the sugar alcohols xylitol, sorbitol, mannitol, maltitol, isomalt, lactitol, hydrogenated starch hydrolysates (HSH), hydrogenated glucose syrups and erythritol, or a combination of these. Further examples are the sugars tagatose and isomaltulose, and the sweetener sucralose. All these are significantly less cariogenic and can replace dietary sugars and syrups.

Noncariogenic carbohydrate sweeteners are slowly metabolized by bacteria and form some acid. However, the rate and amount of acid production is significantly lower than that for sucrose and other carbohydrates and does not demineralize tooth enamel. The noncariogenic carbohydrate sweetener claim, such as the US Federal register 21CFR101.80 regulation, states that the noncariogenic carbohydrate sweeteners 'do not promote' dental caries (or a similar wording).

3.1.3.3 Glycemic Index and Glycemic Load of Sugars

The glycemic index (GI) ranks foods on their influence on increases of the blood glucose level in the first hours after eating. GI values are determined experimentally by consumption of a fixed portion of the food, containing 50 g of carbohydrates, after an overnight fast, and checking the blood glucose level for 2 h at certain intervals of time. Pure glucose is the reference point with a given GI of 100. The GI of maltose is 105, while the GI of sucrose (65), lactose (46) and fructose (23) are much lower. A GI of zero indicates that there is no increase in glucose. A classification and examples are provided in Table 3.9, and GI values for sweeteners are shown in Table 3.10.

The accessibility of carbohydrates for the human digestive enzymes greatly influences the resulting GI. So the GI for waxy starches is higher than for high-amylose starch or other types of resistant starches. The GI classification for sugar wafer cookies tentatively is medium. The glycemic index for a frozen waffle is listed as 76.

An important extension of the GI concept is the glycemic load (GL), which makes allowance for the quantity of available carbohydrates (net carbs) in the consumed portion size of food. Available carbohydrates are those that provide glucose in some way, most importantly from sugar and starch.

$$\mathrm{GL} = \mathrm{GI}/100 \times \text{Net Carbs}.$$

Table 3.9 Glycemic Index (GI) Classification of Foods and Sweeteners

GI Class	GI	Examples
High	Over 70	White bread, boiled/baked potatoes, frozen waffles, candies, glutinous rice, maltose, maltodextrin, trehalose
Medium	56–69	Sucrose, RTE waffles, rye bread, long grain rice, beer
Low	Below 55	Pasta, chocolate, many fruits & vegetables, honey, lactose, maltitol
Very low	Below 40	Milk, apples, pears, legumes/pulses, fructose, xylitol
Sweeteners below 10		Erythritol, isomalt, lactitol, sorbitol, polydextrose, inulin and oligofructose, tagatose, mannitol

Data from Brand-Miller, J., Foster-Powell, M., Colagiuri, St., Barclay, A., 2007. The New Glucose Revolution for Diabetes: The Definitive Guide to Managing Diabetes and Prediabetes Using the Glycemic Index. Da Capo Press, 512 pp, ISBN13 9781569243077; and various sources.

Table 3.10 Glycemic Index of Sugars, Syrups and Bulk Sweeteners

Sugar	GI Value
Maltose	105
Glucose	100
Maltitol	69
Sucrose	65
Golden syrup	63
Isomalt	60
Honey	35–64 (55)
Maple syrup	54
Grape syrup	52
Lactose	46
Maltitol	34
Xylitol	12
Fructose	19
Polydextrose	4–7
Isomalt	2
Sorbitol	<5
Mannitol	<5
Inulin	4
Tagatose	3
Lactitol	2
Erythritol	0

Data from Brand-Miller, J., Foster-Powell, M., Colagiuri, St., Barclay, A., 2007. The New Glucose Revolution for Diabetes: The Definitive Guide to Managing Diabetes and Prediabetes Using the Glycemic Index. Da Capo Press, 512 pp, ISBN13 9781569243077.

The GL refers to the total load of a portion of food consumed. From a nutritional viewpoint carbohydrate-containing foods with a low GL value are preferable. GL data can be found on the Internet. The consumer, especially diabetics, should favour carbohydrate-containing foods with a low GL value.

3.1.3.4 Prebiotic Sugar Replacements and Digestive Health

The microbiota in our intestines greatly influence our health and well-being. These may be positively influenced in two ways.

- Firstly by probiotics—living microorganisms that are typically administered with fermented foods; many of them are dairy-based. Probiotics are 'live microorganisms which, when administered in adequate amounts, confer a health benefit on the host' (WHO, 2006). The most common probiotic bacteria are Lactobacillus and Bifidobacterium
- Secondly by prebiotics, a term defined by Gibson and Roberfroid (1995) as 'non-digestible food ingredients that beneficially affect the host by selectively stimulating

> the growth and/or activity of one or a limited number of bacterial species already established in the colon, and thus in effect improve host health'.

Of higher interest are the prebiotics, primarily because these primarily carbohydrate-based food components are nondigestible substances and fibres for the normal digestive system, but they later stimulate certain bacteria in the human colon, which positively influences our health. Well proven prebiotics such as inulin and fructooligosaccharides, polydextrose, resistant starches and maltodextrins, lactitol and lactulose are discussed in detail below.

3.1.3.5 Sweeteners for Diabetics

People suffering from diabetes must limit their intake of calories and especially in those low molecular weight carbohydrates provoking a fast rise in blood glucose level and a corresponding insulin demand. To prevent diabetics from not being deprived of attractive foods such as wafer cookies, waffles and other sweet-tasting goods, a number of products specifically for diabetics are in the market. The main issues to consider are the following:

- Which sugars are forbidden
- Which sugars are allowed
- Alternatives to sugar for obtaining bulk and sweetness
- Legal requirements—please check the local regulations

Table 3.11 lists important commercially used low molecular weight carbohydrates that should not be added to recipes for diabetics. Basically the content of glucose (dextrose) or its generation from easily hydrolysable saccharides is the critical point.

When looking to replace the nonpermitted sweeteners of Table 3.11, there are a many substitutes available; however the technological properties such as hygroscopicity, browning properties, sweetness or the batter/dough consistency may change greatly. Moreover the costs will increase.

Table 3.12 provides an overview of the bulk substitutes for sugars regarding bulk and sweetness. In case of lacking sweetness HISs are applied additionally.

Table 3.11 Sweeteners Unsuitable in Products for Diabetics

Sucrose (saccharose, cane or beet sugar, white or brown sugar)
Glucose (dextrose), glucose (dextrose) syrups, starch syrups
Corn syrups, corn sweeteners, corn syrup solids
Invert sugar (invert syrup), golden syrup, high fructose corn syrups
Honey
Molasses
Maltose, maltose syrups
Lactose
Maltodextrins

Table 3.12 Sugar Bulk Substitutes in Bakery Products for Diabetics

Ingredient	Functionality	Legal Status in EU	E-No.
Fructose	Sweetness, hygroscopic	Food	–
Erythritol (Zerose)	Some sweetness	Additive	E 968
Isomalt (Palatinit)	Some sweetness, laxative	Additive	E 953
Lactitol	Some sweetness, laxative	Additive	E 966
Maltitol	Some sweetness, laxative	Additive	E 965
Mannitol	Some sweetness, laxative	Additive	E 421
Polydextrose (Litesse)	Nonsweet, hygroscopic	Additive	E 1200
Sorbitol	Some sweetness, laxative	Additive	E 420
Xylitol (Bonadent)	Sweetness, slightly laxative	Additive	E 967

Please check especially which sugar substitutes, listed in Table 3.12, are permitted in your country for these kind of foods and the requirements regarding warning labels due to laxative effects.

3.1.4 Sucrose (Saccharose)

3.1.4.1 Properties and Grades of Sucrose

Sucrose is manufactured industrially from sugar cane or sugar beet by refining. The chemical name is saccharose, a disaccharide from glucose and fructose. In white sugar the substance is present in high purity. The different name for refined sucrose products such as refined sugar, white sugar and semiwhite sugar, rely on refining grades, which define the colour and the content in residual minerals. The whiteness grade technologically for most of our applications is not so critical, with two exceptions:

1. Influence on hygroscopic properties: While white sugar can be considered as nonhygroscopic up to a relative humidity of 60%–65%, that humidity limit for more brownish sugar grades is lower
2. With beet sugar of lower grades, traces of nonseparated proteins, saponins or gum substances result in some colour and in increased foaming when cooking the sugar for fillings such as caramel, marshmallow or jam

Sugar in daily life almost always is in crystalline form; solely during milling or conching the very adsorptive amorphous sugar may occur and bind moisture and flavours more strongly. Some physical properties of sucrose in comparison to other sugars are compiled in Table 3.13.

3.1.4.2 The Importance of Sugar Granulation

In wafers and waffles the granulation of the sugar crystals greatly influences the following:

- The storage, conveying and metering: Coarser crystals because of their lower specific surface area are easier to store, to convey and to dose automatically

Table 3.13 Melting and Solubility of Important Sugars

Parameter	Sucrose	Glucose	Fructose	Lactose	Maltose
Melting point (°C)	186	147	103	202 [a]	103 [a]
Solubility at 20°C (g/100 g water)	200	89.4	383	19	70
Saturation at 20°C (g/100 g solution)	66.7	47.2	79.3	16	41

[a] For the monohydrate form.

- The sugar dissolution time in batter or dough preparation. That time increases with higher particle size due to the lower specific surface area. However, any formation of lumps in powder sugar delays the dissolving as well. For sweet paste baking masses as in vanilla waffles, being low in water powder sugar is required
- The smoothness of texture in filling creams is determined by the sugar granulation because sugar is both a main component and the hardest component in creams

Country by country there are specific granulations available as well as different names for sugars.

The Main Crystal Sugar Sizes (Nordic Sugar, 2009)

1. Coarse grained sugar, large transparent crystals of an average size between 700 and 1400 μm. Frequently the most economic sugar product, suitable for sugar wafer and waffle batters where sufficient water is available. In turbo mixers even at low water temperature the dissolution time is lower than 1 min. Coarse grain sugar is the appropriate sugar for decorating noncreamed wafers
2. Granulated sugar has average crystal sizes in the range of 450–650 μm. It is the most applied type, used in bulk, big bags or bags. Used for batters, doughs and for grinding into powder sugar on site
3. Caster sugar has average crystal sizes in the range of 150–450 μm
4. Powdered sugar is crystal sugar milled in factories to smaller than 120 μm, typically without anticaking agents. For standard cream fillings
5. Icing sugar is finely milled sugar, mostly with anticaking agents such as potato starch or tricalcium phosphate added. The particle size varies between 10 and 40 μm. Icing sugar is used mainly for decoration and the manufacturing of smooth fillings and fondants
6. Fondant sugar (silk sugar) is an extra finely ground, dry sucrose product consisting of small sucrose particles in the range of 10–20 μm, used for dry fondants.

In the United States the designations 4X to 12X for finely powdered icing sugars still are common

- 4X—92% smaller than 75 μm (200 mesh)
- 6X—93.5% smaller than 75 μm
- 8X—96% smaller than 75 μm
- 12X—98% smaller than 45 μm (325 mesh)

- Silk sugar—97% smaller than 20 μm

Instant sugar is made from finely milled sugar, spray-dried onto water droplets. The agglomerates have a porous structure and are rapidly dissolving. The average particle size is 200–400 μm.

Sugar Grinding

Self-grinding of powdered sugar from crystal sugar is economical and done frequently in wafer manufacturing plants. Because of the high risk of dust explosions sugar grinding has to be done in a separate area with provisions to handle the overpressure at such explosions.

Crystal sugar is easy to handle, and the freshly milled powder can be used directly without a lumping risk. The basic requirement for powder sugar fineness in standard wafer creams is 75% smaller than 100 μm (150 mesh). Finer grindings for icing sugar or the 4X to 12X sugars in the United States require additional milling equipment.

Fig. 3.2 provides information about the exponential increase in surface area of sugar powders when reducing the particle size (Stahmer and Gerhold, 2014).

Any prolonged storage of milled powder sugar should be avoided because it is sensitive to the following:

- To moisture sorption and lumping. For nonimmediate use free flowing agents are added, either tricalcium phosphate powder (E 341) at a maximum of 1.5% or predried (!) starch, preferably the finely granulated rice or corn starches at 2%–4%. A moisture

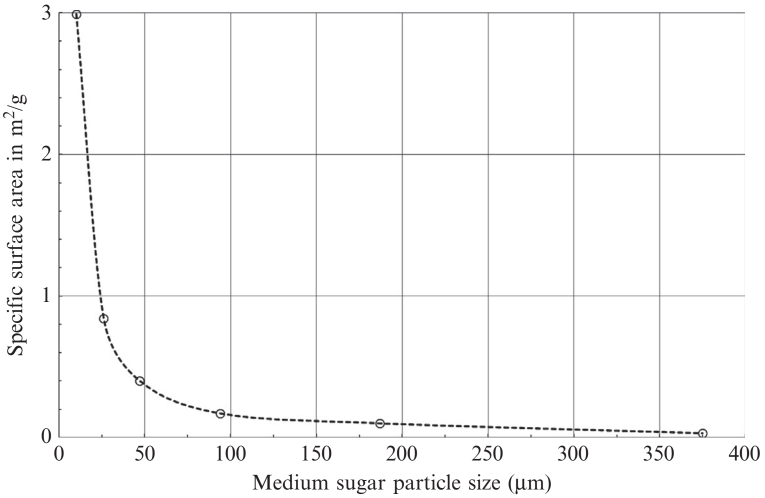

Fig. 3.2 Powder sugar—specific surface area and particle size. *(Data from Stahmer, K.-W., Gerhold, M., 2014. Brenn- und explosionskenngrössen von zuckerstaub. Gefahrstoffe-Reinhalt. Luft 74, 279–285. Available from: http://www.dguv.de/medien/ifa/de/pub/grl/pdf/2014_093.pdf (in German language)).*

content in the sugar as low as possible, typically below 0.04%, is recommendable. Otherwise an increased risk of lumping exists
- The fresh sugar surface after milling is extremely absorptive and besides the effect of moisture, any off-flavours might be adsorbed easily

Powdered Sugar

The particle size of sugar, being the 'hardest' ingredient in sugar–fat creams, determines the mouthfeel and the pleasantness of eating a filling cream. In wafer cookies of low cream percentage, the particle size of sugar is greatly overruled by the particles formed when chewing the crunchy wafer. But in case of thicker cream layers the 'grittiness limit' of the human palate, which is somewhere in the range of 35 μm, has to be observed.

Pearl Sugar for Liège Waffles

Liège waffles (Chapter 9) particularly include coarse sugar pearls that won't melt during baking. The result is a crunchy to soft, sometimes caramelized, eating quality. The typical calibre of the pearls pressed cold at high pressure is 5.6–8 mm. Cf. in Chapter 5, Section 5.4 on inclusions.

Fondant

Fondant is used as icing or filling in baked goods and confectionery, optionally with flavours and colours. Fondant consists of small sugar crystals (<20 μm) in a supersaturated sugar solution. Classical fondant is prepared by boiling a sugar solution to the soft-ball stage, cooling under continuous stirring until it is an opaque paste of creamy texture. Seeding with powdered sugar would result in coarser crystals and a less smooth texture. A certain percentage of invert syrup or glucose syrup humectant is included in the recipe as well. The moisture content is in the range of 10%–12%.

Dry or instant fondant is extra finely ground sugar and has dried glucose syrup powder included. Only water has to be added. A small amount of acid may be added, mainly for partial inversion and taste reasons.

Sugar Handling

For sugar handling during transport, conveying, or storage, coarse white crystal sugar is the best suited sugar type
- The bulk density is in the range of 750–850 kg/m^3
- The lower specific surface of coarser particles reduces moisture sorption. The residual moisture should be not over 0.03%–0.06%
- The granulation should be homogeneous, and the percentage of sugar dust should be as low as one to a few percent in order not to disturb automatic sugar conveying. Inadequate conveying equipment will increase the level of sugar dust as well
- The sugar conveying rate should be in the range of 11–22 m/s

- Sugar is a hard and abrasive material
- Any moisture sorption from air—for white sugar at a relative humidity above ca. 60% and for darker sugar grades at lower RH—will result in sugar lumping
- White sugar therefore has to be stored dry at 20%–60% relative humidity and at a more or less constant temperature, best at ambient. If outside silos in winter time cool down, the relative humidity easily goes over 65% or will even reach the dew point. Then the resulting sugar syrup on the crystals surface causes lumping of the sugar crystals into a hard mass

3.1.4.3 Liquid Sugar (Sucrose Syrup)

Sucrose, dissolved in water, is delivered in bulk at concentrations from 62%–67%. The percents are weight-%, which is gram sucrose in a 100 g solution (°Brix). The typical content of inverted sugar is below 1%. Two examples follow:

- 63% sugar syrup (821 g/l), bulk delivery by truck, handling at 20°C is possible
- 67% sugar syrup (889 g/l), bulk delivery by an isolated truck, held at 30°C–50°C in order to prevent crystallization

See Table 3.14 for a typical specification of liquid sugar and Table 3.15 for compositional data of liquid sugars and syrups.

The advantages of liquid sugar syrup:

- Easy to transport and handle (drain, pump and metre)
- Lower investment for solid sugar conveying and dosage into the batter and dough mixer
- Lower mixing/kneading time due to the predissolved sugar

Table 3.14 Liquid Sugar—A Typical Specification

Parameter	**Value**
Degree Brix	67.5 ± 0.3
Invert sugar, % (dry base)	0.3 max.
pH	7.0–8.0
Sulfated ash (%)	0.05 max.
Colour	Clear to light straw
Specific gravity (g/cm^3)	
20°C	1.3337
25°C	1.3310
30°C	1.3283
35°C	1.3252
40°C	1.3227
Storage temperature (°C)	25–40
Mesophilic bacteria (cfu/10 g)	200 max.
Mould (cfu/10 g)	10 max.
Yeast (cfu/10 g)	10 max.

Table 3.15 Liquid Sugars, Invert Syrups, Golden Syrup

Product	Sucrose (%)	Glucose (%)	Fructose (%)	Colour IU	Density (g/L)	Viscosity (cP 20°C)
Liquid sugar 65	65	–	–	<25	1.32	150
Liquid sugar 67	67	–	–	<25	1.33	230
Liquid sugar 72 invert	29	22	21	<25	1.35	600
Liquid sugar 77 invert	23–31	22–26	22–26	<60	1.39	2400
Liquid invert 68	<4	>32	>32	<120	1.33	80
Liquid invert 70	<3.5	34–36	32–34	<60	1.34	200
Liquid invert 73	<4	Ca. 35	Ca. 34	<150	1.37	590
Golden syrup	26	25	24	850	1.39	2400

Data from Nordic Sugar, 2009. The Functional Properties of Sugar on a Technical Level, 54 pp. Available from: http://www.nordicsugar.com/fileadmin/Nordic_Sugar/Brochures_factsheet_policies_news/Download_center/Functional_properties_of_sugar_on_a_technical_level/Functional_prop_on_tech_level_uk.pdf.

Potential disadvantages of liquid sugar syrup:

- Transport of ~1/3 of water. Sugar crystallization in case of low temperatures. A storage tank is required
- Microbiological issues in the tank if moisture condensation occurs. Careful handling is required: air filters, drying, condensation prevention, periodical sterilization
- Eventually partial sugar inversion. However that will have little influence on the baking properties in sugar wafers such as rolled sugar cones, flute wafers or wafer reels

Even pure dextrose and fructose sometimes are available as liquid sugars in bulk.

3.1.4.4 Invert (Sugar) Syrup, Invert Sugar Crème (Artificial Honey)

Invert syrup is manufactured by the cleaving of sucrose: Saccharose → Glucose + Fructose, which is called inversion. The inversion process is catalyzed either by the enzyme invertase or by acids for food uses (hydrochloric acid, citric acid, tartaric acid). The rate of inversion by acids depends on the proton activities of the acid, which decreases in the following order:

$$\text{Hydrochloric} \gg \text{tartaric, phosphoric, sulphuric} > \text{citric} > \text{lactic} > \text{acetic acid}$$

The degree of inversion is given by the sum of glucose, fructose divided by the sum of sucrose, glucose and fructose.

Invert sugar is available as syrup with dry solids of around 70% (Table 3.16), or as invert crème. Invert sugar crème is manufactured by acid inversion, has at least 50% invert sugar, and less than 22% moisture content. The rest is noninverted sucrose and in some cases up to 20% of low-DE corn syrup for preventing crystallization. From a food technologist viewpoint the following properties of invert sugars are important:

Table 3.16 Composition of Golden Syrups

Component	Content in %
Invert sugar	47 (range 42–51)
Sucrose	32 (range 27–38)
Ash	2 (range 1–5)
Water	18 (range 16.5–20)

- The solubility of invert sugar is higher than that of sucrose or dextrose, which means less transport costs compared to liquid sucrose
- The sweetness is higher: 70% solids invert syrup is about equally sweet to sucrose
- For baking: the browning intensity, Maillard reaction plus caramelization, of invert syrups is higher than for sucrose or dextrose
- The pH value due to neutralization after inversion should only be slightly acid, ~5.5. Otherwise in batters or doughs leavenings are partially or fully neutralized in a non-controllable way. That is particularly important for self-prepared invert syrups, having quite frequently a variable degree of inversion, colour and a low pH value
- Invert sugar is strongly hygroscopic and therefore an important humectant in waffles and caramel fillings

Partially inverted syrups such as ‘golden syrup’

Golden syrup initially is an invert syrup manufactured from the noncrystallizable part of cane sugar manufacturing. It has an amber colour and a honey-like texture and may be used in similar applications as invert syrups. Table 3.16 provides some compositional details.

3.1.4.5 *Boiling of Sugar and Syrup Solutions*

In many applications sugars and syrups are part of boiling mixes in food manufacturing. For wafers, milk caramel (toffee) or marshmallow fillings are of interest. With increasing concentration the boiling point rises (Table 3.17) as well as the browning and degradation reactions.

3.1.4.6 *Analytical Parameters for Sugars*

In Table 3.18 the different analytical parameters for sugars are summarized together with a specific discussion for wafer and cookie manufacturing.

For rapid determination of the concentration in sugar solutions and syrups, refractometers have widely substituted the old areometers (spindles). In Europe two scales are still in use:

- Degree Brix (°Bx) stands for weight-% sugar solids in syrups at 20°C. For other temperatures and for nonsucrose syrups there are correction tables available

Table 3.17 Boiling Points of Saccharide Solutions

Dry Matter (%)	Sucrose	Glucose	64 DE Syrup	42 DE Syrup	Sucrose/64 DE 1/1	Sucrose/42 DE 1/1
50	101.8	100.3	100.4	100.2	100.3	100.2
70	105.1	107.6	105.9	104.2	105.5	104.6
80	109.4	112.8	110.1	107.4	109.8	108.4
85	113.3	118.0	114.1	111.3	113.7	112.3
90	119.3	126.6	121.6	120.0	120.4	119.7
94	126.6	138.6	133.9	133.8	130.3	130.2
98	137.7	153.3	174.4	174.4	156.0	156.0

Data from Hoynak, P.X., Bollenback, G.N., 1966. This Is Liquid Sugar Refined Syrups and Sugars, second ed. Yonkers, New York, 259 pp.

Table 3.18 Analytical Characterization of Sugars for Wafers and Waffles

Parameter	Methods	Importance for Wafers and Waffles
Ash	Conductivity	Less important
Colour (extinction)	ICUMSA units	Less important
Density (spec. gravity)	Hydrometer (areometer)	Check of syrups, liquid sugar
Moisture content	Drying	Sugar handling, lumping prevention
Optical rotation	Polarization	Invert sugar content: colours in baking, humectant in waffles
Raffinose	Polarization	Less important
Refraction index	Refractometer	Concentration in liquid sugar and syrups
Size, granulation	Sieve or optical analysis	Cream fineness; dissolution time
Sugar spectrum	HPLC; enzymatically	Information on composition

- Degree Baumé (°Be) are found specifically for glucose (corn) syrups. For viscosity reasons the measurement temperature is 60°C (140°F) mostly. Again via tables the percentage of dry solids is calculated

3.1.4.7 Brown Sugar, Soft Sugar, Yellow Sugar

In brown sugars remaining molasses impart colour and flavour. They are marketed under various names, such as demerara sugar, muscavado sugar, Barbados sugar, soft sugar, yellow sugar, plantation raw sugar, cane syrup solids or dried cane syrup, or turbinado sugar. There are no sound specifications on these product names. The best way to characterize brown sugars are the four parameters in Table 3.19, which are examples from one sugar manufacturer. The colour intensity rises with the percentage of nonsugar solids, the

Table 3.19 Examples of Industrial Brown Sugars

Type of Brown Sugar	Sugars in %	Moisture in %, max.	Nonsugars in %	Colour ICUMSA units
Golden brown soft	96–98	2.0	~ 1.0	2500–3250
Light brown soft	94.5–96.5	3.0	1.4–2.5	4500–6250
Dark brown soft	93.5–96	2.6	~ 3.6	19,000–29,000
Demerara	>98.5	0.2	–	1500–2500

Data from Tate & Lyle, 2009. Sweeteners, 20 pp. Available from: http://www.tateandlyle.com/ingredientsandservices/Chooseaningredientorservice/EuropeMiddleEastAndAfrica/Documents/SWEETENERSBrochureTateLyleNov09.pdf; Nonsugars include ash and nonsugar organic material.

stickiness with the percentage of residual moisture. Brown sugars are manufactured in any of the following ways:

- In cane sugar refineries by crystallization from the raw cane sugar syrup. Remaining molasses add a small percentage, from <1 to a few percent, of nonsugar components such as moisture, invert sugar, minerals and some genuine colouring and flavouring substances to the sucrose crystals. Very soft brown sugar may contain even up to 12% of nonsugar substances
- White crystal sugar from beet or cane is blended with molasses for surface colour and taste
- In beet sugar manufacturing due to less pleasant byproducts, no flavourful brown sugar products are obtained; at most some yellowish or light-brown sugar results

From a technological viewpoint the pros and cons of brown sugars are the following:

- Additional flavour and colour imparted to sugar cones, flute wafers, waffles and wafer cookie
- Soft brown sugar byproducts in postformed sugar wafers exhibit some ‘sugar-saving’ effect by increasing the flexibility in rolled cones or flute wafers compared to white sugar
- In automatic brown sugar conveying and dosing, the stickiness causes bad handling properties
- Any increase in the content of nonsugar components increases the flexibility and softness for rolling sugar cones and flute wafers. Primarily the content of invert sugar changes the baking properties, the browning intensity, the easiness of rolling and the hygroscopicity of the finished wafer

3.1.4.8 Caramel Sugar Syrup, Burnt Sugar

Controlled thermal degradation of sucrose results in brown-coloured degradation products with a characteristic sweet to bitter taste and caramel flavour. In bakery the application is for colour and flavour. Commercially either concentrated syrups of about 77% solids content or powder products are available and may be used without food additive labelling. Self-preparation is by either the wet or dry cooking method:

- Wet method: Sugar, dissolved in hot water, is cooked until the depth of colour and the intended bitterness in flavour is obtained. At temperatures above 110°C the reaction intensifies and runs increasingly faster with the risk of going quickly into overly burned. If a small quantity of citric acid or cream of tartar is included from the beginning, sucrose inversion intensifies thermal colouration and influences the flavour
- Dry method: Heat crystal sugar in a heavy vessel to first melt the sugar. The reaction intensifies and runs increasingly faster with the risk of going quickly into being overly burned

On the contrary, caramel colours, which are prepared by adding further reactive chemicals for a much higher colour intensity, must be labelled as food additives with the E numbers of E 150a to E 150d.

3.1.4.9 Which Type of Sucrose for Which Application?

Fluid Batters for Sugar Wafers and Waffles

In fluid batters, the water content is high, and the highly soluble sugar dissolves within a short time of mixing. Therefore the cheaper coarse sugar types may be selected. Alternatively, in case of tight mixer capacity, for faster dissolution medium to fine crystal sugar sizes are applied. The actual batter mixing time has to be adapted to the crystal size and the water temperature in order to be sure that the sugar will dissolve fully. Otherwise the nondissolved part will sediment (specific gravity is 1.59 g/cm^3) in the mixer and the batter properties fluctuate, which results in manufacturing troubles.

In case of high-sugar consumption the use of liquid sugar should be considered if it is available. Easier logistics of liquid sugar handling in transport, precision and speed of dosage and mixing are of interest, compared to crystal sugar conveying.

Sweet Pastes for Waffles

In sweet paste baking masses with their higher sugar and fat levels, the water content is restricted. Powdered sugar is required here and even that is just partially dissolved during baking mass preparation.

Short Doughs for Waffles and Wafer cookies

The sugar in some recipes, such as for stroopwafels, is close to the limit of dissolution, which makes powdered sugar preferable. The sugar granulation has to be tailored to the intended product. Important product properties are governed by the dissolved percentage and the granulation of the nondissolved sugar part, such as the stickiness of a dough, the flow during cookie development before fixation, and the texture, mainly hardness and porosity, of the finished cookie.

Other Waffle and Wafer Cookie Doughs

The dough water is high enough to fully dissolve the sugar quantities. Crystal sugar can be used. Liquid sugar might reduce the mixing time slightly. For Liège waffle doughs the dough sugar is low. Just at the end of dough making, the pearl sugar is integrated which should not dissolve.

Creams—Sugar–Fat Fillings

Powdered sugar, being the least expensive ingredient, delivers sweetness and a considerable part of the total cream weight. Depending on the desired cost and cream quality level, sugars will be in the range of about 30%–60%, most frequently from 40% to 50% of the cream weight. The sugar fineness is an important criterion for cream quality. However, the requirements regarding sugar crystal size are less strict than for good chocolate. When eating wafer cookies, there are crunchy, harder elements from the wafer present anyway during the chewing process. There are three principal viewpoints on sugar granulation for filling creams:

1. In some countries creams for top products should be absolutely smooth. That means the sugar crystals should not be felt on the palate anymore, which is the case below a crystal size of ~30–35 μm, similar to good chocolate. Then additional refining by ball milling, five-roller milling, or in a refiner conche is required. However, in case of extreme sugar fineness below 15 μm the cream texture might be increasingly recognized as ‘clingy’ or ‘sticky’
2. In large part the sugar powder as it comes from crystal sugar grinding is used for standard wafer creams. That is typically 75% smaller than 100 μm (150 mesh). Due to the good solubility of sugar during chewing, that is sufficient and economically wise
3. At times in high-sugar creams we even find more coarse sugar particles in filling creams. This may be either because that is typical in a certain region of the world or due to the fact that bigger granules are not fully dissolved in the mouth and the cream will not appear to be as sweet despite an overly high level of the cheap bulk component. The sweetness impression decreases with particle size: fondant sugar > powdered sugar > fine crystal > coarse crystal

Alternatively some of the sucrose powder may be replaced by less sweet sugars, polyols or other low molecular weight carbohydrates having one important common property—to be water soluble and therefore to dissolve in the mouth when the cream is consumed. Most of the less sweet sugar replacements are higher in costs. But in some countries good sugar replacements such as dextrose, dry glucose syrups and maltodextrins are at the same cost level or even cheaper nowadays.

A further option is the presence of small quantities of other components of high impact such as acids, flavours or masking ingredients to lessen the intensity of the overall sweetness impression.

Brown sugar due to its residual moisture results in bad milling properties with syrupy surfaces, sticking, and increased lumpiness and is not recommended for creams.

Cooked Fillings

For cooked fillings—such as toffee, marshmallow or jam fillings—crystal sugar, white or brown, is dissolved in sufficient water for a complete dissolution in the hot cooking mass.

3.1.5 Other Types of Sugars

3.1.5.1 Glucose (Dextrose, Grape sugar)

Dextrose after sucrose is the next important sugar in bakery. Today at even lower costs than for sucrose, the starch industry manufactures pure glucose powder and glucose syrups of DE 95+ from different starches. They are offered as 'liquid dextrose' in bulk as well, delivered in trucks at about 55°C–60°C with 70%–72% solids and a viscosity of 40–50 cP (Schenck, 2006).

Mostly dextrose monohydrate with about 8.5% crystal water is applied, and sometimes anhydrous dextrose is applied with just about 0.5% of residual moisture. For partial sucrose replacement in wafer creams, technologically the following properties of glucose powder are of interest:

- The lower sweetness intensity, just about 70%–75% compared to sucrose
- The distinct 'cooling' sensation of dextrose-containing creams, coming from its higher heat of solution, which is −105.5 J/g for the monohydrate and −59.3 J/g for anhydrous dextrose, compared to −16.1 J/g for sucrose. So the monohydrate is clearly preferable for obtaining the most cooling effect
- The melting point is much lower, compared to sucrose. Glucose monohydrate melts at 83°C, and anhydrous dextrose melts at 146°C, compared to over 180°C for sucrose
- Even more important is the phase change of dextrose monohydrate to anhydrous dextrose at 55°C or lower, setting free one molecule crystal water per molecule dextrose. In cream pumping, due to mechanical shearing the temperature and a dextrose monohydrate containing cream becomes bone-hard. Glucose monohydrate should be stored below 53% RH at 25°C, to avoid product loss due to caking (Scholl, 2014)
- For fermented batters and doughs in waffles or wafers the faster utilization of dextrose by yeasts is of interest
- The browning intensity (Maillard reaction plus caramelization) in baking for dextrose is similar to sucrose
- The caloric value and the digestibility of glucose are similar to sucrose. The glycemic response for glucose, with a GI of 100, is very high, compared to 68 for sucrose. It is not suitable for diabetics.

3.1.5.2 Fructose (Laevulose, Fruit Sugar)

Besides the occurrence as part of sucrose, pure fructose is manufactured by enzymatically converting glucose syrups. Crystalline fructose is available at a residual moisture of about 0.5%. The melting point is 102°C–105°C. The solubility in water is high, 375 g in 100 ml at 20°C. Moreover today 90 DE fructose syrups are available in bulk delivery with about 77% solids and a viscosity of ~600 cP at 27°C (Hobbs, 2009; O'Donnell and Kearsley, 2012). A detailed discussion of fructose-containing syrups (HFCS, isoglucose syrup) and honey, where fructose is the main sugar, follows below.

The resorption of fructose in the human body is slower than for sucrose and is non-insulin dependent. It takes place primarily in the liver. Therefore fructose has a low glycemic index of 19, compared to 100 for dextrose and 68 for sucrose, and it is considered to be suitable for diabetics. There has been some discussion on the connection of fructose overconsumption to 'metabolic syndrome' (insulin resistance, obesity, elevated LDL cholesterol and triglycerides) but the food authorities have found no reason to intervene.

From a food technologist viewpoint the following properties of fructose are important:

- The higher sweetness of 120–150, compared to sucrose. The higher the concentration of sugars is in a system such as in a sugar–fat cream, the higher is the relative sweetness of fructose. At elevated temperature fructose sweetness decreases strongly
- Fructose due to its high hygroscopicity is an efficient humectant. That is important in waffles' shelf life, but it would be negative for unpacked ice cream cones and other sugar wafers
- Fructose is thermally less stable and starts decomposing slightly over 100°C. The browning intensity (Maillard reaction plus caramelization) of fructose in baking therefore is more intensive than of sucrose and results in more bitter taste notes
- Fructose today is one of the most important sugar replacements in sweet products for diabetics. The high sweetness make it an ideal combination with other, less sweet sugar replacements such as most of the polyols
- The caloric value of fructose is similar to sucrose. The glycemic response is low, GI 19

3.1.5.3 Lactose (Milk Sugar)

Lactose is a disaccharide from glucose and galactose. Its main source is from cow's milk where the concentration is about 4.5%. Lactose today is a cheap byproduct from the dairy industry, used widely in filling creams and bakery. Lactose powder is used as monohydrate with about 5% crystal water, or as anhydrous lactose. The slightly yellowish quality ('lactose, edible') which still has ~0.5% protein, is fully sufficient for food applications. Refined edible or pharmaceutical qualities have less protein and are almost white. Lactose is rather stable thermally; the monohydrate melts at 203°C, and the anhydrous lactose melts at 252°C.

From a food technologist viewpoint the following properties are pros and cons for the use of lactose:

- The low relative sweetness, just 30%–35% compared to sucrose, might be interesting for filling creams
- Lactose has a low water solubility, a high hardness of the crystals, and a larger crystal size. A higher lactose concentration occurs, which results in a gritty taste impression in creams
- An important issue is cream hardening during storage and shelf-life time. That is caused by a phase change from lactose monohydrate to anhydrous lactose. The free moisture then hardens the cream. That phase change occurs if the moisture content during shelf life increases slightly and the water activity (AW) rises over about 0.35 at temperatures slightly over ambient.
- For both of these reasons, we recommend formulating for less than about 10% lactose in cream fillings. Cf. Table 4.12 for details on lactose concentration in the various dairy powders for creams
- The browning intensity (Maillard reaction plus caramelization) in baking is similar to sucrose
- The caloric value and the digestibility of lactose is similar to sucrose. The glycemic response of 45 is in the low GI range
- Lactose in lactose-tolerant persons was found to not be laxative, but there is an increasing number of people with lactose intolerance. Due to their lack of the enzyme lactase, in the intestine flatulence and cramping occurs.

3.1.5.4 Maltose (Malt Sugar)

Maltose, a disaccharide built from two glucose units, occurs naturally in malted cereals and is industrially manufactured by starch conversion into high-maltose syrups, as discussed below. Anhydrous maltose melts at ~160°C, and the more common monohydrate melts at 102°C. There is no wide use and availability of maltose powder; it's just locally available in Asia for bakery and filling creams.

From a food technologist viewpoint the following properties of maltose are of interest:

- The lower sweetness, ~30%–50%, compared to sucrose may be of interest in cream fillings for wafers and in waffle batters
- Sweetness reduction in sugar wafer or wafer flute batters by maltose is not recommended because maltose offers lower plasticizing activity in rolling than sucrose
- The browning intensity (Maillard reaction plus caramelization) of maltose is similar to sucrose, and the baking flavour is good but somewhat different than sucrose
- The caloric value and the digestibility of maltose is similar to sucrose. The glycemic response with a GI of 105 is very high. Maltose is not suitable for diabetics

3.1.5.5 Isomaltulose (Palatinose, Lylose)

Isomaltulose is a disaccharide, derived from sucrose, by an enzymatic rearrangement of the glucose–fructose alpha 1,2-linkage to an alpha 1,6-linkage. It is available as a monohydrate. The melting point of isomaltulose is 123°C, and the solubility is just 29% at 20°C in water, compared to 67% for sucrose. Isomaltulose is classified as a 'novel food' in the EU, but it is considered a food in Japan. In the United States is it considered to be generally recognized as safe (GRAS).

From a food technologist viewpoint the following properties of isomaltulose are important:

- The relative sweetness is about 40%, compared to sucrose and slightly increasing at higher levels. The taste of sweetness is clean and similar in its character to sucrose
- The caloric value is the same as for sucrose—4 kcal/g
- The browning intensity in baking (Maillard reaction plus caramelization) is quite high
- Isomaltulose is slightly hygroscopic, stable at low pH values, and does not invert like sucrose
- Isomaltulose is tooth-friendly (anticariogenic)
- The glycemic response of isomaltulose, with a GI of 32, is low
- Isomaltulose is not laxative at single doses of 50 g

3.1.5.6 Trehalose (Ascend)

Trehalose is a nonreducing disaccharide with a 1,1-glucoside linkage of two glucose units, manufactured by an enzymatic process. It occurs naturally in honey, mushrooms and fermented foods but is not widely commercially available. The melting point of trehalose dihydrate is ~97°C. Trehalose has an extremely high glass transition temperature of 117°C and acts as a heat stabilizer and cryoprotector in plant and animal systems. The WHO Joint Expert Commission for Food Additives (JEFCA) in 2000 did not specify an ADI (acceptable daily intake) for trehalose. Since 2001 in the EU trehalose has the ability to be used as a novel food, and in the United States it has GRAS status.

From a food technologist viewpoint trehalose might be of interest for the following reasons:

- The lower sweetness, ~45% compared to sucrose for cream fillings, sugar wafer and waffle batters
- There is little browning intensity (Maillard reaction plus caramelization) in baking
- Trehalose is almost nonhygroscopic
- The caloric value and the digestibility of trehalose is similar to sucrose
- There are some positive properties in cold-stored and frozen doughs
- The laxative limit is around single doses of 50 g

3.1.5.7 Tagatose (Naturlose)

Tagatose is a monosaccharide, occurring naturally in fruits. Industrially it is enzymatically derived from lactose via the galactose part. There are no broad industrial applications.

The WHO JEFCA in 2004 did not specify an ADI for tagatose. Since 2005 in the EU tagatose has been classified as a novel food, and in the United States it has GRAS status. A tagatose brand name is Naturlose. Tagatose is a white, medium hygroscopic, crystalline powder with a melting point at 135°C and a high reactivity in thermal food processing.

From a food technologist viewpoint the following properties of tagatose are of interest:

- The relative sweetness is around 90% of that of sucrose with a similar sweetness profile. There is some cooling effect. The solubility in water is 61% at 20°C
- The browning intensity (Maillard reaction plus caramelization) in baking is high. Tagatose browns intensely and then offers caramel-like and malty flavours
- The caloric value is 1.5 kcal/g (United States), respectively 2.4 in the EU. That allows for manufacturing energy-reduced foods
- The glycemic response of tagatose, with a GI of 3, is very low. Therefore it is well suited for developing sugar-free foods and foods for diabetics
- Tagatose is medium in hygroscopicity and has probiotic properties
- Tagatose is nonfermentable and therefore noncariogenic
- Tagatose is not laxative at single doses of 75 g.

3.1.6 Syrup Sweeteners and Maltodextrins

3.1.6.1 Conversion of Starch

The Dextrose Equivalent

Dextrose equivalent (DE) is the reducing power of a starch hydrolysate expressed as a percent of the reducing power of the same weight of D-glucose. The DE provides a measure of the degree of hydrolysis of starch into maltodextrins and glucose syrups. The higher the DE, the larger the amount of glucose and the smaller the amount of dextrins present.

For nonhydrolyzed starch the DE is zero, whereas pure glucose (dextrose) has a DE of 100 per definition. At a low degree of starch cleavage, from DE 3 to 19, maltodextrins result, which are sold in powder form. If the DE is above 20 it is called glucose syrup (corn syrup, starch syrup, maltose syrup). Depending on the process conditions with increasing starch cleavage the content of glucose (dextrose), maltose and the following oligosaccharides increases at the expense of the higher saccharides. With higher DE values, the viscosity of syrup solutions decreases and they are easier to pump. So cost efficient syrups with high solids may be manufactured.

The DE value of a starch hydrolysate is inversely related to the average degree of polymerization (DP) of the starch hydrolysate. As a rule of thumb, DE × DP (average) is about 120. The process is called conversion (Table 3.20).

Saccharification by Acids and Enzymes

The cleavage of starch by acids and/or enzymes, the saccharification of starch, results in a wide range of sweeteners. The main raw material is corn starch and increasingly wheat starch. In North America syrups are the more important sweeteners today and on a

Table 3.20 Conversion Groups in Starch Saccharification

Conversion Group	DE-Value
Maltodextrins	Below 20
Low conversion	20–38
Intermediate	39–58
High	59–73
Very high conversion	Over 73

worldwide basis their application is increasing as well. The syrups contain about 80% solids (78%–84%) typically. The fluidity at ambient is low, but at 60°C the fluidity and handling properties are good. The typical viscosity is 42–44°Bé. Residual quantities of SO_2 from corn steeping and wet milling are present, however they are usually not over 20 ppm.

By acid hydrolysis in syrup manufacturing DE values up to about 65 are accessible. The syrup types "DE 42" and "DE 60" for long time have been the standard. By additional enzymatic treatment and combined methods, syrups high or extra high in maltose (HM, EHM) as well as glucose syrups up to 95 DE are manufactured. By enzymatic isomerization the HFCS are accessible. High-DE syrups are intermediates for fructose syrup, sorbitol, and fermentation products and find uses in many foods. Table 3.20 provides the typical classification by DE value.

Starch-derived glucose syrups (corn syrups, starch syrups, maltose syrups) in the form of dry glucose syrup (DGS) powders and maltodextrins powders increasingly replace a part of sugar in cream fillings because of cost and reduced sweetness reasons. Further they are used in cooking masses like toffee or jam. However, I have to first point out some potential issues with fluid syrups:

1. The risk of microbial growth whenever any condensed moisture can form or the syrups are diluted. The water activity is high due to reduced solubility of components with higher molecular weight
2. In case of a high solids percentage, whenever the temperature lowers, some crystallization can occur easily. Crystals then interfere with the usual syrup logistics severely
3. Syrups and any residues of syrups are attractive for insects

Not only the syrups, but the volumes of dried powders with just 4%–6% residual moisture manufactured from starch saccharification——either maltodextrins or DGS powders—are on the rise as well. Table 3.21 provides information on the most important maltodextrin and syrup types and their relative sweetness. Table 3.22 has an overview on the technological properties.

3.1.6.2 The Various Starch Conversion Products

Maltodextrins

Maltodextrins are almost nonsweet (0%–5% sweetness of sucrose), but they already are easily soluble in water, which is important for their palatability. Maltodextrins are sold as

Table 3.21 Typical Composition of Starch Conversion Products

	A	A	A/E	A	A	A/E	A/E	E/E	A/E	E/E
Converted by	**DE**									
Substance	**5**	**15**	**28**	**30**	**42**	**42 HM**	**48 HM**	**48 EHM**	**63**	**98**
Glucose	<1	2	5	10	19	6	9	3	37	95
Maltose	<1	3	8	9	14	45	52	71	34	3
Maltotriose	1	4	16	10	11	16	15	14	16	1
Oligosaccharides	>97	>90	71	71	56	33	24	11	13	1
Relative sweetness	0	4	15	20	32	32	38	39	50	73

A, acid cleavage, E, enzyme cleavage.

Data from Alexander, R.J., 1997. Sweeteners: Nutritive. In: Eagan Press Handbook Series, Eagan Press, St. Paul, MN, 120 pp, ISBN 0913250953.

Table 3.22 Technological Properties of Glucose Syrups and Maltodextrins

Property	Low DE Maltodextrin	Medium DE Syrup <50	High-DE Syrup >50
Browning in baking	–	+	++
Viscosity in solution	+++	++	+
Binding, cohesion, body	+++	++	+
Foam stabilization	+++	++	+
Sweetness	–/(+)	+	++
Glossiness	++	+	+
Delay of crystallization	+++	++	++
Preserving activity	–	+	++
Hygroscopic	–	+	++
Water activity reduction	–	–/+	+
Flavour release	+	++	++
Fermentability	+	++	+++
Freezing point reduction	+	++	+++
Nutritional value	++	++	++

–, Absent; +, low; ++, medium; +++, high.

powders with 4%–6% residual moisture. Adding water results in sticky, highly viscous, high-solids solutions applied for foam stabilization, such as in marshmallows, and as tackifiers or binders (see Section 2.4.5 in Chapter 2 for details). From a food technologist viewpoint the following properties of maltodextrins are important (see also Table 3.22):

- Both the very low sweetness and the water solubility make maltodextrins interesting in partial sugar replacement in filling creams, at the expense of some sticky character of the cream texture
- The browning intensity (Maillard reaction plus caramelization) of maltodextrins in baking is low

- The tackiness is an interesting property for adhering particles such as spices or sugar crystals to noncreamed wafers
- Maltodextrins are not suitable as sugar replacements for diabetics

Glucose Syrups and DGS Powders

For glucose-containing syrups the names glucose syrup, starch syrup, and in United States corn syrup are in use. We recommend avoiding the old name 'liquid glucose'. Due to their water content glucose syrups cannot be applied in wafer creams as such. But increasingly DGS powders are becoming available, with a DE mostly between 20 and 43, and they are applied for substituting sugar in creams. From a food technologist viewpoint the following properties these syrups and powders are the most important (see also Table 3.22):

- Low conversion DGS powders with a DE from 20 to 38 due to their reduced sweetness are increasingly important in partial sugar replacement for filling creams. We recommend finer granulations than the standard grade for that purpose. The increasing hygroscopicity with DE imparts a slightly tacky character in eating texture
- In moist fillings such as caramel and toffee, marshmallow, birds milk (Russia), jams and jellies, glucose syrups are applied due to their anticrystallizing properties together with some sucrose
- The browning intensity (Maillard reaction plus caramelization) of glucose syrups in baking increases with DE. In waffle manufacturing a small percentage of medium- to high-DE syrups might be applied for that purpose
- Glucose syrups are not suitable as sugar replacements for diabetics

Maltose Syrups

By enzymatic modification of the starch hydrolysis process, high or extra high-maltose syrups with 45 to about 70% maltose at glucose levels below 10% are manufactured (cf. Table 3.21). Another name is candy syrup due to the good anticrystallizing properties at moderate hygroscopicity. The dry solids of maltose syrups are in the range of over 70% to 80%. The relative sweetness of maltose syrups is low, because maltose itself is just at 40%. They are not suitable as sugar replacements for diabetics.

Fructose-Containing Glucose Syrups: Isoglucose and HFCS

By enzymatic isomerization in glucose syrups a part of glucose is converted to fructose, which increases the sweetness. In the EU, syrups of 10% or more in fructose content are called 'isoglucose' syrups. In North America HFCS (Table 3.23) have been widely used for four decades, though the usage quite recently has been declining. The first two types, HFCS 42 and 55, are obtained without additional enrichment and therefore are more economic. HFCS technologically is similar to invert syrup, which has been discussed in Section 3.1.4.4.

Table 3.23 North American HFCS and Fructose

	Type			
Component	**HFCS 42**	**HFCS 55**	**HFCS 90**	**Fructose crystalline**
Glucose	53	41	9	0
Fructose	42	55	90	100
Oligosaccharides	5	4	1	0
Sweetness (Sucrose = 100)	*92*	*99*	*106*	*117*
Solids content	*71*	*77*	*77*	*100*

Data from Alexander, R.J., 1997. Sweeteners: Nutritive. In: Eagan Press Handbook Series, Eagan Press, St. Paul, MN, 120 pp, ISBN 0913250953.

From a food technologist viewpoint the following properties of HFCS syrups are of interest:

- The solubility of HFCS is higher than of sucrose or dextrose, which reduces the transport costs compared to liquid sucrose
- The sweetness is higher: HFCS 55 is about equally sweet to sucrose, and the cost per sweetness unit is lower
- The browning intensity (Maillard reaction plus caramelization) in baking is higher than for sucrose or dextrose
- The fructose part is strongly hygroscopic and therefore an important humectant such as in waffles and caramel fillings
- HFCS reduces the crystallization tendency in icings

Besides the big group of glucose syrups from starch hydrolysis there are other syrups—natural syrup, such as honey, syrup derived from polyfructans or syrup derived from the cane sugar process.

3.1.6.3 Natural Syrups

Honey

Honey with its natural origin offers a typical flavour with some fluctuations in quality and intensity. The dry solids are about 80% within a range from 78%–86%. In the sugar spectrum, fructose (~38%) is slightly higher than glucose (~31%). Further a few percent of maltose and sucrose is present. Higher saccharides and other components occur just in traces. Some crystallization at temperatures slightly under ambient comes from the glucose part, which is less soluble than fructose.

Besides its quality as an expensive, flavourful ingredient in bakery, the technological functions are similar to those discussed for invert sugar. Typical properties are the humectancy and the heat sensitivity, corresponding to a strong browning in baking.

Syrups Rich in Fructose From Inulin

Chicory and some artichoke types provide inulin (see Section 2.4.5 in Chapter 2 for details), which is the basis for syrups rich in fructose, obtained by hydrolysis. The syrups have about 70%–75% dry matter, of which up to 85% is fructose, ~10% glucose and a few % fructooligosaccharides.

Technologically of interest is the high sweetness, up to 120% compared to sucrose. The syrups rich in fructose are intensely browning (Maillard reaction plus caramelization) in baking and are strongly hygroscopic, being excellent humectants in waffles and caramel (toffee) fillings.

Fruit Concentrate Sweeteners

More recently extract syrups from fruits have been available. They have 70%–75% dry matter and are high in fructose (Table 3.24). The technological properties of fruit concentrate sweeteners are similar to those of invert syrup and HFCS. The syrups are about equally sweet to sucrose and are good humectants. The labelling looks more natural but they are 'added sugars' regardless.

Molasses, Treacle

Food grade molasses are thick, dark brown sugar syrups from the sugarcane refining process, remaining after the white sugar was removed by crystallization. There is a distinct, strong flavour and a slightly bitter taste. The composition depends on the sugarcane processing and can be quite variable. Molasses, as shown in Table 3.25 still contain a lot of sucrose and invert sugar and other sugars and substances from the sugarcane. Depending from which boiling in the process the molasses comes, the colour is from golden to black and the total sugars go down from about 65% to 55% or less. Treacle

Table 3.24 Typical Composition of Natural Fruit Concentrates

Ingredient	Apple Syrup	Pear Syrup	Grape Syrup
Fructose	55–60	60–65	45–55
Glucose	25–30	15–20	45–55
Sucrose	5–10	7–12	–
Sorbitol	3–7	10–15	–
Others	0–2	0–1	0–2

Data from Alexander, R.J., 1997. Sweeteners: Nutritive. In: Eagan Press Handbook Series, Eagan Press, St. Paul, MN, 120 pp, ISBN 0913250953, on dry matter base.

Table 3.25 Typical Composition of Molasses

Ingredient	Example (%)	Range (%)
Sucrose	33	28–39
Invert sugar	27	16–35
Water	17	16–18
Other solids	15	5–24
Minerals	8	4–14

Data from Alexander, R.J., 1997. Sweeteners: Nutritive. In: Eagan Press Handbook Series, Eagan Press, St. Paul, MN, 120 pp, ISBN 0913250953.

is the British word for molasses; at the time the name treacle is used for a combination of some molasses for flavour and colour with sugar and invert syrup.

Molasses from beet sugar manufacturing, due to their content in betaine and in some off-tasting components, are not food grade.

From a food technologist viewpoint the following properties of molasses are significant:

- A strong and typical flavour, some reduced sweetness due to side tastes
- Molasses are hygroscopic and are good humectants
- The brown baking colour of wafers, cones and other bakery products intensifies due to their own colour and to intense browning reactions (Maillard reaction plus caramelization)
- Molasses retard the sugar crystallization, which improves the glassiness and hardness of sugar cones and other wafers from high-sugar batters and has some sugar sparing effect

Malt Extract Syrup, Nondiastatic

Liquid malt syrups are made from the aqueous extraction of malted barley, and after concentration they are supplied as viscous, dark-brown, aromatic liquids. Nondiastatic means that amylases and other enzymes from the malting process are not active anymore. The solids are from 72%–83%, of which 50%–62% are reducing sugars, primarily maltose, dextrins, ~5% protein and 2% minerals. Increasingly spray-dried malt extract powders are available.

Technologically the malt flavour is of interest in cream fillings (malt extract powder). During baking most of the flavour is lost, just intense browning (Maillard reaction plus caramelization) increases the colour. Malt extracts are hygroscopic and are good humectants.

Maple Syrup, Palm (Date) Syrup, Sorghum Syrup

Maple syrup is manufactured by concentrating the sap of maple trees, which has just 2%–2.5% sucrose. This is a typical product of Canada, the United States and Japan and is consumed together with waffles and pancakes. Sometimes it is used as an ingredient in baking or making candy. Sucrose is the prevalent sugar in maple syrup, besides that some invert sugar is formed during concentration, where the typical flavour and darker colour develop. The syrup has from about 68% to 75% solids, and the maple cream content is up to 83%.

Other syrups high in sucrose and invert are palm (date) syrup or sorghum syrup, but there few applications at present.

3.1.7 Sugar Replacement (Substitution), Sugar-Free

3.1.7.1 General Aspects of Sugar Replacement

Sucrose is replaced for specific dietetic requirements such as the following:

- Reduction of added sugar or free sugar calories in the diet, quite recently addressed by new dietary recommendations for Americans (U.S. Department of Health and Human Services, 2015) or the recommendation of WHO (WHO, 2015)

- Health conditions such as diabetes
- Preference for noncariogenic (tooth-friendly) foods
- Diets such as 'low carbohydrate', mostly referring to a 'low GI' and GL

Sugar replacement (substitution) is done by combining other foods and/or food additives to match most or at least some of the technological functions of sugar as listed in Table 3.3. The most important ones are the following:

- Substitution of balanced sweetness and bulk in bakery recipes and filling creams is done by combining other sugars, polyols, bulk replacers and HISs
- Substitution of the colouring functions due to Maillard reactions and caramelization in baking by fructose or food colours
- Substitution of the plasticizing effect in the hot forming of rolled wafer cones and flutes
- Substitutions for dietetic reasons: Calorie reduction, glycemic control in diabetes
- Regulation of the viscosity buildup in the batter/dough phase
- Substitute for the increase of starch gelatinization and setting temperature in baking
- Freezing point depression and water binding in (intermediate) dough freezing

Restoration of the desired functions is the task for the food technologist in every single application. Sugar replacement includes different types of substitutes:

1. Food components such as fructose, a different sugar, resistant maltodextrins or oligofructose
2. Food additives for bulk such as polydextrose or the polyols sorbitol, erythritol, maltitol, isomalt, lactitol, xylitol and mannitol. All of them require E-number labelling in Europe
3. HISs to compensate for any lacking sweetness; examples are sucralose, steviosides, acesulfame K, saccharine or aspartame. They require E-number labelling in Europe

The various foods and food additives mentioned show considerable differences in taste, sweetness quality and aftertaste, in positive or negative sweetness synergy, as well as in suitability for baking applications. Careful selection and fine-tuning is required.

In Table 3.26 the relative sweetness, the energy content and the sweetness per added calorie are tabulated. For most of the polyols the EU has a general 2.4 kcal/g figure; for erythritol the figure is 0 kcal/g. In the United States and Japan these values are closer to the real energy figures from calorimetry, but again they are different. The sweetness per calories therefore is slightly variable for some sugar substitutes.

Sugar Replacement in Sugar Wafers, Creams, and Waffles and Their Adjuncts

The percentage of sugar(s) in our applications such as sugar cones, flute wafers, waffles, wafer fillings and enrobings is from 10% to 40% of the total mass for the baked products and from 30% to 60% in the adjuncts. The exchange of such high shares by components of different technological properties can be a source of issues in various aspects:

Table 3.26 Sugar Bulk Replacers: Relative Sweetness and Energy Content

Substance	Relative Sweetness	Energy Content (kcal/g)	Sweetness per kcal
Sucrose (comparison)	*100*	*4*	*25*
Fructose	110–150	4	28–38
Sorbitol	40–50	2.6	15–19
Erythritol	60	0.2	300
Maltitol	90	2.1	43
Isomalt	50	2	25
Polyglycitol (HSH)	40–60	3	13–20
Lactitol	30	2	15
Xylitol	100	2.4	42
Glycerol	60	4.3	14
Mannitol	40–50	1.6	25–31

Real energy content, the energy content in local food regulations differs.

1. The sweetness profile changes, being most important for creams
2. The solubility in water for preparing the batter or dough frequently is lower, and the influence on the swelling and gelatinization of flour can be different
3. The browning intensity to form the baked colour impression for many substitutes is low
4. The plasticizing effect for postforming hot sugar wafers is less (with a few exceptions) and results in breakage
5. The fragility and eating texture, such as the bite and crumbliness, often change
6. The sugar substitutes frequently impart a more hygroscopic character
7. Due to lower melting points, difficulties with blocked conveyors or pumps are experienced
8. Most of the sucrose replacers are more expensive

For these reasons either just a partial sugar replacement (sugar reduction) is done sometimes, or in case of full exchange two or more replacers are combined in order to meet the original as much as possible. But there are technologically advantageous effects of sugar replacement as well:

1. Some bulk replacers show a higher heat of solution than sugar, which is accompanied by a ‘cooling’ sensation in the mouth. That cooling sensation, being prominent in dextrose, sorbitol and erythritol, is positive for cream fillings
2. The lower solubility of some sugar substitutes influences the overall sweetness impression to less sweet
3. The lower energy content of some substitutes such as erythritol, polydextrose or the polyols is an important feature
4. The presence of other tasty components such as acids, flavours, masking ingredients or salt can modify the intensity and quality of the sweetness impression in a positive way

3.1.7.2 Sugar Alcohols (Polyols) in Sugar Replacement

Polyols occur naturally in various fruits. Chemically they are alcohols, manufactured industrially by the hydrogenation of the corresponding sugars. Along with some sweet taste, some polyol functions are adding bulk and texture, providing sweetness and a cooling effect, preventing thermal browning and acting as humectants to retain the moisture in soft-textured foods such as waffles. Polyols are nutritive sweeteners. However they are absorbed and metabolized incompletely. Consequently they contribute fewer calories than sucrose and are all are assigned in the EU to a calculated caloric value of 10 kJ/g for labelling. The polyols commonly used include sorbitol from glucose, xylitol from xylose, isomalt or palatinit from isomaltulose, mannitol from fructose, maltitol from maltose, lactitol from lactose, erythritol and HSH. Most of them are approximately half as sweet as sucrose and they are combined with HISs. Just maltitol and xylitol are about as sweet as sucrose.

Sugar alcohols are used in sugar-free confectionery and bakery. The low glycemic index makes them suitable for diabetics. The proportion remaining in the intestines can have a laxative effect in larger quantities, typically >25 g/day but there may be a digestive adaptation on regular consumption. There are advantages and disadvantages of polyols due to their following properties (cf. Table 3.27):

Table 3.27 Properties of Sugar Alcohols (Polyols)

Property	Erythritol	Xylitol	Mannitol	Sorbitol	Maltitol	Isomalt	Lactitol	Sucrose
Carbon number	4	5	6	6	12	12	12	12
Molecular weight	122	152	182	182	344	344	344	342
Melting point (°C)	121	94	165	97	150	145–150	122	190
Glycemic index	0	13	0	9	52	9	6	68
Glass transition temp. (°C)	−42	−22	−39	−5	47	34	33	52
Heat of solution (kcal/kg)	−43	−36.5	−28.5	−26	−18.9	−9.4	−13.9	−4.3
Heat stability (°C)	>160	>160	>160	>160	>160	>160	>160	<150
Acid/pH stability	2–10	2–10	2–10	2–10	2–10	2–10	>3	Inversion
Solubility (% w/w at 25°C)	37	64	18	71	60	28	58	67
Hygroscopicity	Very low	Low	Very low	High	Low	Low	Medium	Medium
Relative sweetness	60	100	40–50	40–50	90	50	30	100

Data from Alexander, R.J., 1997. Sweeteners: Nutritive. In: Eagan Press Handbook Series, Eagan Press, St. Paul, MN, 120 pp, ISBN 0913250953.; Mitchell, H. (Ed.), 2006. Sweeteners and Sugar Alternatives in Food Technology, Blackwell, 413 pp; Wilson, R. (Ed.), 2007. Sweeteners, third ed. Wiley-Blackwell, 200 pp, ISBN: 978-1-905224-42-5; Grembecka, M., 2015. Sugar alcohols—their role in the modern world of sweeteners: a review. Eur. Food Res. Technol. 241, 1–14. doi:10.1007/s00217-015-2437-7.

- They are suitable for bulk sugar replacement in wafers, waffles and adjuncts
- Sweetness and hygroscopic properties exhibit big differences; for details see Table 3.27 and the following description of the single polyols
- The reduced energy content of many, not all, polyols is due to their incomplete resorption in the small intestine. The downside of an incomplete resorption is a laxative effect of many of the sugar alcohols which has to be mentioned on the label
- Polyols in baking are not subjected to browning (Maillard reaction plus caramelization)
- Some of the polyols have a higher heat of solution, which results in a cooling effect during consumption
- Sugar alcohols are nonfermentable and therefore low or noncariogenic (tooth-friendly)
- Sugar alcohols are suitable in special diets, such as those for diabetics, and for low GI and low carbohydrate applications
- Polyol-containing foods may cause laxative effects. Foodstuffs containing more than 10% of added polyols must indicate that 'excessive consumption may cause laxative effects'
- Unfortunately their caloric value in big economic areas such as the EU, United States or Japan must be labelled still with different values. Please look for your local regulations

Erythritol (Zerose, Erylite, E 968)

Erythritol naturally occurs in some fruits and fermented foods and is manufactured industrially by fermentation from glucose. The WHO JEFCA in 1999 did not specify an ADI for erythritol. Erythritol has long been in the market in Japan, and it is considered GRAS in the United States and approved in EU and many other countries worldwide. The caloric value is 0.2 kcal/g, just 5% of the sucrose energy value. For the EU and Japan even zero calories can be labelled.

Erythritol is a white, nonhygroscopic, crystalline powder. It melts at about 121°C. It has excellent pH and heat stability in food processing. The relative sweetness is around 60 compared to sucrose. When it comes to taste, erythritol compares well to sucrose in sweetness character. The application range therefore is from drinks and dairy products to confectionery and bakery products. Brand names are Zerose and Erylite. At present the higher costs limit a wider application. From a food technologist viewpoint the following properties of erythritol are of interest:

- In bulk sugar replacement, erythritol offers zero calories and some sweetness reduction if not combined with HISs
- The solubility in water at ambient is just 37%, far lower than for sucrose. The contribution to viscosity is smaller than for other sugars and polyols

- Erythritol has a distinct cooling effect when dissolving in the mouth, especially in combination with softer fats as in wafer creams. In combination to harder fats as used for hot climate, erythritol might aggravate their waxy mouthfeel
- The stability in baking is very good, and there is no browning (Maillard reaction plus caramelization)
- In sugar-free rolled wafer cones and flute wafers erythritol has a great potential. The plasticizing effect is about twice that of sucrose as a sugar replacement (US 7754268 B2), which allows for low sweetness sugar wafer products
- Erythritol has no glycemic response and is well suited for developing wafers and waffles being low in GI and in carbohydrates; it is suitable for diabetics as well
- Erythritol is nonfermentable and therefore noncariogenic (tooth-friendly)
- Erythritol, contrary to other sugar alcohols, has a high digestive tolerance, is almost not laxative and requires no warning labels
- At high erythritol/sweetener ratios, synergistic sweetness effects with HISs such as sucralose, stevioside, acesulfame K, aspartame and thaumatin occur

Sorbitol (Glucitol, E 420)

Sorbitol naturally occurs in some fruits and is industrially easily accessible by hydrogenation from glucose syrups at low costs. The WHO JEFCA in 1982 did not specify an ADI limit for sorbitol. Sorbitol is considered GRAS in United States and is approved in EU and many other countries worldwide and has the highest market share of all polyols at present.

Sorbitol is a white, hygroscopic, crystalline powder. It melts at 97°C and has excellent pH and heat stability in food processing. The relative sweetness is about 50% compared to sucrose. The sweetness profile of sorbitol compares more to glucose than sucrose. The application range is from drinks and dairy products to confectionery and bakery products. In Europe sorbitol has the food additive number E 420. From a food technologist viewpoint the following properties of sorbitol are important:

- In bulk sugar replacement sorbitol has a caloric value of 2.6 kcal/g, in the EU it is 2.4 kcal/g compared to 4.0 for sucrose. It offers some sweetness reduction if not combined with HISs
- The solubility in water at ambient is the highest for all polyols; therefore besides that of the powder, a 70% solution in water is a common distribution form of sorbitol
- Sorbitol and sorbitol syrup are good humectants, but they recrystallize quite easily. The 'noncrystallizing' sorbitol syrup contains some side concentration of mannitol or polyglycitol (HSH) syrup. Handling of sorbitol powder above 55% relative humidity results in lumping and stickiness issues
- The stability in baking is very good, there is no browning (Maillard reaction plus caramelization)

- In sugar-free wafer fillings frequently a combination of fructose powder, having a higher sweetness, and the less sweet and very economic sorbitol is applied
- Sorbitol has a distinct cooling effect when dissolving in the mouth
- Sorbitol has a very low glycemic response; the GI of sorbitol is 9. It is well suited for developing wafers and waffles low in GI and in carbohydrates. It is suitable for diabetics as well
- Sorbitol is nonfermentable and therefore noncariogenic (tooth-friendly)
- Sorbitol is a laxative, which limits general sugar replacement in bulk. The laxative action starts from about 15 g as a single dose or 20 to 40 g/day. If the content in laxative polyols in a food is 10% or higher, a warning label is required in the EU. In United States products with foreseeable higher consumption of sorbitol have to carry a warning label stating that 'excess consumption can cause a laxative effect'
- Synergistic sweetness effects with HISs such as saccharine, acesulfame K and others were found

Isomalt (Palatinit, E 953)

Isomalt is manufactured in a two-step process via isomaltulose (palatinose) from sucrose. The second step is the hydrogenation of isomaltulose. Isomalt is a mixture of two disaccharide polyols. The WHO JEFCA in 1985 did not specify an ADI limit for isomalt. Isomalt is considered GRAS in United States, and it is approved in the EU (E 953) and many other countries worldwide.

Isomalt is a white, nonhygroscopic, crystalline powder with about 5% crystal water. It melts at 145°C–150°C and has excellent pH and heat stability in food processing. The relative sweetness is about 50% compared to sucrose; at low concentrations the sweetness is just about 45%, and at high levels it is up to 60%. When it comes to taste, isomalt compares well to sucrose in its sweetness profile. There is no cooling effect. The application range therefore is from drinks and dairy products to chocolate, confectionery and bakery products. From a food technologist viewpoint the following properties of isomalt are of interest

- In bulk sugar replacement isomalt has a caloric value of 2.0 kcal/g; in the EU it is 2.4 kcal/g compared to 4.0 for sucrose. It offers some sweetness reduction if not combined with HISs
- The solubility in water at ambient is just 24.5%, far lower than for sucrose. A specific quality 'isomalt GS' with a solubility of 41.6% is available
- The stability in baking is very good, and there is no browning (Maillard reaction plus caramelization)
- In sugar-free rolled wafer cones and flute wafers isomalt works as a 1:1 sugar replacement (US 7754268 B2)
- Due to its low hygroscopicity, up to about 85% rH, isomalt offers some retardation of moisture absorption for wafers (Tiefenbacher 2002, unpublished)

- Isomalt has a very low glycemic response; the GI is 2. It is well suited for developing wafers and waffles being low in GI and in carbohydrates, and it is suitable for diabetics as well
- Isomalt is orally nonfermentable and therefore noncariogenic (tooth-friendly)
- For sugar replacement applications in chocolates and refined coatings an 'isomalt LM' (low moisture) quality with less than 1% moisture content is available
- Isomalt has some laxative effects, up to 50 g/day is well tolerated. Within the EU if the polyol content of a product is 10% or higher, a warning label is required
- The sweetness synergy of isomalt is known in combination with other polyols. Isomalt masks any bitterness of HISs

Xylitol (E 967)

Xylitol (birch sugar) naturally occurs in some fruits and vegetables. It is manufactured by hydrogenation of xylose, accessible from hemicelluloses. The WHO JEFCA in 1983 did not specify an ADI for xylitol. Xylitol is considered GRAS in the United States. It is approved in the EU, with the food additive number E 967, and in many other countries.

Xylitol is a white, hygroscopic, crystalline powder. It melts at about 92°C–96°C and has excellent pH and heat stability in food processing. The relative sweetness is 100, similar to sucrose. In taste, xylitol compares more to dextrose in sweetness profile with a slightly scratchy and burning side taste. Today's main application range is in chewing gums and sugar-free candies. A xylitol brand name is Bonadent.

From a food technologist viewpoint the following properties of xylitol are important:

- The caloric value for xylitol is 2.4 kcal/g in the EU and in the United States; it is 3.0 kcal/g for Japan
- The solubility in water at ambient is 62%. The water activity of xylitol solutions is lower than for sucrose. Xylitol is hygroscopic, more than sucrose but less compared to sorbitol. The contribution to viscosity is smaller than with other sugars and polyols
- The stability in baking is very good, and there is no browning (Maillard reaction plus caramelization)
- In sugar-free rolled wafer cones and flute wafers xylitol works as a 1:1 sugar replacement (US 7754268 B2)
- Xylitol has a very low glycemic response; the GI is 12. It is well suited for developing wafers and waffles being low in GI and in carbohydrates. It is suitable for diabetics as well
- Xylitol is nonfermentable and therefore noncariogenic (tooth-friendly)
- Some prebiotic and satiety increasing effects of xylitol are reported
- There are sweetness synergies of xylitol with sorbitol and maltitol
- Xylitol has a distinct cooling effect
- Xylitol is laxative with a tolerance in the range of 50–70 g/day. However, adaptive effects of the body are reported. If the content in laxative polyols in a food is 10% or

higher, a warning label is required in the EU. In the United States products with foreseeable higher consumption of sorbitol have to carry the warning label that excess consumption can cause a laxative effect

Mannitol (E 421)

Mannitol naturally occurs in some fruits and vegetables and algae. It is manufactured via fructose hydrogenation and separation from the coproduct sorbitol. The WHO JEFCA in 1986 did not specify an ADI for mannitol. Mannitol is considered GRAS in the United States and is approved in the EU, food additive number E 421, and many other countries.

Mannitol is a white, nonhygroscopic, crystalline powder. It melts at about 165°C–169°C and has excellent pH and heat stability in food processing. The relative sweetness is around 40–50, compared to sucrose. In taste, mannitol compares more to dextrose in sweetness profile. Today's main application range is in chewing gums and sugar-free candies. From a food technologist viewpoint the following properties of mannitol are important:

- The caloric value for mannitol is 2.4 kcal/g for the EU, 1.6 cal/g in the United States, and 2.0 kcal/g for Japan
- The solubility in water is low, just 20% at ambient. Due to the low solubility there is no cooling effect in the mouth
- The stability in baking is very good, and there is no browning (Maillard reaction plus caramelization)
- Mannitol is nonfermentable and therefore noncariogenic (tooth-friendly)
- Mannitol has zero glycemic response and is well suited for developing wafers and waffles being low in GI and in carbohydrates; it is suitable for diabetics as well
- However, mannitol is highly laxative with a tolerance in the range of just 10–20 g/day. If the content in laxative polyols in a food is 10% or higher, a warning label is required in the EU. In the United States products with foreseeable higher consumption of sorbitol have to carry the warning label that excess consumption can cause a laxative effect

Lactitol (E 966)

Lactitol industrially is easily accessible by hydrogenation from lactose. The WHO JEFCA in 1983 did not specify an ADI limit for lactitol. It is considered GRAS in the United States and is approved in the EU, food additive number E 966, and many other countries.

Lactitol is a white, nonhygroscopic, crystalline powder and is available either as monohydrate or in anhydrous form. But there is a dihydrate form existing as well. It has excellent pH and heat stability in food processing. The relative sweetness is 30–40. When it comes to taste, lactitol compares well to sucrose in sweetness character. The application range therefore is from drinks and dairy products to confectionery and bakery products. Lactitol in Europe has the food additive number E 966. From a technological viewpoint the following properties of lactitol are of interest:

- The caloric value for lactitol is 2.0 kcal/g in the United States and Japan, and it is 2.4 kcal/g in the EU
- The solubility of lactitol in water is high—58% for the monohydrate at ambient
- Anhydrous lactitol has a low cooling effect when dissolving in the mouth, similar to sucrose, while the mono- and dehydrates are medium in cooling
- The stability in baking is very good. There is no browning (Maillard reaction plus caramelization). The low hygroscopicity increases the crispness and reduces the softness of bakery products
- The glycemic response of lactitol, the GI is 6, is very low. Lactitol is well suited for developing wafers and waffles being low in GI and in carbohydrates, and it is suitable for diabetics. It has some prebiotic properties
- Lactitol is nonfermentable and therefore noncariogenic (tooth-friendly)
- For sugar replacement applications in chocolate enrobings, anhydrous lactitol is well suited due to its good conching properties and the low cooling effect, but some sweetness compensation by HISs is required
- Lactitol is a good laxative from about 20 g as a single dose or 20 to 50 g/day and has some limitations in general bulk sugar replacement. In the United States products with foreseeable higher consumption have to carry a warning label that excess consumption can cause a laxative effect. Within the EU if the polyol content of a product is 10% or higher, a similar warning label is required.

Maltitol and Maltitol Syrups (E 965)

Crystalline Maltitol Maltitol industrially is easily accessible by hydrogenation from maltose. The WHO JEFCA in 1993 did not specify an ADI limit for maltitol. Maltitol is considered GRAS in United States, in the EU—with food additive number E 965—and in many other countries worldwide.

Maltitol is a white, nonhygroscopic, crystalline powder with a maltitol content of 98% or more. It melts at about 148°C (298°F) and has excellent pH and heat stability in food processing. The relative sweetness is from 80% to 90% of that of sucrose. Maltitol compares well to sucrose in its sweetness profile. The application range therefore is from drinks and dairy products to confectionery and bakery products. From a food technologist viewpoint the following properties of crystalline maltitol are of interest:

- In bulk sugar replacement isomalt has a caloric value of 2.1 kcal/g (United States); in the EU it is 2.4 kcal/g, and for Japan it is 2.0 kcal/g, compared to 4.0 for sucrose. It offers some sweetness reduction if not combined with HISs
- The solubility in water at ambient is 58%, not much lower than for sucrose
- The stability in baking is very good, and there is no browning (Maillard reaction plus caramelization)

- Maltitol has a low glycemic response, the GI is 36 compared to 68 for sucrose. It is suited for developing wafers and waffles being low in GI and in carbohydrates, and it is suitable for diabetics as well
- Maltitol is orally nonfermentable and therefore noncariogenic (tooth-friendly)
- For sugar replacement applications in creams and enrobings, maltitol offers a good sweetness as a sole substitute and a low moisture content
- However, maltitol has some limitations in general bulk sugar replacement because there is some laxative action from about 20 g as a single dose or 30 to 50 g per day. In the United States products with foreseeable higher consumption have to carry a warning label that excess consumption can cause a laxative effect. Within the EU if the polyol content of a product is 10 or higher, a similar warning label is required

Maltitol Syrups (Lycasin, Maltilite) Maltitol syrups industrially are easily accessible by hydrogenation from high-maltose glucose syrups. The maltitol content has to be higher than 50%, based on dry matter. Further components are sorbitol and higher hydrogenated oligosaccharides. Maltitol syrups in Europe carry the same food additive number E 965 as the crystalline maltitol. The technological properties are quite similar to crystalline maltitol with just a few shifts:

- The relative sweetness is at 60%–80%, compared to sucrose
- The caloric value for maltitol syrup is 3.0 kcal/g (United States), 2.4 kcal/g in the EU and 2.3–3.4 kcal/g for Japan
- Depending on the content of higher hydrogenated oligosaccharides the suitability for diabetics may be reduced. The GI proportionally increases from 36 for crystalline maltitol up to about 53
- The hygroscopic properties are higher than that for crystalline maltitol
- Small additions of maltitol syrup will reduce in other polyol syrups, such as sorbitol or xylitol, the tendency to crystallize

Polyglycitol Syrup (E 964, HSH) HSH is easily accessible by hydrogenation from glucose syrups. The name polyglycitol or HSH is used if there is no dominant polyol such as maltitol or sorbitol in the mixture. HSH contains some sorbitol (from glucose), maltitol (from maltose), maltotritol (from maltotriose) and so on. The WHO JEFCA in 1998 did not specify an ADI limit for HSH syrups due to its similarity to maltitol syrups. HSH is considered GRAS in the United States, and in the EU it has been recognized by the food additive number E 964 since 2012.

The sweetness of polyglycitol syrups is 20–50, compared to 100 for sucrose; this is higher than it is for the originating glucose syrup due to the maltitol content. From a food technologist viewpoint the following properties of HSH syrups are of interest:

- The caloric value for HSH syrup is 3.0 kcal/g for the United States, 2.4 kcal/g for the EU, and 2.3–3.4 kcal/g for Japan

- The solubility in water is high, and the dry matter of the viscous syrups is 70% or more; there are also some humectant properties
- The stability in baking is very good, and there is no browning (Maillard reaction plus caramelization)
- HSH is not fermentable; therefore it is low cariogenic and increasingly applied in sugar-free products
- The glycemic index for HSH is 39, which is low compared to 68 for sucrose
- Small additions of HSH syrups reduce the crystallization tendency in other polyols syrups such as sorbitol or xylitol syrups

Glycerol (Glycerin, E 422) Glycerol is a 10% byproduct in the transesterification of vegetable oils ('biodiesel'). The WHO JEFCA in 1976 did not specify an ADI for glycerol. Glycerol is considered GRAS in the United States, and it is approved in the EU and in many other countries. Glycerol is a colourless, odourless, viscous liquid polyol, freely miscible with water. It melts at 18°C, and the boiling point is 290°C. It has excellent pH and heat stability in food processing. The relative sweetness is 55–70. However, the sweetness profile is not very favourable because it has a strong burning character and a short duration of the sweetness impact. The application range is in confectionery and bakery products.

From a food technologist viewpoint the following properties of glycerol are of interest:

- The caloric value of 4.3 kcal/g is slightly higher than for sucrose
- Glycerol is an excellent humectant and plasticizer in waffles and other baked foods. Glycerol imparts a low water activity for milk caramel (toffee) and fruit fillings; it is suitable even for crisp wafers. In icings and candies glycerol is applied for preventing hardening and crystallization
- It is important to define the moisture content. 99% glycerol is clearly preferable over higher moisture qualities
- The reactive stability in baking is very good. There is no browning (Maillard reaction plus caramelization), but steam distillation will occur
- The glycemic response of glycerin, the GI is 5, is very low. It is well suited for developing wafers and waffles being low in GI and in carbohydrates, and it is suitable for diabetics
- Glycerol is nonfermentable and therefore noncariogenic (tooth-friendly)
- It is used as a solvent for flavours, colours and other additives
- Glycerol, contrary to other sugar alcohols, has a high digestive tolerance and is not laxative. No polyol laxative warning labels are required.
- The sweetness character of glycerol is slightly sharp and less pleasant

3.1.7.3 Nonpolyol Bulk Replacers of Sucrose

The still increasing commercial importance of 'sugar free' sparked considerable interest in bulk replacers for sugar. We find sugar substitutes in the group of oligo- and polysaccharides, which provide many of the important technological properties wanted, such as the following:

1. They are water soluble during eating
2. There is no excessive buildup of viscosity, which would result in sticky impressions
3. An additional feature in a time of frequent overconsumption in calories is a lower or zero energy content due to limited digestion or differences in excretion, possibly with some prebiotic properties
4. They provide volume and texture similar to sucrose

Most of the classical polysaccharide fibres such as celluloses, hemicelluloses, pectins and gums cannot fulfil these conditions sufficiently. But more groups of materials being of high interest in sucrose substitution have been discussed extensively in Chapter 2, Section 2.4.5 of this book:

Resistant starches (RS)—cf. Table 2.51
Resistant maltodextrins such as ‘Nutriose’, ‘Fibersol’ or ‘Promitor’
Alpha-Cyclodextrin
Inulins
Fructose-Oligosaccharides (FOS, Oligofructose)
Polydextrose (Litesse, Sta-Lite, Trimcal, E 1200)

3.1.8 High-Intensity Sweeteners

3.1.8.1 Introduction

High-intensity or nonnutritive sweeteners, many of them of artificial origin, are applied for different reasons:

- To substitute sugar calories for weight loss reasons without missing sweet foods. Due to the sweetness potency of HISs the caloric contribution, if any—such as in protein- or glycoside-based HISs—is negligible. Nonnutritive sweeteners contribute less than 2% of the calories of sugar for equal sweetness
- To reduce the consumption of high-glycemic food such as with followers of ‘low-carb’ nutrition schemes or diabetics
- In dental care, the erosion of enamel by acids converted by adhering bacteria from sugars is reduced
- Combinations of sweeteners including HIS at certain sweetness levels offer synergistic sweetness increases or they are applied to mask some off-taste of single HISs
- HIS offer a cost reduction for equal sweetness and are regulated as food additives

From different consumer groups some HISs are questioned with respect to safety despite the thorough admission procedures of the food authorities. Application of those in new product development therefore should be considered carefully.

In The EU acesulfame K, aspartame, salt of aspartame–acesulfame, cyclamates, saccharin, sucralose, thaumatin, neohesperidine DC, steviol glycosides, neotame and advantame are the currently permitted HISs.

In the United States the HISs saccharin, aspartame, acesulfame potassium (Ace-K), sucralose, neotame and advantame are FDA-approved food additives; for steviol glycosides and Luo han guo (monk fruit) GRAS notices exist. Cyclamates are not permitted anymore in the United States.

3.1.8.2 Acesulfame K (E 950, Sunett, Sweet One, Sweet and Safe)

Acesulfame K, the potassium salt of acesulfame, is prepared by chemical synthesis and is one of the newer 'universal' HISs. The WHO JEFCA in 1991 set an ADI for acesulfame K of 0–15 mg/kg BW/day. It is approved in many countries worldwide for a wide range of applications. In the EU for acesulfame K the maximum permitted dosage is 2000 mg/kg in cornets and wafers, for ice cream with no added sugar, and in sweetened wafer paper ('essoblaten'). The maximum dosage per day is1000 mg/kg in 'fine bakery products' for specific nutritional uses. In other areas of the world such as the Americas and Asia fewer or no such specific limitations are in place. However, please check your actual local food regulation.

Acesulfame K is a white, nonhygroscopic, crystalline powder with a high solubility in water (220 g/L at 25°C). There is also quite some solubility in sugar syrups, polyol syrups, and in ethanol/water mixtures. It melts at temperatures over 200°C (decomposition) and has excellent pH and heat stability in food processing. The application range therefore is from drinks and dairy products to confectionery and bakery products. From a food technologist viewpoint the following properties of acesulfame K are important:

- The typical acesulfame K application range in bakery products is around 0.1% (1000 mg/kg). The relative sweetness in such foods is around 130 times sweeter than sucrose
- The stability in baking is very good. It shows no browning reactions, which is important for perfectly white sweet wafer paper (oblaten)
- In sugar replacement it offers sweetness in combination with less sweet sugar bulk replacers, as most of the polyols are. In the sweetness profile, the acesulfame K sweetness occurs faster than the late polyol sweetness, which combines favourably. Acesulfame K sweetness has a similar duration as sucrose, but there is a slightly bitter aftertaste
- Significant synergistic sweetness and taste profile effects with aspartame, cyclamate and sucralose are found; but it is little to none for sucrose or saccharine

3.1.8.3 Aspartame (E 951, Nutrasweet, Equal) and Alitame

Aspartame is the methyl ester of the dipeptide of the natural amino acids L-aspartic acid and L-phenylalanine. The WHO JEFCA in 1981 set an ADI for aspartame of 0–40 mg/kg BW/day. FDA has set an ADI of 0–50 mg/kg BW/day.

It is approved in many countries worldwide for a wide range of applications. In the EU for aspartame there is a maximum usable dose of 1000 mg/kg in essoblaten, and the maximum is1700 mg/kg in 'fine bakery products' for specific nutritional uses. In other areas of the world such as the Americas and Asia, fewer or no such specific limitations are in place. However, please check your actual local food regulation. There is an obligatory statement to protect those with PKU: 'Contains a source of phenylalanine'.

Aspartame is a white, hygroscopic, crystalline powder with solubility in water of ~1% at 25°C. It decomposes before melting. The stability is best around pH 4.3; at nonacidic conditions it is poor. The application range therefore is mainly in drinks, dairy products and confectionery. From a food technologist viewpoint the following properties of aspartame are important:

- The stability in baking is just fair. Like many other peptides, aspartame hydrolyses into its constituent amino acids under conditions of elevated temperature or higher pH value and undergoes Maillard reactions. Aspartame therefore is undesirable as a baking sweetener
- In sugar replacement for nonheat applications such as creams, it offers sweetness in combination with less sweet sugar bulk replacers as most of the polyols are. The relative sweetness in such foods is around 130 times sweeter than sucrose
- In the sweetness profile aspartame's core sweetness is similar to sucrose, but there is a longer lasting, lingering sweet aftertaste. To some people aspartame creates an odd taste note, and many describe it as a watery aftertaste
- There are significant synergistic sweetness and taste profile effects with acesulfame K, saccharine, cyclamate, steviosides, sucrose (acid pH), glucose, fructose and polyols but not for sucralose
- While aspartame, like other peptides, has a caloric value of 4 kcal (17 kJ) per gram, the about 0.1% of aspartame required for a sweet taste is so small that its caloric contribution into the final product is negligible

The artificial sweetener aspartame has been the subject of public controversy regarding its safety and the circumstances around its approval. The European Commission in 2002 issued an 'update on the safety of aspartame': http://ec.europa.eu/food/fs/sc/scf/out155_en.pdf. It was reconfirmed by the European food safety agency EFSA in 2013: www.efsa.europa.eu/en/efsajournal/pub/3504.

Alitame

Alitame is a further development after the introduction of aspartame. The WHO JEFCA in 1996 set an ADI for alitame of 0–1 mg/kg BW/day. Products made with alitame require a special labelling for PKU.

Alitame is a white to off-white powder, and the solubility in water is over 10%. Alitame has a sweet taste like sugar, with a bitter side-taste. The relative sweetness is about 2000. It is not sufficiently stable for most cooking and baking applications. There is no approval in the United States, Canada, the EU and Japan.

3.1.8.4 Aspartame–Acesulfame K Salt (E 962, Twinsweet)

The salt is prepared by heating a 2:1 mixture of aspartame and acesulfame K in solution at acidic pH. The salt is a white, crystalline, nonhygroscopic powder of higher stability than aspartame alone. It decomposes before melting, has a solubility in water of 2.75% at ambient, and is soluble in ethanol. The application range therefore is from drinks and dairy products to confectionery and bakery products.

The WHO JEFCA set an ADI for aspartame of 0–40 mg/kg BW/day in 1981 and an ADI for acesulfame K of 0–15 mg/kg BW/day in 1990, which covers both of the parts of the salt. In the European Union for the salt E 962 there is a maximum usable dose of 1000 mg/kg in 'essoblaten' and in 'fine bakery products' for specific nutritional uses. In other areas of the world such as the Americas and Asia there are fewer to no specific limitations in place. However, please check your actual local food regulation. There is an obligatory statement for people with PKU: contains a source of phenylalanine

From a food technologist viewpoint the following properties of aspartame–acesulfame salt are of interest:

- In sugar replacement it offers sweetness in combination with less sweet sugar bulk replacers as most of the polyols. The relative sweetness at higher sweetness levels is around 200 times sweeter than sucrose
- The stability in baking is fair to good. The aspartame part is the less stable one with some potential for Maillard browning reactions. Therefore we consider it not as a primary candidate for sucrose replacement in bakery products
- In the sweetness profile that blend of aspartame with acesulfame tastes more similar to sugar than the single components. Due to sweetness synergies, the salt is about 50% sweeter than the single components

3.1.8.5 Sucralose (E 955, Splenda, SucraPlus)

Sucralose is prepared by chemical derivatization of sucrose. The WHO JEFCA in 1990 set an ADI for sucralose of 0–15 mg/kg BW/day. Since then it has been approved in many countries worldwide for a wide range of applications. In the EU for sucralose there is a maximum usable dose of 800 mg/kg in cornets and wafers for ice cream with no added sugar and for essoblaten. The limit is 700 mg/kg in 'fine bakery products'. In other areas of the world such as the Americas and Asia few to no specific limitations are in place. However, please check your actual local food regulation.

Sucralose is a white, nonhygroscopic, crystalline powder with a solubility of 282 g/l at 20°C in water. It is insoluble in oils. The melting point is 125°C, and the stability regarding pH and heat in food processing is good. The application range therefore is from drinks and dairy products to confectionery and bakery products. From a food technologist viewpoint the following properties of sucralose are important:

- Sucralose offers sweetness in combination with less sweet sugar bulk replacers as most of the polyols. The typical sucralose application range in bakery products is just

0.01%–0.035% (100–350 mg/kg). The relative sweetness in such foods is around 400 times sweeter than sucrose

- The stability in baking is good. Be aware of any undissolved sucralose such as in doughs in order to avoid darker spots of Maillard reaction products
- In the sweetness profile sucralose compares well with sucrose with the exception of a somewhat longer duration of the sweetness impact. There is no bitter or metallic aftertaste
- Some synergistic sweetness effects with fructose (Table 3.28), acesulfame K, saccharine and cyclamate were found, but not with sucrose or aspartame

3.1.8.6 Saccharine and Its Sodium, Potassium and Calcium Salts (E 954)

Saccharine is prepared by chemical synthesis and is the oldest of the universal HISs. The WHO JEFCA in 1993 set an ADI for saccharine of 0–5 mg/kg BW/day. It is approved in many countries worldwide for a wide range of applications. In the EU for saccharine there is a maximum usable dose of 800 mg/kg in cornets and wafers with no added sugar for ice cream, as well as in essoblaten; and the maximum is 170 mg/kg in 'fine bakery products'. In other areas of the world such as the Americas and Asia, less or no such specific limitations are in place. However, please check your actual local food regulation.

Saccharine and its salts are white, crystalline powders. The solubility in water at ambient is as follows:

Type of Saccharine	g/100 g Solution
Saccharine, acid form	0.2
Saccharine, sodium salt	100
Saccharine, calcium salt	37

The stability of saccharine in the neutral range of pH and the heat stability in food processing are good. The application range therefore is from drinks and dairy products

Table 3.28 Sweetness Synergy of Fructose and Sucralose (Splenda)

	Fructose		Sucralose
Sweetness in % From Fructose/Sucralose	g/100 g	% relative	mg/100 g
100/0	8.54	100	0
75/25	5.49	64	4.64
67/33	4.82	56	6.02
50/50	3.27	38	8.30
33/67	2.35	28	12.10
25/75	1.74	20	13.25

Data from Nelson, A.L., 2000. Sweeteners: Alternative. In: Eagan Press Handbook Series. Eagan Press, 100 pp, ISBN 9781891127113.

to confectionery and bakery products. From a food technologists viewpoint the following properties of saccharine are important:

- The maximum sweetness level achievable by saccharine is equivalent to 10% sucrose sweetness. The relative sweetness at higher sweetness levels is up to 300 times sweeter than sucrose
- The stability in baking is good. But the main applications are in beverages and tabletop sweeteners. We consider it not as a primary candidate for sucrose replacement in bakery products
- In the sweetness profile there is a well-known bitter and metallic side taste of saccharine. Therefore usually it is used solely in blends with polyols and nonnutritive sweeteners, preferably with cyclamate and/or aspartame
- Some synergistic sweetness with polyols and other HISs is observed, but not with sugars. But such positive synergistic effects are found just at lower total sweetness levels, up to around 5% sucrose equivalent

3.1.8.7 Cyclamate (E 952)

Cyclamate is the common name for the synthetically prepared sodium or calcium salts of cyclohexlsulfamic acid. It has a comparatively low relative sweetness of ~30, has been used for over 50 years, and most frequently is applied in a 10:1 combination with saccharine for synergistic and flavour masking reasons. The WHO JEFCA in 1982 set an ADI for cyclamate of 0–11 mg/kg BW/day, expressed as cyclohexlsulfamic acid. It is approved in many countries worldwide for a wide range of applications. In the EU for cyclamate, EC No. E 952, there is a maximum usable dose of 1600 mg/kg in 'fine bakery products' for special nutritional uses. In other areas of the world such as the Americas and Asia less or no such specific limitations are in place—please check your actual local regulation.

The cyclamate salts are white, crystalline powders with the following water solubility at ambient:

Cyclamate Form	Gram/litre
Cyclamic acid	133
Cyclamate, sodium salt	200
Cyclamate, calcium salt	250

Cyclamate salts have a perfectly neutral pH and some heat stability in food processing. The main application is in combination with saccharine for drinks and tabletop sweeteners. From a food technological viewpoint the following properties of cyclamate are important:

- Cyclamate has positive synergistic sweetness effects with most other HISs, polyols and sugars with a maximum effect at lower total sweetness levels (around 5% sucrose equivalent). The strongest synergy is with acesulfame and stevioside
- The relative sweetness is up to 30 times sweeter than sucrose. Therefore it is applied solely in combination. Main applications are in beverages and tabletop sweeteners. It is not a primary candidate for sucrose replacement in bakery products
- In the sweetness profile there are some bitter and salty side tastes of cyclamate, which are masked quite well in the usual blends with saccharine, acesulfame K or aspartame

3.1.8.8 Steviol Glycosides (E 960, Stevia, Rebiana, Truvia, PureVia)

The product is obtained by water extraction and concentration from the leaves of Stevia rebaudiana Bertoni. The active substance is a mixture of several steviol glycosides with the main glycosides stevioside and rebaudioside A. The WHO JEFCA in 2008 set an ADI of 0–4 mg/kg BW/day, expressed as steviol. In the EU steviol glycosides have been approved since 2011 for limited applications. There is a maximum usable dose of 330 mg/kg in essoblaten. In Japan and other Asian countries as well as in some South American countries it has been permitted for a longer time. Typical uses are Asian foodstuffs such as sauces and pickles, refreshing drinks, tabletop sweeteners and sweets. In the United States rebaudioside A-based natural sweeteners obtained a GRAS approval in 2008.

Stevia is a white to light powder, having no less than 95% of the total of seven named steviol glycosides. The powder is freely soluble in water and insoluble in oils. The stability regarding pH and heat in food processing is good. The application range therefore is from drinks, dairy products and tabletop sweeteners to confectionery and bakery products. From a food technologist viewpoint the following properties of stevia are important:

- The relative sweetness of stevia is around 200 times sweeter than sucrose
- The stability in baking is good
- In the sweetness profile there are some licorice-type bitter and flavour-modifying side tastes and a longer duration of the sweetness impact

3.1.8.9 Neohesperidine Dihydrochalcon (NHDC, Hesperetine, E 959)

The product is obtained by chemical synthesis or modification of citrus flavanones. The water solubility at ambient is 0.45 g/l. NHDC is a white powder. The taste characteristics are a slow onset of sweetness; sweet lingering aftertaste; and slightly bitter, cooling and licorice notes. It has flavour-modifying/enhancing effects.

The EU SCF in 1988 set an ADI of 0–5 mg/kg BW/day. In the EU it has been approved as a sweetener since 1994, and for the United States at present there is no approval or GRAS listing. However, it is approved in Australia and New Zealand. In the EU for NHDC there is a maximum usable dose of 50 mg/kg in cornets and wafers and for ice cream with no added sugar. There is a maximum of 150 mg/kg in ‘fine bakery products’ for special nutritional uses.

- The typical application range is around 10–20 mg/kg as a sweetener, and a few ppm as a flavour modifier to improve the mouthfeel and creaminess. The relative sweetness is around 350–500 times sweeter than sucrose
- It does not promote tooth decay and is suitable for diabetics
- Significant synergistic sweetness and taste profile effects with acesulfame K, aspartame, saccharin, cyclamate, sucralose and polyols are found

3.1.8.10 Thaumatin (E 957, Talin)

Thaumatin is a mixture of intensely sweet proteins (thaumatin I and II), extracted with water from the arils of the fruit of *Thaumatococcus daniellii* together with minor amounts of plant constituents. It is an odourless, cream-coloured powder and functions primarily as a flavour enhancer and as a HIS. The taste characteristics are the slow onset of sweetness and a sweet aftertaste. It is soluble in water.

Thaumatin is nontoxic and makes an insignificant contribution to the normal protein intake. Therefore the WHO JEFCA in 1985 specified it to have no ADI. Thaumatin is about 2000 times sweeter than sucrose. Thaumatin is an approved sweetener in the EU for limited uses; currently there is no EU approval for bakery applications. It has a GRAS listing in the United States.

3.1.8.11 Neotame (E 961, Newtame)

Neotame is a derivate of aspartame. The WHO JEFCA in 2004 set an ADI for neotame of 0–2 mg/kg BW/day. FDA-approved neotame in 2002, and the EU approved it in 2010. Products made with neotame require no special warning label for PKU. Neotame is a white to off-white powder, and the solubility in water at ambient is 13 g/l; in ethanol it is easily soluble. Neotame has a sweet taste like sugar, with some licorice aftertaste.

- The relative sweetness is up to 8000, compared to sucrose
- Neotame enhances or extends the sweetening and flavouring properties of some flavours, especially mint
- Neotame due to its stability may be used in both cooking and baking applications

3.1.8.12 Advantame (E 969)

Advantame is an N-substituted derivative of the sweetener aspartame, a phenylalanine derivate. The WHO JEFCA in 2013 set an ADI for advantame of 0–5 mg/kg BW/day. In 2014 the US FDA rated advantame to be safe as a general-purpose sweetener and flavour enhancer in food. In the EU it has been an approved sweetener since 2014.

Advantame is a free flowing, water soluble, white to yellowish crystalline powder that is stable even at higher temperatures, and it can be used as a tabletop sweetener as well as in cooking applications.

- It is about 6500 times sweetener than sucrose and 50 times sweetener than aspartame
- The taste is similar to aspartame but with a slightly enlarged duration. It enhances flavours such as dairy, fruit, citrus or mint

3.1.8.13 Pscicose (Allulose)

D-psicose, a rare sugar in nature, is manufactured from fructose by enzymatic epimerization and was first introduced in Japan. There are recent GRAS notifications from the FDA. Currently (2016) there is no approval in the European Union (Astraea™ Allulose, 2015).

Allulose is a white, free-flowing crystalline powder, and the melting point is 109°C. It is available as 70% syrup as well. Many technological properties are close to fructose. The commercialization of allulose is just in the beginning. There is not yet wide experience in the industrial application of allulose. From a food technologist viewpoint the following properties are of interest:

- The relative sweetness, compared to sucrose is 70. The taste is clean-sweet
- Allose, due to its high hygroscopicity, is an efficient humectant. However there is no general application at present and data for waffles does not yet exist
- The browning intensity (Maillard reaction plus caramelization) in baking is high
- The glycemic index is supposed to be very low or zero
- The caloric value of allose is 0.2 kcal/g. It is not metabolized and is excreted, similar to erythritol

3.1.8.14 Luo Han Guo (Monk Fruit, Mogrosides, PureLo, Fruit Sweetness)

Mogrosides are triterpene glycosides extracted from the sweet fruit Siraitia grosvenori (monk fruit, a pumpkin type), which is a traditional sweetener in Southeast Asia. Mogroside V is the main glucoside. The fruits and extracts are foods in China and Japan. In the United States there is a GRAS listing. No sweetener approval in the European Union exists as of 2016.

- A concentrated mogroside extract, a creamy white water-soluble powder, is about 150 times sweeter than sugar with some licorice and cooling aftertaste

3.2 TECHNOLOGY OF OILS AND FATS FOR WAFERS AND WAFFLES

3.2.1 Introduction

3.2.1.1 Oils and Fats in Wafer and Waffle Manufacturing

The technology of oil and fat ingredients, their right handling, and potential technological and nutritional issues require extensive discussion. Oils and fats are ingredients of high importance in manufacturing wafers, waffles, as well as in adjuncts such as fillings and enrobings in order to obtain products of good shelf life and eating quality, even if they are not always a main component. Wafer sheets and wafer cones contain only small quantities of oils and fats, a few percent for providing a good mould release. Here their quality and quantity determine both the ease of production and the storage stability of the final wafer products. To the contrary, filling creams as well as enrobings typically will be in the range of 30%–38% in terms of fat content. In wafer-filling creams fats provide the adhesion to the wafers, act as a flavour carrier, and finally result in a smooth, creamy eating texture.

To understand the reasons for any issues, we will start with theoretical information on the structure, the composition, and the reactivity of oils and fats. The first section highlights the chemistry and physics of fat and oils with a specific emphasis on properties of importance for wafers and waffles. In the second part the technological functions of oils and fats in wafers, waffles, fillings and enrobings are discussed in detail.

Oils are fluid at ambient temperature while fats are solid. Table 3.29 concentrates on the most important sources of oils/fats for our subject. In the table the recommended oils and fats for wafer baking are in italic letters. Most critical here are the polyunsaturated fatty acids C18:3 and C18:2. The data of Table 3.29 reflect average values of traditional oil/fat compositions. However, today oils from genetically modified plant sources are available such as high oleic varieties of soybean oil or sunflower seed oil. Their lower degree of polyunsaturation increases the thermal and oxidative stability.

Table 3.29 Native Oils and Fats—The Content in Important Fatty Acids

Source—Fatty Acids	<C12:0	C12:0 +14:0	C16:0 +18:0	C18:1	C18:2	C18:3	Iodine value
Coconut oil (lauric)	14.5	65	11	7	1.5		6–11
Babassu oil (lauric)	11.5	61	11	14	2.5		13–17
Palm kernel oil (lauric)	8	62	10	16	2.5		14–21
Butter fat (nonvegetable)	9	14	39	29	3	0.5	25–42
Cocoa butter			62	33	3		34–40
Lard (nonvegetable)		1.5	40	44	9.5	0.5	48–65
Palm fat		1.3	48	40	10	0.2	50–55
Palm olein		1.3	44	43	11	0.2	56–60
Olive oil			15.5	71	11	0.5	75–94
Peanut oil			12.4	43	36	0.3	86–107
Sesame oil			13	43	43		104–120
Cottonseed oil		0.7	25	17.5	55	0.3	100–115
Maize oil (corn)			13	29	56	1	107–135
Canola oil (Low erucic rapeseed)			5.5	60	20	11	105–126
Sunflower oil			9.5	25	64	0.3	118–141
Safflower oil			6.5	15	77		135–148
Soybean oil			14	23	54	7.5	124–139

Most recommended oils and fats for wafer baking are in italic letters.

Data from Bockisch, M., 1998. Fats and Oils Handbook. AOCS Press, Published by Elsevier, 848 pp, ISBN 9780981893600; ISEO 2016 and other sources, modified.

For waffles the fat content is an important part in waffle release, texture and taste. In chocolate enrobings, the fat quality is essential for a rapid and good hardening as well as a stable, glossy and nonchanging surface look.

3.2.2 Structure and Origin of Edible Oils and Fats

3.2.2.1 Fatty Acids and Triglycerides: Structure, Stability and Melting Range

Chemically speaking, fats are mixtures of triglyceride molecules where each molecule is composed from glycerol and three fatty acids. The most abundant and important fatty acids in natural oils and fats are listed in Table 3.30, together with their chain length and their number of unsaturated bonds. These properties govern the melting behaviour and the stability of the corresponding triglycerides, both in baking and product storage.

Saturated fatty acids, without any double bonds of higher reactivity, are found primarily in coconut oils, palm kernel oils, palm fat and animal fats such as from butter, pork or beef. Monounsaturated fatty acids with one double bond are abundant in canola oil, high oleic sunflower oil and olive oil.

Trans fatty acids are monounsaturated too but with a different configuration, formed during the process of 'partial hydrogenation' of polyunsaturated oils. Find more about trans fats in Section 3.2.7.1. Hydrogenation turns liquid oil into a semisolid form, such as in shortening or margarine, and improves the shelf life and processability.

Polyunsaturated fatty acids with two or more double bonds are most common in sunflower, corn, soybean and fish oils. The more double bonds there are in a fatty acid, the more that both the thermal instability and the tendency for oxidation (rancidity) increase.

Natural fats are mixtures of triglycerides, which have either one, two or three different fatty acids. Their melting temperature is governed by their content of main fatty acids. It decreases with both a shorter chain length and a higher number of double bonds of its fatty acids. Table 3.31 provides the melting points of uniform triglycerides in their stable

Table 3.30 Main Fatty Acids in Edible Oils and Fats

Fatty Acid	Chain Length: Double Bonds	Main Sources
Lauric acid	C12:0	Coconut, Palm kernel, Babassu
Palmitic acid	C16:0	Palm, Lard, Butter, Cocoa butter, Beef tallow, Cottonseed
Stearic acid	C18:0	Cocoa butter, Beef tallow, Lard, Butter
Oleic acid	C18:1	Olive, Canola, Peanut; Sesame
Linoleic acid	C18:2	Safflower, Sunflower, Corn, Cottonseed, Soy
Linolenic acid	C18:3	Linseed, Canola, Soybean

Table 3.31 Melting Points of Triglycerides

Fatty Acid Triglyceride	Melting Point (°C)
Stearic acid (C18:0) triglyceride	+73.5
Lauric acid (C12:0) triglyceride	+46.5
Oleic acid (C18:1) triglyceride	+5
Linolenic acid (C18:3) triglyceride	−18

crystal form to demonstrate the range. In cases of big structural variability, additional softening effects apply.

Lauric Fats

The common term 'lauric' fats comes from the fact that coconut and palm kernel fats from various species of the oil palm are high in the shorter chain lauric acid C12. Lauric fats typically contain 40%–50% lauric acid in combination with smaller amounts of myristic acid C14, compared to the nonlauric C18 oils and fats. Characteristic for lauric fats is the high solid fat index at lower temperatures, which means they are hard, quickly solidifying fats exhibiting a cool melting sensation.

Origin and Manufacturing of Edible Oils and Fats

On a worldwide basis the 2006 production data of the most important edible oils and fats (Belitz et al., 2009) were the following:

Vegetable fats (over 70% of world production) in million tonnes, rounded

Palm oil: 37; soybean: 35; canola: 18; sunflower: 11; cottonseed: 5; peanut: 4; palm kernel: 4; coconut: 3

Animal fats

$$\text{Beef tallow, edible} > \text{Butter fat} > \text{Lard} > \text{Marine oils}$$

From the raw materials in several steps—pressing, extraction or dripping—followed by bleaching and deodorizing (refining), edible oils and fats that are neutral in odour and taste are obtained. Physical methods such as fractionation into solid or liquid parts may be applied as well.

3.2.2.2 Methods of Fat Technology

There are a lot of possibilities modern fat technology is offering to obtain fat properties for specific applications.

Partial Hydrogenation/Hardening of Oils

Partial hydrogenation of oils (PHO) is a chemical modification by adding hydrogen with the help of catalysts to (poly)unsaturated fatty acids of the triglycerides. The process of hydrogenation is performed under high temperature and pressure in the presence of a metal catalyst, such as nickel. It transforms oils to more stable and less fluid fats (shortenings), suitable for cream preparation. The oxidative stability increases alongside the modification of its physical and functional properties. Hydrogenation results in higher melting points, higher solid fat contents, and a longer shelf life. PHO is used less today because of the inevitable formation of trans-fatty acids (TFA) in the process. See Section 3.2.7.1 for a detailed discussion on trans fats.

Fractionation

This is a controlled crystallization and separation technique involving the use of approved solvents, detergents, or simply cold dry pressing or filtration to separate hard and soft fractions of an oil–fat mixture after holding it at a specific temperature. This occurs so that it is partially liquid and partially solid. The solid fraction may be used as a trans fat-free alternative to a PHO or in the production of 'winterized' oils, high-stability frying oils and cocoa butter alternative (CBA) fats.

Interesterification

By chemical exchange reactions with the aid of a catalyst, the fatty acids in the triglycerides with respect to the 1, 2 and 3 positions of the glycerol molecule can be rearranged randomly. By such modifications, oils are processed into stable fats with optionally adjustable properties such as soft/hardness, plasticity, melting behaviour or oxidative stability.

Interesterification of, for example, a fully hydrogenated fat with a native, more unsaturated oil results in a mix of triglycerides that have a final melting profile tailored to a specific application such as for wafer creams. However, it does not contain trans fats such as in partially hydrogenated oils. Interesterification with a natural, nonhydrogenated hard fat such as palm stearin, obtained from fractionation avoids the 'hydrogenated' labelling. The process changes the physical properties of a fat but the degree of unsaturation, compared to the starting oil and fat, does not change.

3.2.3 Changes in the Crystal Form of Fats Cause Well-Known Issues

3.2.3.1 Polymorphic Fats: Crystal Forms and Cream Texture

Polymorphism is the ability to exist in more than one crystalline form. Depending on the cooling conditions, most fats crystallize in one of at least three crystal forms: alpha, beta and beta prime. They are polymorphic. From cocoa butter in real chocolate six polymorphic forms are known. The polymorphic nature determines in part the physical properties of fats such as the melting point and the performance of the fat in a cream, a bakery food or an enrobing.

The polymorphic form with the highest melting point typically is the most stable one and the other forms tend to change into that one. In the order as given below, both the stability of that crystal form and its melting point increase. Either during processing or later during storage there is a strong tendency to change into a more stable, and finally into the most stable, crystalline form.

- α—Alpha is formed when a fat after melting is subjected to a strong cooling. That extremely unstable form rearranges quickly into β′
- β′—Beta prime is formed by just slight undercooling. The typical view in the microscope is of small needles, occurring in clusters which are able to hold much liquid oil phase. This is the preferable crystal form for filling fats (shortenings) with their desired soft and plastic properties
- β—Beta is the most stable form with a platelet-type structure but little oil-holding capacity
- 'Going beta'—Whenever in a fat cream a change from β′ into β crystal structure occurs, the result is a 'sandy' texture and 'oiling out', due to warm storage or fat composition. Table 3.32 provides information on oils/fats with a beta prime or beta crystal habit. 100% soybean- or sunflower oil-based fats, for example, will end up with the β-form. But, if just 5%–7% palm or cottonseed based fats are admixed, the β′-crystal structure will be sufficiently stable, as is required for soft and plastic sugar–fat creams.

For pumpable baking fats for easier handling β-crystals are required in order to keep the fat flowing easily.

Cocoa butter in real chocolate has one of the most complicated melting diagrams with six polymorphic forms. See Talbot (2006) for details that are out of the scope of this book.

3.2.3.2 Eutectic Fat Softening

Whenever fats with rather different triglyceride sizes are combined, although being fully miscible in the liquid state, they are insufficiently compatible after cooling and crystallization. As a consequence, the percentage of solid fat in the mixed fat is lower than what we might expect from the melting properties of the two original fats. That means the

Table 3.32 Crystal Types of the Main Fat Sources

'Beta Prime' Crystal Type Good for Creams	**'Beta' Crystal Type Good for Fluid Fats**
Cottonseed, hydrogenated	Canola, hydrogenated
Palm	Soybean, hydrogenated
Milk fat	Sunflower, hydrogenated
Coconut	Peanut, hydrogenated
Palm kernel	Corn, hydrogenated
Tallow	Cocoa butter
Canola oil, hydrogenated	Lard

Data from ISEO 2016; O'Brien, R.D., 2004. Fats and Oils: Formulating and Processing for Applications, second ed. CRC Press, 574 pp, ISBN 0849315999.

melting temperature is lower and the enrobing is softer than expected. Examples for such eutectic melting point depressions are the following:

a. Hydrogenated vegetable oil, nonlauric, glycerides with C18 fatty acids mainly in combination with lauric coconut or palm kernel fats with C12 containing glycerides primarily

b. Nonhydrogenated palm fat, nonlauric, containing mainly glycerides with C18 fatty acids in combination with lauric coconut or palm kernel fats made of C12 glycerides primarily

c. Cocoa butter, glycerides with C18 fatty acids in combination with butter fat (short glycerides). Therefore milk chocolates are always softer than dark ones

Palm fat, cocoa butter and many hydrogenated vegetable oils contain dominantly C18-fatty acids. Coconut and palm kernel fats are high in the shorter chain lauric acid C12; therefore it has the common name lauric fats. Butter fat as well has a range of short fatty acids, starting with C4 (butyric acid). When it comes to crystallization in mixtures, the preferred crystals of triglycerides with similar chain length cannot form. The mixtures do not crystallize as easily and stay softer, and the solid-to-liquid ratio is smaller.

Crocodile Effect Due to Eutectic Softening: A Real Example

Eutectic fat softening increases the risk for a rare variant of the 'crocodile effect' (Chapter 8), not related to moisture migration but to an incompatibility of the wafer cream fat and the wafer-enrobing fat. The example from a real wafer plant situation illustrates eutectic softening as a rare reason for a crocodile effect in enrobed wafer fingers of 85 mm length:

- Wafer cream fat, data in Table 3.33: a soft fat, hydrogenated vegetable oil, nonlauric with some butter fat from whole milk powder included
- Wafer enrobing fat, data in Table 3.34: a hard cocoa butter substitute, lauric palm kernel fat, additionally some cocoa butter from cocoa powder

The combination of a lauric fat in the enrobing and a nonlauric one in the cream softens the enrobing at the contact points of cream and enrobing. Then cracking easily results in

Table 3.33 Specification of the Wafer Cream Fat, Nonlauric

Parameter	Value
Moisture and volatile impurities (% max.)	0.2
Iodine value (Wijs)	70–77
Slip melting point (°C)	32–34
Solid fat content at	
20°C	28–32
30°C	10–15
35°C	0–5

Contains about 6.1% butter fat additionally; Reduced list of parameters.

Table 3.34 Specification of the Wafer Enrobing Fat, Lauric

Parameter	**Value**
Moisture and volatile impurities (% max.)	0.1
Iodine value (Wijs)	<1
Slip melting point (°C)	33.5–35.5
Solid fat content at	
10°C	96–97
20°C	95–96
25°C	88–90
30°C	48–54
35°C	3–5

Contains about 6.2% cocoa butter from cocoa powder; Reduced list of parameters.

any case of mechanical stress or even just small wafer expansion due to moisture migration.

3.2.3.3 Fat Bloom Issues

Bloom is the appearance of a dull-, dusty- or even mouldy-looking surface in chocolate caused by the formation of either fat crystals (fat bloom) or, less frequently, by sugar crystals (sugar bloom). Consumers frequently confuse that physical defect with the growth of moulds or believe such a product is old. The basic mechanisms for fat bloom are either phase separation or polymorphic transformation effects.

Phase separation—The enrobing fat is a mixture of various triglycerides with different melting temperatures. During warmer storage or fluctuating temperatures the lower melting triglycerides melt. The liquid phase occupies more volume and migrates to the surface through micro pores in the enrobing. With any recooling, the liquid phase recrystallizes and fat bloom occurs.

Polymorphic transformation—As discussed in Section 3.2.3, fats may crystallize in several forms. Bloom here occurs by an uncontrolled polymorphic transformation of cocoa butter from less stable forms (IV or V) to the most stable one, VI. In blooming fat crystals of enrobings the most stable, 'VI', of the six known polymorphs of cocoa butter forms.

Fat bloom in enrobings occurs due to temperature fluctuations with melting/resolidification events or in filled enrobed sweets. Due to migration of oils from ingredients such as nuts, unstable cocoa butter crystals are present. These within days or weeks transform into the stable V crystals, depending on storage temperature. The surface can then look greyish and unsightly.

Correct enrobing with real chocolate ensures that in the final product the stable form of cocoa butter will exist only. In poorly tempered chocolate, form IV will transform to V and eventually form VI, resulting in fat bloom. Even in well-tempered chocolate, elevated and/or fluctuating temperatures during the distribution of the products promote bloom formation. However, it is found that the change into form VI from form V does not always result in bloom.

Fat Bloom Reasons in Compound (Nontempering) Enrobings

1. Incorrect cooling, including overly cold centres
2. The migration of soft or incompatible fats from the covered centres
3. Warm storage conditions and any bigger day/night temperature fluctuations

Fat Bloom Reasons in Real Chocolate (Tempering) Enrobings

1. Insufficient tempering capacity
2. Selection of an incorrect tempering temperature for the actual fat composition
3. The addition of fats incompatible with cocoa butter

Ways to Minimize the Risk for Fat Bloom

- Use compatible fats, both in the centre and the enrobing
- Apply a fat-based barrier coating between the domains differing in fat content and composition such as nuts
- Add a bloom inhibitor such as butter stearin
- Add seeding crystals of the correct crystal form
- Maintain an appropriate product storage temperature to avoid warm/cold cycles

3.2.4 Fat Specifications Reflect Important Properties

3.2.4.1 Fat Specifications, Why and How

A fat specification is important—both for the user and the supplier of a fat to find the same language regarding user-specific properties, ordering and evaluating the fat. A specification may contain just a few or many elements, depending on your requirements and the potential of the fat supplier. Not all parameters listed here are necessary present all the time but they can assist in clarifying issues.

Potential Elements of a Fat Specification

- Food grade; optionally: purely vegetable, halal or kosher
- Type of fat—Soybean oil; cream fat; enrobing fat
- Fat processing—Refined, bleached, deodorized (RBD); hydrogenated; aerated by nitrogen
- Any additives—Emulsifiers, antioxidants, sequestrants, colours, vitamins. Examples: BHA (200 ppm), vitamin E (1000 I.U.), soy lecithin-type xyz (1%)
- Moisture content for fats as well as for margarines
- The intended end-use—wafer baking fat, wafer cream fat, cookie-spraying oil, enrobing fat

- Sensory attributes—neutral in smell and taste, bland, absence of flavour notes such as old, rancid, soapy or tallowy—checked after melting at 40°C
- Slip melting point, alternatively clear melting point
- Solid fat percentage—SFC (NMR) or SFI at temperatures important for processing. Cf. the discussion on melting curves below
- Limit in trans fat content, at least less than 1%
- Analytical data with method of analysis
  - Stability (AOM or Rancimat)
  - Free fatty acids (expressed as oleic acid) or acid value
  - Peroxide value, below 1.0 but preferably below 0.5
  - Iodine value
  - Saponification value
  - Volatile matter
  - Foreign fat level
- Delivery mode—bulk; barrel 200, pallet of 36 cartons/50 pounds each
- Supplier—company, address, name and contact data of a responsible person
- Product code or number—both within suppliers' and users' logistics
- Name of document owner, approver and supervisor for this specification with signatures—according to the actual quality assurance system

3.2.4.2 The Melting Point and the Melting Curve

Melting Point

For fat melting there are two different terms, the slip (melting) point and the clear (melting) point. In practice the slip point is most important because it determines at which temperature the fat becomes fluid. If the clear point is much higher, the fat contains some high-melting triglycerides from fully hydrogenated fats. That can be important for structuring a filling to reduce oil migration.

Melting Curve and Solid Fat Percentage

Commercial fats are mixtures of triglycerides, and each of them has a different melting point. In such a mixture, depending on the actual temperature, just a part of the fat is solid, and the rest is oil. The 'solid fat content' (SFC) describes the percentage of solid fat at a range of temperatures. The SFC is measured by a rapid instrumental NMR method and has substituted widely the 'solid fat index' (SFI), determined by the more tedious dilatation method.

The melting curve characterizes fats in relation to their physical properties, such as hardness and thermal behaviour. The right fat for the climate (winter, summer, tropical) is selected according to the melting curve. From the SFC diagram (melting curve), some examples are in Fig. 3.3, we can see many relevant properties of a fat, desired fat properties and less desired ones:

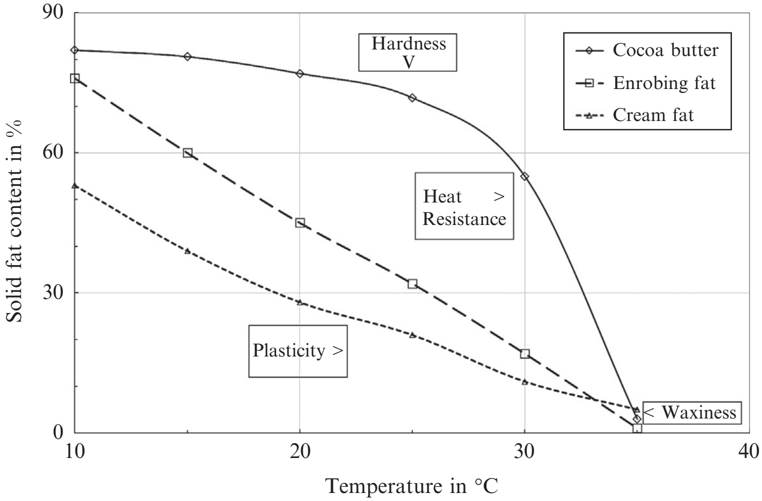

Fig. 3.3 Melting curves of important fats.

- A certain stiffness at ambient temperature, being in parallel to the SFC at that temperature, is important for a fast cream solidification in the cream cooler and to avoid flowing out of cream in warm environments
- The heat resistance of a cream fat is proportional to the decrease in SFC between 25°C and 30°C
- The cooling sensation of a fat in the mouth is proportional to the difference in SFC between 27°C and 35°C. That difference is high for lauric fats. A high-solid fat percentage requires much heat for melting it in the mouth
- The right melting point for the climate (winter, summer, tropical). If the point is incorrect, about 99% of the fat melts at body temperature, a greasy or even waxy mouthfeel occurs, and the flavour release may be compromised. This is a condition that cannot be met easily for a hot climate
- Plasticity (spreadability, creaminess) is reflected by a moderate SFC, smoothly decreasing with temperature, compared to the high SFC and its sharp decrease in cocoa butter or lauric fats. For a fast, good aeration of a cream the SFC must be in the range of 10%–25%. Both oils (no SFC left) and hard fats (high SFC) cannot be aerated. Additionally a beta prime fat structure is required here

3.2.4.3 Specifications for Fats of Importance in Wafer and Waffles

In *wafer baking* the preferred oils are native coconut oil, native palm kernel olein and native palm olein (Tables 3.35–3.37). The term olein means the liquid fraction of the physically fractionated native fat/oil. These three oils offer the advantages of (a) being liquid at ambient, which is important for easy dosage and (b) offering good stability in

Table 3.35 Specification for a Wafer-Baking Fat—Coconut Oil
Coconut Oil, Native, RBD

Typical applications	Wafer baking oil, spraying oil for wafer reels, wafer snacks/frying oil, fat for ice cream enrobing
General properties	Refined, bleached, deodorized (RBD), nonhydrogenated, a lauric fat
Features	Trans fat-free, high content in saturated fatty acids, absolutely bland in flavour, high stability
Supply	200 L drums, liquid in bulk
Storage	Store dark and cool in original container or blanketed tank, use within 9 months

Specifications	**Value**
Slip melting point (°C)	24 ± 1
SFC (NMR)	
% at 15°C	70 ± 5
% at 20°C	34 ± 3
% at 25°C	1 ± 1
Peroxide number (meq/kg max.)	0.5
Free fatty acids (ffa) (% max.)	0.1
Acid value (max.)	0.2
Moisture content (% max.)	0.15

Table 3.36 Specification for a Wafer-Baking Fat—Palm Kernel Olein
Palm Kernel Olein, Native, RBD

Typical applications	Wafer baking oil, oil spraying in wafer reels, wafer snacks/frying oil, fat for ice-cream enrobing
General properties	Refined, bleached, deodorized (RBD), nonhydrogenated, a lauric fat
Features	Trans fat-free, high content in saturated fatty acids, absolutely bland in flavour, high stability
Supply	200 L drums, liquid in bulk
Storage	Store dark and cool in original container or blanketed tank, use within 9 months

Specifications	**Value**
Slip melting point (°C)	25 ± 2
SFC (NMR)	
% at 15°C	39 ± 3
% at 20°C	21 ± 2
% at 25°C	6 ± 2
Peroxide number (meq/kg max.)	0.5
Free fatty acids (ffa) (% max.)	0.1
Acid value (max.)	0.2
Moisture content (% max.)	0.15

Table 3.37 Specification for a Wafer-Baking Fat—Palm Olein
Palm Olein, RBD

Typical applications	Wafer baking oil/oil for soft cream fillings/oil spraying in wafer reels, wafer snacks/frying oil
General properties	Liquid fraction of native palm oil/fat, refined, bleached, deodorized (RBD), nonhydrogenated, a nonlauric fat
Features	Trans fat-free, moderate content in saturated fatty acids, neutral in taste, good stability
Supply	200 L drums, liquid in bulk
Storage	Store dark and cool in original container or blanketed tank, use within 9 months

Specifications	**Value**
Slip melting point (°C)	21 ± 3
SFC (NMR)	
% at 10°C	40 ± 4
% at 15°C	19 ± 4
% at 20°C	6 ± 2
% at 25°C	1 ± 1
Peroxide number (meq/kg max.)	0.5
Free fatty acids (ffa) (% max.)	0.1
Acid value (max.)	0.2
Moisture content (% max.)	0.15

thermal processing. If not available, melted cream fats (Tables 3.38–3.41) are the next best recommendation. We recommend concentrating on the most important specification criteria as individually required and outlined above: avoid too much analytical data that is lengthy and expensive to check.

Specifications for Cream and Enrobing Fats

For moderate climate the lauric hydrogenated coconut fat (Table 3.38), partially hydrogenated nonlauric oils (PHO, Table 3.39), or palm kernel fats (Table 3.41) are suitable for cream fillings. PHO are being increasingly phased out due to their trans fat content, see Section 3.2.7.1 for details. Fractionated palm fats (Table 3.40) nowadays replace hydrogenated oils increasingly.

Cream fats for hot climate and enrobing fats are from similar sources have a slightly harder texture (Table 3.41).

3.2.5 Good Baking Fats Are Stable Against Oxidation and Polymerization

For a trouble-free operation the selection of a stable fat is recommended. First look into fat degradation mechanisms via oxidation and how to measure the stability. Then, from experience look into two parameters: the iodine value and the frying stability.

Table 3.38 Specification for a Wafer Cream Fat—Coconut Oil, Hardened
Coconut Oil, Hydrogenated, RBD

Typical applications	Fat for wafer creams and enrobings for moderate climates
General properties	Refined, bleached, deodorized (RBD), hydrogenated, a lauric fat
Features	Trans fat-free, high content in saturated fatty acids, cool and fast meltdown, good stiffness at ambient temperatures, absolutely bland flavour, high stability
Supply	20 kg cartons, liquid in bulk
Storage	Store dark and cool in original container or blanketed tank, use within 9 months

Specifications	**Value**
Slip melting point (°C)	33 ± 1
SFC (NMR)	
% at 15°C	76 ± 5
% at 20°C	54 ± 4
% at 25°C	20 ± 3
% at 30°C	5 ± 2
% at 35°C	1 ± 1
Peroxide number (meq/kg max.)	0.5
Free fatty acids (ffa), (% max.)	0.1
Acid value (max.)	0.2
Moisture content (% max.)	0.1

Table 3.39 Specification for a Wafer Cream Fat—Vegetable Oil, Hardened
Cream Fat—Vegetable Oil, Hydrogenated, RBD

Typical applications	Fat for wafer fillings not for hot climate
General properties	Refined, bleached, deodorized (RBD) hydrogenated, a nonlauric fat
Features	Good Plasticity slightly over ambient temperatures, contains trans fats, neutral flavour
Supply	20 kg cartons, liquid in bulk
Storage	Store dark and cool in original container or blanketed tank, use within 9 months

Specifications	**Value**
Slip melting point (°C)	35 ± 1
SFC (NMR)	
% at 15°C	60 ± 5
% at 20°C	45 ± 5
% at 25°C	32 ± 4
% at 30°C	17 ± 2
% at 35°C	1 ± 1
Peroxide number (meq/kg max.)	1
Free fatty acids (ffa), (% max.)	0.1
Acid value (max.)	0.2
Moisture content (% max.)	0.1

Table 3.40 Specification for a Wafer Cream Fat—Palm Fat, Fractionated
Cream Fat—Palm Fat, RBD, Fractionated

Typical applications	Soft, plastic fat for wafer fillings, wafer-baking fat
General properties	Refined, bleached, deodorized (RBD), nonhydrogenated, a nonlauric fat
Features	Good Plasticity slightly over ambient temperatures, trans fat-free, neutral flavour
Supply	20 kg cartons, liquid in bulk
Storage	Store dark and cool in original container or blanketed tank, use within 9 months

Specifications	Value
Slip melting point (°C)	36 ± 4
SFC (NMR)	
% at 15°C	35 ± 5
% at 20°C	26 ± 4
% at 25°C	16 ± 3
% at 30°C	10 ± 2
% at 35°C	5 ± 2
Peroxide number (meq/kg max.)	1
Free fatty acids (ffa), (% max.)	0.1
Acid value (max.)	0.1
Moisture content (% max.)	0.1

Table 3.41 Specifications for Wafer Cream and Enrobing Fats—Palm Kernel
Hard Butters—Palm Kernel Oil, Hydrogenated, RBD

Typical applications	Fat for wafer enrobing (Cocoa butter substitute), wafer cream, Caramel filling, for hot climate
General properties	Refined, bleached, deodorized (RBD), hydrogenated, fractionated (optionally), a lauric fat
Features	Low in trans fat, high content in saturated fatty acids, cool and fast meltdown, absolutely bland flavour, good stiffness at ambient temperature, high stability
Supply	25 kg cartons, 190 kg drums, liquid in bulk
Storage	Store dark and cool in original container or blanketed tank, use within 9 months

Specifications	A	B	C	D	E
Slip melting point (°C)	36 ± 1	38 ± 1	40 ± 1	42 ± 1	44 ± 1
SFC (NMR)					
% at 20°C	83 ± 4	87 ± 4	89 ± 4	90 ± 4	90 ± 4
% at 25°C	57 ± 3	63 ± 3	67 ± 3	70 ± 3	70 ± 3
% at 30°C	25 ± 3	32 ± 3	37 ± 3	39 ± 3	40 ± 3
% at 35°C	7 ± 2	11 ± 2	14 ± 2	16 ± 2	18 ± 2
% at 40°C	0	5 ± 2	7 ± 2	8 ± 2	10 ± 2
Peroxide number (meq/kg max.)	0.5	0.5	0.5	0.5	0.5
Free fatty acids (ffa), (% max.)	0.1	0.1	0.1	0.1	0.1
Moisture content (% max.)	0.1	0.1	0.1	0.1	0.1

3.2.5.1 Autoxidation and Oxidative Stability of Fats

Autoxidation is a chemical reaction of unsaturated fats with oxygen from air, leading to staling and rancidity. The reaction is a free radical chain reaction via peroxides and hydroperoxides. Fat oxidation is the most important reason for quality losses in wafers, waffles and similar bakery items. The basic mechanisms of autoxidation are the following:

1. An initiating reaction step at an unsaturated bond of the fatty acid, triggered by heat, UV radiation, oxygen or catalysts. Table 3.42 provides information on how big the influence of the degree of unsaturation of the fatty acids on the reaction rate is. Polyunsaturated fatty acids react much faster than the monounsaturated oleic acid
2. The 'induction period' follows. Any of the antioxidative components in the oil protect against deterioration until they are used up
3. Then the self-propagating 'autoxidation' can proceed. The first phase of oxidation, even before any rancid notes may be recognized by sensory testing, can be monitored by determining the peroxide value (POV). Hence the POV is an important parameter in measuring the quality of a fat

The Induction Period

The length of this induction period, which is the time of resistance of the product to oxidation, depends on the following:

- The concentration of polyunsaturated fatty acids
- Any thermal predamage due to overheating of oil, fat or lecithin
- Any light influence, depending on time, light colour and intensity (photo-oxidation)
- Any reaction catalysts such as copper and iron ions or other prooxidants
- The lacking of natural or added antioxidants and synergists in the fat such as the following
  - *Natural*: Oil tocopherols, plant phenols, carotenoids, Maillard reaction products
  - *Added*: Antioxidants (BHA, BHT, tocopherols, gallates, TBHQ); even vanillin is active here
  - *Synergists*: Lecithin, citric acid
- Presence or exclusion of oxygen from air
- An increased storage temperature

Table 3.42 Relative Rate of Oxidation and Induction Periods

Fatty Acid	Relative Rate of Oxidation	Induction Period (h)
Stearic acid C18:0	1	–
Oleic acid C18:1	100	82
Linoleic acid C18:2	1200	19
Linolenic acid C18:3	2500	1.34

Data from Belitz, H.-D., Grosch, W., Schieberle, P., 2009. Lipids. In: Food chemistry, fourth ed. Springer, New York, 1070 pp.

- Mixing with already oxidized fats, which may happen, for example, in insufficiently cleaned lines, pipes, and tanks or by using up old ingredients

In short, the rule is to keep cool, keep covered, and don't combine old and new fats.

Testing the Stability of an Oil/Fat

Well-known rapid test methods to determine the induction period are the 'active oxygen method' (AOM), the 'Rancimat' test, and the similar 'Oxygen Stability Index' (OSI) tests.

The principle of all these tests is that a stream of air is bubbled through the oil sample at elevated temperatures (100°C–130°C in different methods). The hours required for approaching a certain POV or some other degradation product level are recorded. Native soybean or sunflower food oils takes just a few hours, and very stable oils take 100 h or more.

3.2.5.2 The Iodine Value Measures the Unsaturation in Oils and Fats

The iodine value is in direct proportion to the number of mono- and polyunsaturated bonds within the constituent fatty acids. In our experience, it is an important and easily available parameter in fat selection. The iodine value for native oils/fats of defined plant origin is easily accessible from tables or from the fat supplier (Table 3.43).

Oils with high iodine values contain more of the highly unsaturated fatty acids that are prone to fast degradation reactions such as autoxidation or polymerization. Particularly during baking, these reactions are forced by the high temperatures and the dissolved oxygen being present from air. Oils with an iodine number higher than 115 are considered to be 'drying oils'. Drying means hardening into a polymerized, tough and solid film after exposure to air, a reaction sequence that is accelerated by elevated temperatures. During the chemical reaction the components are crosslinked by the action of oxygen and any metal catalysts present.

While Table 3.43 has the iodine values of the main natural oils and fats, in Table 3.44 the influence of hydrogenation on the number of double bonds becomes visible. The important conclusion for selecting a baking fat is that all fats being higher in iodine value than a monounsaturated C18:1-triglyceride of the theoretical iodine value 86 definitely are not the first choice. Therefore most of the common vegetable oils, being abundantly available and cheap, are not good for wafer baking. Here the oils/fats with low iodine values are much better suited.

3.2.5.3 The Frying Stability, Another Indicator of Oil Stability

In wafer and waffle baking, on the hot baking mould surfaces some degradation of the fat by polymerization, induced by high temperature and steam, occurs. A resinous surface film forms that, after many baking cycles, together with any charred food components other than fat will end in the buildup of dark residues on the baking moulds.

Table 3.43 Iodine Values of Natural Oils and Fats

Oil/Fat Type	Iodine Value
Fully hydrogenated fats, waxes	<1–3
Coconut oil	6–11
Babassu oil	13–17
Palm kernel oil	14–21
Palm kernel olein	20–28
Butter fat	25–42
Tallow (beef)	40–55
Cocoa butter	34–40
Lard	48–65
Palm oil	50–55
Palm olein	56–72
Peanut oil	86–107
Cottonseed oil	100–115
Maize oil (corn)	107–135
Sesame oil	104–120
Canola (low erucic rapeseed)	105–126
Wheat germ oil	115–126
Sunflower seed oil	118–141
Sunflower seed oil, mid-oleic	94–122
Sunflower seed oil, high oleic	81–91
Soybean oil	124–139
Safflower seed oil	136–148
Safflower seed oil, high oleic	82–92
Chia seed oil	209–211
Oleic acid-triglyceride (theoretical value)	*86*
Linoleic acid-triglyceride (theoretical value)	*173*
Linolenic acid-triglyceride (theoretical value)	*262*

Data from AAK Handbook Vegetable Oils and Fats, 2007, AAK, Denmark, second ed., modified.

Table 3.44 Iodine Values of Partially Hydrogenated Soybean Oils

Fat type	Iodine value
Very slightly hydrogenated	110–114
Partially hydrogenated, baking fat	75–81
Partially hydrogenated, cookie-filling fat	72–78
Partially hydrogenated, wafer cream fat	69–75
Partially hydrogenated, higher stability fat	68–72

As both the high temperature and the presence of moisture in wafer and waffle baking are similar to the fat frying of foods, a comparison to the results of frying tests is meaningful for baking fat selection as well. Table 3.45 provides data on the relative frying stability of various oils and fats.

Table 3.45 Relative Frying Stability of Oils and Fats

Oil/Fat Type	Relative Frying Stability
Peanut oil, hydrogenated	4.4
Coconut oil	2.4
Tallow, beef, native	2.4
Butter fat	2.3
Soybean oil, hydrogenated	2.3
Lard	2.0
Palm oil	1.5
Peanut oil	1.2
Soybean oil	1
Canola oil	1
Sunflower oil	1

Data from Belitz, H.-D., Grosch, W., Schieberle, P., 2009. Lipids. In: Food chemistry, fourth ed. Springer, New York, 1070 pp.

Table 3.46 Chemical Changes During Frying

Parameter	In Fresh Oil % by Weight	In Used Oil % by Weight	Change in %
C18:0	4.53	4.45	−2
C18:1	45.3	42.9	−5
C18:2	37.0	29.6	−20
C18:3	2.39	1.67	−30
Free fatty acids	0.03	0.59	+1867
Diglycerides	1.18	2.73	+131
Iodine value	108.9	101.3	−7

Slightly hydrogenated soybean oil/80 h/195°C.
Data from Belitz, H.-D., Grosch, W., Schieberle, P., 2009. Lipids. In: Food chemistry, fourth ed. Springer, New York, 1070 pp.

Table 3.46 compiles the changes in various oil parameters during continued frying. The polyunsaturated fatty acids linolenic (C18:3) and linoleic (C18:2) degrade preferably. On a weight basis most degradation products come from the much more abundant linoleic acid. The very reactive free fatty acids increase greatly.

3.2.6 The Handling of Oils and Fats

Recommended practices in the procurement of oils and a few handling and processing rules help to avoid any issues related to these ingredients. Contemporary knowledge on the pathways of fat quality losses, cf. the previous Section 3.2.5, helps in manufacturing better products with an increased shelf life.

3.2.6.1 Fat Supply and Storage in Blocks

Delivery and storage of cream fat packed plastic bags and cartons in blocks of about 20–25 kg still is the preferred practice in many in factories. These cartons can be stored for long periods without suffering noticeable oxidation. In the cartons there is proper light protection—the other requirements are just dry and cool storage—for a few days even at ambient, 18°C–32°C depending on climate and fat type; otherwise they can be stored in a cold storage room.

For temperature equilibration before use, a 'warming room' is good practice for obtaining a soft, plastic fat texture. The 'thumb test', pressing the thumb into the fat to ensure a hole remains, indicates a proper fat texture for sugar–fat cream mixing or other mixing and kneading processes. The cutting of the whole blocks into smaller pieces before filling to the mixer eases and shortens the mixing procedure additionally.

Mechanical plasticizers for cold fat blocks are the second best option in preparing fats for cream mixing. The fat becomes more plastic but still is rather hard due to the almost unchanged temperature.

3.2.6.2 Bulk Fat Supply, Warm and Liquid in Trucks

For high-capacity cream users, fat delivery and storage in liquid form in bulk is recommended, if available. The advantages are in simplified logistics. The fat comes in trucks, is pumped into a storage tank, and is kept under inert gas (nitrogen) at ~45°C. Check and clean the tanks periodically. From here the fat is dosed fully automatically by volumetric metering into the mixer. All labour-intensive manual handling is obsolete. Cream mixing is faster due to the faster incorporation of the fluid fat.

For most applications, where no aerated cream is used, this is the most economical way of cream preparation. The warm and fluid cream even may be distributed over some distance to the point of application. If cream aeration is required, place a station with a precooling unit and a mechanical aerator station close to the cream spreader. The required specific gravity can be adjusted here in a tailor-made way; cf. Section 5.2.4 in Chapter 5 for details.

3.2.6.3 Precautions for Working With Oils and Fats

There are a few more potential causes of fat quality issues:

- Avoid any air incorporation via leaky piping.
- Keep clean and dry all materials in contact such as vessels, machines, moulds and working cloths. Washing piping and vessels with water may do more harm than by simply dry wiping. Otherwise thorough drying is required before any recontact with fats.
- Avoid contamination with dust or traces of metal ions that catalyze oxidation, such as rust or copper. Since traces of copper suffice to accelerate fat spoiling, eliminate any copper or brass equipment such as containers, fittings or pipes. Suitable materials for equipment and containers to come into contact with fats are stainless steel, aluminium and some plastics.
- Protect from direct and prolonged (sun)light in any processing stage.

- Do not leave fat residues in the equipment. Never use them later together with fresh material. Avoid the admixing of old fat or cream batches as much as possible.
- Oils and fats absorb all kinds of odours very easily—not only positive ones. Some off smell or taste of products in the market might come from their packaging materials such as paper and cardboards or freshly applied film printing or labelling materials (printing inks, adhesive glues). It may also come from improperly packed co-stored products such as solvents or spices.
- Soapiness from fat cleavage: Soapy flavours make a food product practically inedible. At the beginning of the widespread use of lauric fats, soapy flavours were greatly feared due to the extremely low off-flavour threshold of lauric acid. Soapiness comes from an enzymatic triglyceride cleavage into free fatty acids by lipases. Lipase enzymes might come into creams from ingredients such as soy flours, peanuts, hazelnuts, cereal flours or spices. However, this would happen only if the enzyme was not inactivated thermally by sufficient toasting. Microbial contamination by moulds, yeasts or bacteria also might release lipases. With today's ingredient qualities and production hygiene soapiness issues are almost gone.
- For any lipase-activated fat cleavage at least some moisture is required. For crisp sugar wafer cookies that is not the case. Their cream fillings are typically lower than 1% in moisture content. Just for the soft-textured meringue-filled wafers and for waffles sufficient moisture is present to activate any lipases. Then only are the lauric fats risky to use.

3.2.7 Current Fat-Related Nutritional Aspects

From a nutritional viewpoint, fats are energy-dense foods providing 37 kJ (9 kcal) per gram, whether being saturated, monounsaturated or polyunsaturated. Fats are required to carry, supply and aid in the absorption of the fat-soluble vitamins A, D, E and K and carotenoids. Some polyunsaturated fatty acids, primarily the omega-3 ones, are important for reducing cardiovascular disease (CVD) risks.

Generally caloric overconsumption is detrimental to our health. Excess energy intake is stored as body fat and, over time, promotes the development of obesity, which increases the risk of developing conditions such as heart disease, type 2 diabetes and cancer. In times of growing obesity in industrialized countries, the high-calorie content of fats and questions of fat reduction are actively in discussion. A reduction of saturated fats in our nutrition is one of the most important goals. Some of the specific issues to discuss affect wafer manufacturing as well.

3.2.7.1 TFA or Trans Fat

What Is Trans Fat and How Is It Formed?

The FAO/WHO Codex Alimentarius defines TFA as the geometrical isomers of monounsaturated and polyunsaturated fatty acids having nonconjugated carbon–carbon double bonds in the trans configuration. This definition excludes specifically healthy natural TFA such as vaccenic acid and conjugated linoleic acid, which are present in milk, dairy products and beef for example.

Trans fats form when hydrogen is added to liquid vegetable oils in a process called hydrogenation or hardening. The shortenings obtained increase the shelf life and flavour stability of foods containing these fats. Wafer fillings from PHO solidify quickly on cooling. PHO is the main source of industrial trans fats in processed foods today. Trans fat potentially can be found in vegetable shortenings (wafer and cookie cream fats), some margarines, all kinds of bakery products, snack foods, fried foods, chips and in breaded goods.

Why Trans Fat Is Significant for Health

The effects of both natural and industrially produced sources of TFA were examined by a multidisciplinary research team from worldwide research institutes in the TRANSFACT study, showing effects on CVD factors. The deleterious property of TFA to lower the 'good cholesterol' (HDL-C) and to raise the 'bad cholesterol' (LDL-C) was shown to be specific to industrially produced fat sources. Although saturated fat is the main dietary culprit that raises LDL-C, trans fat and dietary cholesterol also contribute significantly. The findings, however, suggest that consumption of TFA from natural sources, even at levels well above current human consumption, does not impact the CVD risk.

Actions in Public Health Are Required

The critical public health goal is to find ways to reduce the intake of industrially produced TFA. Since 2006 in the United States and Canada trans fat must be labelled in the nutrition facts panel on the package. But quantities below 0.5 g TFA per serving are considered TFA-free, which might be up to 2% TFA in the total product. In 2015 the US FDA set the date of Jun. 2018 when at latest food manufacturers have to eliminate all PHO from food. The European Union has not yet held a common position (Laaninen, 2016). Starting in 2003, Denmark, Switzerland, Austria, Iceland, Hungary and Norway made legislation to limit industrially produced trans fats to a maximum of 2 g per 100 g of fats.

The urgency of replacing PHO-containing fats in fillings and enrobings for wafers and waffles requires modifications in processing and recipes. For a full discussion see Section 3.2.8.2.

Food authorities in dealing with issues such as malnutrition, nutrition, and health or over caloric nutrition and obesity specify nutrient claims and health claims to guarantee reliable labeling information of health-conscious consumers.

3.2.7.2 Nutrient Profiles of Foods

Nutrient profiling according to WHO definition is the 'science of classifying or ranking foods according to their nutritional composition for reasons related to preventing disease and promoting health'. Nutrient profiling provides a means of differentiating foods in relation to certain nutrients with either a positive or, more frequently, negative nutritional impact because they may contribute to excess consumption of energy, saturated fats, trans fats, sugar or salt. Nutrient profiling is a tool to categorize foods, not diets, but it can be used through policy to improve the overall nutritional quality of diets (WHO, 2015). A certain level of nutrients in a food may not be exceeded or undercut if this food is to bear a nutrition or health claim on food labels or in product advertising. Besides the disqualifying nutrients, as mentioned above, at the time qualifying nutrients are in discussion, such as dietary fibre, calcium, omega-3 fatty acids and folate or other vitamins. Nutrient profiles are related to a reference quantity of food, preferably expressed by weight/volume (per 100 g or 100 ml), on an energy basis (per 100 kcal or 100 kJ) or per serving as is common in the United States, Canada and Australia.

The New WHO Europe Model for Nutrient Profiling

The theme nutrient profiles began quite ambitiously by the European parliament about 10 years ago but interventions ceased later. Now WHO Europe has begun a new initiative in 2015 to define nutrient profiles for restrictions on marketing foods to children.

In the proposal the nutrients covered within 17 food subcategories by the new WHO model are the following: total fat, saturated fat, total sugars, added sugars and salt. Energy is included for category 9 (ready meals, convenience foods and composite dishes), while nonsugar sweeteners have also been included for subcategory 4b, milk drinks and 4d, other beverages. Of the subcategories 5 of the 17 are 'not permitted' for marketing to children. Four of them affect wafers and waffles:

1. Chocolate and sugar confectionery, energy bars and sweet toppings and desserts. Chocolate-covered wafers and waffles are included here
2. Cakes, sweet cookies and pastries; other sweet bakery wares, and dry mixes for making such. Wafers and waffles are included here
3. Beverages: Here the subcategories (a) juices and (c) energy drinks are not permitted
4. Edible ices. Ice cream in wafers is included here

In category 9 on 'convenience food' RTE waffles are subjected to limits in total fat, saturated fat, total sugars, salt and energy content.

Marketing to children shall be prohibited if the product contains >1 g per 100 g total fat in the form of industrially produced TFA, or $\geq 0.5\%$ of total energy in the form of alcohol.

Nutrient Profiles Only for a Children's Diet?

The initiative on children's diet restrictions via nutrient profiles may be just a first step. It could also serve later on to identify foods to be

- eligible to bear health claims when complying fully to the nutrient profile

- eligible to bear nutrition claims if complying to the nutrient profile except for one nutrient
- ineligible to bear either a nutrition or health claim either

In addition to scientific considerations, issues to be taken into account as well include the following:

- Is the forthcoming nutrient profile scheme understandable to (nonscientific) consumers?
- The world trade situation. In other big markets such restrictions are not in place. Can products imported from there be banned if they don't have the nutritional profile as required?
- Will product innovation be affected negatively?
- Is it, from a public health viewpoint, really better to have 'nonnutrient profile conforming' but widely consumed products excluded from adding any positive nutrients?

3.2.7.3 Nutrition Claims

What Is a 'Nutrition Claim' and a 'Nutrient Content Claim'?

Products with increased or reduced levels of a certain nutrient may use nutrition claims on labels and in marketing, provided the claim is substantiated by the recipe. Tables 3.7 and 3.8 in Section 3.1.3.1 inform on such claims as permitted in the European Union and in the United States (Table 3.47). Here just an overview on the nutrition claims related to fats (retrieved 07-2016) follows:

For the EU 'Nutrition Claims'

http://ec.europa.eu/food/safety/labelling_nutrition/claims/nutrition_claims/index_en.htm

Low fat—no more than 3 g of fat per 100 g for solids or 1.5 g of fat per 100 ml for liquids; 1.8 g of fat per 100 ml for semiskimmed milk

Table 3.47 For the United States 'Nutrient Content Claims'

Label Nutrient	**Free**	**Low**	**Reduced/Less**
Total fat	Less than 0.5 g per RACC and per labelled serving	3 g or less per RACC, and per 50 g if RACC is small	At least 25% less fat per RACC than an appropriate reference food
Saturated fat	Less than 0.5 g saturated fat and less than 0.5 g trans-fatty acids per RACC and per labelled serving	1 g or less per RACC and 15% or less of calories from saturated fat	At least 25% less saturated fat per RACC than an appropriate reference food

http://www.fda.gov/Food/GuidanceRegulation/GuidanceDocumentsRegulatoryInformation/LabelingNutrition/ucm064911.htm.

Fat-free—no more than 0.5 g of fat per 100 g or 100 ml
Low saturated fat—the sum of saturated and trans-fatty acids in the product does not exceed 1.5 g per 100 g for solids or 0.75 g/100 ml for liquids, and the sum of saturated fatty acids and trans-fatty acids must not provide more than 10% of energy
Saturated fat-free—the sum of saturated fat and trans-fatty acids does not exceed 0.1 g of saturated fat per 100 g or 100 ml
Source of omega-3 fatty acids—the product contains at least 0.3 g alpha-linolenic acid per 100 g and per 100 kcal, or at least 40 mg of the sum of eicosapentaenoic acid and docosahexaenoic acid per 100 g and per 100 kcal
High omega-3 fatty acids—the product contains at least 0.6 g alpha-linolenic acid per 100 g and per 100 kcal, or at least 80 mg of the sum of eicosapentaenoic acid and docosahexaenoic acid per 100 g and per 100 kcal
High monounsaturated fat—at least 45% of the fatty acids present in the product derive from monounsaturated fat under the condition that monounsaturated fat provides more than 20% of energy of the product
High polyunsaturated fat—at least 45% of the fatty acids present in the product derive from polyunsaturated fat under the condition that polyunsaturated fat provides more than 20% of energy of the product
High unsaturated fat—at least 70% of the fatty acids present in the product derive from unsaturated fat under the condition that unsaturated fat provides more than 20% of energy of the product

3.2.7.4 Health Claims

What Is a Health Claim?

Health claims on food labels highlight that there is a relationship between a specific food and an improvement in health, or that a food can reduce the risk of a particular disease. They are widely used in Japan, North America, and in the European Union. In Europe food manufacturers can use health claims only if the following conditions are met:

- They are included in a positive list of permitted claims in the EU
- The claims are scientifically proven by clinical studies and evaluated positively by the European Food Safety Authority (EFSA)

The options for EU health claims are

1. ‘*Function Health Claims*’ such as ‘Calcium is important for healthy bones’. These claims are
   - Relating to the growth, development and functions of the body
   - Referring to psychological and behavioural functions
   - Regarding slimming or weight-control
2. ‘*Risk Reduction Claims*’ on reducing a risk factor in the development of a disease. An example: ‘Plant stanol esters have been shown to reduce blood cholesterol. Blood cholesterol is a risk factor in the development of coronary heart disease’

3. '*Health Claims referring to children's development*'. For example: 'Vitamin D is required for the normal growth and development of bone in children'

For cream-filled wafer cookies due to their higher levels of sugar there is no chance for bearing any nutrition or health claim in the EU: No more vitamin, calcium or whatever wafers with claims will be available. Consumers who want this characteristic should research American or Japanese wafer products.

3.2.7.5 Fat Replacement

From the market side, there are repeated questions about fat reduction or replacement. Fat has the most calories compared to proteins and carbohydrates. Fat replacers in many foods are applied to save calories and to duplicate the taste and texture of fats. In wafers the target is the filling cream; for waffles it is the total fat content and the level of saturated fats. The different types of fat-replacing ingredients provide some of the functions of fats but not all of them. There are a lot of limits such as a lack of stability to heat processing, or the moisture content required to unfold the function. The three main groups of fat replacers are based on lipids, proteins or carbohydrates (Akoh, 1998; Chavan et al., 2016).

Lipid-Based Fat Replacers

This sounds contradictory, but fat calories are reduced by the following:

(a) *Water-based emulsions*—Fat-based mono- and diglyceride emulsifiers together with some water replace all or a part of the shortening. This is a strategy not suitable in combination with the hygroscopic crisp wafers.

(b) *Modified triglyceride structure*—A part of the long-chained fatty acids in the triglycerides is replaced by short ones. The triglyceride molecules thereby come down from 9 to 5 or 6 cal/g. Examples are Caprenin and Benefat (Salatrim). These behave similarly to fat and are in principle applicable in wafers and waffles.

(c) *Nondigestible fat substitutes*—The best known example is Olestra, brand name Olean, a sucrose-fatty acid polyester, which has a limited approval by FDA for cookies. The issues can be seen from the mandatory warning label that the FDA demands: 'Olestra may cause abdominal cramping and loose stools. Olestra inhibits the absorption of some vitamins and other nutrients. Vitamins A, D, E and K have been added'. Therefore an application in wafers or waffles is not foreseeable. For other products such as Sorbestrin, sorbitol fatty acid esters or 'esterified propoxlated glycerol' (EPG), no food approvals exist.

Protein-Based Fat Replacers

Protein-based fat replacers simulate the mouth feel of fat and can also help to stabilize emulsions in sauces, spreads, and salad dressings. Microparticulated proteins such as Simplesse are from whey protein or milk and egg protein. Further products based on gelatin, egg whites, milk, or whey proteins (Dairy-Lo) were proposed here.

Because these proteins are active just in combination with water to get their creamy, fat-like texture, an application in dry crisp wafers and wafer cookies cannot replace important fat functions such as shortening the texture and providing a release film in baking moulds.

Carbohydrate-Based Fat Replacers

These fat reducers include ingredients such as cellulose, gums, fibres, dextrins, modified food starch and polydextrose. Modified food starches, maltodextrins and dextrins absorb water to form gels that mimic the texture and mouth feel of fat. Polydextrose acts as a bulking agent to replace volume lost when fat is removed from a food. Gums provide a creamy mouth feel and help to stabilize emulsions. Cellulose gel is cellulose ground to tiny particles that supply a mouth feel that is similar to fat. Inulin has proven to be more a partial sugar substitute than fat substitute in sugar–fat creams.

Because these carbohydrates again are active just in combination with water to get their creamy, fat-like texture, an application in dry crisp wafers and wafer cookies cannot replace important fat functions such as shortening the texture and providing a release film.

Summary

The different fat replacers currently available have not proven to substitute for important functions of fat in general manufacturing of wafers, wafer cookies and waffles.

3.2.8 Oils and Fats for Wafer and Waffle Manufacturing

This section is on the application of the know-how on fats and oils as outlined above. Further the handling of these ingredients and potential issues will be discussed.

3.2.8.1 Technological Functions of Oils and Fats in Wafers, Waffles and Fillings

Fats and oils fulfil various technological functions in wafers and waffles, and their fillings and enrobings. Table 3.48 offers an overview.

Mould Release in Baking Wafers, Wafer Cookies and Waffles and Mould Residues

No/low sugar wafers such as sheet wafers, or wafer cones as well as sugar wafers (cones, flutes, reels), require just a few percent of oils/fats for mould release. However, the fat/oil quality is of great influence for both the ease of production and the storage stability of the final products.

The mould release is based on a thin oil film at the surface of the hot baking mould, continuously supplied from the oil/fat content in the recipe. Best recommended are stable oils and fats, being as low as possible in polyunsaturated fatty acids. The iodine value (Tables 3.43 and 3.44) is a good guidepost here. The fats on top of Table 3.43—coconut, babassu, and palm kernel and palm or, if those are not available, partially hydrogenated

Table 3.48 Functions of Oils/Fats in Wafers, Waffles, Fillings and Enrobings

Technological Effect or Property	Comment
Mould release in wafers, wafer cookies and waffles	A thin lipid film prevents sticking
Participant in the building of baking mould residues	Polymerization of polyunsaturated lipids primarily at the high-temperature mould surface
Flavour improvement in wafer reels and noncreamed wafers	Oil spraying provides less dryness and more flavour
Binder in sugar–fat fillings	Terms like plasticity, spreadability, or creaminess of fat characterize that function
Flavour carrier and texturizer in filling creams	The melting of fats releases flavours. The fat composition governs for a soft, hard or waxy mouthfeel:
Providing a short, soft eating texture in waffles	Fat has a shortening action and reduces the firming during shelf life
Mediator of gloss, hardness and stability in enrobings	A property of cocoa butter and its replacers and substitutes
Occurrence of old and rancid flavours	Staling and oxidation transform into flavour issues
Nutritional concerns: Calories, saturated and trans fats	Fats provide many calories

fats such as cream fats (Table 3.44)—are well suited. We recommend avoiding any oils/fats with iodine values over 85 in wafer baking for two main reasons:

- To minimize any thermally induced fat degradation and polymerization, which results in the formation of residues on the baking mould surfaces and overly short mould cleaning intervals
- To increase the shelf life of the wafers, which otherwise shortens from oxidative reactions (autoxidation), greatly triggered by the high-baking temperature. Quite often the shelf life printed is unduly long. During the shelf life the fat, finely dispersed over a large surface, is prone to air oxygen, both entrapped within the package and diffusing through the barrier film

For all baking operations fats with AOM values (Section 3.2.5) over 75 h are preferable. See the specifications for recommended baking fats in Tables 3.35–3.37 (Section 3.2.4).

How Much Fat Is Needed for Mould Release?

While an excessive oil/fat dosage in wafer and waffle baking is not recommended, a minimum quantity in the recipe is required to safely avoid any sticking after baking (Table 3.49). This minimum oil/fat quantity depends on the following:

- The recipe and the ingredients, primarily the level of sticky ones (cf. Table 9.13)
- Wafer and waffle characteristics such as reeding depth and sugar content
- Any baking mould seasoning or surface coating such as chromium plating or coating with Teflon

Table 3.49 Oil/Fat in Wafer and Waffle Recipes

Product	Oil/Fat in %
Flat wafers, hollow wafers	0.5–2
Sugar cones	3–9
Wafer flutes (sticks)	1–3
Waffles	10–28

In bakers percentage.

- The actual surface condition of the baking moulds. Worn-out or dirty plates may require greatly increased levels of oil/fat in the recipe.

Spraying Oils for Flavour Improvement

Some freshly baked wafers, while still being hot, are coated with oils by spraying or passing through an oil curtain. Sugar wafer reels for instance are oil sprayed immediately after baking, similarly to crackers and some hard cookies, and thereby they pick up around 10% by weight of oil.

Another example includes noncreamed sheet wafers, which after baking pass an oil spraying section. The oil may be flavoured additionally and assist in the adhesion of flavourful powders such as spices.

The main functions of oil treatment are the following:

- Achieving a more tender, delicate bite
- Reducing any 'dry' mouthfeel when eating the otherwise pure wafer
- A more shiny and appealing surface look
- The oil may be used as a carrier for added flavourings

Bland and stable oils, either coconut oil, palm kernel olein, or palm olein, are recommended here. For the specifications see Tables 3.35–3.37. If these tropical oils are disliked, select trans fat-free high-stability food oils or partially hydrogenated oils with an iodine value not over 90 and AOM stability values over 100 h.

Fats in Sugar–Fat Filling Creams for Cohesion, Flavour and Eating Texture

Fats are main components in filling cream recipes, ranging from 32% to over 40% of the cream weight. The specifications have been discussed in detail in Section 3.2.4. Fat functions in creams are the following:

- Provide internal cohesion of the powder components of the cream and adhesion to the wafer layers or waffles
- Carry most of the flavours and release them after melting
- Mediate the smooth, creamy eating texture that is in proportion to the fat level in the cream
- Cream fats can be the carrier for any functional ingredients, including heat-sensitive ones such as vitamins or essential fatty acids

The freshness and sensory quality of the cream fat is essential for the final quality and the shelf life of the products. In case of an insufficient fat quality potential issues can be the following:

- Flavour/taste issues because of rancid, old or off-flavour notes
- Greasy or waxy mouthfeel due to a fat fraction not melting at body temperature
- In wafer cookies the loss of shape due to an overly soft and flowing cream fat
- In filled flute wafers (wafer sticks) cream flow-out and soiling due to a high-fat percentage or coarse powder ingredients

Suitable cream fats are the following:

- Hardened coconut oil—lauric, for moderate climate only, almost no trans fats
- Hardened palm kernel oil—lauric, almost no trans fats
- Partially hardened vegetable oils—nonlauric, possibly high in trans fats
- Fractionated palm fat—nonhydrogenated, nonlauric, trans fat-free

For detailed specifications see Tables 3.38–3.41. Creams based on lauric fats in processing easily behave between runny, very liquid in texture when being too warm, and hard solid at any cold spots in the cream line. Their advantages are in the rapid solidification in the cooler and the cool melting sensation when eating the cream.

Fat Components in Wafer Cookies

Crisp wafer cookies in fat content are between wafers and waffles, and closer to that of waffles. All the arguments on release action, fat stability and influence on eating texture, flavour release and taste apply in a similar way.

Functionality of Fat Components in Waffles

Soft-textured waffles in their fat content range between about 5% in some of the frozen North American waffles and 26% for some vanilla waffles. There has been a general trend for reducing the fat content over the last decade. Fat functions in waffles are the following:

- Improve the heat conduction during baking
- Provide a thin release film for an easy take-out of the waffles from the baking mould
- Impart a pleasant taste and flavour. Fats/oils are carriers for added flavours
- Shorten the texture in proportion to the quantity of oil and fat. That results in a softer, less cohesive waffle with a better melt-away
- The right total fat level for RTE waffles depends on the recipe, the ingredient, and the customer-specific waffle taste
    - At high-fat levels increasing amounts of fat may accumulate on the baking mould surfaces, which impairs the waffle baking, especially the even surface look of the baked waffles
    - In case of oil dripping into the oven even the safety of operation is compromised
    - For low-fat waffles permanent brush cleaning or Teflon coating of the baking moulds is essential in order to avoid sticking

  - RTE waffles of higher fat/oil content are texturally denser. Any fat-related baking mass aeration collapses at the baking temperature and the higher fat level interferes with the egg-white related aeration

Fat Components in Enrobings for Wafers, Wafer Cookies and Waffles

Fats bring gloss, hardness, and mechanical stability to enrobings. Besides the traditional cocoa butter for real chocolate enrobings, different cocoa butter replacers and substitutes such as CBE, CBR nonlauric, and CBS lauric are applied for reducing both costs and processing time. For full details see Chapter 5 of this book.

The most economic enrobings are prepared from hydrogenated lauric fats. Hydrogenated coconut is suitable for moderate climate solely, but higher-melting palm kernel fats with melting points of 38°C–42°C are available for hot environments. Find specifications for enrobing fats in Table 3.41. Fat functions and potential issues in enrobings are the following:

- Ensure a rapid and good hardening without tackiness in cooling as well as a stable, glossy surface
- For enrobed wafers and waffles the compatibility of the enrobing fat to fats in the centre pieces (cream fat, waffle fat) is essential to minimize issues such as crocodile effect, oil migration, and fat bloom
- In particular, combining lauric and nonlauric fats results in such issues
- Some percentage of butter fat, directly added or from whole milk powders, softens the enrobing but may retard fat bloom
- Any nut oils in centre piece creams increase oil migration and fat bloom effects. Fat migration from the centre to the enrobing is reduced by the following:
  - Storage not over the ambient temperature
  - An increased percentage of solid fat in the cream filling
  - The same fat type in the filling and enrobing, either all lauric or all nonlauric
  - Possibly spray an intermediate layer such as from hard fat and sugar

Occurrence of Old and Rancid Flavours

These issues based on oxidative stability of fats and autoxidation have been discussed extensively in Section 3.2.5.

Nutritional Concerns: Calories and Saturated and Trans Fats

See the general discussion in Section 3.2.7.

3.2.8.2 Elimination of PHO-Based Trans Fats in Creams and Enrobings

After the thorough discussion of TFA in Section 3.2.7.1, the required change to trans fat-free in fillings and enrobings for wafers and waffles is the more difficult part.

Table 3.50 Trans Fats and Saturated Fats in Potential Wafer Cream Fats

Type of Fat	Trans Fat Content	Saturated Fat Content	Melting Point (°C) [a]	Lauric Fat
Coconut oil, hydrogenated	Very low	Very high	33–35	Yes
Palm kernel oil, hydrogenated	Very low	Very high	33–42	Yes
Palm fat, nonhydrogenated	Very low	Medium/high	33–42	No
Hydrogenated oils from canola, cottonseed, soybean, sunflower	Medium/ high	Medium	33–42	No

[a] Select the melting point according to climate, if possible below 37°C.

Table 3.50 compiles our current options for wafer cream fat and general fat selection at acceptable costs.

There is a relationship between crystallization behaviour, microstructure and macroscopic properties in filling and enrobing fats. Their good technological functionality is connected to the following:

- A rapid crystallization for fast cooling
- The forming of small fat crystals relates to cream smoothness
- Crystalizing into stable crystal forms of the polymorphic fats
- A high-final hardness of the filling/enrobing for easy and fast processing in cutting or packaging

Trans-containing fats crystallize faster and in smaller crystals compared to trans-free ones. The crystallization behaviour of the trans-free filling fat is more complex because different polymorphic forms occur. The hardness of the fillings is not solely governed by the quantity of solid fat present but also by the structure of this network. A trans-containing fat yields both a greater hardness and less negative effects from the usual compositional variation on the crystallization process.

For *transfat-free fats*, the chemical composition is much more critical in determining the crystallization rate, the solid fat content, and the final hardness value.

What Are the Options for TFA Replacement?

Why do we use a partially hydrogenated fat in wafer and waffle manufacturing? Depending on the application there are many answers:

- For release action in baking, fats require the high stability of nonpolyunsaturated fats regarding (a) polymerization reactions at high-baking temperatures, which influences plate-cleaning needs intervals extremely positively, and (b) their good oxidation stability helps during shelf life to avoid staling and rancidity
- In fats for filling creams, the fast crystallization, the fine structure of the fat crystals, and the good hardness of the fillings against squeeze and flow-out are important
- For enrobing fats similar arguments as for fillings apply in an even more pronounced way

A common aspect in trans fat replacement for creams and enrobing is that a certain level of solid fat is required to meet these functionalities. If trans fats are not present, only some percentage of saturated fat guarantees this. Unless ways for a trans-free hydrogenation are not available as a replacement other methods of fat selection and fat technology (Section 3.2.3) are required:

a. Select fats that naturally contain some solid fat. Here in sufficient quantities just lauric fats (coconut, babassu, palm kernel) or palm fat and cocoa butter are available. Out of these, palm fat is the most economic and flexible base for the following processing options
b. Fractionation of natural fats
c. Complete hydrogenation of oils: All of the original unsaturated double bonds, even some intermediate trans bonds, are converted to saturated single bonds. Then no TFA remains and the product can be considered to trans-free. Disadvantages are the labelling requirement 'hydrogenated fat' and the high-melting point, well above body temperature
d. However fully hydrogenated fat can be a basis fat for interesterification with oils. One option to avoid the hydrogenated label is to use the hard palm stearine from fractionation for the interesterification process
e. Blending is the simplest process option and may use any of the products of the processes already discussed to obtain a trans-free declaration, with or without the 'hydrogenated' label

A Caveat to All Saturated Fat and TFA Exchange Strategies

It is not just a matter of matching the melting profile of the partially hydrogenated fat to be replaced. Mostly the fat stability factors are much more important:

- Most of the less saturated fats behave badly in release for baking. More sticking then requires higher fat levels and again a more frequent plate cleaning. Therefore a replacement of the small quantity of baking fats by highly unsaturated ones is less recommended
- Less saturated trans-free fats may compromise the wafer product shelf life. Shorter induction periods and increased rancid and old flavour notes will be observed. You might have to reduce the 'best before' period on the label
- Because trans-free fats crystallize much more slowly, additional investment in cooling capacity is required to increase the cooling time for wafer books and enrobings. Additionally a unit for temperature adjustment and mechanical precrystallization is required, or even a full tempering equipment for the cream upfront the cream spreading operation
- In enrobed products, the PHO to be replaced is not the only fat in the system. Fats of different types interact in different ways. The characteristics of the combined fat

phase—especially in terms of melting profile (eutectic softening)—lower crystallization rate, and reduced final hardness must be evaluated

- Trans-free fats behave differently in storage. Partially hydrogenated fats postharden efficiently in storage but this quality might lack after replacement. Possibly a colder intermediate storage area will be required as well
- Replacing partially hydrogenated oils with trans-free ones typically increases the ingredient costs

3.3 LECITHIN AND OTHER EMULSIFIERS IN WAFERS AND WAFFLES

Lecithin and other emulsifiers are minor ingredients with technologically valuable functions in the manufacturing of wafers, wafer cookies, waffles, filling creams and enrobings.

3.3.1 Functions and Types of Emulsifiers

Emulsifiers are active in any kind of interfacial phenomena between immiscible phases such as oil and water by reducing the interfacial energy. Another name for emulsifier is 'surface active substance' or surfactant. Emulsifier molecules such as lecithin consist of a hydrocarbon chain and a polar group. The bipolar chemical structure with a hydrophilic and a hydrophobic part facilitates the dispersion of one phase into the other and stabilizes the resulting emulsion. The hydrocarbon chain has an affinity for lipids, while the polar group has an affinity to water. Emulsifiers with more hydrocarbon groups than polar groups are lipophilic in nature and are at least partially oil soluble. Vice versa, surfactants with a high ratio of polar groups are more hydrophilic in nature and at least partially water soluble. In milk, the proteins for example are efficient emulsifiers for the milk fat.

3.3.1.1 The Various Functions of Emulsifiers

(a) The emulsification of immiscible oil and water phases into small droplets, being stable against coalescence, such as in milk caramel(toffee) manufacturing

(b) To make compatible hydrophobic and hydrophilic materials in disperse systems, such as the fine dispersion of oils/fats in chocolate or filling creams

  - Emulsifiers reduce the viscosity and the yield value in chocolate, enrobings, creams or toffees
  - Emulsifiers improve the wetting of hydrophobic surfaces such as in chocolate conching

(c) The modification of fat crystallization in polymorphic systems (chocolate, cream filling)

(d) Emulsifiers frequently reduce the rate of crystallization with the consequence of a longer cooling time required

(e) Emulsifiers in fat crystallization change the size and shape of fat crystals

(f) Emulsifiers retard an oil migration such as from centre pieces to enrobings

(g) In cold batters, emulsifiers retard the recrystallization of added fats

(h) The dispersion of particles is improved, which avoids flocculation or sedimentation in batters

(i) The conditioning of batter and dough mixes by complexing starch and proteins to do the following:
  - Improve the mixing efficiency and the mixing tolerance
  - Reduce the stickiness of baking masses

(j) Stabilize the surface of gas pores in aerated systems to a more foamy and viscous texture by influencing the size and distribution of pores

(k) The enabling of phase changes such as to facilitate the steam escape in wafer baking (positive) or the migration of moisture into baked wafers (negative)

(l) Crumb softening and antistaling effects in soft bakery products such as in RTE waffles. The complexation of emulsifiers with amylose retards the retrogradation of starch, accompanied by firming the texture

We make use of some of these properties favourably in wafer and waffle manufacturing. The most interesting substances are listed in Table 3.51 together with their HLB (hydrophilic–lipophilic balance) value and typical applications. The HLB system was introduced in 1948 by W.C. Griffin to classify surface active substances according to their lipophilic or hydrophilic character. Most surface active materials are with a range of HLB values from 1 to 20. Values below 10 indicate that the material is more lipophilic. The HLB value for lecithin is for the natural mixture in raw lecithin. All emulsifiers are classified as food additives. Their E-numbers are listed as well in Table 3.51.

Table 3.51 Emulsifiers and Their Application

Substance and E-Number	HLB Value	Potential Applications
Lecithin (E 322)	3–5	Wafer batter, wafer baking and release, wafer cream, enrobings, chocolate, caramel filling
Mono-, diglycerides of fatty acids (E 471)	3–4	Waffles, flute wafer filling, caramel filling
Polyglycerol polyricinoleate PGPR (E 476)	1	Enrobings
Citric esters of Mono/Diglycerides (E 472c)	9–11	Enrobings
Ammonium phosphatides (E 442)	2–3	Enrobings
Polyglycerolesters of fatty acids (E 475)	5–10	Aeration emulsifiers

3.3.2 Lecithin

Lecithin is a natural emulsifier, a byproduct in vegetable oil manufacturing. For human nutrition lecithin is a very valuable nutrient. Apart from the baking industry, lecithin is also used in other food products, as a nutrient in dietetic products and pharmaceuticals, in cosmetics, and as a technical emulsifier. The most common type of lecithin is soy lecithin. However, due to concerns on GMO issues, lecithin from other sources such as canola, corn, sunflower, or peanut is increasingly available. Lecithin, as a synergist, has a slightly antioxidative activity, which may offer some shelf-life extension additionally.

In older wafer recipes, at times when these plant lecithins were not yet available, we find egg yolk, being rich in egg lecithin, regularly as a component.

On the European list of food additives, lecithin has the number E 322, which means it is considered to be a food additive despite its natural origin. Depending on local regulations, the indication of the functional properties of such an emulsifier and/or the substance name (soy) lecithin can replace the E number on the label. With soy-based lecithin the allergen labelling for soy products has to be observed.

3.3.2.1 Commercially Available Lecithin Products

(1) Mostly the cheaper fluid lecithin is used. It typically consists of about 62% lecithin substances (raw lecithin) and 38% soybean oil. If the raw lecithin concentration increases, the mix will become plastic at ambient temperature. For most of our bakery products the use of more highly refined lecithin of a lighter colour is not required

(2) Many companies offer carrier-bound lecithin powders containing fluid lecithin sprayed onto powder carriers such as wheat flour, soy flour, starch, milk-derived powders or lactose. Lecithin powders are of interest primarily for manufacturing plants relying in baking mass preparation fully on dry materials metering. In sugar wafer manufacturing, powder lecithin preparations with milk component carriers have been seen to be quite effective

When comparing the costs, the lecithin content, typically from just 10% to 50% at maximum, as well as the nature of the carrier medium must be considered. The declaration of the manufacturers here refers to the content in fluid lecithin, which has just 62% of the active ingredient raw lecithin

(3) Pure lecithin powders are deoiled and contain from 90% to 97% raw lecithin. These are more expensive but not necessarily better for our bakery products. One advantage is that the highly instable soybean oil part is absent

(4) Fractionated or modified lecithin has an increased HLB value, which in our experience does not result in significant improvements for the kind of products discussed here

3.3.2.2 The Composition of Raw Lecithin

Lecithin chemically speaking is phosphatidylcholine (PC). But every 'raw lecithin' additionally contains a number of related phosphatides (or phospholipids) as well as some glycolipids (Table 3.52). The phospholipids are the active constituents of lecithin. As in any emulsifier they consist of a polar (hydrophilic) and a nonpolar (lipophilic) region in their molecules. Phospholipids may differ in type of polar head group as well as the length and saturation level of the nonpolar fatty acid chains.

All of the raw plant lecithins are obtained during vegetable oil refining. When degumming the crude oil, polar lipids hydrate and separate as 'lecithin sludge', which is processed further by some of these processes, most of them not required for fluid standard wafer lecithin:

- Solvent extraction for deoiling
- Enzymatic modification such as partial hydrolysis
- Fractionation with ethanol for enrichment of phosphatidylcholine (PC)
- Purification by chromatographic methods

Because different phospholipids show individual functionalities, by modification of the phospholipid pattern a variety of products are generated.

3.3.2.3 Issues With Genetically Modified Soybean Lecithin

Since 1995 there has been some discussion on ingredients from genetically modified organisms (GMO), primarily in European countries, with the consequence that some lecithin alternatives were applied in the market:

- Identity preserved (IP) products from certified suppliers, guaranteeing the non-GMO status of their soybean lecithin
- Alternative lecithin preparations in fluid or powders such as from sunflower or canola oil manufacturing
- Reverting back to the old recipes with high egg yolk content, delivering egg lecithin and cholesterol

In case of GMO issues the soybean lecithin replacement would be just a partial solution because soybean in finished products may come from soybean-based cream fats or soy flours as well.

Table 3.52 Composition of Deoiled 'Raw' Lecithins From Various Sources

Origin Lipid	Soybean	Canola	Sunflower	Egg Yolk
Phosphatidylcholine (PC)	20–23	25	25	74
Phosphatidylethanolamine (PE)	16–21	22	11	19
Phosphatidylinositol (PI)	12–18	15	19	<1
Other phospholipids	8–13	24	3	4
Glycolipids	~10	10	–	–

Data from Degussa Food Ingredients leaflet, Düsseldorf, 2004.

3.3.2.4 Physical Characteristics of Lecithin

Raw lecithin is an emulsifier with an HLB value of 3–5, being typical for water-in-oil emulsifiers. As an emulsifier it has a lipophilic, mostly fat-soluble part and a hydrophilic, mostly water-soluble part and tends to concentrate in the interfacial regions of water–oil mixtures. Lecithin disperses in water after intensive mixing only. Then it swells and builds lamellar structures, which become globular in case of increased dilution. The lipophilic fatty acid residues are in the interior of the globules. Lecithin is slightly acidic and has a pH value around 6.

3.3.2.5 Physiologically Advantageous Properties of Lecithin

Lecithin is an important building element in our brain and nerves. There are many claimed positive effects from lecithin consumption for the body:

- Controlling and activating the metabolism of lipids, the liver function, supplying energy for the muscles and brain
- Reducing the recovery time after physical activity
- Improving mental performance, being advantageous for elder people

3.3.2.6 Handling of Lecithin in Manufacturing

Lecithin is sensitive to heat and decomposes with increasing temperature—especially beyond 55°C–60°C, accompanied by darkening to almost black—loss of performance, and an increasingly bitter taste. Phosphatidylethanolamine as well as any lysolecithine present increase the darkening. It is important that the temperature is kept well below 60°C in case of any ball milling or conching operations of fillings and enrobings.

Fluid lecithin preferably is applied in a premix with oil. Quite frequently in batter or dough preparations a fat–lecithin mix is used at a temperature of about 40°C. The advantage is that these premixes are more fluid than the thick, sticky standard lecithin, which improves both the pumping and the automatic dosage. We recommend a separate jacketed, temperature-controlled storage vessel to prepare and keep the mix required for up to 1 day's production. Lecithin–oil premixes are miscible in any proportion, and therefore no emulsions as commonly termed.

Please note: Avoid the preparation of the fat–lecithin premixes for addition to batters directly on a heating plate. If this does occur, overheating, strong darkening and partial or full inactivation of the heat-sensitive lecithin will take place.

3.3.2.7 The Functionality of Lecithin in Wafers and Waffles

(a) Batter preparation

A batter ideally is a suspension of flour in a fluid watery phase. As in wafer batters there is little oil present; lecithin here does not act as an emulsifier primarily, but it is adsorbed together with the oil on the surface of the flour particles. Its function here is that of a wetting and later on of a release agent after the baking step. While lecithin powders are added with other small ingredients to the mixer before the flour, fluid lecithin is added as a premix with oil or warm liquefied fat after the flour is included and mixed up briefly. Lecithin may be applied for dust control in the manufacturing of powder premixes and improves the rewetting of powder premixes (instantinization).

Different dosing levels of fluid lecithin are found in wafer batters:

- From 0.1 to 1.2 parts per 100 parts of flour, quite often 0.2–0.6 parts, with problem flours around 1 part
- In many sugar cone batters the lecithin dosage is on the higher side of that range
- Lecithin powders require at least the same dosage
- For waffle batters the lecithin dosage is found to be related to the smoothness and shine of the waffles surface after baking quite frequently

(b) The baking process

Lecithin has influence on the release of steam during baking, leading to the typical foamed wafer structure due to steam leavening. Lecithin facilitates and accelerates the steaming, which for most products is positive. Lecithin compensates for any negative influence of the hydrophobic oil/fat component in the batter on steam release. The pressure maximum in the initial baking phase is lowered, which is positive for reducing the baking waste flashings. In addition, an interaction with gluten proteins can be assumed. Lecithin is used as a component in release lubricants and sprays

(c) Issues related to lecithin in baking

Besides all the desirable properties, some negative aspects require mentioning:

- Lecithin is not fully neutral in taste, and higher levels result in a side taste
- Lecithin enhances the colour differences between the depositing area and the edges within sheet and cone wafers
- Thermal decomposition of lecithin occurs at the temperatures reached during baking

(d) The mould release

For a smooth demoulding the mould release action of lecithin is essential. The hydrophilic part of the molecule is attached to the starch-gluten structures and the lipophilic part acts in mould release similar to oil.

(e) Lecithin in filling creams and enrobing chocolates—the ‘fat-sparing’ function

The addition of 0.1%–0.3% of lecithin together with the fat typically is sufficient for a reduction in viscosity, if desired. I do not recommend adding much lecithin in hot climate environments because it facilitates the flowing out of cream in finished products at elevated temperatures during distribution. Lecithin moreover retards the fat crystallization in cooling slightly

The question of applying lecithin in wafer creams and enrobings due to its fat-sparing function requires careful consideration.

1. Whenever a *reduction of the fat and calorie content* is a primary goal, lecithin enables a 2% or 3% reduction of fat in the recipe. Thus lower-fat products being comparable in their spreading or enrobing properties as well as in their sensory quality can be manufactured. In chocolates, for example, without the addition of lecithin the cocoa butter would have to be increased by 2%–4% for obtaining similar flow characteristics. Lecithin performs similarly within wafer creams, primarily in refined creams with particle sizes below 30–50 μm
2. However, if *sweetness reduction* is an issue, the application of lecithin is less favourable. Without lecithin a few percent more of fat is required, which reduces the sugar level and improves cream smoothness and eating quality
3. Lecithin improves the *moisture tolerance* of sugar–fat compositions such as creams and enrobings. With the addition of some moisture with small recipe components such as rework, flavours, or acid solutions, the moisture content rises and the flow of the cream/enrobing might be impaired; this is an effect that is counteracted efficiently by the emulsifier lecithin
4. Lecithin in creams and coatings improves the *flavour release* during chewing and eating. The emulsifying action brings smaller oil droplets about, connected to a better flavour release and flavour perception

3.3.3 Monoglycerides and Mono/Diglycerides

Mono/diglycerides and distilled monoglycerides (E 471) are emulsifiers of the same group but with a different application profile.

Mono/diglycerides are manufactured by interesterification from triglycerides and glycerol. Mono/diglycerides are mixtures of mono-, di- and triglycerides, and they emulsify water in oil systems such as in toffee (milk caramel) cooking

Distilled monoglycerides are prepared by molecular distillation from there and have these main functions:

- Being part of aeration emulsifiers in cake and waffle batters, frequently together with propylene glycol esters of fatty acids (E 477). Then air incorporation results in a viscous batter of fine and even porosity. After baking volume, tenderness, and moisture retention are improved
- Monoglycerides prepared from saturated fatty acids are able to complex amylose starch molecules efficiently in the baking process. That complexation results in an increased softness of waffles, cakes, or breads. That effect is primarily governed by monoglycerides with saturated fatty acid chains that interact with the amylose part of the starch

There are two forms of application of distilled monoglycerides

1. Very fine powder for direct incorporation
2. ‘Hydrate paste’, a gel form structured as lamellar phases, prepared after monoglyceride melting and mixing with water, some additives, and cooling. In the paste the alpha

crystal form is stabilized, being the most active one compared to beta or beta prime (Section 3.2.3)

3.3.3.1 Application in Wafers and Waffles

a. For crisp wafers these emulsifiers are less suitable recipe components. The complexation and aeration properties result in a lighter, softer, and more tender wafer texture, being usually overly fragile in further processing. Just in case you require a lower sheet weight and a more tender texture it is recommended to replace part of the lecithin by monoglyceride paste in the recipes. Do not heat or melt the paste but place it directly to the batter mixer

b. In the manufacturing of flute wafers (wafer sticks), monoglyceride fine powder has a lubricant, antiblocking function in direct cream filling. Then the addition of 0.5%–1% of monoglyceride fine powder reduces any blocking of the filler hole, which occurs more frequently in 'white' creams, since they are richer in dairy-based powders

c. In enrobed wafer confectionery products monoglycerides in the enrobing recipe slightly retard the migration of oils into the enrobing

3.3.4 Other Emulsifiers

3.3.4.1 Polyglycerol Polyricinoleate PGPR (E 476)

The review by Bastida-Rodríguez (2013) provides information on general properties and applications of PGPR. In the area of wafers and waffles the main function of PGPR is in enrobings. Adding PGPR raises the fluidity of the enrobing chocolate by reducing the 'yield value'. That allows the ability to apply thinner layers onto wafer cookies and waffles. For the enrobing recipe, a level of about 0.3% lecithin/PGPR mixture in a ratio of 2/1 is a good starting point for obtaining a combined reduction in viscosity and yield value.

In creams for filling flat wafers a reduction in yield value by PGPR is not recommended because the risk of issues with cream flowing out increases.

3.3.4.2 Citric Esters of Mono/Diglycerides (E 472c)

Around 1995 the discussion on GMO in some European countries created demand for lecithin replacement in batter recipes. The Canadian patent application CA 2308294 A1, pages 70 to 71 from 1998 teaches the application of citric esters of mono/diglycerides in sugar wafer cones. In flat wafer manufacturing, from my experience, these emulsifiers offer no advantage in the substitution of lecithin.

3.3.4.3 Ammonium Phosphatides (E 442)

Ammonium phosphatides (AP) are ammonium salts of phosphorylated glycerides, derived from oils such as canola oil. A mono- or diglyceride moiety may be attached to the phosphorus. For AP, JEFCA in 1974 established an ADI of 0–30 mg/kg bodyweight. FDA published a GRAS notification in 2007 for ammonium phosphatide as an emulsifier in chocolate and vegetable fat enrobings for levels up to 0.7%.

AP, another name is lecithin YN, is an alternative for soy lecithin with similar activity. Since the 1960s AP has been applied in the chocolate industry to lower the viscosity and the yield value of chocolates and enrobings.

At present I am not aware of AP applications for batters or creams in wafers and waffles. Potential advantages may be the following:

- AP require neither an allergen labelling nor is there a GMO risk
- They are more neutral in flavour, compared to lecithin
- AP is liquid at ambient and offers an improved thermal stability and less browning compared to fluid lecithin; however there is a higher cost

3.3.4.4 Aeration Emulsifiers

For the aeration of batters/baking masses, frequently combinations of two or more emulsifiers are applied

- Mono- and diglycerides of fatty acids, E 471
- Acetic acid esters of mono- and diglycerides, E 472a
- Lactic acid esters of mono- and diglycerides, E 472b
- Polyglycerol esters of fatty acids, E 475
- Propylene glycol esters of fatty acids, E 477

Monoglycerides in most cases are part of such mixed aeration emulsifiers in powder or paste form. In waffle batters such aeration emulsifiers improve the waffle texture by making it lighter and more tender.

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