Useful Properties of Maltose

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THE MAIN SWEETENERS in commercial starch hydrolysates are D-glucose (dextrose), maltose (4-O-α-D-glucopyranosyl-D-glucopyranose), and D-fructose (levulose). To increase sweetness in some corn syrups, D-fructose is produced by enzymatic isomerization of a part of the D-glucose (1). At present, of these three sugars, only D-glucose is sold at low cost in pure, crystalline form. Dextrose sales amounted to 575,000 tons in 1968 (2). Maltose and D-fructose have not been produced as crystalline sugars on nearly such a large scale.

Recent development of stable isoamylases (amylo-1,6-glucosidases), which completely debranch the amylopectin fraction of gelatinized starch to linear polyglucose segments (3,4,5), coupled with the availability of low-cost β-amylase extracted from wheat bran (6), has now made feasible a large-scale, economical production of maltose from starch (7). Whereas, much is known about the properties of dextrose that govern its uses, much less is known about the corresponding properties of maltose sugar.

Our investigation of maltose properties was also prompted by the doubt that has been cast on the healthfulness of our common table sugar, sucrose; i.e., for classes of people (or strains of rats) with certain types of metabolic aberrations (8-15). Among the ill effects attributed to high-sucrose diets that have been observed in some experimental animals and humans are: increased triglyceride and cholesterol levels in the blood, sticky blood platelets, hyperinsulinism, atherosclerosis, fatty livers, enlarged kidneys, slower growth rates, shorter life spans, and increased incidence of dental decay. Comparable experiments with starch, starch hydrolysates, maltose, and dextrins were quite acceptable.

Levulose may not be acceptable if sucrose is not. It might be that the D-fructose half of sucrose, produced by hydrolysis in vivo, is a major cause of increased blood-lipid levels and fatty deposits in susceptible people (9,15). If future research finds this to be true, then pure D-fructose would be eliminated as a possible contender on the sweetener market.

Should we consider lactose, so much of which is being wasted today? Of all the common sugars, lactose has the lowest sweetness—moderate amounts are tolerated by most people but large amounts have induced diarrhea and cataracts; furthermore, a few people cannot digest lactose at all and become quite ill from it. Physiologically ill effects have also been reported for galactose, xylose, and lyxose, whereas mannose is bitter, as well as sweet, and is poorly regulated in the diets of a significant number of people for health reasons. The question then arises whether industry would have available suitable replacements for sucrose. We must realize that here we are talking about the most widely used sweetener in foods—more than 10 million tons is consumed each year in the U.S. alone.

For industrial use, liquid starch hydrolysates would probably fill the bill. Starch hydrolysates already have replaced some of the sucrose in many food applications. But what would we use for household sugar? We have become accustomed to handling sugar in a dry, crystalline, free-flowing form. Can we provide sweet starch hydrolysates in a suitable dry, nonhygroscopic, free-flowing form?

Crystalline dextrose would be among the first to be considered as a substitute for table sugar. However, experimental subjects have rejected daily high-dextrose diets, because of nausea, dizziness, and an unpleasant quality of sweetness believed to be inherent in dextrose (15). On the other hand, D-glucose syrups (starch hydrolysates) containing maltose and dextrins were quite acceptable.

Levulose may not be acceptable if sucrose is not. It might be that the D-fructose half of sucrose, produced by hydrolysis in vivo, is a major cause of increased blood-lipid levels and fatty deposits in susceptible people (9,15). If future research finds this to be true, then pure D-fructose would be eliminated as a possible contender on the sweetener market.

Let us suppose that these findings against sucrose will stand affirmed and that the consumption of sucrose may be
metabolized (16). One can conclude that the human body is structured to favor D-glucose metabolism. Normally, it will tolerate other sugars, but D-glucose is preferred.

Among the innocuous sugars that might readily be produced in large quantities for table use is maltose. Maltose is hydrolyzed to D-glucose in vivo. Admittedly, maltose is only about one-half to two-thirds as sweet as dextrose in aqueous solutions; but unlike dextrose, it gives a highly acceptable quality of sweetness. Rats have shown a preference for maltose solutions over those made of dextrose or sucrose (17,18). In caramelization and sugar-amine browning reactions, maltose produces more of the sweetness-enhancer maltol than either dextrose or sucrose (19,20,21). Is maltose an acceptable candidate for our household sugar of the future? The answer to this question will come as we accumulate more knowledge on the properties of crystalline maltose: its solubility, osmotic, hygroscopicity, complexing, and sweetness properties in foods. We have begun to know more about these properties, and shall review some of our results.

Several years ago we tried to find recorded evaluations of the sweetness of readily prepared derivatives of maltose, such as the reduction product maltitol (4-O-α-D-glucopyranosyl-D-glucitol) and the ketose isomerization product maltulose (4-O-α-D-glucopyranosyl-D-fructose). The literature was bare. We prepared pure maltitol from maltose by sodium borohydride reduction, acetylation to the crystalline nonaacetate, and then deacetylation (22). We judged maltitol to be much sweeter than maltose and just about as sweet as sucrose in 20% aqueous solutions. Furthermore, the quality of maltitol sweetness seemed to be above reproach. Other investigators have also reached similar conclusions (23). So here is another starch-derived sweetener whose properties should be examined in detail to determine its usefulness. Maltitol is claimed to be a dietetic sweetener, a crystallization-inhibiting thickener, a humectant, and a stabilizer (23).

We have prepared maltulose by chemical isomerization of maltose with sodium aluminate. Proceeding from advice by Frederick W. Parrish of the U.S. Army Natick Laboratories, we used the method that Boehringer and Sons have patented for converting D-glucose to D-fructose (24), and that Guth and Tumerman recently patented for converting lactose to lactulose (25). Although these patents claim only 70% conversions, we obtained 95% conversions of maltose to maltulose.

We developed a gas-chromatographic method for estimating maltulose in mixtures with maltose, D-fructose, and D-glucose. Figure 1 shows the results of a partial isomerization of maltose in aqueous solution, with dicyclohexylamine as the base (26). The maltulose peak is positioned between the two maltose peaks. Although there is some overlap here, the separation achieved allowed us to follow developments of the maltulose peak in isomerization mixtures. By programming the gas chromatograph over temperature, we could also estimate the concentrations of D-glucose and D-fructose present in the reaction mixture.

Figure 2 shows the increasing yield of maltulose obtained upon heating maltose in aqueous sodium aluminate at 50°C., pH 11.5, for 2, 3, and 5 hr. Samples of the reaction mixture were evaporated with pyridine under vacuum before trimethylsilylation and injection into the gas chromatograph (27). Very little color and decomposition develop by the aluminate method, and pH remains nearly constant throughout the heating period. After 6 hr. conversion is nearly quantitative.

The alumina was precipitated from the reaction mixture as aluminum hydroxide, and D-glucose and D-fructose were extracted from the deionized, concentrated filtrate with acetone. When the syrupy product was extracted with boiling absolute ethanol, a molecular complex containing one-half mole of ethanol and one-half mole of water per mole of maltulose was crystallized. This complex was very hygroscopic. It required several cycles of hydration and dehydration under vacuum to remove the complexed ethanol.

By superficial testing, maltulose was judged sweeter than maltose, but not so sweet as maltitol or sucrose. Sophisticated evaluations of the sweetness of maltitol and maltulose in relation to sucrose are now being conducted by Howard Moskowitz at the U.S. Army Natick Laboratories.

We have not yet obtained a nonhygroscopic solid form of maltulose, or of maltitol. Maltitol also can be crystallized
as a hygroscopic ethanol complex. Let us turn now to the several properties of maltose that we have studied.

**Crystalline Forms of Maltose**

Maltose has been difficult to prepare in a pure form, free of oligosaccharides and dextrins. Several of the physical properties of maltose reported in the literature are inaccurate. The few sweetness values that have been reported on maltose were obtained without reference to its purity.

Crystalline maltose hydrate of the purest grade available commercially, and purchased from five different suppliers, contained only 90 to 92% maltose on a dry basis, as estimated by J. Lehrfeld of our group using quantitative gas chromatography. Three paper chromatograms that he obtained for maltose are seen in Fig. 3.

![Fig. 3. Paper chromatograms of purified maltose (A) and commercial maltose (B and C). Chromatograms A and B were first sprayed with amyloglucosidase and then dipped into alkaline silver reagent. Chromatogram C was treated only with alkaline silver reagent.](image)

Chromatogram A is purified maltose. Chromatogram B is commercial maltose in which the oligosaccharide and dextrin impurities have been made clearly visible. Both chromatogram A and B were first sprayed with amyloglucosidase to hydrolyze any dextrins to glucose before application of alkaline silver reagent. Chromatogram C is commercial maltose that was treated only with alkaline silver reagent. A comparison of C with B shows that without an amyloglucosidase treatment, all the dextrins present in a commercial sample are not revealed (28).

As we shall see, the 8 to 10% of D-glucose, oligosaccharide, and dextrin impurities greatly affects the solubility and hygroscopicity of maltose. We prepared D-glucose- and oligosaccharide-free β-maltose hydrate from amyllopectin and pure β-amylase by our published method (29). Properties of this pure maltose hydrate were compared with those of commercial maltose hydrate.

**With Vacuum**

\[
\begin{align*}
\text{At } 40^\circ: & \quad \beta(99\%) \cdot \text{Maltose} \cdot H_2O \quad \rightarrow \beta(93\%) \cdot \text{Maltose} \\
& \quad \text{[m.p. 122-125]} \quad \text{[m.p. } \sim 120-125]\ \\
\text{At } 56^\circ: & \quad \beta(99\%) \cdot \text{Maltose} \cdot H_2O \quad \rightarrow \beta(93\%) \cdot \text{Maltose} \\
& \quad \beta(96\%) \cdot \text{Maltose} \cdot H_2O \quad \rightarrow \beta(93\%) \cdot \text{Maltose} \\
\text{At } 92^\circ: & \quad \beta(96\%) \cdot \text{Maltose} \cdot H_2O \quad \rightarrow \beta(87\%) \\
\end{align*}
\]

**Without Vacuum**

\[
\begin{align*}
\text{At } 92^\circ: & \quad \beta(95\%) \cdot \text{Maltose} \cdot H_2O \quad \rightarrow \beta(67\%) \cdot \text{Maltose} \\
\text{At } 120^\circ: & \quad \beta(90\%) \cdot \text{Maltose} \cdot H_2O \quad \rightarrow \alpha(73\%) \cdot \text{Maltose} \\
& \quad \text{[m.p. 121-125]} \quad \text{[m.p. 166-175]} \\
\end{align*}
\]

Fig. 4. Dehydration of crystalline β-maltose-H₂O under various conditions of temperature and pressure.

Anhydrous, Crystalline β-Maltose

The anhydrous β-form of maltose has not been accurately defined because, in its preparation from the β-hydrate, there is difficulty in removing water of hydration, and heating the hydrate causes anomerization of the maltose from the β-form to the α-form. Commercial maltose hydrate is already 5 to 10% anomerized. We followed the anomerization of maltose hydrate through different heating and drying processes by gas chromatography (Fig. 4). Even with the mildest drying at
40°C. under high vacuum, which required 3 weeks to lose 5.0% water. β(99%)-maltose hydrate was anomerized to anhydrous β(93%)-maltose. Stronger heating conditions dehydrated the maltose faster, but high vacuum was necessary to prevent greater anomerization of the β-form to the α-form. Heating without a vacuum extensively anomerized the maltose at 92°C. At 120°C., the β(90%)-anomer, which melts near 125°C., was converted to an α(73%), β(27%)-anomeric complex that showed a much higher melting range (168° to 175°C.).

Figure 5 shows a scanning electron microscope (SEM) picture of pure β-maltose hydrate crystals, as obtained by a slow recrystallization from aqueous tetramethylurea. Other solvents lead only to complex clusters of microcrystals not suitable for detailed X-ray studies. Even in aqueous tetramethylurea, there is a tendency to develop complex clusters; yet, a few isolated, thin, triangular plates can be seen. These are approximately 0.1 mm. across and very thin.

Fragments of larger crystals of β-maltose hydrate (Fig. 6a and 6b) were examined at a magnification five times lower than that used for Fig. 5. In Fig. 6c are shown similar fragments that have been dehydrated at 56°C. under high vacuum. At first glance, dehydration appears to have caused little change in the chunky, crystalline forms. However, we do see a more rounded shape and notice that several fissures developed when the hydrate water vapor escaped. Furthermore, the dehydrated fragments are easily crumbled and seem to be composed of small microcrystals. An X-ray-diffraction pattern of these microcrystals is entirely different from that of the parent β-maltose monohydrate. So, with proper drying under high vacuum, anhydrous crystalline β-maltose can be obtained, with an increase of only 6% in the α-anomeric content. This form is extremely hygroscopic and soon reverts to the β-monohydrate on standing in humid air. It does not appear to be useful—only novel.

**Anhydrous, Crystalline α,β-Complex of Maltose**

Another new crystalline form of maltose was obtained by heating the β-form, anhydrous or hydrate, either in molten form or in a partial solvent. We saw in Fig. 4 that merely heating β-maltose hydrate at atmospheric pressure at 120°C. for 1 day converts it to α(73%)-maltose melting at 168° to 175°C. There the anomerization stops.

Table I shows the results of treating β-maltose with anhydrous solvents (water excepted) in which it is partially or completely soluble. For most of the listed solvents, conversion to a regular composition of α- and β-anomeric forms is evident. The fairly narrow melting ranges, considered with the consistent 3:1 ratio of anomers, indicate a crystalline molecular addition compound of α-maltose and β-maltose.

To obtain the crystalline complex from an aqueous 60% (wt./wt.) maltose syrup, it was necessary to evaporate the water from a layer of the syrup at 80° to 100°C. When the concentrated syrup became tacky, it was seeded while hot to crystallize the high-melting α,β-complex. A 70% yield of α(70%)-maltose was obtained after washing the filter cake with methanol.

Spray-dried maltose syrup made from a commercial
Table I. Conversion of β-anomer to crystalline α,β-maltose complex

<table>
<thead>
<tr>
<th>Solvents</th>
<th>Temp. °C</th>
<th>α (%)</th>
<th>M.P. °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-Methoxyethanol</td>
<td>25</td>
<td>73</td>
<td>163-167</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>77</td>
<td>170-173</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>72</td>
<td>172-177</td>
</tr>
<tr>
<td>Methanol</td>
<td>66</td>
<td>79</td>
<td>181-185</td>
</tr>
<tr>
<td></td>
<td>100 (sealed tube)</td>
<td>77</td>
<td>165-179</td>
</tr>
<tr>
<td>Water</td>
<td>98</td>
<td>70</td>
<td>166-167</td>
</tr>
<tr>
<td>1,4-Dioxane</td>
<td>100</td>
<td>70</td>
<td>163-165</td>
</tr>
<tr>
<td>γ-Butyrolactone</td>
<td>100</td>
<td>68</td>
<td>164-166</td>
</tr>
<tr>
<td>1-Propanol</td>
<td>100</td>
<td>74</td>
<td>164-166</td>
</tr>
<tr>
<td>1-Butanol</td>
<td>100</td>
<td>77</td>
<td>165-167</td>
</tr>
<tr>
<td>Benzyl alcohol</td>
<td>100</td>
<td>72</td>
<td>165-168</td>
</tr>
<tr>
<td>Tetramethylurea</td>
<td>95</td>
<td>75</td>
<td>...</td>
</tr>
</tbody>
</table>

Fig. 7. SEM photograph of α,β-maltose complex prepared in γ-butyrolactone. View is of the surface of a spherical crystal aggregate.

Maltose of 92% purity, and containing 0.7% water, consisted of amorphous beads of 48% α, 52% β-maltose. When this product was refluxed overnight in anhydrous methanol or isopropanol, a crystalline 3:1 α,β-complex was obtained.

The crystallinity of the α,β-complex can be observed by means of scanning electron microscopy. Figure 7 is a photomicrograph of typical conglomerates of microcrystals that make up the surface of a particulate cluster. In one experiment, however, we were pleasantly surprised when large single crystals were deposited from a heated methanol solution of an impure commercial maltose, after charcoal treatment and the addition of propanol. Figure 8a shows these crystals as they are seen through an ordinary low-powered microscope. They measure about 2 mm. across. In Fig. 8b, the same crystals are viewed by polarized light. Note that one of the crystals is oriented so as to nearly extinguish the polarized light. The interference patterns seen on the sloping edges of the crystals are like those seen for quartz crystals. They should not be interpreted as an indication of a laminated crystal structure. Yet, we wonder how anhydrous β-maltose is contained in these crystals.

Fig. 8. Photomicrographs of single crystals of α,β-maltose complex grown in methanolic media: a) under ordinary light, and b) under polarized light. Crystals measure approximately 2 mm. across.

These well-formed crystals were shown by gas chromatography to have an anomeric composition corresponding, within 1%, to four molecules of α-anomer per one of β-anomer (80% α, 20% β). Although one-fifth of the crystal is anhydrous β-maltose, we could find no trace of the anhydrous β-maltose X-ray-diffraction pattern. The diffraction pattern for these crystals was distinctly different from that for either the anhydrous or the hydrated β-maltose. Furthermore, although anhydrous β-maltose is very hygroscopic, the crystalline α,β-complex is not. For example, the 3:1 or 4:1 α,β-complexes have remained anhydrous and stable through storage for several months at 25°C. under constant 71% relative humidity (r.h.).
Anhydrous, Crystalline $\alpha$-Maltose

The most surprising property of the crystalline 3:1 or 4:1 $\alpha,\beta$-complex of anhydrous maltose is that the $\beta$-maltose part can be extracted from the crystals without changing the X-ray-diffraction pattern. We have extracted the $\alpha,\beta$-complex by successive brief treatments with warm methanol, or cold, aqueous 2-methoxyethanol. These extractions cause a gradual rise in the $\alpha$-anomeric content, with accompanying elevations of melting point and specific optical rotation (Fig. 9).

Finally we achieved a residual $\alpha$ (94 to 95%)-maltose, melting at 191° to 193°C., $\left[\alpha\right]_D^{25} + 175^\circ$ in dimethylformamide. The X-ray-diffraction pattern of this highest purity $\alpha$-maltose was qualitatively the same as that of the crystalline $\alpha,\beta$-complex, but the concentric rings were more sharply defined. The unanswered question is, how can well-formed crystals lose 15 to 20% of their solid content and still not lose their specific X-ray-diffraction pattern?

Solubility of Maltose Anomers

When reducing sugars are dissolved in water, they come to an equilibrium of anomic forms. We usually follow this anomerization by the change in optical rotation known as mutarotation. Anomerization also can be followed by gas chromatography. With maltose, equilibrium is established at 42% $\alpha$, 58% $\beta$-anomer, as determined by gas chromatography. Because it takes time for sugars to dissolve in water, solubilities of pure anomeric forms at zero time are difficult to measure; however, one of us (Rendleman) has estimated the solubility of anomerically pure $\alpha$-maltose at 20°C. to be near 175 g. per 100 ml. of water or 64% by weight, whereas the solubility of $\beta$-maltose hydrate is only 39 g. per 100 ml. of water, or 28% by weight (Table II). His method for determining these values consisted of: 1) stirring a mixture of water and excess sugar at 20°C. until saturation was attained, 2) centrifuging the resulting mixture, and then 3) analyzing polarimetrically a weighed portion of the centrifugate for total maltose content. Finally, from a knowledge of rates of anomerization, anomic purity of starting material, and length of time between mixing and centrifugation, the solubility of pure anomer could be calculated. Polarimetry cannot ordinarily be used to determine the solubility of commercial-grade maltose, because of the presence of optically-active impurities that lead to erroneous results. Saturated solutions of commercial maltose are best analyzed by quantitative gas chromatography where an internal standard is employed.

Anhydrous, amorphous, commercial maltose (prepared by spray-drying an aqueous solution) has a solubility of at least 60% by weight at 20°C. The addition of seed crystals of $\beta$-monohydrate to a 60% solution of commercial maltose initiates a crystallization of $\beta$-monohydrate that is extremely slow; even after four weeks, the concentration of maltose is still very high, about 56% by weight. Because
60% solutions (supersaturated) of highly purified β-monohydrate do not exhibit this unusual behavior, it appears that the oligosaccharide and dextrin impurities in commercial maltose greatly affect the rate of crystallization of β-monohydrate and, probably, its solubility.

Anhydrous β-maltose is quickly and extensively soluble in absolute methanol, whereas the β-monohydrate is much less soluble at the outset. Apparently, the intermolecular forces within the crystalline hydrate are much stronger than those within the anhydrous β-form. It is possible that anhydrous β-maltose accepts methanol at the same site that binds a molecule of water in crystalline β-monohydrate.

Complexing Properties of Maltose

Maltose forms complexes with many polar compounds. Some of those isolated and analyzed are given in Table III. α-D-Glucose does not form isolable complexes with these compounds as does maltose, except for the crystalline 1:1 complex with urea. β-D-Glucose does not form an isolable urea complex. The maltose complexes are not crystalline and are generally hygroscopic. They may contain different ratios of α- to β-anomer, but often we measured very close to a 1:1 anomic ratio. Several other organic compounds could have been included here. Flink and Karel (30) demonstrated that small amounts of several organic solvents, especially alcohols, are entrapped in freeze-dried solutions of sugars, including maltose. In our own experiments, we have found that maltulose, an isomeric form of maltose, probably has a higher affinity than maltose for alcohols and esters. Complexes of maltose or maltulose with flavor compounds should be investigated to promote the preservation of food flavors during dehydration processes.

<table>
<thead>
<tr>
<th>Compound</th>
<th>α-D-Glucose: Compound</th>
<th>α,β-Maltose: Compound</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urea</td>
<td>1:1</td>
<td>4:1, 2:1, 1:1</td>
</tr>
<tr>
<td>Thiourea</td>
<td>−</td>
<td>2:1</td>
</tr>
<tr>
<td>Methylurea</td>
<td>−</td>
<td>2:1</td>
</tr>
<tr>
<td>Imidazole</td>
<td>−</td>
<td>2:1</td>
</tr>
<tr>
<td>Methanol</td>
<td>−</td>
<td>2:1</td>
</tr>
<tr>
<td>2-Oxazolidinone</td>
<td>−</td>
<td>+</td>
</tr>
<tr>
<td>N,N-Dimethylformamide</td>
<td>−</td>
<td>+</td>
</tr>
<tr>
<td>Hexamethylphosphoramide</td>
<td>−</td>
<td>+</td>
</tr>
</tbody>
</table>

* A negative sign indicates that attempts to isolate a complex were unsuccessful.

Hygroscopicity of Maltose

The solubility of β-maltose in water and the extent of its water sorption in humid atmospheres depend largely upon its purity with respect to oligosaccharides and dextrins. In Fig. 10 is plotted the water sorption by pure, anhydrous β-maltose at 84% r.h. compared to that of a commercial product. The lower curve shows that pure, anhydrous β-maltose rapidly takes up slightly more than the 5% water needed to form the monohydrate; but, as the monohydrate crystallizes (within less than 1 day), the water content remains constant at 5.0 to 5.1% indefinitely. The pure β-monohydrate is stable at 84% r.h. On the other hand, the commercial β-hydrate that contains about 8% oligosaccharides and dextrins equilibrates at 6.5% water content. If the commercial β-maltose hydrate is first dried (with 5 to 10% anomerization) and then subjected to humidification, its weight increases by 12% in 1 day, before slowly diminishing to a constant 8.5%. Note that it does not return to the 5% level of pure β-maltose hydrate. If commercial maltose is dissolved in a minimum amount of water by heating and then spray-dried, the fine, amorphous beads that form show a 50:50 ratio of α- to β-anomer by gas chromatography and a water content of 0.7%. This amorphous 1:1 anomic form, at 84% r.h., takes up 20% water within 2 days (5 moles per mole of maltose). When crystallization of the hydrate begins, the water content slowly returns to about 8.5%, the same as for the anhydrous β-anomer from commercial maltose.

Hygroscopicity of anhydrous α-maltose or of the anhydrous, crystalline 3:1 α,β-complex is not evident at 71% r.h.; but at 84% r.h., like dextrose and sucrose (31), they both take up water very slowly and continuously (Fig. 11). They anomerize as the water is sorbed, and finally, after 2 to 3 months, only crystalline β-monohydrate remains.

Apparently the β-monohydrate is the most stable form of maltose. Nevertheless, crystallization of the α,β-complex could be advantageous commercially (Table IV). Here are compared properties of the α,β-complex and the β-monohydrate of maltose. In the crystalline 3:1 or 4:1 complex, there would be 5% less weight to transport per lb. of useful sugar. The complex is more quickly soluble in cold water. It might be crystallized either on a drum dryer or by recycling spray-dried syrup with seed crystals through the same or a second spray dryer. It crystallizes quickly from syrup in comparison with the β-hydrate. It is clearly the less-soluble form at elevated temperatures when the water content is minimal. Its high melting and decomposition points render it more stable to thermal degradation and caramelization reactions.

For many years, two crystalline forms of dextrose have been sold—the monohydrate and the anhydrous. If markets for crystalline maltose should develop, we would now have a choice between two stable crystalline forms of maltose—the monohydrate and the α,β-anhydrous.
TABLE IV. COMPARISON OF PROPERTIES OF TWO STABLE CRYSTALLINE FORMS OF MALTOSE

<table>
<thead>
<tr>
<th>Property</th>
<th>α-Maltose</th>
<th>β-Maltose + H₂O</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anhydrous</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nonhygroscopic at 71% relative humidity</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High m.p., &gt;165°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dissolves rapidly in cold water</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crystallizes quickly from hot, viscous syrups</td>
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</table>

**Summary**

Technology is now available for preparing starch hydrolyzates that contain 90% or more maltose. Maltose should be a desirable sugar from a physiological standpoint. Its sweetness is low in water solutions, but the quality of its sweetness is high. Sweeter carbohydrates are obtained from maltose by isomerization to maltulose or by reduction to maltitol. Solubility and hygroscopicity properties of maltose vary widely with its purity and anomeric composition. Maltose forms complexes with many polar organic compounds. To promote markets for maltose, we have shown that 90% syrups can readily be crystallized in a new stable, anhydrous, high-melting form that contains 75 to 80% α-maltose and 20 to 25% β-maltose.

**Acknowledgments**

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