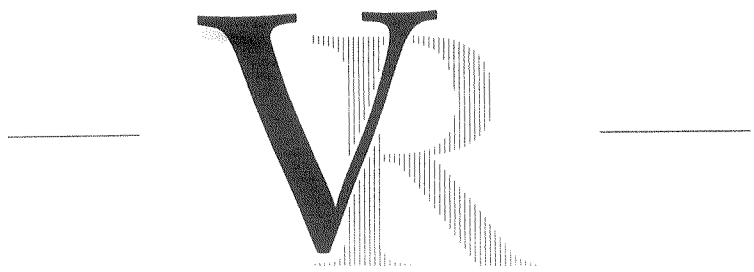
VOEDINGSRAAD

The energy value of sugar alcohols



NUTRITION COUNCIL

THE ENERGY VALUE OF SUGAR ALCOHOLS

Recommendations of the Committee on Polyalcohols.
The Hague, June 1987.

NUTRITION COUNCIL

Advisory Board to the Minister of Welfare, Health and Cultural Affairs and to the Minister of Agriculture and Fisheries, regarding Nutrition and Food Supply.

Set up pursuant to the Act of 23 June 1952 (Stb. 350)

THE ENERGY VALUE OF SUGAR ALCOHOLS

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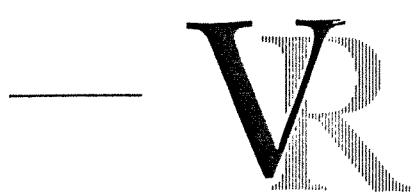

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SUMMARY

In 1986 the State Secretary for Welfare, Health and Cultural Affairs requested the Nutrition Council to recommend a realistic set of energy values for sugar alcohols. This report, which has been written in response to the request first defines the terms energy content and energy value, before proceeding to describe the chemical structure of the compounds concerned. A classification system in terms of monosaccharide, disaccharide and oligosaccharide sugar alcohols has been used throughout this report.

The energy value of sugar alcohols can be determined in various ways. These include both techniques based on direct or indirect measurements, as well as factorial methods. The committee felt that there was insufficient evidence to be able to draw firm conclusions regarding the energy values of sugar alcohols from the results of direct or indirect measurements. The energy value of 2 kcal/g (8.4 kJ/g) given for isomalt and maltitol in Swiss legislation is mainly based on this type of investigation. These values are not significantly different from those arrived at by the committee by means of the factorial method. However, the committee is of the opinion that the latter values are more soundly based. After all, the factorial approach involves separate assessments of the various processes which determine the amount of energy that is eventually used by the body.

The energy value of sugar alcohols is primarily dependent on the percentage that is actually absorbed in the small intestine. This process mainly concerns the absorption of hydrolysis products rather than the original polyols. A further consideration is the extent to which the body can use the energy from sugar alcohols following absorption in the small intestine. A third factor of importance for determining the energy values of these compounds relates to the processes which occur in the large intestine. This specifically concerns the remaining products not already absorbed through the intestinal wall. As a result of the lack of oxygen in the large intestine the decomposition of sugar alcohols produces volatile fatty acids, occasionally lactic acid, carbon dioxide, hydrogen, sometimes methane, bacterial growth and some heat. It is therefore important to know how much energy is lost in this process in order to be able to determine the energy value of sugar alcohols.

The following equation can be used to calculate the energy value (E_W) of a sugar alcohol (without water of crystallization):

$$E_W = [(A \times B) + (1 - A) \times 0.5] \times 16.5 \times R_e \text{ kJ/g}$$

where for the particular sugar alcohol concerned:
A = the fraction absorbed from the small intestine;
B = the fraction utilized by the body after absorption from the small intestine;
R_e = the ratio of the energy content of the alcohol concerned compared with

that of saccharose;
0.5 = the proportion of utilizable energy available from the large intestine;
16.5 = the energy content of saccharose in kJ/g.

Using this method, the following approximate energy values can be determined: xylitol 15 kJ/g, sorbitol 12.5 kJ/g, mannitol 8 kJ/g, maltitol 12 kJ/g, isomalt 10 kJ/g and lactitol 8.5 kJ/g. All the above values refer to compounds in their dry state, without water of crystallization.

It should be noted that the calculations have been carried out for situations in which complaints such as diarrhea and flatulence do not occur. Such problems can be avoided if the maximum daily intake is limited to 20 g.

The energy values which have been calculated by the committee must be regarded as preliminary estimates. As soon as more accurate data become available, these values will be modified by substituting new information into the equation above.

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1. Introduction.

In September 1986 the State Secretary for Welfare, Health and Cultural Affairs requested the Nutrition Council to recommend realistic energy values that could be applied to the various sugar alcohols designed to be used as substitutes for sugar (Appendix 1). To authorize the use of sweeteners such as sugar alcohols, estimates are required of the amount of energy they provide in order to specify the nutritional values of food products.

It was requested that the above recommendations be drawn up as quickly as possible and in view of this, the Chairman of the Nutrition Council convened a committee to specifically address these matters under article 9 of the Council's charter. The committee was made up of the following members:

Chairman: prof.dr. A.J.H. van Es, Associate Professor, Department of Animal Physiology, Agricultural University, Wageningen.
*Secretary:*ir. A. van Beem, Nutrition Council, Secretariat, The Hague.
Nutrition Council Member: dr. W.H.M. Saris, Senior Lecturer, Human Biology Department, University of Limburg, Maastricht.
Experts: dr. D.C. Leegwater, biochemist/toxicologist, TNO-CIVO Toxicology and Nutrition Institute, Zeist; drs. E.J. Sinkeldam, biologist/toxicologist, TNO-CIVO Toxicology and Nutrition Institute, Zeist.

Although the term "polyols" was used in the official letter requesting advice on this subject, the committee felt that it would be more appropriate to adopt the term "sugar alcohols" as this more precisely describes the compounds concerned. The group of substances known as polyols (or polyalcohols) contain more compounds than the specific class of sugar alcohols, which as energy-containing sweeteners find application as substitutes for sugar. In addition, the committee has also included isomalt among the group of sugar alcohols to be considered, as a significant amount of research has been carried out on this compound.

The energy value that is generally attributed to sugar alcohols and which is currently specified in the legislation is 17 kJ/g. Switzerland has, however, adopted a value of 2 kcal/g (8.4 kJ/g) in its legislation for isomalt and maltitol. This came about as a result of the manufacturers of these products being able to convince the Swiss authorities of the validity of their case; hence the formal adoption of these values in the laws of that country.

Sugar alcohols can be classified as either monosaccharide, disaccharide or oligosaccharide sugar alcohols. In considering the energy value of these compounds, a distinction needs to be made between the various groups. In the case of monosaccharide sugar alcohols, the energy value depends on the amount of absorption that takes place from the small intestine and on the degree of fermentation of the remaining product which occurs in the large intestine. For the disaccharide and oligosaccharide sugar alcohols it is important to know what proportion of the product can be absorbed directly from the small intestine and what proportion can be

absorbed after hydrolysis has taken place. In addition the possible fermentation process of the remaining product reaching the large intestine must be considered.

When sugar alcohols are used to replace saccharose in food-stuffs it should be realized that the intake of such compounds can influence the total amount of energy absorbed from the food ingested. The overall energy value could, for instance, be affected by sugar alcohols competing with monosaccharides to be actively absorbed through the intestinal wall, as well as by change in transit time of the food through the intestinal tract. At the moment, insufficient knowledge is available to be able to quantify these effects.

In this advisory report energy values of sugar alcohols are derived under the condition that the amount of sugar alcohols ingested is below the level at which complaints such as diarrhea and flatulence are likely to occur. An amount of 20 g per day is normally regarded as a safe upper limit in this respect (1, 2). The susceptibility of people to ingesting larger amounts, very much depends on the individual concerned. When complaints occur as a result of using sugar alcohols, it should be assumed that the metabolism of the body has been disturbed to such an extent that the amount of energy absorbed from these compounds and from the remainder of the food, will decrease.

For the purpose of this advisory report the following definitions have been adopted in respect of energy content and energy value:

* The energy content of a sugar alcohol is taken to be the amount of energy released during its complete oxidation to carbon dioxide and water.
* The energy value of a sugar alcohol is taken to be the proportion of the energy content which can actually be used by the body.

The energy value of macro-nutrients is usually calculated on the basis of the energy content of the products concerned, with an allowance being made for the energy losses associated with the faeces and urine. Normally, in such calculations fixed coefficients are taken to represent the losses associated with the faeces and urine. However, in the case of sugar alcohols it appears that other factors must be used to describe the amount of energy loss encountered. In addition the body forms less ATP per unit energy content from the conversion products of sugar alcohols absorbed from the large intestine, than from monosaccharides absorbed from the small intestine. This results in the energy values of sugar alcohols being lower than the value of 17 kJ/g that up to now was always assumed, based on the generally accepted methods of calculating this quantity.

As in the majority of studies carried out in this field, it was decided to adopt the convention of comparing the energy value of sugar alcohols with that of saccharose. This reflects the fact that the chief use of sugar alcohols is as a replacement for saccharose.

2. Chemical structure of sugar alcohols.

2.1 Monosaccharide sugar alcohols.

The pentitol, xylitol and the hexitols, sorbitol (synonym: glucitol) and mannitol belong to the group of monosaccharide sugar alcohols. The chemical structure of these compounds is shown in figure 1.

These compounds are commonly found in a large number of plants and are produced industrially by the catalytic hydrogenation of xylose, glucose and fructose respectively.

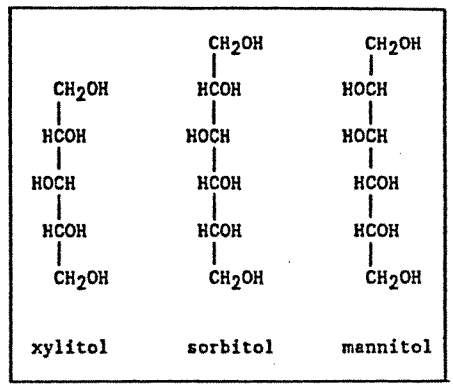

Figure 1.

2.2 Disaccharide sugar alcohols.

Maltitol (trade name: Maltit), isomalt (trade name: Palatinit) and lactitol (trade name: Lacty) belong to the disaccharide sugar alcohols. The chemical structure of these compounds is given in figure 2. These compounds do not occur naturally, but are manufactured industrially.

Maltitol is a dissacharide with an alpha glycoside link (alpha-1,4-glucopyranosylsorbitol). It is produced by the catalytic hydrogenation of maltose.

Isomalt is an equimolar mixture of two dissacharides both with alpha glycoside links, namely alpha-1,6-glucopyranosylsorbitol and alpha-1,1-glycopyranosylmannitol. It is manufactured by the catalytic hydrogenation of palatinose (alpha-1,6-glycopyranosyl-fructose). The commercial product Palatinit contains 5% water of crystallization.

Lactitol is a dissacharide with a beta glycoside link (beta-1,4-galactosylsorbitol). It is produced by the catalytic hydrogenation of lactose. The commercial product Lacty contains 9.5% water of crystallization.

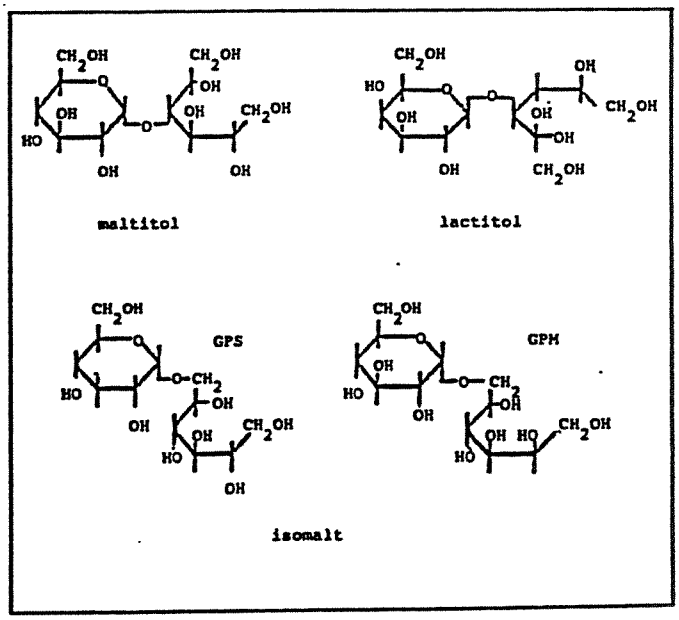

Figure 2.

2.3 Oligosaccharide sugar alcohols.

Catalytic hydrogenation of glucose syrup, which results from the partial hydrolysis of starch, produces a product that consists of a mixture of sorbitol, maltitol, maltotriitol and higher polyglucosylsorbitols with alpha glycoside links. Hydrogenated glucose syrup, as defined in the Commodities Act, is a mixture containing 50-95% maltitol, <8% sorbitol, 5-25% maltotriitol and <30% other polyols.

Lycasin is one of the products that belongs to this group of compounds. However, an exact composition cannot be given for Lycasin since this varies as a function of the raw materials used. According to the specification "Lycasin 80/55" contains: 7% sorbitol, 52% "hydrogenated disaccharides", 23% "hydrogenated trisaccharides up to heptasaccharides", 18% "hydrogenated higher polysaccharides" and a maximum of 3% "hydrogenated polysaccharides with a degree of polymerization greater than 20" (3).

3. Determination of the energy values of sugar alcohols.

Information about the energy values of sugar alcohols can be obtained from studies based on either direct or indirect measure-ments, or by employing the factorial method. The direct measurement of energy values usually involves comparing the energy balances or growth curves derived from food/ fodder containing the sugar alcohol under study, with that of the corresponding data for that food without this compound. Indirect measurement techniques which might be used are the measurement of the glucose level in the blood or an analysis of exhaled air. To apply the factorial method, all the energy losses that occur when sugar alcohols are processed by the body, must be considered as separate entities and quantified independently.

- *Direct measurement techniques.*

Almost all the observations made on the basis of directly measuring the energy value of a particular sugar alcohol suggest that lower energy values should be attributed to these compounds than to saccharose. However, the committee does not attach great significance to these findings since only a limited number of sugar alcohols have been studied in any depth and those trials that were of relevance have usually involved animals rather than human beings. Furthermore, these investigations suffer from one or more of the following drawbacks:

* administering large doses of sugar alcohols in order to reduce the influence of unavoidable measuring errors. It is known however, that large doses of these compounds can disturb the normal digestive process;
* when small doses were used (for instance equivalent to the approximate limit of 20 g/day in humans) then tests of too short a duration were carried out, or too small a number of experimental animals or subjects were used, in comparison with the size of the measurement errors;
* little or no attention was paid to the possible changes in the physical activity of

the experimental animals or subjects which can result from the development of intestinal complaints due to the ingestion of sugar alcohols;

* lack of certainty concerning the actual amount of food ingested by the experimental subjects;
* using changes in body weight as a criterion for determining the energy value of sugar alcohols. The committee felt that this criterion was insufficient to be used on its own as the composition of the body can change if saccharose is replaced by sugar alcohols in food-stuffs (4). The composition of the body must therefore also be regarded as a criterion.

It must be noticed that, particularly in studies in which growcurves have been measured, usually no supplementary measurements have been done, as determination of the body composition and urea content of the urine. If a lower energy value than those of saccharose is found, similar measurements are necessary to determine the cause of this lower value. Without these data these studies do not contribute to the knowledge of the several processes that are involved in the decomposition of sugar alcohols.

- *Indirect measurement techniques.*

Indirect measurements of energy values based on, for instance, monitoring the amount of hydrogen in the exhaled air or the level of the glucose in the blood, only address one aspect of the digestive process. In order to estimate the energy values of sugar alcohols, certain assumptions have had to be made with regard to the remaining aspects.

- *Factorial approach.*

The factorial approach allows an insight to be gained into the causes of possible differences in energy values by examining the various phases in the decomposition process. A study of these different phases often allows the investigator to extrapolate the results obtained from one particular sugar alcohol to other such compounds, which may theoretically be expected to react in the same way.

On the basis of the above reasoning, the committee feels that it is not possible to draw firm conclusions about the energy values of sugar alcohols on the data obtained from the series of direct and indirect measurements carried out to date. The committee has therefore decided to use the factorial approach for its method of assessment, even though accurate estimates of a number of the factors involved are not currently available. These factors could be the subject of future research which would allow the committee's original calculations to be revised at a later date.

The remaining sections of this report deal with the amount of energy that is obtained by absorbing sugar alcohols from the small intestine; this is followed by a discussion of the energy available to the body from the processes that take place in the large intestine and finally the actual proportion of the energy content of ingested sugar alcohols that can be used by the body is reviewed.

4. Absorption of sugar alcohols from the small intestine.

4.1. Monosaccharide sugar alcohols.

Although in the literature it is generally stated that monosaccharide sugar alcohols are less well absorbed from the small intestine than glucose, little quantitative information is given to support this view (5, 6, 7, 8, 9, 10). The absorption of monosaccharide sugar alcohols takes place by passive diffusion and is not supported by an active process such as is the case with glucose and galactose (9, 11).

Research has shown that the amount of mannitol that is absorbed from the small intestine is limited (5). Tests carried out on patients that had had a colostomy showed that 76+8% of a 10 g oral dose had not been absorbed into the body by the time it had passed to the end of the small intestine. The committee is not aware of similar research having been carried out with sorbitol and xylitol. It is, however, possible to obtain an indirect estimate of the absorption of sorbitol and xylitol from the small intestine by using the procedure outlined below.

Too high an influx of monosaccharide sugar alcohols into the large intestine leads to more frequent defecation, softer faeces and diarrhea (10). This results from the high osmotic value that is associated particularly with monosaccharide sugar alcohols, as well as with the volatile fatty acids and lactic acid formed by bacterial action on these polyols. A team of researchers from the FAO/WHO reported that oral doses of 10-20 g mannitol, 20-30 g sorbitol and 30-40 g xylitol represented limiting values above which complaints were likely to be received about the excessive laxative effects of these compounds (10). Wiggins showed that the laxative action of mannitol is twice that of sorbitol (7). It can be assumed that, in the case of passive diffusion processes, a fixed percentage of given doses of mannitol, sorbitol or xylitol will be absorbed per unit time from the small intestine. The time available for such absorption processes is relatively short (4-6 hours). This time period may even be reduced as a consequence of the high osmotic value of sugar alcohols. By assuming that the osmotic values of one gram of mannitol, sorbitol and xylitol, including their fermentation products, are equal when present in the large intestine and that 25% of mannitol is absorbed from the small intestine (5), then it can be estimated, on the basis of the laxative effect of these compounds, that the absorption of sorbitol and xylitol from the small intestine will be approximately 50% and 75% respectively.

4.2. Disaccharide sugar alcohols.

Little information is available about the absorption characteristics of disaccharide sugar alcohols.

An in vitro investigation on a rabbit using the everted sac technique (with a portion of the small intestine turned inside out) revealed that only minute traces of unconverted maltitol could be found in the diffusion products. It was also shown that

an appreciable amount of maltitol had been hydrolyzed in the mucosa of the small intestine (12). Studies have also been carried out with rats which were fed very large doses of maltitol (5-10 g/kg body weight). The researchers reported that only very small amounts of unconverted maltitol could be found in the urine (13).

Tests on the urine of volunteers who were given a 50 g dose of lactitol, detected only small traces of the original compound that had not been broken down (14). Similar results have also been reported with isomalt (15).

An investigation using in vitro techniques with the glycosidases that are present in the small intestine showed that these enzymes are slow to break down disaccharide sugar alcohols. Recent findings from a study in which disaccharide sugar alcohols were treated with homogenates from the human small intestine gave the following relative speeds for hydrolysis (maltose = 100): maltitol 8%, isomalt 0.8% and lactitol 0.08% (16). Under the same conditions the relative speed for hydrolyzing lactose and isomaltose was 15% and 32% respectively. The fact that only such a small amount of lactitol was broken down can possibly be explained by a lack of sufficient beta-glycosidase, which is normally necessary for this type of reaction to take place. Maltitol and isomalt were not affected by this as these compounds are hydrolized by an alpha-glycosidase enzyme. The amount of beta-glycosydase present in the small intestine is very much smaller than the corresponding amount of alpha-glycosidase.

In addition, the disaccharide sugar alcohols are not readily absorbed. This means that for practical purposes, it may be assumed that in as far as the "absorption" of disaccharide sugar alcohols is concerned, this effectively refers to the absorption of the monosaccharide groupings that make up the diasaccharide molecules. Monosaccharide groupings are formed by the action of enzymes breaking down disaccharide sugar alcohols. These arguments are supported by the findings of a series of tests on volunteers in which the ingestion of a 70 g maltitol sample led to an increase of about 20% in the glucose level in the blood (12). Similar tests with 100 g isomalt samples produced no measurable change in the glucose level in the blood (15). A series of volunteers who were given 50 g of lactitol did, however, experience a limited increase in the glucose level in the blood. This varied from between 2 to 11%. In comparison, ingestion of 50 g of lactose increased the glucose level in the blood from 11 to 60% (14).

It should be noted that work carried out with pigs, in which re-entrant fistulas were attached at the end of the small intestine, showed that considerably less than 100% of the oral doses of isomalt could be detected by the time the product had passed to the end of the small intestine (17). Furthermore, hydrolysis products from isomalt were found, which together with the isomalt that had not been broken down, accounted for some 60 - 80% of the original dose ingested. This reduced percentage may have been caused by the hydrolitic activity of bacteria on isomalt in the first section of the stomach and in the distal part of the small intestine. Considerably fewer bacteria are found in the stomach and small intestine of humans than in pigs (18). This implies that bacterial hydrolysis of isomalt will hardly ever occur in the human stomach and small intestine. In contrast, the pH level in the first section of

the pig's stomach (pH = 6) is relatively high in comparison with that of humans. This organ fulfils to a small extent a similar function to that of the forestomachs in ruminants (19, 20).

Based on the above information, the committee has decided that it is reasonable to assume that the maximum amount of maltitol, isomalt and lactitol that can be absorbed from the small intestine is 40, 20 and 0% respectively. It is recognized that the greater part of the absorption process will take place after hydrolysis has occurred.

4.3. Oligosaccharide sugar alcohols.

The same principles that apply to disaccharide sugar alcohols are, of course, also relevant to the oligosaccharides: these compounds will only be partially hydrolyzed in the small intestine by the action of the intestinal glycosidases. For commercial products containing polyglucosylsorbitols as well as sorbitol and maltitol, the information given in §4.1 and §4.2 about the latter two compounds can still be considered as relevant.

5. Energy values of sugar alcohols absorbed from the small intestine.

5.1. Monosaccharide sugar alcohols.

It is known that xylitol and sorbitol can be assimilated during the intermediate stage of metabolism (7, 8, 10, 11). The energy value of the proportion of these compounds that is absorbed is approximately equal to that of glucose. It is less clear to what extent this also applies to mannitol. Apparently, mannitol is assimilated slowly since several studies have shown that considerable amounts of mannitol (80-90%) were excreted via the urine after large initial doses had been administered (10, 11). The proportion that was not excreted was probably converted to fructose, which is known to have an energy value comparable to glucose (10, 16).

The committee has assumed that in the case of small doses, about half the absorbed amount of mannitol will be excreted in the urine. The energy value per unit weight of the products absorbed will be practically equal to half that of glucose, sorbitol and xylitol which is absorbed.

5.2. Disaccharide sugar alcohols.

In §4.2 it is noted that disaccharide sugar alcohols are hardly ever absorbed in their original form. Disaccharide sugar alcohols taken intravenously are excreted almost completely unchanged (13, 15, 21). This means that the energy value of

"absorbed" disaccharide sugar alcohols is almost solely determined by the amount of monosaccharide components that are formed during the breakdown of the disaccharide base compounds in the small intestine. The hydrolysis products that are formed in the case of maltitol are glucose and sorbitol whereas with isomalt, mannitol is also produced.

5.3. Oligosaccharide sugar alcohols.

The energy value of oligosaccharide sugar alcohols is dependent on the degree to which these compounds are hydrolyzed in the small intestine. The monosaccharide groupings that are produced in this process are almost totally absorbed and, apart from mannitol, are completely available for use by the body.

6. Utilisation of sugar alcohols or their hydrolysis products in the large intestine.

The anaerobic decomposition of food-stuffs including partially digested products, which occurs as a result of bacteria present in the gastrointestinal tract is a fairly common process in the animal kingdom (20, 22). It can be traced back to the earliest stages of evolution. Considerable similarities exist in this respect between different species of animals. In particular the process that occurs in the multiple forestomachs of ruminants can be readily compared with the action of bacteria in the large intestine of animals with one stomach. It is generally accepted that sugar alcohols and the resulting hydrolysis products are readily converted by bacteria in the large intestine (7, 23, 24). This is certainly the case for humans if less than 20 g of sugar alcohols per day are ingested. If large doses are taken, too much acid is formed which tends to slow the decomposition process down because of the lower pH level. A consequence of this is that insufficient time remains for complete conversion (7). The same is also true if, as a result of the higher doses, diarrhea is caused. Since oxygen is not present in the large intestine the decomposition products that are formed from sugar alcohols comprise: the volatile fatty acids acetic acid, propionic acid and butyric acid and sometimes small amounts of lactic acid, in addition to carbon dioxide, hydrogen and also occasionally methane. Furthermore, a certain amount of bacterial growth takes place, as well as the release of some heat energy (7, 23, 25). The above reactions represent a loss of useful energy to both humans and animals. The major factors involved can be quantified as follows:

* volatile fatty acids and lactic acid are readily absorbed into the blood stream (6, 23). On a unit energy basis these compounds have lower energy values than glucose. For humans this results in 15-20% less energy being available from volatile fatty acids and 5% less from lactic acid (26, 27, 28). During the intermediate stage of metabolism lower amounts of ATP are formed from these compounds than from glucose;
* hydrogen and methane both contain significant amounts of energy (25). The pro-

duction of these gases in the large intestine leads to energy losses of the order of 3-8% of the energy content of the sugar alcohols entering this part of the gastrointestinal tract (25, 29, 30, 31, 32). In the case of lactitol, tests carried out on subjects under 30 years of age showed that 3% of its energy content was lost in the form of hydrogen (25). In pigs some species of bacteria convert the hydrogen that is released to methane. This produces a much larger energy loss, which can be as high as 8% (29, 30, 31, 32). The production of methane can also occur in the intestinal tract of humans, particularly with older people that have slower rates of passage in the large intestine (33). bowel movements (33). It cannot be ruled out therefore, that these people will have energy losses in excess of 3%;

* bacteria present in the large intestine can use the energy that is released during the decomposition of sugar alcohols for their main tenance metabolism and for growth. All the energy that is used for maintenance is converted into heat, while a part of the energy that is used for growth eventually becomes converted to heat. The amount of energy that is actually generated by these processes in humans is not known. Estimates made for animals suggest that this could total 60% of the energy present in the hydrogen and methane produced (26). This amounts to 60% of the 3-8% loss of energy, attributed to hydrogen and methane formation which was mentioned above.
* bacteria need nitrogen as well as energy in order to grow (23). Although sufficient supplies of nitrogen-containing compounds are provided from the small intestine (34), there is normally a shortage of energy in the large intestine. This means that not all the nitrogen that is present can be converted into bacterial protein. In this case the majority of the nitrogen-containing compounds are broken down into ammonia (35, 36). Most of the ammonia is absorbed into the blood stream and eventually excreted in the urine as urea. This represents a further energy loss to the body as urea is an energy-containing compound. However, the ingestion of sugar alcohols provides a sufficient supply of energy to the large intestine, to promote bacterial growth. This reduces the amount of ammonia that is produced from the breakdown of nitrogen-containing compounds, including that of any bacterial protein formed. Since the majority of the bacteria is excreted along with the faeces, the amount of energy lost in this way tends to increase. It has been shown by van Es et al, that if 5-10% of the energy supplied in the food comes from sugar alcohols rather than saccharose, the additional faecal energy losses will amount to 1-2% (4). If this is converted to an equivalent consumption of 100% sugar alcohols it would represent a loss of some 20%.

It might be thought likely that ingesting sugar alcohols would lead to a reduction in the energy lost via the urine as a result of the lower excretion of urea (23). However, there is little if any evidence to substantiate this hypothesis (25, 31). Microbial processes in the intestinal tract usually produce compounds that require detoxifying after absorption. Detoxification products contain a relatively large amount of energy and are often excreted along with urine (30, 37). On balance, this tends to compensate for the reduced amount of energy lost via the urine, brought about by the lower urea production.

The increase in microbial activity in the large intestine which follows the consumption of sugar alcohols nearly always coincides with a larger intestinal filling (25, 29, 31). It is not known whether this creates an extra demand for energy, for instance, to carry the larger body weight.

Summation of the energy losses from the sugar alcohols present in the large intestine shows that about half of their energy content is lost either directly or indirectly (table 1).

Table 1
Energy losses during the decomposition of sugar alcohols in the large intestine.

	energy losses in %
formation of volatile fatty acids	15-20
formation of gases	3-8
production of heat	2-5
bacterial growth	±20
total	40-53

7. Estimation of the energy values of sugar alcohols.

A comparison of the energy values of sugar alcohols and saccharose is usually based on the ability of these compounds to supply ATP (38). The additional OH grouping present in sugar alcohols provides slightly more ATP. However, due to the lower energy content of monosaccharide sugar alcohols compared with saccharose this effect is partially compensated for in terms of weight. If the conditions for complete absorption and utilization are satisfied then the potential supply of ATP from saccharose would be exceeded by 2.5% in the case of xylitol and 1% for sorbitol and mannitol. Maltitol, isomalt and lactitol would be able to supply 3% more ATP than saccharose if complete hydrolysis, absorption and utilization of the hydrolysis products were to take place. The relative differences between these compounds and saccharose (energy content 16.5 kJ/g) correspond almost completely with the different energy contents per gram. However, the absorption and utilization of sugar alcohols tends to be incomplete as was mentioned in the previous sections. If these effects are taken into account, the following equation can be derived to calculate the energy value (E_W) of a sugar alcohol in the absence of its water of crystallization:

$$E_W = [(A \times B) + (1 - A) \times 0.5] \times 16.5 \times R_e \text{ kJ/g}$$

where for the particular sugar alcohol concerned:
A = the fraction absorbed from the small intestine;
B = the fraction utilized by the body after absorption from the small intestine;
R_e = the ratio of the energy content of the alcohol concerned compared with that of saccharose;
0.5 = the proportion of utilizable energy available from the large intestine;
16.5 = the energy content of saccharose in kJ/g.

* *Xylitol.*

In the case of xylitol, 75% is absorbed from the small intestine. The energy value of the absorbed product is approximately equal to that of glucose. For the 25% that reaches the large intestine the effective energy reduces by 50%. The total energy value is therefore: (0.75 x 1.00 + 0.25 x 0.50) x 16.5 x 1.025 = approx. 15 kJ/g.

* *Sorbitol.*

Similarly the calculation for sorbitol is as follows: 50% is absorbed from the small intestine, the rest being fermented in the large intestine. Substituting these values in the equation above gives: (0.5 x 1.00 + 0.5 x 0.50) x 16.5 x 1.01 = approx. 12.5 kJ/g.

* *Mannitol.*

The proportion of mannitol absorbed from the small intestine amounts to 25%, of which 50% is useable energy. The total energy value is therefore calculated as: (0.25 x 0.50 + 0.75 x 0.50) x 16.5 x 1.01 = approx. 8 kJ/g.

* *Maltitol.*

With maltitol, 40% is absorbed in the form of glucose and sorbitol from the small intestine. This gives a total energy value of: (0.4 x 1.00 + 0.6 x 0.50) x 16.5 x 1.03 = approx. 12 kJ/g.

* *Isomalt.*

Isomalt is absorbed from the small intestine as glucose, sorbitol and mannitol in the ratio 2:1:1. The total energy value is therefore: (0.2 x (0.75 x 1.00 +0.25 x 0.50) + 0.8 x 0.50) x 16.5 x 1.03 = approx. 10 kJ/g.

* *Lactitol.*

Lactitol is not absorbed from the small intestine. Complete fermen-tation of this product in the large intestine produces an energy value of: (1.0 x 0.50) x 16.5 x 1.03 = approx. 8.5 kJ/g.

* *Oligosaccharide sugar alcohols.*

The energy value of oligosaccharide sugar alcohols is normally close to that of maltitol. The precise value varies however with composition.

8. Discussion and conclusions.

At present insufficient information is available to be able to calculate the precise energy values of sugar alcohols. It is apparent that the energy values in question are dependent on more factors than could possibly have been included in the committee's current analysis. The factors involved are of a highly individual nature,

concerning, for instance, the amount of sugar alcohol that is consumed, the composition of the remaining food and individual variations in the pattern of metabolism.

The energy values of sugar alcohols can be determined in several ways, namely by means of direct or indirect measurements, or by the factorial approach. The value of 2 kcal/g (8.4 kJ/g) for maltitol and isomalt that has been adopted in Switzerland, is based on the results of tests employing direct and indirect measurement techniques to determine energy values. The value arrived at by the Swiss authorities does not differ significantly from those calculated by the committee using the factorial approach. This is partly a reflection of the way in which the figures are rounded off when calories are converted to Joules or vice versa.

In spite of this, the committee believes that the values which have been derived by means of the factorial method have a better scientific basis. After all, the factorial approach utilizes the results of more types of investigation than are involved in the direct or indirect measurement of an energy value.

The energy values calculated by the committee are valid for situations in which the intake of sugar alcohols amount to less than 20 g/day. It must be assumed that, if larger amounts are ingested then, depending on the individual response, the energy value of the sugar alcohols consumed will be lower.

Table 2
Proposed energy values of sugar alcohols (without water of crystallization) for human consumption of up to 20 g/day.

sugar alcohol	energy value kJ/g
xylitol	15
sorbitol	12.5
mannitol	8.5
maltitol	12
isomalt	10
lactitol	8.5

1) Palatinit (isomalt) is a commercial product containing 5% water of crystallization and therefore has an energy value of 9 kJ/g.
2) Lacty (lactitol) is a commercial product containing 9.5% water of crystallization and therefore has an energy value of 8 kJ/g.

It should also be noted that the values arrived at by the committee in this advisory report, are only a first estimate. The accuracy of the experimental data concerning the absorption, enzymic transformation and utilization of sugar alcohols in the body is still insufficient to allow more reliable estimates to be made. However, it is clear that an energy value of 17 kJ/g which up to now has commonly been applied to sugar alcohols is too high and that the actual value will be closer to about 10 kJ/g. If more reliable estimates are required, further research will have to be carried out into the absorption, the utilisation in the intermediary metabolism and the fermentation in the large intestine of sugar alcohols. This new information could then be substituted into the equation given in §7 to update the energy values listed in table 2.

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Appendix I

Ministry of Welfare, Health
and Cultural Affairs.

P.O. Box 5406
2280 Rijswijk
Telephone:(070) 407911

To: The Nutrition Council,
P.O. Box 95945,
2509 CX The Hague.

Leidschendam 11 September 1986	Encl:	Your letter of:	Your Ref:
Re:		Ext:	Our Ref: DGVgz/VVP/L no. 213119.

It is acknowledged that the use of sweeteners can only be permitted in the preparation of food-stuffs when there are technological or nutritional reasons for doing so. The polyols (sorbitol, xylitol, maltitol, mannitol, lactitol and hydrogenized glucose syrup) can act as stabilizers or moisturizers for food products and also have a lower cariogenic potential. However, doubts have existed as to whether these compounds offer the advantage of lower energy values. The energy values of polyols have been specified in the EC Directive on Commodities for Special Food-stuffs as 17 kJ (4 kcal).

Recent research has shown that various polyols may in fact have a lower energy value (8.5 kJ 2 kcal). It would therefore seem desirable that these studies be assessed. Lower energy values have already been adopted in a number of countries, such as Switzerland (2 kcal/g) and Belgium (probably 2 kcal/g).

Since the nutritional values of food products must be specified, it is essential that the relevant energy values of sugar alcohols be made available. I therefore request the Nutrition Council to prepare such estimates as quickly as possible.

for the State Secretary of Welfare,
Health and Cultural Affairs,
the Head of the Nutrition and
Veterinary Branch and Product
Safety,
p.p.

(G.H. Schipper)