

Aspartame Structure

COOH



Aspartame

OCH<sub>3</sub>

Sucrose

Formula - C<sub>12</sub>H<sub>22</sub>O<sub>11</sub>

Isomaltulose

Formula - C<sub>12</sub>H<sub>22</sub>O<sub>11</sub>



# Sweeteners and Sugar Alternatives in Food Technology

SECOND EDITION

Edited by Kay O'Donnell & Malcolm W. Kearsley



 WILEY-BLACKWELL

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# Sweeteners and Sugar Alternatives in Food Technology

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Second Edition

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# Preface

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Indulgence in sweet foods and drinks is a human weakness and both are consumed far beyond their value in relieving hunger and thirst. Sweetness is most commonly associated with sucrose, and this is the most widely consumed sweetener in the world although it has been criticised for many years by some with regard to its contribution to obesity, dental caries and other diseases. While glucose (and fructose) syrups are widely used to replace sucrose in foods, this is largely a cost-saving exercise and does not address many of the problems associated with 'sugar' consumption.

Over the last 30 years, a wide range of sugar replacers have been developed and marketed. These include the bulk sweeteners – the polyols, which replace sucrose and glucose on a weight for weight basis, and the high-potency sweeteners where a kilogram of sugar in a food product might be replaced by a few grams of a very sweet material. In the case of high-potency sweeteners, this has led to the development of a parallel industry to provide ingredients, which can be used in conjunction with the sweetener to retain the 'bulk' of the traditional product. More recently, sugars with many of the properties of bulk sweeteners and sweet taste enhancers that increase the potency of sweet compounds have been new additions to the market.

Replacement of sugars in foods has given us a new perspective on healthy foods where claims such as 'sugar-free', 'no-added-sugar' and 'reduced calorie/sugar' are being exploited by food manufacturers.

The use of ingredients to improve the nutritional status of a food product is one of the major driving forces for new product development, and sugar replacement is still seen as an area for development. This book provides a unique reference for food scientists and technologists with information on sugar replacement options to produce foods that not only taste and perform as well as sugar-based products but also offer consumer benefits including calorie reduction, dental health benefits, digestive health benefits and improvements in long-term disease risk through strategies such as dietary glycaemic control.

This second edition of *Sweeteners and Sugar Alternatives* follows the same basic layout as in the successful first edition with many of the same authors contributing to their relevant areas of expertise. New chapters on isomaltulose, trehalose and developments in sweeteners have been included to reflect changes in the use and understanding of sweeteners and sweet taste. For ease of reference, the book is set out as follows:

*Part One: Nutrition and Health Considerations.* This part considers the physiological effects and subsequent health benefits of sweeteners and sugar alternatives. Subjects include improved glycaemic control, dental health, digestive health and the role of these products in calorie control and weight management.

*Part Two: High-Potency Sweeteners.* This part describes the properties and applications of the most commonly used sweeteners. These products are unique in that they provide high sweetness without bulk and without any major impact on calories.

*Part Three: Reduced-Calorie Bulk Sweeteners.* This part describes both the properties and applications of polyols and includes reference to polyglycitols, hydrogenated glucose syrups containing less than 50% maltitol. Bulk sweeteners provide the physical characteristics of sugar and glucose but with reduced calories and other physiological benefits.

*Part Four: Other Sweeteners.* This part describes new developments in sweeteners and specifically how they elicit a sweet taste when consumed. Also included are chapters on isomaltulose and trehalose that, although classed as sugars, exhibit many of the properties of the bulk sweeteners.

*Part Five: Bulking Agents – Multi-Functional Ingredients.* This chapter focuses on the oligo- and polysaccharide materials that are most applicable as sugar alternatives and that have sugar-like properties in food applications and, often, prebiotic properties. They allow greater flexibility when replacing sugar in formulations and complement the use of all types of sweeteners in foods.

The summary tables at the end of each chapter and the extensive references are meant to inspire those who wish to learn more.

A sincere thanks to all the contributors to the book.

Kay O'Donnell and Malcolm W. Kearsley

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# Part One

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## Nutrition and Health Considerations

# Glycaemic Responses and Toleration

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## 1.1 INTRODUCTION

Sugars and sweeteners have an important role in the human diet and choosing the right ones in the right amounts can influence health. Knowledge will enable good choices, and further research and understanding of the literature will confirm or deny how good our choices are, and where improvements are possible. Choice is not simply a matter of which is the healthier or healthiest, since the technological properties and economics of sugars and sweeteners impact on which of them can be used suitably in a particular food.

A wide range of potential influence on health is offered by sugars and sweeteners when selected appropriately, as will be evident in detail from other chapters. These include the following:

- A reduced risk of dental caries.<sup>1</sup>
- Potential for improved restoration of the early carious lesions.<sup>2</sup>
- A reduction in caloric value that may contribute towards a lower risk of overconsumption, obesity and improved survival.<sup>3,4</sup>
- Substrate for butyrate production, and potentially reduced risk of colon cancer.<sup>5</sup>
- The formation of osmolytes efficacious for laxation and lower risk of constipation or accumulation of toxic metabolites.<sup>6</sup>
- Substrate for saccharolytic and acidogenic organisms in the colon that contribute to prebiotic and 'digestive health' potentially including improved immunological function.<sup>7,8</sup>

Each of these can influence the choice of sugars and sweeteners. Of particular relevance is the impact on glycaemic response and potential to contribute to low glycaemic index (GI) or glycaemic load (GL) diets.

Lowering post-prandial glycaemia and insulinaemia through an appropriate choice of sugars<sup>9</sup> and sweeteners,<sup>7</sup> together with other low-glycaemic carbohydrates,<sup>10</sup> fibre, protein, lower energy intake and exercise,<sup>11</sup> can each improve glycaemic control. In turn, this appears to lower the prevalence and risk of developing metabolic diseases including metabolic syndrome, diabetes (and associated complications), heart disease, hypertension, stroke, age-related macular degeneration and certain cancers.<sup>12-16</sup>

In those who are susceptible, lower glycaemic carbohydrate foods may also benefit appropriate weight gain during pregnancy,<sup>17</sup> limit insulin requirements in gestational diabetes,<sup>18</sup> potentially allow favourable foetal growth patterns and fat accretion,<sup>19</sup> reduce neural tube defects<sup>20</sup> and aid recovery from surgery.<sup>21</sup>

Meta-regression of interventional studies of lower GI or GL diets show a time-dependent low body weight over a 1-year period<sup>22</sup> and supports weight maintenance after weight loss.<sup>23</sup> Reduced food intake in humans<sup>4</sup> may be partly responsible for weight loss and maintenance. Lowering of body weight improves survival among newly diagnosed diabetes patients,<sup>24</sup> and may contribute to long survival beyond old age as seen in animal studies while lowering glycaemia with isomalt.<sup>4</sup>

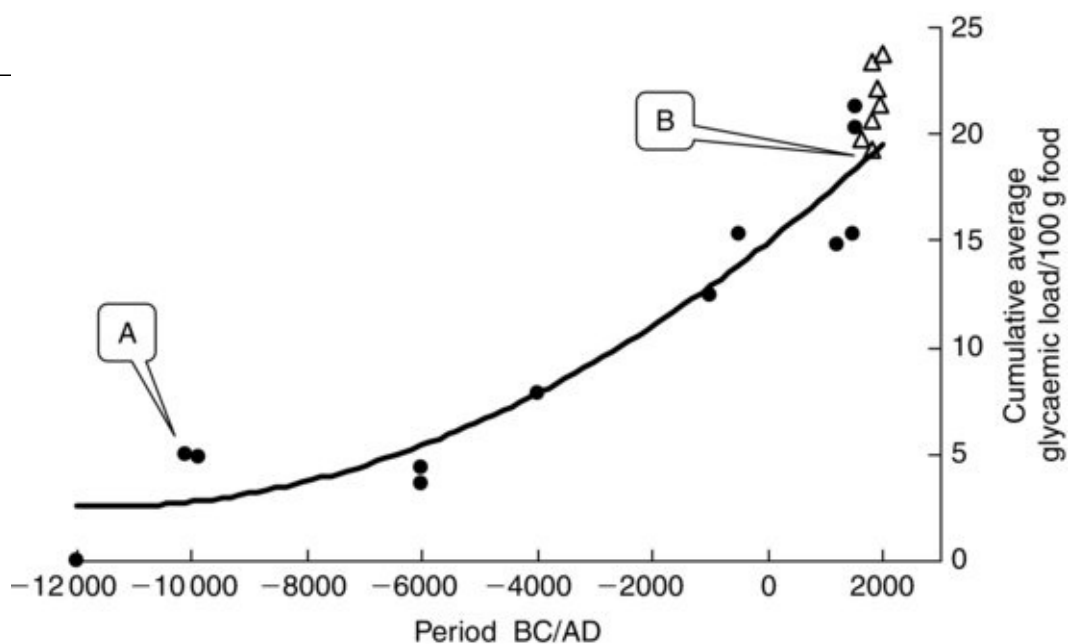
The converse of all aforementioned is that, given the right circumstances, a poor choice of type and amount of all carbohydrates, including sugars and sweeteners, could augment ill health. Attributes of sugars and sweeteners affecting health via the glycaemic response are nutritional and need to be seen in the context of the whole diet. It is appropriate, therefore, to consider the glycaemic aspect of diet and health from ancient to the present and future times – so far as these can be ascertained, explained and envisaged.

## 1.2 GLYCAEMIC RESPONSE IN ANCIENT TIMES

It is often argued that our genes might not cope with diets that are substantially different from those eaten by our ancestors.<sup>25–30</sup> Quite what these diets were or how tolerant ancient genes have become are matters of uncertainty. Successful genes were in existence for both herbivorous and carnivorous diets prior to humankind; however, no early diet appears to have been high glycaemic. Those peoples who would normally consume ‘early’ or rudimentary diets, such as recent hunter–gatherers, experience low levels of diabetes and respond adversely to diets we may now consider high glycaemic.<sup>26,31</sup> This is consistent with the notion that early genes were unadapted to high-glycaemic responses, and also consistent with a notion of adaptation having occurred in the people of today’s relatively more glucose-tolerant ‘western’ cultures, at least among a large proportion of them. Those not having adapted, contribute to prevalent diabetes and other conditions mentioned that are currently experienced, which is far higher than in either hunter–gatherers or rudimentary horticulturalists or simple agriculturalists or pastoralists.<sup>26</sup> For the people of these ‘basic’ cultures and for ‘unadapted’ westerners (easterners or southerners or northerners), a high-glycaemic response remains a health hazard, for which a variety of strategies exist to help them cope.<sup>11</sup> Europe has a rich culture and documented history of its foods, and so we can obtain some idea of how the glycaemic character of diets may have developed over time.

Generally, we may assume diets to partly reflect the foods that can be found or are made available to eat. If this is so, examination of the inventory of foods identified in European history may shed some light on what was eaten and what might now be eaten for optimal health. Such an inventory was provided by Toussaint-Samat<sup>32</sup> from which an assessment of the development in the glycaemic character of contemporary diets has been made taking account of the protein, fat, fibre and sources of carbohydrate ([Figure 1.1](#)). The picture cannot be accurate but what is clear is a progressive increase in the GL, with a markedly rapid increase in this GL following industrialisation. We cannot be sure of the prevalence of disease in Europe throughout the whole of this timescale, but we would not like to dispute that the prevalence of obesity and metabolic disease is as high now as ever.

**Fig. 1.1** Evolutionary adaptation to ancient diets of low glycaemic load may have left mankind genetically predisposed to non-communicable diseases provoked by today’s high-glycaemic diets. Based on the history of foods in Europe,<sup>32</sup> with calculations by this author (A, agricultural revolution; B, industrial revolution). Open symbols show values post the industrial revolution.



Such a trend is argued to also have occurred throughout more recent times in the United States with recent emphasis on reducing the fat content of the diet, a doubling of flour consumption during the 1980s and an increase overall in sugar, corn syrup and dextrose consumption prior to the end of the millennium.<sup>33–35</sup> These together with a lower dietary fibre content of foods<sup>34</sup> imply exposure to diet eliciting a high-glycaemic response.

### 1.3 GLYCAEMIC RESPONSE APPROACHING THE MILLENNIUM

Much of our understanding of the interplay between health and the glycaemic response to foods has arisen from investigations into the dietary management of diabetes. Whereas very low-glycaemic carbohydrate foods such as Chana dahl were used in ancient India for a condition now recognised as diabetes,<sup>36</sup> nineteenth century recommendations in western cultures were for starvation diets, which were, of course, non-glycaemic. The drawback of such is obvious and in 1921, high-fat (70%) low carbohydrate (20%) diets were recommended,<sup>37</sup> which by definition would be low glycaemic. The gradual reintroduction of carbohydrate into recommendations for diets for diabetic patients arose as carbohydrate metabolism came under some control using drugs, but mainly because ‘dietary fat’ was recognised to have a causal role in coronary heart disease, to which diabetics and glucose intolerant individuals succumb, more readily in some cases than others.<sup>38–41</sup> The metabolic advantages of replacing dietary fat (saturated fat) with high-fibre high-carbohydrate was lower fasting glycaemia, lower total-, HDL- and LDL-cholesterol and lower triglycerides.<sup>42–46</sup> Such benefits may in part be related to dietary fibre or its influence on the glycaemic response.<sup>47,48</sup> Certainly, the non-digestible carbohydrate in these diets would ensure some degree of lower glycaemia for a given carbohydrate intake and support beneficial effects from lower saturated fat intake.

During these times, the adverse influence of higher glycaemia or more dietary carbohydrate was either unrecognised or the risk was accepted by the medical profession in fear of (or compromise for) the adverse effects of ‘dietary fat’. The adverse influence of higher glycaemia may also have been overlooked due to the apparent benefits of the non-digestible carbohydrate in the high-carbohydrate foods. Indeed, the Institute of Medicine has recommended high-fibre diets to combat coronary heart disease,<sup>49</sup> and this builds upon the dietary fibre hypothesis that proposed higher prevalence

diabetes, heart disease and other conditions associate with diets deficient of fibre.<sup>50,51</sup> An absence of fibre in high-sugar products left sugar (sucrose) vulnerable; nevertheless, this sugar remained preferable among nutritionists to high (saturated) fat, which it might displace from the diet, giving rise to the concept of the ‘sugar–fat-seesaw’ discussed elsewhere.<sup>52–54</sup>

Throughout the whole of these times, the primary purpose of recommending energy from carbohydrate was to displace the intake of energy as fat. In part, this is because carbohydrate supplies energy, but also because carbohydrate counters the insulin desensitising influence of both mobilised body fat and dietary fat.<sup>55–57</sup> This purpose for carbohydrate was retained in the GI concept, where low-glycaemic carbohydrate of low-glycaemic response further improved glycaemic control in diabetes patients and possibly the plasma lipid profile.<sup>58</sup>

However, it must be considered whether carbohydrates have a long-term future as a means to displace fats from the diet. It is noteworthy that the increasing carbohydrate content of diets throughout European history, which partly explains the higher GL ([Figure 1.1](#)), has not adequately displaced ‘fats’ from the diet or prevented obesity. Excess of carbohydrate prevents the use of fat stores and encourages dietary fat to be stored. In general, elevating the consumption of monounsaturated and polyunsaturated (bar trans) fats is considered beneficial in respect of diabetes, coronary heart disease and a variety of conditions<sup>59–62</sup> and is consistent with early diets.<sup>63</sup> In addition, there is little or no evidence that carbohydrate ingestion can selectively limit the ingestion of saturated fats. Proponents of the Mediterranean diet (high in mono- and polyunsaturated fats) would hold that the use of carbohydrate for the purpose of limiting fat intake is unsound.

## 1.4 THE GLYCAEMIC RESPONSE NOW AND IN FUTURE NUTRITION

The general picture now for glycaemic control is that a high-fibre, low-glycaemic and low-saturated fat diet is optimal.<sup>63</sup> With obesity being a major problem and a risk factor for type-2 diabetes and heart disease, an appropriate energy balance has become of major importance.<sup>64</sup> Weight loss has for some time been recognised as important to the survival of newly diagnosed type-2 diabetes patients and improvement in prognosis for cardiovascular disease.<sup>65,66</sup> These are practical examples of how caloric restriction improves survival in at-risk groups. Of course, caloric restriction implies here a diet reduced in energy via lower saturated fat and lower GL than is generally consumed.

It is clearly preferable to limit the intake of both saturated fat and high-glycaemic carbohydrate energy sources to facilitate weight reduction, rather than simply to exchange energy sources. Previous nutritional debates of ‘fat versus carbohydrate’ might now be viewed as too imprecise in both the description of the food components and how the components are pitched against each other. A similar concern arises when it is argued that low-GI foods should find automatic favour over low-GL foods when in communication with the consumer. Choosing low-GI foods does not automatically mean maintaining a lower fat intake since approximately 50% of the variance in the GI of foods can be attributed to their fat content. The nutrition debate still needs to provide greater scope for consideration of the adverse influence of ‘saturated fats *plus* high-GL’ together in general nutrition.

Sugars and sweeteners provoke a range of glycaemic responses related to the carbohydrate structure without the need to ask whether the glycaemic response is actually brought about by co-ingested dietary fat,<sup>7,9,67</sup> and so may variably promote, defer or help prevent ill health. Various research groups indicate at the time of writing that ‘the concepts and methods regarding the GI [or GL] are sufficient

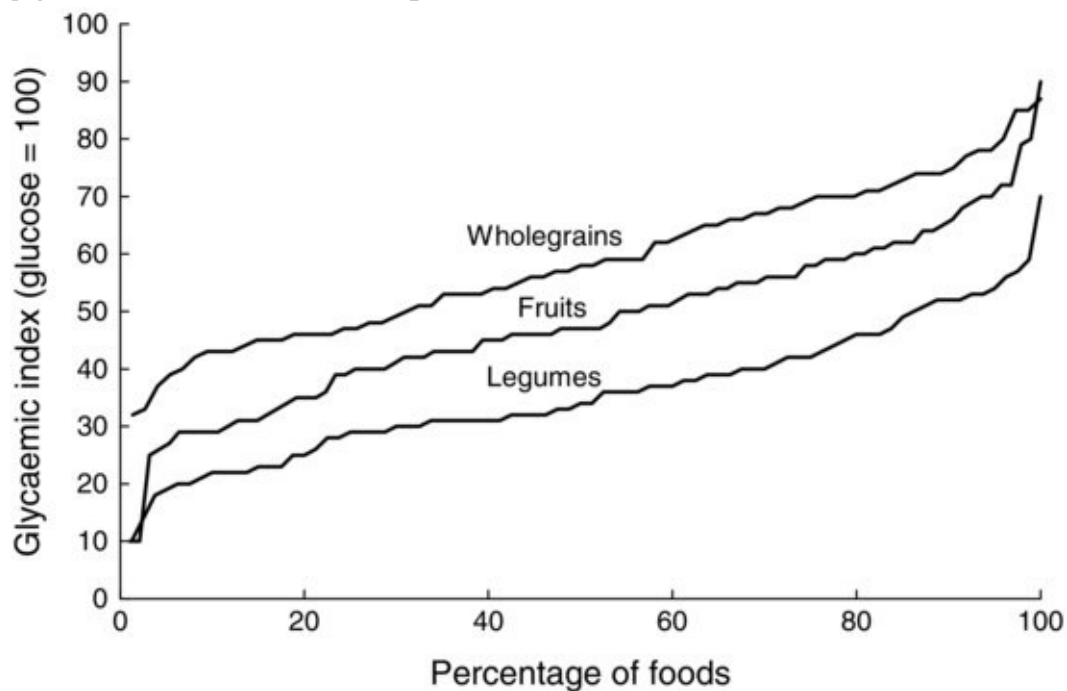
mature to recommend preparing the population to use GI as a way to help choose healthier foods... This is a position consistent with that over a decade ago in the WHO/FAO recommendations to primary producers and processors of foods: 'Consider how existing and new technologies can be used to help meet dietary goals regarding the quantity and nutritional properties of food carbohydrates... and to 'provide appropriate information to the consumer on food labels.'<sup>68</sup>

## 1.5 GLYCAEMIC RESPONSE AND ADVERSE OUTCOMES: BOTH PHYSIOLOGICAL AND IN RESPONSE TO ADVICE

Advice to consume a diet of low-, in exchange for high-glycaemic foods has raised consideration about whether this would detract from other nutritional advisory messages. There are, however, no known adverse effects of choosing a diet including low-glycaemic carbohydrate foods instead of high-glycaemic ones,<sup>69</sup> other than for occasionally temporal gastrointestinal discomfort whenever this is accompanied by excessive low digestible carbohydrate ingestion (discussed in Section 1.10).

Occasionally claims are made that the benefits of low GI can be achieved by selecting whole grain foods, fruits and legumes, and that low-glycaemic advice would interfere with this whole food advice. However, such benefit of whole foods is hardly ever likely to be achieved optimally because the glycaemic indices of foods in these food categories cover wide ranges of GI values (Figure 1.2). Intervention choosing low instead of high-GI fruits is shown to be of benefit to diabetes patients, for example.<sup>70</sup>

**Fig. 1.2** Wholegrain, fruit and legume foods each span a wide range of glycaemic index (GI) values. Information is on 74 wholegrain food, 94 fruit foods and 80 legume foods from the 2008 International Tables of GI and glycaemic load,<sup>79</sup> and are presented in order from the lowest to the highest GI.



## 1.6 MEASUREMENT AND EXPRESSION OF THE



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