4 Carbohydrate

4.1 Introduction

Carbohydrates may be classified according to their degree of polymerisation and may be divided into three principal groups i.e. sugars (monosaccharides, disaccharides, polyols), oligosaccharides (malto-oligosaccharides, other oligosaccharides) and polysaccharides (starch, non-starch polysaccharides). Each of these three groups may be further subdivided on the basis of the monosaccharide composition of the individual carbohydrates. The joint FAO/WHO Expert Consultation on Carbohydrates (FAO/WHO, 1998) discussed various issues related to terminologies in carbohydrate. It pointed out that in deciding how to classify dietary carbohydrate, the principal problem is to reconcile the various chemical divisions of carbohydrate with that which reflects physiology and health.

The FAO/WHO Consultation pointed out that there could be several problems associated with the use of the term "total carbohydrates" in most food composition tables. Firstly the figures given are obtained "by difference" and are therefore not very accurate. Moreover, a single global figure for carbohydrates in food was felt to be uninformative because it fails to identify the major types of carbohydrates in a food and thus to allow some understanding of the potential physiological properties of these carbohydrates.

With regard to the terms available and unavailable carbohydrates, the Consultation felt that in view of the improved understanding of carbohydrate physiology, a more appropriate substitute for these terms would be to describe carbohydrates as glycaemic (ie providing carbohydrate for metabolism) or non-glycaemic. The Consultation also felt that the use of the term "complex carbohydrate" to substitute starch is inappropriate and it is better to discuss carbohydrate components by using their common chemical names. It is also now evident that the terms "soluble" and "insoluble" fibre may not be very useful as the physiological properties of the two groups become not so distinct.

The main components of dietary fibre are derived from the cell walls of plant material in the diet and comprise cellulose, hemicellulose and pectin (the non-starch polysaccharides). Lignin, a non-carbohydrate component of the cell wall is also often included. The concept of dietary fibre has changed over the years. Fibre was originally described as plant cell wall material which simply passed through the gut unchanged and provided bulk to faeces. There is currently no consensus as to which components of carbohydrates should be included as dietary fibre. The American Association of Cereal Chemists (AACC) (2001) adopted the definition of dietary fibre as the edible parts of plants or analogous carbohydrates that are resistant to digestion and absorption in the human small intestine with complete or partial fermentation in the large intestine. Dietary fibre includes polysaccharides, oligosaccharides, lignin and associated plant substances. Dietary fibres promote beneficial physiological effects including laxation, and/or blood cholesterol attenuation, and/or blood glucose attenuation. The matter is also currently being discussed by the Codex Alimentarius and the proposed includes both the chemical properties as well as the physiological effects (FAO/WHO, 2004).

4.2 Roles in health and disease

Carbohydrates are an important source of energy in human diets comprising some 40 – 80% of total energy intake. There are several reasons why it is desirable that carbohydrates should provide the main source of energy (FAO/WHO, 1998). In addition to providing easily available energy for oxidative metabolism, carbohydrate-containing foods are vehicles for important micronutrients and phytochemicals. Dietary carbohydrate is important to maintain glycaemic homeostatis and for gastrointestinal integrity and function. Unlike fat and protein, high levels of dietary carbohydrate, provided it is obtained from a variety of sources, is not associated with adverse health effects. Finally, diets high in carbohydrate as compared to those high in fat, reduce the likelihood of developing obesity and its co-morbid conditions.

The primary role of carbohydrate (sugars and starches) is to provide energy to the brain which is the only carbohydrate-dependent organ in the body (IOM, 2002). Humans have the ability to starve for weeks in the absence of an exogenous supply of glucose monosaccharides (fructose and galactose) convertible to glucose in the liver. This phenomenon indicates that there is no lower limit of dietary carbohydrate compatible with life, provided that adequate amounts of protein and fat are consumed. However, the amount of dietary carbohydrate that is required for optimal health in humans is unknown (FAO/WHO, 1998).

Dietary fibre is not categorised as an essential nutrient. Over the years, it has become recognised as an important component of a healthy diet and plays important roles in health and disease. It is known to be an important moderator of digestion in the small bowel and insufficient intake from the diet can result in inadequate faecal bulk and may affect overall health. It is a major substrate for fermentation in the colon, where the non-starch polysaccharides of the plant cell wall are metabolised to short-chain fatty acids. Absorption of the latter provides some energy. In addition, it has been shown that other carbohydrates are present in the diet which enter the colon and are fermented, including resistant starch and non-digestible oligosaccharides.

4.3 Food sources

Food balance sheet data over the years have shown that the major sources of carbohydrate in the human diet are cereals, root crops, sugar crops, pulses, vegetables, fruits and milk products. In the Malaysian diet, starch is naturally abundant in grains and vegetables such as rice, wheat, maize, barley, cassava, potatoes and sweet potatoes. Natural sugars are found in fruits and juices. Sources of added sugars in diets are carbonated drinks, fruit juices / drinks, desserts, cakes, biscuits and candies.

Carbohydrates serve as the main source of energy for many communities. However, there has been a fall in carbohydrate intake in many countries. In Malaysia, an analysis of the food balance sheet data for the past 3 decades showed that the intake of

carbohydrates, notably cereals, has declined from 60% in the 1960s to 40% in the late 1990s (Tee, 1999). There has also been a definite decline in the proportion of energy from carbohydrate from 72% in the 1960s to about 60% in the 1990s. Within these national averages, there is considerable variations between rural and urban population groups. A study by Chee *et al.* (1997) among rural and urban adults residing in four regions of Peninsular Malaysia and Sarawak indicated that the distribution of nutrients to the total energy were 66% for carbohydrate, 13% for protein and 19-21% for fat in rural population. Whereas, among urban groups, the distribution of carbohydrate, protein and fat to the total energy intake were 55%, 14% and 29-30% respectively.

Dietary fibre is present in the majority of fruits, vegetables and refined grains (IOM, 2002). Nuts, legumes and high fibre grain typically contained more than 3% of dietary fibre. About a third of the fibre in legumes, nuts, fruits and vegetables is present as hemicelluloses. Approximately one-fourth of the fibre in grains and fruits and one-third in nuts and vegetables consist of cellulose. Although fruits contain the greatest amount of pectin, 15-20% of the content in legumes, nuts and vegetables is pectin. There has been some work on the analysis of dietery fibre content of local foods, but an extensive list of such results has yet to be published. This has hampered the collection of data on dietary fibre intake of communities.

4.4 Factors affecting requirements of carbohydrate

The minimal amount of carbohydrate required, either from endogenous or exogenous sources, is determined by the brain's requirement for glucose (IOM, 2002). The brain is the only true carbohydrate-dependent organ in that it oxidises glucose completely to carbon dioxide and water. Normally the brain uses glucose almost exclusively for its energy needs. The endogenous glucose production rate in a post-absorptive state correlates very well with the estimated size of the brain from birth to adult life. However, not all of the glucose produced is utilised by the brain. The requirement for glucose has been reported to be approximately 110 to 140 g/day in adults.

Nevertheless, even the brain can adapt to a carbohydrate-free, energy sufficient diet, or to starvation, by utilising ketoacids for part of its fuel requirements. When glucose production or availability decreases below that required for the complete energy requirements of the brain, there is a rise in ketoacid production in the liver in order to provide the brain with an alternative fuel. This has been referred to as a "ketosis". Generally this occurs in a starving person only after glycogen stores in the liver are reduced to a low concentration and the contribution of hepatic glycogenolysis is greatly reduced or absent.

FAO/WHO (1998) highlighted that the minimal amount of carbohydrate in the human diet that is needed to avoid ketosis is 50 g/day in adults. Apart from that, the additional energy requirements should be met by nutrient-dense carbohydrate foods, adequate intake of protein to supply essential amino acids and essential fatty acids from

fat. Intake of added sugar and/or sugar-rich foods should be in moderation in order to provide palatability and nutrients to the diet.

The available evidence based on the majority of studies on the relationship of dietary fibre to gastrointestinal health, several chronic diseases (colon cancer, breast cancer), glucose tolerance, insulin response as well as weight control and maintenance, indicated that the beneficial effects of fibre in humans are most likely related to the amount of food consumed but not the individual's age or body weight (IOM, 2002).

4.5 Setting requirements and recommended intakes of carbohydrate

Total carbohydrates

In the population nutrient intake goals recommended by WHO (1990, 2003) for the prevention of diet-related chronic diseases, intake of total carbohydrate has been suggested to be from 55% to 75% of total energy. This range was based on the remaining percentages of protein energy (10-15%) and fat energy (15-30%). Complex carbohydrate intake, in particular, was set at 50 to 70% of total energy. A daily minimum intake of 400 g of vegetables and fruits, including at least 30 g of pulses, nuts and seeds, should meet this recommendation.

A similar recommendation has been made by the joint FAO/WHO expert consultation on carbohydrate (1998). An optimum diet for all ages (except for children under the age of two) should consist of at least 55% of total energy from a variety of carbohydrate sources .

The IOM (2002) report indicated that the RDA for carbohydrate is based on the average minimum amount of glucose that would provide the brain with an adequate supply of glucose fuel without the requirement for additional glucose production from ingested protein or triacylglycerols, which is set at 130 g/day for adults and children. The median intake of carbohydrate has been derived from data from the Continuing Food Survey of Intakes by Individuals (CSFII) in 1994-1996 and 1998 i.e. 200 to 330 g/day for men and 180 to 230 g/day for women. This represents 45% to 65% of energy sufficient diet containing an Acceptable Macronutrient Distribution Range of carbohydrate intake.

Technical Sub-Committee (TSC) on Energy and Macronutrients considered these various recommendations. It was felt that the appropriate proportion of energy from carbohydrate should be mid-way between the recommendations of WHO (2003) and IOM (2002). The TSC recommended that in the revised RNI, carbohydrate should comprise 55-70% of total energy. This decision takes into consideration the proportion of energy contributed by fat and protein, described in chapters 3 and 5 of this monograph.

Sugars

The population nutrient intake goals of WHO (2003) for the prevention of diet-related chronic diseases has recommended that not more than 10% of total energy should be from free sugars. The term "free sugars" refers to all monosaccharides and disaccharides added to foods by the manufacturer, cook or consumer, plus sugars naturally present in honey, syrups and fruit juices. The DRI committee of IOM (2002) has recommended an upper limit of 25% of total energy for sugar intake.

There are no available reports quantitating sugar consumption among Malaysians. Based on food balance sheet data for Malaysia, the available sugars in the country was estimated to be about 86 g/day or 13% of total energy in 1985. This was found to have increased to 104 g/day or 14% of total energy in 2002 (FAO, 1985; 2002).

The TSC on Energy and Macronutrients considered the recommendations of WHO and IOM and the local dietary pattern. The TSC recommends sugar intake to be not more than 15% of total energy. This is felt to be a realistic figure and appropriate advice for the local population.

Glycaemic response, glycaemic index and glycaemic load

Carbohydrate-containing foods have a wide range of effects on blood glucose concentration during the course of digestion (glycaemic response), with some resulting in a rapid rise followed by a rapid fall in blood glucose concentration. Others result in a slow extended rise and a slow extended fall. Prolonging the time over which glucose is available for absorption in healthy subjects greatly reduces the post-prandial glucose response (IOM, 2002).

The glycaemic index (GI) has been proposed as a method to classify foods based on their blood glucose-raising potential. It is defined as the incremental area under the blood glucose response curve of a 50 g carbohydrate portion of a test food expressed as a percentage of the response to the same amount of carbohydrate from a standard or reference food taken by the same subject (FAO/WHO, 1998). The standard food has been glucose or white bread although the former is preferred. Several reports of GI of foods have been published in other countries. FAO/WHO (1998) consultation report has compiled a list of some commonly consumed foods, with GI values ranging from a low of 50 for foods such as several legumes to a high of over 100 for foods such as rice cake, puffed rice and corn flakes. There is no wide accepted classification of GI values of foods although Brand-Miller, Foster-Powell & Colagiuri (1996) had suggested a system several years ago. The Consultation report also explained how GI can also be applied to mixed meals or whole diets by calculating the weighted GI value of the meal or diet.

The concept of glycaemic load (GL) stresses the fact that the amount of carbohydrate in a food is important in determining fasting triglyceride and the post-prandial plasma glucose response. The GL, the product of the food carbohydrate content by its GI, is a measure that incorporates both the amount and quality of dietary carbohydrate. The GL of a specific food serves as a basis to evaluate the total GL of the diet. Hence, a food with very high GI but with only a small amount of carbohydrate will have a small GL.

In Malaysia, research into glycaemic response of foods is still at its infancy. However, interest in the subject has been increasing. Some data on GI values of nine frequently consumed Malaysian foods are given in Table 4.2.

Table 4.2 Glycaemic index value* of selected Malaysian foods

Food / Drink	GI
Fried meehoon	99
Fried macaroni	74
Fried rice	59
Roti canai & dhal	71
Sardine sandwich	73
Currypuff	54
Doughnut	57
Nasi lemak	66
Teh tarik	78

* glucose was used as the reference food
(Source: Nik Shanita, 2004)

There are a number of longer-term implications of altering the rate of absorption, or GI, of dietary carbohydrate (FAO/WHO, 1998). Reducing diet GI, for example, has been shown to improve overall blood glucose control in subjects with diabetes and reduce serum triglycerides in subjects with hypertriglyceridemia. There is some evidence that the GI is relevant for sports nutrition and appetite regulation.

Used in conjunction with information about food composition, GI has thus been proposed to guide consumers in food choices. The practical application of GI has however been the subject of much controversy. Its practical use worldwide has also been limited to a few countries. The practical use of GI of single food items has been particularly doubtful because glycaemic responses to foods are influenced by many factors including its carbohydrate content and the other food components present and even cooking or food processing methods (FAO/WHO, 1998) (Table 4.3). Some low GI foods may not always be a good choice because they are high in fat. Conversely, some high GI foods may be a good choice because of convenience or because they have low energy and high nutrient content. It is not necessary or desirable to exclude or avoid all high GI foods. The TSC on Energy and Macronutrients therefore has no definite recommendations on the use of GI or GL at this time. It however recommends research

and practitioner groups in the country to continue to monitor global developments on the matter and to actively research the subject.

Table 4.3 Food factors influencing glycaemic responses

Amount of carbohydrate
Nature of the monosaccharide components
Glucose
Fructose
Galactose
Nature of the starch
Amylose
Amylopectin
Starch-nutrient interaction
Resistant starch
Cooking/food processing
Degree of starch gelatinization
Particle size
Food form
Cellular structure
Other food components
Fat and protein
Dietary fibre
Antinutrients
Organic acids

Source: FAO/WHO (1998)

Dietary fibre

There is no biochemical assay that reflects dietary fibre status of an individual. Clearly one cannot measure blood fibre concentration since, by definition, fibre is not absorbed. Hence the DRI Committee of IOM (2002) had reviewed the potential health benefits of fibre consumption, which may be compromised by lack of fibre in the diet. These include a number of epidemiological studies conducted to evaluate the relationship between fibre intake and risk of chronic diseases. The Committee recommended an adequate intake ranging from 19-25 g/day of total fibre for young children whereas intakes for adolescents range from 26-38 g/day, the lower figures being for girls. Adult intakes are recommended to be 25 g/day for women and 38 g/day for men. Intakes for adults more than 51 years are 20% lower whilst for pregnant and lactating women, 12% higher.

The American Dietetic Association (ADA, 2002) has recommended intakes which are slightly lower than those of IOM, ie 20-35 g dietary fibre/day or 10-13 g per 1,000 kcal for adults. Although recognising there is a lack of clinical data, the ADA

recommends that for children older than 2 years, the dietary fibre intake should be equal to or greater than their age plus 5 g/day.

The nutrient intake goals recommended by WHO (2003) for the prevention of diet-related chronic diseases has indicated a total dietary fibre intake of >25 g per day whereas non-starch polysaccharides (NSP) intake is recommended to be >20 g per day. The report further recommends that whole grain cereals, fruits and vegetables are the preferred sources of NSP.

Upon reviewing all available information, the TSC for Energy and Macronutrients decided to adopt the Malaysian Dietary Guidelines (NCCFN, 1999) recommendations of 20-30 g of dietary fibre per day for all age groups. This is felt to be a realistic recommendation although greater efforts have to be made to encourage communities to consume a wide variety of plant foods in order to meet the recommendations.

4.7 Toxicity and tolerable upper intake levels

There is no evidence of adverse effects arising from overconsumption of carbohydrates. The FAO/WHO (1998) suggested total carbohydrate intake should be 55-75% of total energy. The Consultation recognised that carbohydrate intake of 75% or more of the total energy can have significant adverse effects on nutritional status by exclusion of adequate quantities of protein, fat and other essential nutrients.

Positive energy balance and obesity occur when total energy intake exceeds total energy expenditure. Much controversy surrounds the extent to which sugars and starch promote obesity. The FAO/WHO (1998) consultation found no direct evidence to implicate either of these groups of carbohydrates in the aetiology of obesity. It was nevertheless reiterated that excess energy in any form will promote body fat accumulation. There is no evidence of a direct involvement of sucrose, other sugars and starch in the aetiology of diet-related chronic diseases. Nevertheless, excessive intakes of sugars which compromise micronutrient density should be avoided.

The WHO (1990) report recognised that studies have indicated that the rates of dental caries and dental plaque formation were not solely due to high sucrose intake but depend on the oral hygiene practices of the population and it appears that other commonly used sugar-based sweeteners also have cariogenic effects. Nevertheless, there are evidences that the level of dental caries is low in countries where the consumption of free sugars is below 15-20 kg/person/year or equivalent to 44-55 g/person/day (6-10% of total energy) (WHO, 2003). There was concern about the excessive use of free sugars which only provide energy without associated nutrients and therefore displace nutrient-containing foods. It was also felt that free sugars contribute to the overall energy density of diets and can promote a positive energy balance. Both the WHO (1990) and WHO (2003) reports have thus recommended that the upper limit for free sugars should be

around 10% of total energy.

Based on the available data on dental caries, behaviour, cancer, risk of obesity and risk of hyperlipidaemia, the DRI Committee (IOM, 2002) concluded that there is insufficient evidence to set a UL for total or added sugars. However, a maximum intake level of 25% or less of energy from added sugars has been suggested based on observations that there could be decreased intake of some micronutrients for persons exceeding this level.

Upon reviewing the literature, the DRI committee (IOM, 2002) felt that dietary fibre can have variable compositions and it is difficult to link a specific fibre with a particular adverse effect, especially when phytate is also often present. The Committee concluded that a high intake of dietary fibre as part of an overall healthy diet will not produce significant harmful effects in healthy individuals. Therefore, a tolerable upper intake level (UL) was not set for dietary fibre.

4.8 Research recommendations

The following priority areas of research are recommended:

- Improved methodologies for the measurement of carbohydrates and their components in foods
- Improved national food composition table with data on types of carbohydrates (starch, total and individual sugars)
- Studies related to glycaemic response (including glycaemix index and glycaemic load) of carbohydrate-containing food based on local foods
- Obtain data on the content of dietary fibre in local foods for inclusion in the national food composition table.

4.9 References

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