BRITISH Nutrition FOUNDATION

A summary of evidence on the digestion, absorption and metabolism of white bread carbohydrates

The British Nutrition Foundation was commissioned by The Federation of Bakers to review the scientific evidence base for this report.

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Remit:

The British Nutrition Foundation was commissioned to write an independent report reviewing current evidence on the digestibility of white bread, factors influencing this and possible effects on satiety and appetite. The review provides an overview of this area, identifying key papers and highlighting areas of uncertainty for future research where possible.

This report will review:

- The digestion of carbohydrate, with a focus on starch
- Factors affecting starch digestibility
- Glycaemic index and modifying factors
- Glycaemic index and satiety
- The effects of white bread on satiety and body weight
- Dietary guidelines relevant to bread
- Ongoing research on bread

Executive summary

Carbohydrates are an important source of dietary energy. In the UK, the proportion of energy derived from carbohydrates is close to the national dietary reference value (around 50% of total dietary intake). Carbohydrates are a relatively diverse group of compounds, classified according to molecular size and individual monomer units present, both of which can determine the site and rate of digestion and blood glucose response. Bread is rich in complex carbohydrates, particularly starch which is predominantly digested in the small intestine where it is broken down to its constituent glucose monosaccharide units. The rate of starch digestion mainly depends on the structure of the starch granules (ratio of amylose and amylopectin polysaccharides, protein and lipid content) and processing techniques (e.g. milling, refining and cooking). Bread made with refined, high amylopectin, low protein and/or low lipid wheat flour and baked to achieve an open crumb and thick crust is likely to result in most rapid starch digestion. Factors intrinsic to the consumer (e.g. degree of mastication, salivary α-amylase production and digestive transit time) and meal composition (e.g. protein, fat and fibre content of foods eaten at the same time or in previous meal) can also affect starch digestion and glucose absorption.

The glycaemic index (GI) is a measure of the rise in blood glucose after eating a specific food. Carbohydrate in a low-GI food is digested and absorbed at a slower rate than carbohydrate from a high-GI food, although there is large variation in glycaemic responses between and within individuals. White bread, as well as brown and wholemeal bread, is generally classified as a high-GI food due to the highly gelatinised starch it contains, low fibre content and porous physical structure, which is easily broken down during digestion. However, the GI can vary depending on the raw ingredients, processing method and what it is consumed with. Granary bread and some white breads (e.g. sourdough and pitta bread) have a 'medium' or 'low' GI rating. The GI may be reduced by the addition of fibre (e.g. intact grains or viscous soluble fibres - although the fibre type, dose and processing method appear to be important in terms of effect size), fat (e.g. olive oil) or with the presence of organic acids (e.g. from sourdough fermentation). Bread is rarely eaten in isolation and foods commonly consumed with white bread (e.g. fat spreads, cheese and meats) can reduce the glycaemic response to bread. A food with a low-GI is not always a healthier choice as low-GI foods can be high in fat and energy.

The original aim of classifying foods according to GI was to help improve glycaemic control in individuals living with diabetes. In healthy individuals, blood glucose concentrations are homeostatically controlled within a fairly narrow range. After a carbohydrate-containing meal, there is a very small increase in blood glucose in healthy individuals, with levels

returning back to baseline after a couple of hours. Nevertheless, there is some evidence to suggest that glycaemic excursions within the normal physiological range may temporarily increase oxidative stress which could have an impact on the inflammatory response and blood vessel elasticity. In addition, upon review of the evidence, the Scientific Advisory Committee on Nutrition (SACN) found high-GI diets to be associated with an increased incidence of type 2 diabetes. However, this does not indicate causality and other factors (e.g. low fibre diet) may be responsible for this finding.

A number of acute studies of varying quality and design have investigated the effect of GI on satiety and appetite control. Over half have reported an inverse association between GI and satiety, with significant differences being reported for subjective satiety and hunger ratings and/or objective energy intake at a subsequent meal. However, a systematic review looking specifically at the effect of low- vs. high-GI breakfast meals failed to find a significant effect on subsequent energy intake, and upon reviewing the evidence on GI and appetite control, SACN also found no significant effect. Evidence to support a long-term impact on GI and appetite control (i.e. weight loss or maintenance) is also lacking, although one high-quality clinical study has shown a beneficial effect of a low-GI diet on weight maintenance. Low-GI foods are often higher in fibre and disentangling the potential effect of GI with that of increased fibre content is difficult. Furthermore, it has been hypothesised that the effect of low-GI foods/diets on appetite control observed in some studies may be underpinned by the fibre content of the food/diet rather than the glycaemic response. Fibre may help to increase satiety rating via metabolic signals sent between the gut and the brain, such as those transmitted by stretch receptors in the stomach (which sense physical fullness), gut hormones and short-chain fatty acids produced during fibre fermentation in the gut.

A number of studies have indicated that wholegrain bread (which is higher in fibre) is more satiating than white bread and adding fibre-containing flours or ingredients to white bread may increase satiety ratings (dependent on fibre type, dose and format). However, there is a lack of long-term studies investigating the effect of satiety-enhancing bread on long-term energy intake and body weight. Standard white wheat bread is commonly perceived amongst consumers to be associated with weight gain. However, the evidence to support this perception is somewhat limited. Most observational cohort studies indicate a possible positive association between white bread consumption and abdominal fat. However, it is difficult to determine from these studies whether it is the white bread per se causing the effect or other foods or behaviours associated with intake of white bread (e.g. low intake of fruit and veg, other high fibre foods and higher intake of energy-dense, high-fat foods).

Food-based dietary guidelines in the UK have recently been updated in light of the recent recommendations of SACN's *Carbohydrate and Health* report (no more than 5% of dietary energy as free sugars for those aged over 2 years and an increase to 30 g fibre a day for adults). Updates include an increase in the starchy carbohydrate segment in the refreshed *Eatwell Guide* from 33% to 38% and greater focus on wholegrain and high-fibre foods. Globally, starchy carbohydrates are recognised as the cornerstone of the diet and most countries promote the consumption of wholegrains.

To conclude, research on the health impact of white bread is relatively limited. There may be a health benefit to consumers in selecting lower-GI options within a food category, such as wholegrain rather than white bread. However, the associations highlighted in the scientific literature between low-GI diets and health (e.g. reduction in risk of type 2 diabetes and weight maintenance) could be driven by other dietary and lifestyle factors, such as the fibre content of the diet. Both the GI and satiety rating of white bread appears to depend on the raw ingredients and processing method with improvements being particularly noted with the addition of specific fibres. Further research investigating the effect of incorporating different ingredients into bread on GI and satiety is currently underway and will help to increase our understanding of this topic. It is possible that satiety-enhancing breads, in combination with other approaches, could aid weight loss or weight maintenance but further long-term studies would be required to substantiate any health claims in this area.

1. Carbohydrate digestion

1.1 Brief introduction to dietary carbohydrate classification and digestion

Carbohydrates are a source of energy, principally synthesised by plants from water and carbon dioxide using the sun's energy. Quantitatively, carbohydrates are the most important dietary energy source for humans, accounting for around 40-80% of total energy intake across different global population groups (Gibney et al., 2009).

In the UK, it is recommended that carbohydrates are the main source of energy in a healthy balanced diet, providing around 50% of energy. This recommendation was maintained following the recent in-depth review of all the scientific evidence by the expert Scientific Advisory Committee on Nutrition (SACN, 2015), and is broadly similar to recommendations from governments around the world and the World Health Organization. National and international dietary guidelines typically recommend high consumption of vegetables, fruit, wholegrains, and other fibre-providing carbohydrate-rich foods, and low consumption of free sugars, saturated fatty acids and salt (USDA and USDHHS, 2015, PHE, 2016, The_Nordic_Council, 2012, NHMRC, 2013, FSAI, 2011).

Gram for gram, carbohydrates provide fewer calories compared to the other main energy providers, such as fat (see Table 1.1).

Table 1.1: The amount of energy provided per gram

Source	Kcal (KJ) per gram
Carbohydrate*	3.75 (16)
Protein	4.0 (17)
Fat	9.0 (37)
Alcohol	7.0 (29)
Fibre	2.0 (8)

*Glycaemic carbohydrates (see overleaf)

Carbohydrate classification

Carbohydrates are classified according to molecular size (defined by degree of polymerisation and type of linkage) and the individual monomers present (Table 1.2).

Table 1.2: Classes of dietary carbohydrates

Class	Degree of polymerisation	Examples	Site of digestion
Monosaccharides	1	Glucose	Small intestine
		Fructose	Small intestine
Disaccharides	2	Sucrose	Small intestine
		Lactose	Small intestine
Polyols	1-2	Xylitol	Predominantly large intestine
		Erythritol	Small intestine
Oligosaccharides	3-9	Maltodextrin	Small intestine
		Inulin	Large intestine
		Fructo-oligosaccharides	Large intestine
Polysaccharides	≥10	Starch	Predominantly small intestine
		Non-starch polysaccharides	Large intestine

Carbohydrate digestion

For absorption from the small intestine into the peripheral circulation, carbohydrate polymers need to be broken down to their constituent monosaccharide units. The bonds between the units are split by hydrolytic enzymes (e.g. α-amylase), which are secreted in the mouth, the pancreas and on the surface of the cells within the small intestine. Around 95% of carbohydrates in most human diets are digested and absorbed in the small intestine (often termed **glycaemic carbohydrates**). Carbohydrates which are not broken down sufficiently by hydrolytic enzymes in the small intestine enter into the large intestine (often termed **non-glycaemic carbohydrates** and includes **dietary fibres**). These non-glycaemic carbohydrates include resistant starch, non-starch polysaccharides, inulin and fructo-oligosaccharides.

In the UK, dietary fibre is defined as all carbohydrates that are neither digested nor absorbed in the small intestine and have a degree of polymerisation of three or more monomeric units, plus lignin.

The UK definition of dietary fibre (AOAC) includes:

- Non-starch polysaccharides (NSP) (e.g. cellulose, pectins, glucans, arabinogalactans, arabinoxylans, gums and mucilages)
- Resistant starches
- Non-digestible oligosaccharides
- Inulin
- Lignin

Carbohydrate content of bread

Bread is rich in complex carbohydrates, particularly starch which accounts for around 90% of the total carbohydrate content (1-2% of which is resistant starch) of both white and wholemeal wheat bread (Hiller et al., 2011). Other polysaccharides such as cellulose, hemicellulose and lignin are also present but in lower amounts. Bread also contains dextrins, maltose and glucose, which are produced from the breakdown of starch (EUFIC, 2016). Dietary fibre is concentrated in the bran of cereals, which is removed to obtain white flour for the production of white bread. As a result, the fibre content is much higher in wholegrain bread compared to white bread (see Table 1.3). The amount of dietary fibre can also increase with the addition of other ingredients (e.g. oats, grains or seeds).

Table 1.3: Total carbohydrate and dietary fibre content in different breads

Bread	Total carbohydrate (per 100g)	Dietary Fibre AOAC (per 100g)
White	46.1	2.5
White 'with added fibre'	53.7	4.8
Brown	42.1	5.0
Wholemeal	42.0	7.0
Malted wheat	47.4	5.3
Seeded	43.8	6.2
Wheatgerm	39.5	5.7

(Finglas et al., 2015)

Factors affecting the rate of carbohydrate digestion

The rate and site of dietary carbohydrate digestion predominantly depends on the structure of the carbohydrate and the food matrix (as this determines the rate of hydrolysis) (see Box 1.1). The rate of carbohydrate digestion is also partly determined by factors intrinsic to the consumer (see Box 1.1). These will be discussed in more detail in section 1.2.1.

Box 1.1: Factors affecting the rate of carbohydrate absorption

Food factors

- Primary structure of the carbohydrate
- Particle size and ratio of different carbohydrate polymers
- Structure of the food (particularly whether cell walls are intact) and food matrix
- Cooking/ food processing
- Lipid, fibre and protein content of meal
- Presence of enzyme inhibitors

Consumer factors

- Degree of mastication
- Rate of gastric emptying
- Small bowel transit time

(Gibney et al., 2009)

The non-glycaemic carbohydrates pass into the large intestine where they are partially or completely broken down by the gut bacteria. Carbohydrates which enter the large intestine (e.g. dietary fibre and a limited number of shorter chain carbohydrates) do so because:

- The monosaccharide transporter does not exist in the small intestine or has low affinity (e.g. fructose – if not in the presence of glucose and xylose)

  OR
- The enzymes needed to digest the carbohydrate are not present in the small intestine or cannot function at a high enough rate (e.g. lactose in some individuals, certain types of resistant starch, non-starch polysaccharides)

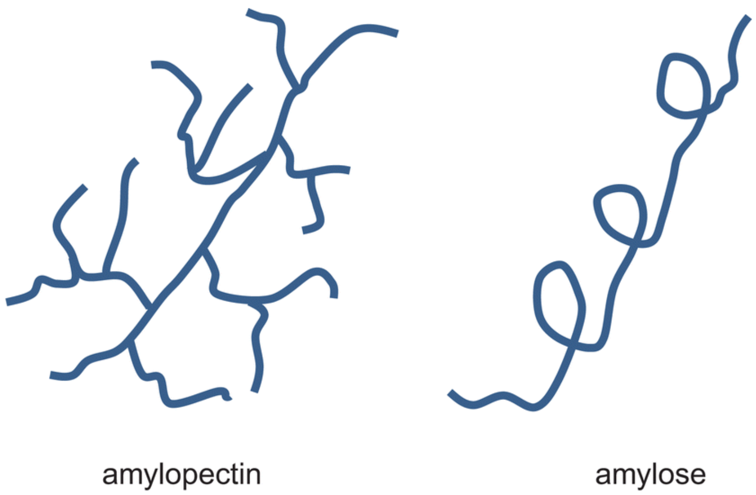
  OR
- The enzymes can't gain access to the carbohydrate (e.g. most resistant starches)

Non-glycaemic carbohydrates, many of which are also classed as dietary fibre, may still provide energy (in the form of short-chain fatty acids as a result of bacterial fermentation in the large intestine) but as this energy isn't in carbohydrate form it does not alter blood glucose concentrations (hence the term non-glycaemic carbohydrates). Part of the energy produced from the fermentation process is lost in the form of gas or within the faeces. This is why dietary fibre has been assigned a lower energy value, compared to glycaemic carbohydrates (2 kcal rather than 3.75 kcal per gram).

1.2 Digestion of starch

Starch is the primary storage form of carbohydrate contained within cereals, the major carbohydrate staples in the diet (e.g. rice, wheat, maize, barley, rye and oats) and some root vegetables (e.g. potatoes), fruits (e.g. bananas) and pulses. The starch in these plant foods consist of amylose and amylopectin polysaccharides, stored in the form of partially crystalline granules. Amylose contains only α-(1,4) bonds between glucose monomers creating a linear polymer, whilst amylopectin contains α-(1,4) bonds and α-(1-6) bonds resulting in a highly branched structure (see Figure 1.1). Most common cereal starches comprise 15-30% amylose but some starches, including waxy corn and rice starches, contain proportionally less amylose and more amylopectin. In wheat endosperm, around 20-25% of starch is amylose (Slade et al., 2012). The ratio of amylose and amylopectin, the crystalline configuration formed and the structure of the native starch granules dictate ease of access for digestive enzymes. Native cereal starches tend to be more favourable substrates for digestive enzymes compared to the native starches in tubers and pulses which have a different crystalline structure. However, digestion rate is dependent on domestic and commercial food processing as heat can break down the crystalline structure of the starch. For example, the α-amylase catalytic rate for potato starch has been reported to increase over 100-fold after thermal-processing (Butterworth et al., 2011).

Figure 1.1: Amylose and amylopectin structure



(Lederer and Burchard, 2015)

Salivary α-amylase, secreted in the mouth, begins the process of starch digestion by hydrolysing internal α-1,4-linkages in amylose and amylopectin molecules to yield the oligosaccharides: maltose, maltotriose and dextrins. The activity of this hydrolysis enzyme is thought to be mostly inhibited when the ingested food hits the high pH of the stomach. However, pancreatic α-amylase secreted in the small intestine, continues the hydrolysis process following gastric emptying.

The oligosaccharides produced from the breakdown of the starch are subsequently hydrolysed by oligosacchridases secreted from the cells lining the small intestine. The resulting glucose monomers are then absorbed from the small intestine and transported via the portal vein to the liver. Around two thirds of the absorbed glucose is transported from the liver into the peripheral circulation for utilisation by the body's tissues (Moore et al., 2003).

Starch which escapes digestion in the small intestine is called resistant starch. Starches within cereals may remain undigested if physically inaccessible to the digestive enzymes (e.g. enclosed in whole grains) or if the starch is retrograded (i.e. disrupted amylose and amylopectin polymers re-associate into an ordered structure; for example, following cooking and refrigerator storage).

1.2.1 Factors affecting starch digestion

Foods containing the same amount of starch may have distinct effects on post-prandial (after meal) blood glucose levels. This is because the rate and extent of starch digestion is mainly dependent on the following two factors:

a) Structure of the starch granules

- Amylose is digested more slowly compared to amylopectin as the linear, more compact structure of amylose is less accessible to α-amylase and has an increased tendency to aggregate and crystallise during retrogradation (Slade et al., 2012). Therefore, starches with a high proportion of amylose will take slightly longer to digest. For example, postprandial 2-hour glucose area under the curve (AUC) was found to be around a third lower after the consumption of bread containing 70% compared to 30% of starch as amylose (Behall and Hallfrisch, 2002).
- Proteins or lipids within the starch granule can hinder starch-α-amylase interactions, lengthening the digestion time. For example, lipid-amylose complexes have been found to inhibit enzymatic hydrolysis of amylose by ~35% (Crowe et al., 2000). In addition, strong interactions between starch and protein can slow down starch digestion. For instance, hard wheat, which is used to make pasta, has stronger starch-protein interactions than soft wheat which is used in bread-making. This may partly explain why consumption of pasta results in a lower glycaemic response, compared to bread (Fardet et al., 2006) (see section 2).

b) Processing technique

The amount of resistant starch, starch granule integrity and degree of crystallinity can be decreased by processing techniques such as milling, refining and cooking. As such, these processes increase the rate of starch digestion. On the other hand, processes such as post-cooking refrigerated storage or, in the case of bread, storage conditions resulting in staling can decrease starch digestibility as a result of increased starch retrogradation (Singh et al., 2010, Bosmans et al., 2013).

The physical characteristics of a food may also influence digestion by altering the amount of mastication required, the secretion of saliva and the starch-α-amylase interactions. For example, the bolus created after mastication of French bread has been shown to contain more saliva and smaller particles, compared to the bolus of other types of bread (Gao et al., 2015). This is likely to be due to the thick, dry crust (which requires greater chewing effort and saliva infiltration) and the porous open crumb structure (which increases starch-α-amylase interactions) of French bread (Gao et al., 2015). This may help to explain the marginally higher glycaemic index value of French bread, compared to other breads (see section 2).

Other factors

Consumer factors, such as the degree of mastication, mouth size, quantity and activity of salivary α-amylase, rate of gastric emptying and small intestine transit time can all have an impact on the rate of starch digestion and glucose absorption (Ranawana et al., 2010, Mandel et al., 2010, Gibney et al., 2009, Jourdren et al., 2016). For example, there is significant variation in the production and activity of salivary α-amylase between individuals. This is due to both environmental (e.g. stress, circadian rhythms and dietary intakes) and genetic factors (Mandel et al., 2010). A study using rheological measures of starch viscosity (measurement of the flow and deformation of starch under applied forces) found that the impact of saliva on starch viscosity varied between individuals from virtually no effect to a rapid decrease within a few seconds (Mandel et al., 2010). Interestingly, when starch is delivered directly into the small intestine, skipping the salivary amylase digestion stage, significantly less digestion and glucose absorption occur. Therefore, individuals who produce high levels of salivary amylase may experience a higher blood glucose incremental area under the curve (iAUC - plot of concentration of glucose in blood over time) after a high starch meal, compared to individuals who produce low levels, but further research is needed to confirm this (Mandel et al., 2010).

Accompanying foods and the foods eaten in the previous meal can also have an effect on starch digestion and glucose absorption. Protein, fat and fibre can slow down the rate of carbohydrate digestion when consumed as part of the same meal or within the food matrix (Meynier et al., 2015, Granfeldt et al., 2006, Singh et al., 2010). In addition, the rate of starch digestion has been found to be influenced by the fat and fibre content of the previous meal (Granfeldt et al., 2006, Robertson et al., 2002). For example, Granfeldt *et al.* (2006) found that breakfast blood glucose levels were 23% lower following an evening meal containing barley kernels (which contain high levels of dietary fibre) compared to white bread (amount matched for carbohydrate content).

Key points

- Glycaemic carbohydrates appear as glucose in the peripheral circulation.

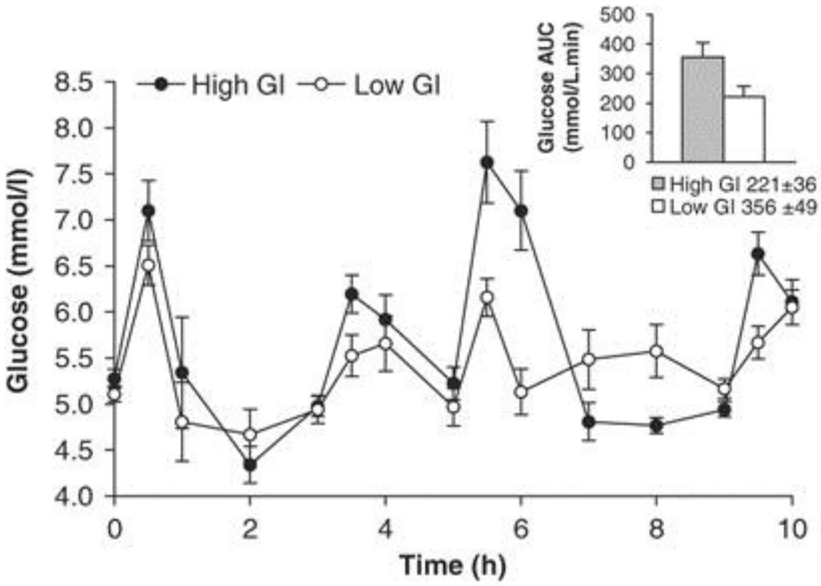
- Rate of absorption is influenced by food characteristics, the presence of other foods/nutrients and individual factors. Bread with a low fibre content, open crumb and thick crust is likely to lead to a greater rate of glucose absorption compared to a high fibre, dense and soft crust bread.

- Non-glycaemic carbohydrates are fermented by bacteria in the large intestine, producing short-chain fatty acids which may be beneficial to health.

2. Glycaemic index and glycaemic load

Glycaemic index (GI), first termed in the 1980s, is a measure of the postprandial rise in blood glucose after eating a specific food. GI is determined by comparing the glycaemic response to 50g of available carbohydrate from the test food to the same amount of available carbohydrate from a reference food (typically either glucose or white bread made from wheat flour). Foods are sometimes categorised as high (≥70), medium (55-69) and low (<55) GI. Carbohydrate in a low-GI food is digested and absorbed at a slower rate than carbohydrate from a high-GI food, which results in very slightly reduced peaks in postprandial blood glucose (see Figure 2.1). Typically, high-GI foods include those with easily digested starches (e.g. refined grains and cooked potatoes) and foods with high amounts of glucose or disaccharides which are hydrolysed to glucose. Low-GI foods generally contain more slowly digested or resistant starches and/or higher fibre content (e.g. unprocessed grains and beans).

Figure 2.1: Mean blood glucose responses in healthy participants over 10 h on a high-GI and low-GI diet (containing four meals)



(Reynolds et al., 2009)

If a food is low-GI does that mean it is healthy?

A food with a low GI is not always a healthier choice. For example, watermelon and parsnips are high-GI foods, while chocolate cake has a lower GI value.

Low-GI foods can be high in fat and energy and eating a diet consisting entirely of low-GI foods is likely to be lacking in variation. Also the GI of a food is not fixed and depends on a range of factors [e.g. how it has been cooked, stored, what it is consumed with and how ripe it is (for fresh fruit and vegetables)].

Consumers need to think of the bigger picture and choose foods low in fat, saturated fat, salt and free sugars and high in vitamins, minerals and fibre as part of a healthy, balanced diet.

The application of the GI is made difficult because the GI value of many common foods, including composite foods, is not known. In addition, for some foods the GI values reported by different laboratories vary widely, which can relate to different protocols used and also natural variances between different crop varieties and random, day-to-day variation of glycaemic responses within participants (Wolever et al., 2003). As such, GI values published by different research groups may be subject to variation. The GI values of various breads and cereal products shown in Table 2.1 were obtained from the Diogenes GI database, which assigned the values according to a standardised approach (Aston et al., 2010).

Table 2.1: Glycaemic index values of commonly consumed cereals and cereal products in the UK

Food	Glycaemic index	Fibre (AOAC) (g) per 100g
Breads		
White bread, French stick	95	3.3
Wholemeal bread	73	7.0
Brown bread	73	5.0
White bread	72	2.5
Crumpets	69	3.1
Pitta bread, white	67	2.3
Granary bread	62	5.3
Wheat roti	62	-
Malt bread	59	3.5
Sourdough bread	54	-
Chapatti	50	-
Wheat tortilla	30	3.6
Grains and pasta		
Couscous	65	2.2
Egg noodles, boiled	63	3.0
White rice, glutinous, boiled	63	Trace
Brown rice, boiled	55	1.5
White rice, easy cook, boiled	49	0.7
White pasta, boiled	45	2.6
White Spaghetti, boiled	44	1.7
Wholewheat spaghetti, boiled	37	4.2
Breakfast cereals		
Cornflakes	93	2.6
Wheat flake biscuits	75	9.7
Branflakes	74	13.4
Porridge, made with water	51	1.0

(Aston et al., 2010, Finglas et al., 2015) High-GI Medium-GI Low-GI

The GI provides a measure of carbohydrate quality but it does not take into account carbohydrate quantity. As both the quantity and quality of carbohydrate can influence the glycaemic response, the concept of **glycaemic load (GL)** was introduced. It is calculated as follows:

GL = (GI x available carbohydrate in a portion)/ 100

2.1 Factors affecting the GI and GL of white bread

White bread, like potatoes and glutinous white rice, is generally classified as a high-GI food. This is due to the highly gelatinised starch it contains and also its porous physical structure, which is easily destructed during digestion (Fardet et al., 2006). Multigrain and granary breads and breads produced from some speciality grains (e.g. rye) contain some starch which is not as readily accessible to α-amylase; this often results in these breads being classified as medium- or low-GI (Aston et al., 2010, Atkinson et al., 2008). Within the category of white bread, the GI can vary depending on the raw ingredients, processing method (e.g. mixing, proofing and cooking method) and what it is consumed with (i.e. the other components of a meal). This variation is underpinned by the extent to which α-amylase is able to access the starch.

Raw ingredients

Starch accessibility in white bread can be modified through the choice of raw ingredients. Most white breads are made with white refined wheat flour, which contains around 30% amylose. By mixing wheat flour with other types of flours, with a higher amylose content (e.g. flour from high-amylose varieties of barley or corn), it is possible to reduce the GI of the bread (Ekstrom et al., 2013, Fardet et al., 2006, Scazzina et al., 2013). For example, bread made with high-amylose (65-75%) corn starch (600 g) and wheat flour (900 g) has been shown to reduce the GI value of the bread by 40 units, compared to a reference standard white wheat bread (Hoebler et al., 1999).

Box 2.1: Amylose content of different grains

Wheat – normally contains around 30% amylose

Corn – can contain up to 70% amylose

Barley – can contain up to 44% amylose

(Fardet et al., 2006)

The main strategy used to reduce the GI of bread is the addition of fibre, although the fibre type, quantity and processing method appear to be important in terms of the effect size (Gonzalez-Anton et al., 2015). This is illustrated in Table 2.1, which shows higher fibre content does not necessarily equate to a lower GI value. The addition of coarse or intact grains (e.g. granary bread) results in a lower GI value compared to the use of finely milled wholegrain flour (e.g. wholemeal bread). Adding viscous soluble fibres to bread, such as guar gum, beta-glucan and arabinoxylan, has been shown to reduce glycaemic response, possibly by reducing starch-α-amylase interactions and/or delaying gastric emptying (Ekstrom et al., 2013, Scazzina et al., 2013). For example, in an acute study, a breakfast meal containing white wheat bread with 15% arabinoxylan fibre was found to have a lower GI value (GI 59) than the reference white wheat bread breakfast meal (GI 100) (Lu et al., 2000). Adding whole or partly milled grains and seeds containing resistant starch to white wheat flour has also been shown to lower the postprandial blood glucose response of bread (Scazzina et al., 2013). For instance, wheat flour bread containing 50% buckwheat whole seeds was found to have a medium GI value of 66 (Skrabanja et al., 2001). However, added ingredients can sometimes disrupt the gluten network, which is thought to act as a makeshift barrier to α-amylase, and reduce the rate of starch digestion (Jourdren et al., 2016, Ronda et al., 2012). Further research is needed to determine the impact of different types and quantities of fibre on the glycaemic response to bread.

The addition of organic acids or sourdough fermentation have been shown to reduce the GI of white bread. In the Diogenes GI database, sourdough bread has a low GI rating (see Table 2.1) (Aston et al., 2010). The organic acids may reduce the GI by decreasing the rate of gastric emptying, increasing the interactions between starch and gluten, or in the case of sourdough, increasing the resistant starch content of the bread (Scazzina et al., 2013).

Other commonly used additives may also reduce the GI of bread. For example, monoacylglycerols (sometimes used to prevent bread staling), have been found to bind to α-amylase, inhibiting its function, which may lead to a slightly slower rate of starch digestion (Fardet et al., 2006). There is a lack of research quantifying the impact of these additives on the GI value of bread, but there is some indication that significant shifts in GI ratings are unlikely (Fardet et al., 2006).

Adding fat (e.g. olive oil) to the bread dough can also attenuate starch digestion, due to the formation of amylose-lipid complexes during baking which resist enzymatic digestion. For example, the blood glucose iAUCs in response to consumption of breads baked with butter, coconut oil, grapeseed oil or olive oil (20% w/w of dough) were around 20% lower than for breads baked without oil (Lau et al., 2016).

Bread structure

When food enters the mouth, it is progressively transformed into a bolus suitable for swallowing. Bolus formation involves the mechanical breakdown of food by mastication, hydration and lubrication by saliva and enzymatic degradation (by salivary α-amylase in the case of starchy foods). In addition to individual variation in oral processing, the textural characteristics of food, which are influenced by the processing and cooking method, can have an impact on bolus formation and the digestion of starch (Fardet et al., 2006).

Extensive degradation of starch by salivary α-amylase may occur if the structure of the bread requires prolonged mastication to form a bolus (e.g. thick crust) and if the bread has a high hydration capacity (e.g. dry crust), leading to better incorporation of saliva into the bread. This may partly explain why French bread has a higher GI value compared to standard white wheat bread (see Table 2.1).

The accessibility of the starch within the bread matrix to α-amylase can also be affected by the crumb structure. When bread has a high density or more compact structure (closed rather than open porous crumb), the accessibility of α-amylase to the starch is reduced.

Box 2.2: Possible methods to lower the GI of bread

- Using flour with a higher amylose content

- Addition of specific fibres

- Addition of coarse or intact grains/seeds

- Sourdough fermentation

- Creating a soft moist crust (requiring shorter mastication)

- Creating a dense crumb structure

Meal composition

Foods are rarely eaten in isolation and consuming a combination of foods within a meal can influence digestion and glucose absorption. As previously discussed, protein, fat and fibre can delay the absorption of glucose from carbohydrates eaten within the same meal and, therefore, influence the GI. Foods commonly eaten with white bread (e.g. fat spreads, cheese, meats), could help to reduce the glycaemic response to bread. For instance, an acute study comparing the GI of different breakfasts found that the GI of white bread was substantially reduced when consumed with butter and cheese (GI of 100 for the reference bread was reduced to a low GI of 30 with the addition of butter and cheese) (Flint et al., 2004). The rate of gastric emptying is also influenced by meal composition. Factors such as high energy (calorie) content, meal volume or fat content and the presence of organic acids have all been found to delay gastric emptying and may, as a result, postpone the glycaemic response to the meal (Bornhorst and Paul Singh, 2014).

Does white bread have a high GI?

The GI of white breads varies. Standard white bread is generally classed as a 'high' GI food although some white breads (e.g. sourdough and pitta bread) have 'medium' or 'low' rating (lower than the GI for wholemeal bread).

Foods are not often eaten in isolation, and the GI of white bread is frequently lowered by other foods that it is consumed with. For example, fat spreads and protein sandwich fillings can lower the GI value of a meal containing bread.

Key points

- The GI value of white bread can vary depending on the raw ingredients, processing method and what it is consumed with. A low GI is not always healthier (e.g. adding lots of butter to white bread would lower the GI but the energy density would be higher).

- The addition of dietary fibre to white bread may lead to a reduction in the GI, although fibre type, quantity and processing method appear to be important in terms of the effect size.

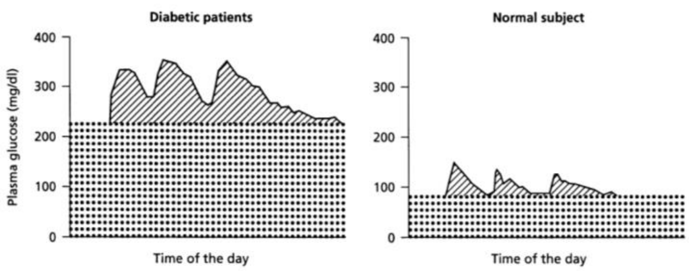
3. Glycaemic index and health

Do blood glucose levels vary widely throughout the day?

In healthy individuals, blood glucose concentration is homeostatically controlled within a fairly narrow range, principally by the pancreatic secretion of insulin and glucagon. Levels rarely fall below 5 mM, even after a long period of fasting (Gibney et al., 2009). Sufficient levels of blood glucose are needed at all times because certain tissues in the body, such as the brain, can only use glucose as a substrate for energy. During prolonged fasting glucose has to be produced from non-carbohydrate sources by gluconeogenesis. After a carbohydrate-containing meal, there is a very small increase in blood glucose (up to 8 mM) but secretion of insulin returns it back to baseline levels within a couple of hours in individuals without diabetes or pre-diabetes.

The original aim of classifying foods according to GI and GL was to help improve glycaemic control in individuals living with diabetes (Ford and Frost 2010). Type 1 diabetes is characterised by the lack of production of insulin and type 2 diabetes by a decrease in response to insulin (insulin resistance). In both cases, carbohydrate ingestion can lead to wide fluctuations in blood glucose concentrations (see Figure 3.1). Individuals with diabetes can use the GI and GL values of different foods to help manage their blood glucose levels.

Figure 3.1: Plasma glucose 24h profile in a typical patient with type 2 diabetes and a healthy individual (Del Prato, 2002)



In healthy individuals, there is some evidence to suggest glycaemic excursions within the normal physiological range can have a small but significant effect on levels of oxidative stress which may impact on the inflammatory response and elasticity of blood vessels. However this effect appears to be relatively short-lived, with oxidative stress levels returning back to baseline after a couple of hours (Blaak et al., 2012).

A limitation of classifying foods based on GI or GL is that there is large inter-individual variation (due to the reasons discussed in section 1.2), intra-individual variation and inter-laboratory variation. For example, an inter-laboratory study which tested the GI of white bread reported a range in mean GI between laboratories of 64.2±15.4 – 78.9±26.1, which could represent a medium- or high-GI classification, depending on the laboratory chosen (Wolever et al., 2003). Different glycaemic responses to a particular food can be observed day-to-day and even at different times of the day in the same individual. In addition, as previously discussed, the GI of a food can change depending on what other foods it is consumed with, or after. The accuracy and usability of GI and GL as markers of carbohydrate quality are, therefore, debated. Despite this, low-GI diets have been associated with improved glucose control in individuals with type 2 diabetes. A recent systematic review carried out by the Scientific Advisory Committee on Nutrition (SACN), which assessed the evidence on the links between consumption of carbohydrates and a range of health outcomes, found high-GI and GL diets to be associated with an increased incidence of type 2 diabetes. However, SACN reported no effect of GI on fasting glucose, fasting insulin or insulin sensitivity/resistance (diabetes risk factor markers) (SACN, 2015). A high-GI diet in these type of intervention studies, usually involves the consumption of higher GI staple foods within the diet, such as white bread, glutinous white rice, cornflakes and mashed potato, with the remainder of the diet being chosen *ad libitum* by the participants.

3.1 Glycaemic index, satiety and appetite

Interest in glycaemic index and the potential effects on satiety and appetite control have stemmed from the glucostatic hypothesis. In this theory, fluctuations in blood glucose level are thought to be the main determinant of hunger and satiety (Anderson and Woodend, 2003). Although both high-GI and low-GI meals increase blood glucose levels, this is relatively short-lived for high-GI meals whilst being more sustained for low-GI foods, which according to the glucostatic theory could impact on satiety. However, the glucostatic theory is now only considered to partly explain one element of appetite control. Other factors involved in appetite control include environmental cues and cognitive factors, and also metabolic signals between the gut and the brain, such as those transmitted by stretch receptors in the stomach (which sense physical fullness) and gut hormones (Blundell et al., 2010).

In the majority of acute human studies an inverse association between GI and satiety has been found, with significant differences being reported for subjective satiety and hunger ratings and/or objective subsequent energy intake measures between low-GI and high-GI foods/mixed meals (Ford and Frost, 2010, Bornet et al., 2007). However, the evidence is not entirely clear cut and some high-GI foods have been found to be highly satiating and vice versa (Holt et al., 1995). In addition, a recent meta-analysis looking specifically at the effect of low- *vs.* high-GI breakfast meals in healthy adults, failed to find a significant effect of GI on subsequent energy intake (Sun et al., 2016), perhaps because of the variability in study quality and design in this research area. In the recent systematic review, *Carbohydrates and Health*, conducted by SACN, seven randomised controlled trials were identified that presented evidence on GI in relation to appetite in adults. The heterogeneity of these studies meant that performing a meta-analysis was not possible. Nevertheless, only one of the studies reported a significant effect of dietary GI on subjective ratings of appetite, with hunger and desire to eat being rated lower with the low-GI diet, compared to the high-GI diet (Bellisle et al., 2007). Therefore, SACN concluded that there was no significant effect of GI on appetite control (SACN, 2015).

The impact of consuming foods which increase satiety and reduce subsequent energy intake could be improved body weight management. However, there is a lack of quality long-term studies on the impact of GI on body weight and weight loss (Hooper, 2014) and upon reviewing the existing evidence, SACN concluded that there was 'no effect' of GI or GL on weight change (SACN, 2015). With regards to weight maintenance, current evidence suggests that a low-GL diet may be beneficial (Bosy-Westphal and Muller, 2015). Indeed, there is high-quality clinical study showing a beneficial effect of a low-GI diet on weight maintenance (Larsen et al., 2010). This study enrolled overweight adults from eight European countries and assigned them to a low-calorie diet. Those that lost at least 8% of their initial body weight (n = 773) were entered into the second phase of the study which investigated five different *ad-libitum* diets for the prevention of weight regain; a low-protein and low-GI diet, a low-protein and high-GI diet, a high-protein and low-GI diet, a high-protein and high-GI diet, and a control diet over a 26-week period. Only the low-protein and high-GI diet was associated with subsequent significant weight regain (1.67 kg; 95% CI, 0.48 to 2.87). Weight regain was 0.95 kg less (95% CI, 0.33 to 1.57) in the groups assigned to a low-GI diet than in those assigned to a high-GI diet (P=0.003) (Larsen et al., 2010).

As low-GI foods are often higher in fibre, disentangling the potential effect of GI with that of increased fibre content is complex. Furthermore, it has been hypothesised that the mechanism underpinning GI and appetite regulation may relate to the increase in the fibre content of the diet, rather than the small differences in postprandial blood glucose seen after a low-GI compared to high-GI meal in healthy individuals. Non-glycaemic carbohydrates (which are a type of dietary fibre) are fermented in the large intestine and it has been proposed that the short-chain fatty acids produced during this fermentation process could increase satiety by binding with free fatty acid receptors located in the brain, liver and adipose tissue (Hooper, 2014, Halford and Harrold, 2012). The bulking effect of fibre can also increase chewing time and gastric distension, promoting satiation and satiety. However, upon reviewing the evidence, SACN reported no effect of dietary fibre intake on body weight change or energy intake. Although, there was a limited amount of evidence to suggest a higher wholegrain intake may decrease total dietary energy intake. Nevertheless, it is possible that GI and dietary fibre have additive effects on appetite and body weight maintenance and further studies are needed to identify the exact mechanisms responsible.

Key points

- The glycaemic response to a food can vary between individuals and within the same individual (e.g. day-to-day and at different times of the day).

- The classification of foods according to GI and GL was originally used to help individuals with diabetes control their blood glucose levels. In healthy individuals, blood glucose is maintained within a fairly narrow range.

- In observational studies, high GI and GL diets have been found to be associated with increased incidence of type 2 diabetes. However, this does not indicate causality and other confounding factors may be responsible for this finding (e.g. low fibre diet).

- Evidence is somewhat conflicting but most short-term studies have found low-GI foods/mixed meals to increase satiety ratings and reduce energy intake at a subsequent meal, compared to high-GI foods/mixed meals.

- Long-term studies investigating the impact of a low-GI diet on weight loss are lacking.

- There is a limited amount of research which suggests a low-GI diet may be beneficial for weight maintenance. However, SACN did not find sufficient evidence to support a link between low GI and GL diets and appetite control or weight change.

4. The effects of white bread on satiety and body weight

4.1 White bread and satiety

The extent to which cereal grains are processed and refined has been found to influence satiety (Gonzalez-Anton et al., 2015, Slavin and Green, 2007). Wholegrain foods tend to contain more dietary fibre than foods produced from refined grains and some specific dietary fibres and mixed high-fibre diets have been shown to have satiety-enhancing effects (Slavin and Green, 2007, Halford and Harrold, 2012, Wanders et al., 2011, Clark and Slavin, 2013). This is consistent with studies indicating that wholegrain bread is more satiating than white wheat bread (Gonzalez-Anton et al., 2015). Possible mechanisms leading to increases in satiety after fibre intake include increased stomach distention, reduced rate of stomach emptying, changes in gut hormone release and production of short-chain fatty acids during gut fermentation (Clark and Slavin, 2013, Halford and Harrold, 2012).

A limited number of studies have investigated whether the addition of less-commonly used fibre-containing flours (e.g. lupin kernel flour, buckwheat flour and high-amylose corn flour) or specific fibres (e.g. guar gum, inulin type fructans, alginates and β-glucan) into white wheat bread increases satiety (Gonzalez-Anton et al., 2015, Morris et al., 2015, Yuan et al., 2014). A recent systematic review has assessed the impact of different fibre-containing ingredients on the satiety response to bread (Gonzalez-Anton et al., 2015). Study results were found to be very mixed, owing to the diversity of ingredients and breads studied and variations in study design and quality (Gonzalez-Anton et al., 2015). For example, a cross-over study comparing white wheat bread containing 10% lupin flour with a white wheat bread control found that adding lupin flour to bread reduced its GI from 100 to 76, but this had no effect on satiety responses or energy intake (Hall et al., 2005). In contrast, a cross-over study comparing the satiating effects of bread made with 40% lupin kernel flour with a white wheat bread control, found that the lupin-enriched bread significantly increased subjective satiety ratings and reduced energy intakes at the following meal (on average, 117 kcal lower) (Lee et al., 2006). In another study, Keogh *et al.* (2011) compared the satiating effects of three different breads: bread containing 40% lupin flour (which also contained wholegrain rye flour), a wholemeal and seeds bread (containing wheat, rye, oats and barley) and a white wheat bread. Consumption of the lupin-enriched bread and wholemeal and seeds bread resulted in higher fullness ratings compared to the white wheat bread, but subsequent energy intake was found to be significantly reduced only after the wholemeal and seeds bread (on average, 118 kcal lower) (Keogh et al., 2011). In the case of β-glucan, a cross-over study conducted by Vitaglione *et al.* (2009), found that a 3% barley β-glucan enriched white wheat bread resulted in significantly higher satiety ratings and lower energy intakes at a subsequent meal (on average 172 kcal lower), compared to a white wheat bread control (Vitaglione et al., 2009). However, a separate study comparing the satiating effects of three types of bread: bread enriched with wheat fibre, oat fibre (containing β-glucan) and a white wheat bread control, found that the three breads were equally satiating (Weickert et al., 2006). It is probably that the impact of fibre-containing ingredients on satiety responses is dependent on fibre type, dose and format (e.g. milling process). Further well-designed randomised controlled trials are required to explore the impact of adding fibre-containing ingredients to bread on satiety (Gonzalez-Anton et al., 2015, Houghton et al., 2015). This is also the case for the incorporation into bread of other ingredients which have been purported to have a satiating effect (such as proteins) (Gonzalez-Anton et al., 2015, El Khoury et al., 2015). There is currently insufficient research investigating the effects on satiety of breads containing other ingredients.

As mentioned in sections 1.2 and 2.1, the processing method used to produce bread can also have an effect on the rate of carbohydrate digestion, which could possibly also influence satiety. For example, bread density has been shown to be positively associated with satiety ratings (Burton and Lightowler, 2006). Additionally, the use of a fermented sourdough starter during bread production may also have a positive impact on the satiety-inducing qualities of the bread. Sourdough bread has an increased concentration of organic acids and lower pH compared to standard white wheat bread, which is thought to interfere with the rate of carbohydrate digestion and result in lower postprandial glucose concentrations (Najjar et al., 2009, Ostman et al., 2005). A limited amount of research has suggested that sourdough fermentation or the direct addition of particular organic acids into bread may increase satiety (measured subjectively and with blood biomarkers of glucose homeostasis) (Najjar et al., 2009, Ostman et al., 2005). However, it would appear that unless the organic acids are naturally formed during bread production (as is the case with sourdough bread), the amount of added organic acid needed to demonstrate an effect on satiety would negatively impact on the taste and consumer acceptability of the bread (Gonzalez-Anton et al., 2015).

4.2 Satiety and bodyweight

Currently, the benefits of satiety-enhancing foods to health are under researched. Ultimately, the purpose of the search for ingredients to increase feelings of satiety is to reduce energy intake and, possibly in combination with other approaches, improve weight loss or weight maintenance. There are a number of acute studies, of varying quality, investigating satiety-enhancing foods on subsequent energy intake, with promising findings. However, there is a distinct lack of long-term studies investigating whether or not this effect on satiety and energy intake is sustained and if there is any impact on weight loss or maintenance. This is particularly true of studies investigating satiety-enhancing breads. There are only a limited number of acute studies showing reductions in energy intake following the consumption of satiety-enhancing breads and the impact of long-term consumption on energy intake and bodyweight is currently unknown.

In the recent SACN *Carbohydrates and Health* report (2015), it was concluded (from evidence provided by three intervention studies) that higher consumption of wholegrain foods, rather than refined grain foods, could lead to reductions in energy intake (SACN, 2015). However, there was insufficient evidence to assess the impact of wholegrain intake on change in body weight (SACN, 2015). Likewise, the European Food Safety Authority (EFSA), which is responsible for assessing the science behind proposed food and drink health claims, has failed to give positive scientific opinions during its assessment of satiety-enhancing ingredients due to the lack of long-term studies demonstrating the benefit to health (i.e. improved weight loss or weight maintenance) (EFSA, 2012).

Nevertheless, market research shows consumers would be interested in purchasing and consuming products supported by claims referring to increased satiety (which is often understood by consumers as feeling of fullness) (Hetherington et al., 2013). Feeling of hunger is one of the main reasons for failing to comply with a weight loss diet and satiety-enhancing ingredients and diets may be of great assistance, particularly within today's obesogenic environment, and research should continue to try and understand which ingredients, foods and diets might be of most benefit.

4.3 White bread and obesity

It has been hypothesised that the general increase in the GI of the diet over the last century, as a result of the variation in the types and quality of carbohydrates eaten, has contributed to the rise in rates of obesity (Gross et al., 2004). A common belief among consumers is that bread, particularly white bread, is associated with weight gain. However, the scientific evidence to support this perception is relatively limited. A systematic review has been performed to assess associations between specific dietary patterns, which included bread, and obesity or abdominal adiposity in healthy subjects or in those undergoing obesity management (Bautista-Castano and Serra-Majem, 2012). Studies meeting the inclusion criteria were mainly observational in design (22 cross-sectional, 11 prospective cohort studies), with the exception of five intervention studies. The authors found that dietary patterns which included wholegrain bread tended not to be associated with weight gain (Bautista-Castano and Serra-Majem, 2012). For dietary patterns which include white bread, study results were mixed with most cross-sectional studies suggesting no association or an inverse relationship with bodyweight and the majority of well-designed cohort studies indicating a possible positive association with excess abdominal fat (Bautista-Castano and Serra-Majem, 2012). Intervention studies provide better evidence for demonstrating causality compared to observational studies, due to the control of other dietary and lifestyle factors which could confound the results. However, the intervention studies captured in the systematic review were highly variable in design and only two studies differentiated between the types of bread. One small study, which recruited 16 overweight males, found greater weight loss (on average, 2.5 kg more) with a 8-week diet containing 12 slices a day of wholegrain bread, compared to a diet containing the same amount of white bread (Mickelsen et al., 1979). The other study of 19 overweight females, found no differences in body weight following diets containing bread of either high- or low-GI for 12 weeks (Aston et al., 2008). Upon revisiting this systematic review in 2015, the authors also considered the 4-year follow-up data from a large randomised controlled trial (PREDIMED) investigating the effects of three dietary patterns (two Mediterranean diets with different fat sources and a low-fat diet) on risk of cardiovascular disease (Serra-Majem and Bautista-Castano, 2015). The authors found that gaining weight (classed as >2 kg) or waist circumference (classed as >2 cm) over the 4-year period was not associated with an increase in bread consumption. However, subjects who increased their white bread consumption the most over the 4 years were 33% and 36% less likely to lose weight and reduce their waist circumference, compared to those who increased consumption the least (Serra-Majem and Bautista-Castano, 2015). Nevertheless, results from this data analysis should be interpreted with caution as it is not clear whether other aspects of the diet, such as total carbohydrate intakes, differed between those that increased their white bread consumption the most and the least. Many dietary changes were made as part of this intervention study and accurately defining the health impact of a change in intake of only one food item is difficult.

More recently, the Avon Longitudinal Study of Parents and Children (ALSPAC) (n= 6772) found that energy-dense, high-fat, low-fibre dietary patterns (characterised by low intakes of fruit, vegetables and high fibre breakfast cereals and high intakes of confectionery, crisps, low fibre bread, cakes and biscuits), assessed at 7, 10 and 13 years of age, were associated with increased fat mass at 11, 13 and 15 years of age, respectively (Ambrosini et al., 2012). However, again, it is unclear which element of the diet was driving this association and it is possible that lifestyle behaviours related to this type of diet could have confounded the results. Another recent study involving the Seguimiento Universidad de Navarra (SUN) cohort (n= 9267 university graduates), found no correlation between white bread consumption and yearly weight gain but an association between high white bread consumption (≥2 portions/day, ≥6 slices/day) and greater risk of becoming overweight/obese was evident (de la Fuente-Arrillaga et al., 2014). Although observational and dietary pattern studies can add to the evidence-base, causality cannot be established from these studies. As exemplified in ALSPAC, white bread consumption may be part of a dietary pattern characterised by lower intakes of fruit, vegetables, other high fibre foods and higher intake of energy-dense, high-fat foods, including confectionary, crisps, cakes and biscuits. Other lifestyle behaviours, such as physical activity, could also be confounding factors within these studies. Hence, the observed effect on body weight of white bread may not be due to the consumption of white bread *per se* rather the foods or behaviours associated with intake of this food. Therefore, high-quality long-term intervention studies to investigate the impact of white bread on body weight are warranted before any conclusions are made.

Is white bread fattening?

There is some evidence to suggest that higher fibre breads may increase feelings of satiety and reduce energy intake at a subsequent meal. However, the effect appears to vary according to the amount and type of fibre the bread contains. The long-term effect of different fibres on body weight is currently under researched.

There is also a limited amount of evidence suggesting that dietary patterns which include white bread may lead to an increase in body weight over time. However, other dietary and lifestyle factors may be responsible for this finding. For example, these dietary patterns tend to also include high-fat, energy-dense foods.

Consuming more energy than that expended will lead to weight gain, irrespective of whether it is from carbohydrate, fat or protein (or alcohol). Gram for gram carbohydrate provides fewer than half the amount of calories provided by dietary fat.

Although bread is a low-fat food, spreads and fillings commonly added can increase the fat content and energy density of what is consumed. These ingredients can sometimes contribute more to the energy content of the meal, than the bread itself.

Key points

- Adding fibre to white bread may help to increase feelings of satiety. However, fibre type, quantity and format appear to be important.

- There is a limited amount of research suggesting sourdough bread may have a higher satiety rating compared to standard white wheat bread, which may be due to the presence of organic acids.

- The benefits of satiety-enhancing foods to weight loss or maintenance are currently under researched.

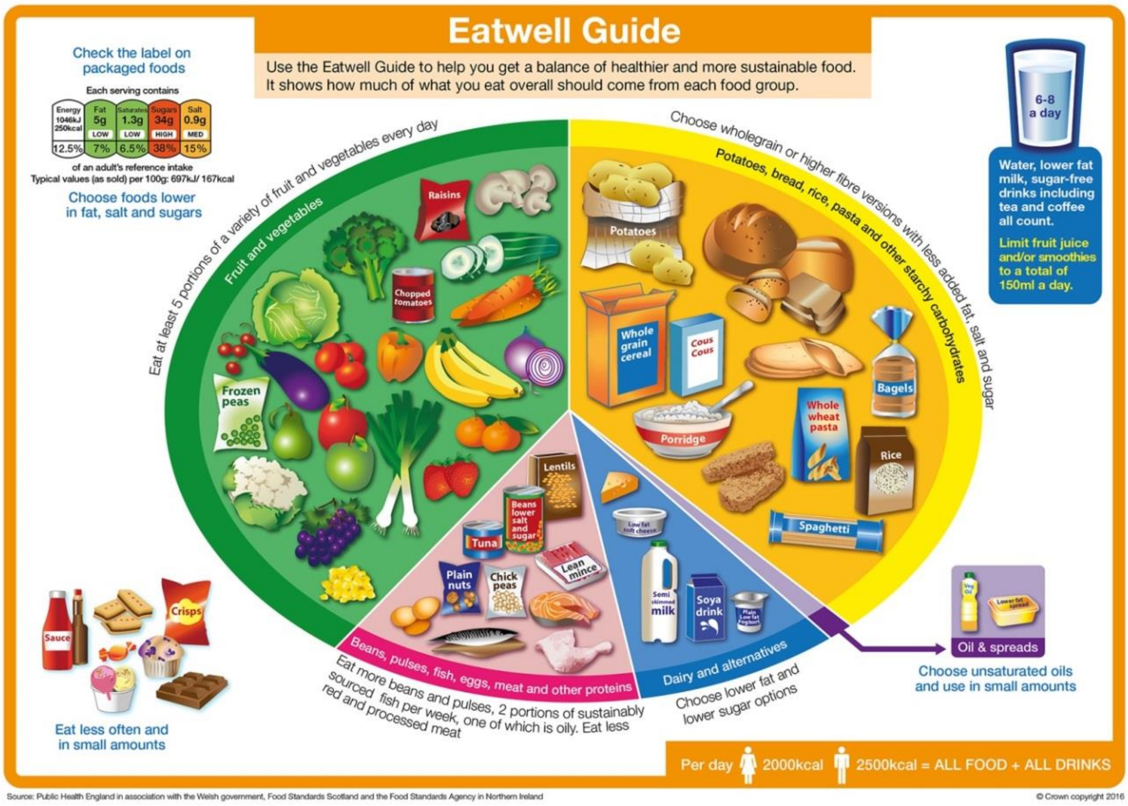
- Studies investigating the relationship between white bread consumption and bodyweight have shown mixed findings. A limited number of observational studies have shown an association, but not a causal relationship, between high white bread consumption and increased body weight, though it is possible that other related dietary and lifestyle factors may explain this finding.

5. Dietary guidelines relevant to bread

5.1 UK Dietary guidelines

The UK dietary guidelines have recently been updated by Public Health England (PHE) in light of the conclusion and recommendations of SACN's *Carbohydrate and Health* report (2015). In 2015 the new recommendations for free sugars (no more than 5% of dietary energy for all those aged over 2 years) and fibre (an increase to 30 g a day for adults), as well as the recommendation that the dietary reference value for carbohydrates be maintained at a population average of approximately 50% of total dietary energy intake, were accepted. PHE sought to ensure, as part of its role in promoting evidence-based public health messages, that nutrient-based guidelines were aligned with food-based dietary recommendations. The refreshed *Eatwell Guide* (which has replaced the *Eatwell plate*) is a pictorial representation of the UK dietary guidelines and is used to help communicate the basis of a healthy balanced diet to consumers (see Figure 5.1) (PHE, 2016). It shows the different types of food we should eat (and in what proportions) to have a healthy, balanced diet. Segment sizes have been adjusted compared to the previous *Eatwell plate* model. For example, the starchy carbohydrate segment has increased from 33% to 38% of total food intake and the fruit and vegetable segment has also increased from 33% to 40% (Buttriss, 2016). In addition, there is a greater focus on wholegrain products (PHE, 2016). This is to reflect current government advice, and in particular the revised carbohydrate recommendations, on decreasing free sugars and increasing fibre as part of a healthy, balanced diet.

Figure 5.1: The UK *Eatwell Guide*



(PHE, 2016)

Starchy carbohydrates

One of the main dietary messages of the *Eatwell Guide* is to:

- *Base meals on potatoes, bread, rice, pasta or other starchy carbohydrates; choosing wholegrain versions where possible.*

Additional messaging with relevance to bread, provided by PHE to give consumers further guidance, includes:

- *Starchy food is a really important part of a healthy diet and should make up just over a third of the food we eat.*
- *Choose wholegrain or higher fibre versions with less added fat, salt and sugar.*
- *Wholegrain food contains more fibre than white or refined starchy food, and often more of other nutrients. We also digest wholegrain food more slowly so it can help us feel full for longer.*
- *Higher intakes of fibre have been associated with a lower incidence of heart disease, stroke, type 2 diabetes, and colorectal cancer.*

- *Remember, you can also purchase high fibre white versions of bread and pasta which will help to increase your fibre intake using a like-for-like substitute of your family favourites.*
- *Some people think starchy food is fattening, but gram for gram it contains less than half the calories of fat. You just need to watch the fats you add when you're cooking and serving this sort of food, because that's what increases the calorie content.*

Do we need to cut down on the proportion of energy derived from carbohydrates in the UK?

Currently, the proportion of energy derived from carbohydrate is close to the national dietary reference value (estimate of dietary requirement), being on average around 50% of total energy intake (Bates et al., 2014). However, carbohydrates are a relatively diverse group of compounds and foods and drinks containing free sugars (sugars added to foods and drinks by manufacturers, cooks or consumers, and also sugars found naturally in honey, syrups and fruit juice) should be limited in preference for healthier sources of carbohydrate such as wholegrains, potatoes (with skins), vegetables, fruits, beans, legumes and pulses.

A recent opinion piece from a pressure group, the National Obesity Forum (NOF) in association with the Public Health Collaboration (PHC), criticising the current recommendations for fat and carbohydrates, received widespread media coverage. This document argued that the Department of Health's current dietary guidelines are directly contributing to the high prevalence of obesity and that starchy and refined carbohydrates should be limited to prevent and reverse type 2 diabetes. This report was branded as 'irresponsible' by Public Health England and provides advice discordant with the international consensus (for a full critique see Spiro, 2016). Modelling work has shown that in order to achieve sufficient fibre in the diet (adult dietary reference value 30g/day), meals must be based on starchy foods (BNF, 2015). Current advice remains to consume a diet containing a moderate amount of fat (<35% fat), replacing saturated fat with unsaturated fat, cutting back on free sugars and opting for wholegrain and high fibre varieties, where possible.

5.2 Dietary guidelines in other countries

The recommendation that carbohydrate should provide around 50% of energy intake is consistent with the recommendations from the WHO (50-75% of total energy intake) (Mann et al., 2007) and many other countries, including the US (45-65% of energy intake) (IOM, 2002).

Food-based dietary guidelines in other countries

Food-based dietary guidelines, which are usually developed by expert panels under the instruction of government bodies, are used in many countries to translate nutrient population goals into healthy eating messages at a national level. Information is presented in a number of consumer-friendly formats, such as a food pyramid, which is the most widely used graphical representation of food-based dietary guidelines. Most formats recommend that foods from the main (or largest) groups are consumed every day. The dietary messages can vary from being very broad, such as 'eat wholegrains' to more specific, such as 'eat at least 48 g of wholegrain foods'.

Table 5.1: Examples of dietary messages with relevance to bread in food-based dietary guidelines across the globe

Country	Food group containing bread	Dietary messages relevant to bread
Australia	Grain foods	• Eat mostly wholegrain and/or high cereal fibre varieties. • At least two-thirds of our choices should be wholegrain varieties.
Canada	Grain products	• Make at least half of your grain products wholegrain each day. • Eat a variety of wholegrains such as barley, brown rice, oats, quinoa and wild rice. • Enjoy wholegrain breads, oatmeal or whole wheat pasta. • Choose grain products that are low in fat, sugar or salt. • Compare the Nutrition Facts table on labels to make wise choices. • Enjoy the true taste of grain products. When adding sauces or spreads, use small amounts.
France	Starchy foods: bread and all bread products, grains and legumes	• Eat starchy foods at each meal according to appetite. • Products with complex carbohydrates and wholegrain are preferred.
Germany	Cereal, cereal products and potatoes	• Cereal and cereal products, potatoes, vegetables and fruit represent the basis of a nutritious diet. • Choose cereal products made from wholegrain.
Ireland	Cereal, cereal products and potatoes	• These foods are the best energy providers for your body, so the more active you are, the more you need. • You can choose any 6 or more servings per day, or up to 12 servings if you are active. • Wholegrain choices contain fibre to help your digestive system. • Have at least half your servings as wholegrain breads and high fibre breakfast cereals.
India	Grains	• Make half your grains wholegrains. • Reduce refined carbohydrates. • Freshly made refined grain products are better than packed refined grain products.
New Zealand	Grain foods	• Eat at least 6 servings every day – choose mostly wholegrain and those naturally high in fibre.

Poland	Cereal and cereal products	• Cereal products should be your main source of calories. • Eat at least five portions of cereal products every day.
Spain	Cereals and potatoes	• Cereals and potatoes should be the basis of everyday diet. • Try to include 4-6 servings a day of food items from this group. • Introduction of wholegrain cereals and wholegrain bread is recommended.
USA	Grains	• At least half of all the grains eaten should be wholegrains.

(USDA and USDHHS, 2015, Australian_Government, 2015, Health_Canada, 2008, DGE, 2016, van Dooren and Kramer, 2012, Ireland_Department_of_Health, 2012, CCDC, 2006, NZ_Government, 2016, Aranceta and Serra-Majem, 2001, NFNI, 2009)

Globally, cereal and cereal products (sometimes referred to as grains and grain products) are recognised, alongside other carbohydrate rich-foods, as the cornerstone of a healthy, balanced diet, providing energy, fibre and micronutrients. Indeed, consistent with the UK's *Eatwell Guide*, the segment containing cereals and cereal products is the largest in size (or is equivalent to the fruit and vegetables segment), for most of the food based dietary guidelines around the world. However, there are differences in the foods which have been put in the same category as cereal and cereal products. Some countries, such as the UK, include potatoes, and France also includes legumes within the same category. Inclusion of non-cereal based products within the starchy carbohydrate category may mean that the proportion of cereals and cereal products recommended in a healthy, balanced diet is reduced. In addition, whilst most countries promote the consumption of wholegrains, there is variation in the importance given and the specificity of the messages (Seal et al., 2016).

Key points

- The UK dietary guidelines have recently been updated and include new recommendations for free sugars (no more than 5% of dietary energy) and fibre (an increase to 30 g a day for adults).

- The UK *Eatwell Guide* recommends that just over one third of the foods we eat should be starchy carbohydrates (choosing wholegrain or higher fibre versions where possible).

- Globally, starchy carbohydrates are recognised as the cornerstone of the diet and most countries promote the consumption of wholegrains.

6. Ongoing research of relevance to bread

There are a number of ongoing research projects covering some of the topics discussed within this report, including bread GI values, satiety and body weight maintenance.

The SATIN project

The EU-funded SATIN (SATiety INnovation) research project aims to identify which ingredients and processing methods of several food components (proteins, carbohydrates, fats) and categories (including bread) accelerate satiation, suppress appetite and increase satiety (Johnstone et al., 2012). The 5-year project (which commenced in 2012) also hopes to increase understanding of the biological mechanisms underpinning appetite control and evaluate whether diets containing satiety-enhancing foods can help with weight management (Johnstone et al., 2012).

Full4Health project

Full4Health is an EU-funded 5-year project investigating biological and psychological mechanisms underpinning hunger, satiety and eating behaviour. The project is exploring how appetite control changes across the life course, the effects of dietary components and food structure on satiety, and ways in which eating behaviour can be targeted to address obesity, chronic disease and under-nutrition (Amin and Mercer, 2016). Full4Health was launched in February 2011 and project findings are currently being disseminated.

High Fibre Wheat for Healthier White Bread project

An industry-led 5-year project, funded by the Biotechnology and Biological Sciences Research Council (BBSRC), is currently underway to create a high fibre white wheat bread. The aim of this research is to identify a high soluble fibre wheat variety, suitable for UK growing conditions and with good bread making qualities, to help increase population dietary fibre intakes. It is possible the high fibre white wheat bread will have a slightly lower GI compared to standard white wheat bread and may be associated with higher satiety ratings, but appropriate testing would be needed to confirm this. This project started in April 2014 and is due to finish at the end of March 2019 (RCUK, 2016).

Other studies of interest

Acute intervention studies:

There are ongoing research projects investigating glycaemic responses after the intake of different types of bread, including breads enriched with specific fibres (e.g. β-glucan, legume flour, guar gum, konjac mannan) and breads created by varying production methods (e.g. different dough fermentation times) (Bo, 2016, S, 2016, Baumer, 2015, Unilever, 2016, Nilsson, 2016). This will help to further our knowledge on the fibre types, doses and formats, and production methods which can alter the GI value of bread.

There is also growing interest in the impact of polyphenols on postprandial glycaemic responses when consumed alongside a high-GI food or drink. Emerging research suggests certain polyphenols may decrease the rate of glucose absorption from the gut, possibly by binding to digestive enzymes or gut glucose transporters (Kim et al., 2016). More studies are underway to investigate this further (Williamson, 2016, Unilever, 2015, Nyambe, 2016).

Long-term intervention studies:

A randomised placebo-controlled 8-week intervention study is currently in progress at the University of Ljubljana in Slovenia, investigating the impact of bread containing 3.4% beta-glucans on lipid and glucose metabolism and gut microbiota in individuals with metabolic syndrome (Mlinotest_Zivilska_Industrija, 2016).

Research on wheat varieties and genomics

There are a number of BBSRC-funded projects focused on the identification or development of new varieties of wheat with specific traits, including varieties lacking B-type starch granules, those with low protein content or high dietary fibre content (BBSRC, 2016, Griffiths, 2016). Selection of these specific wheat varieties for bread making could influence carbohydrate metabolism and the GI value of bread.

Research on alginates added to bread

Studies funded by BBSRC have demonstrated that alginates (dietary fibres from seaweeds) can reduce fat digestion and absorption, which could potentially lead to body weight loss or maintenance (Chater et al., 2015). Newcastle University and Gregg's PLC have since conduced further human research with a bread based alginate product to help generate evidence to support a weight loss health claim application (Pearson, 2015).

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