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REVIEW ARTICLE

FODMAPs: food composition, defining cutoff values and international application

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Abstract

The low-FODMAP diet is a new dietary therapy for the management of irritable bowel syndrome that is gaining in popularity around the world. Developing the low-FODMAP diet required not only extensive food composition data but also the establishment of "cutoff values" to classify foods as low-FODMAP. These cutoff values relate to each particular FODMAP present in a food, including oligosaccharides (fructans and galacto-oligosaccharides), sugar polyols (mannitol and sorbitol), lactose, and fructose in excess of glucose. Cutoff values were derived by considering the FODMAP levels in typical serving sizes of foods that commonly trigger symptoms in individuals with irritable bowel syndrome, as well as foods that were generally well tolerated. The reliability of these FODMAP cutoff values has been tested in a number of dietary studies. The development of the techniques to quantify the FODMAP content of foods has greatly advanced our understanding of food composition. FODMAP composition is affected by food processing techniques and ingredient selection. In the USA, the use of high-fructose corn syrups may contribute to the higher FODMAP levels detected (via excess fructose) in some processed foods. Because food processing techniques and ingredients can vary between countries, more comprehensive food composition data are needed for this diet to be more easily implemented internationally.

Introduction

The benefits of a low-FODMAP diet in people with irritable bowel syndrome (IBS) are now well established, with numerous trials from around the world confirming that the diet improves symptom control in most people with IBS.[1–11] The establishment of this evidence base has been critical to justify clinicians' prescription of the diet to patients with IBS, while the creation of comprehensive and accurate FODMAP food composition data has enabled the diet to be implemented in a form that is varied, nutritionally adequate, minimally restrictive, and acceptable to diverse patient groups with ranging tastes, preferences, cultural needs, and nutritional requirements.

The Monash University Department of Gastroenterology has performed extensive work for over 10 years to quantify the FODMAP composition of hundreds of foods. Foods tested for FODMAP content represent a range of categories, including fruit and vegetables; grains, cereals, pulses, nuts, and seeds; dairy products and dairy free alternatives; meat, fish, poultry, and eggs; fats and oils; beverages; and condiments and confectionary. Some of these data have been published previously[12–14] and are summarized in Figs 1 and 2. With growing international interest in the low-FODMAP diet, our program of FODMAP food analysis is expanding to include more international foods. This paper will discuss the criteria for classifying food as low in FODMAPs and the challenges encountered in analysing food for FODMAP content.

FODMAP food analysis. FODMAPs (fermentable oligo-, di-, and mono-saccharides and polyols) include lactose, fructose in excess of glucose, sugar polyols (sorbitol and mannitol), fructans, and galacto-oligosaccharides (GOS—stachyose and

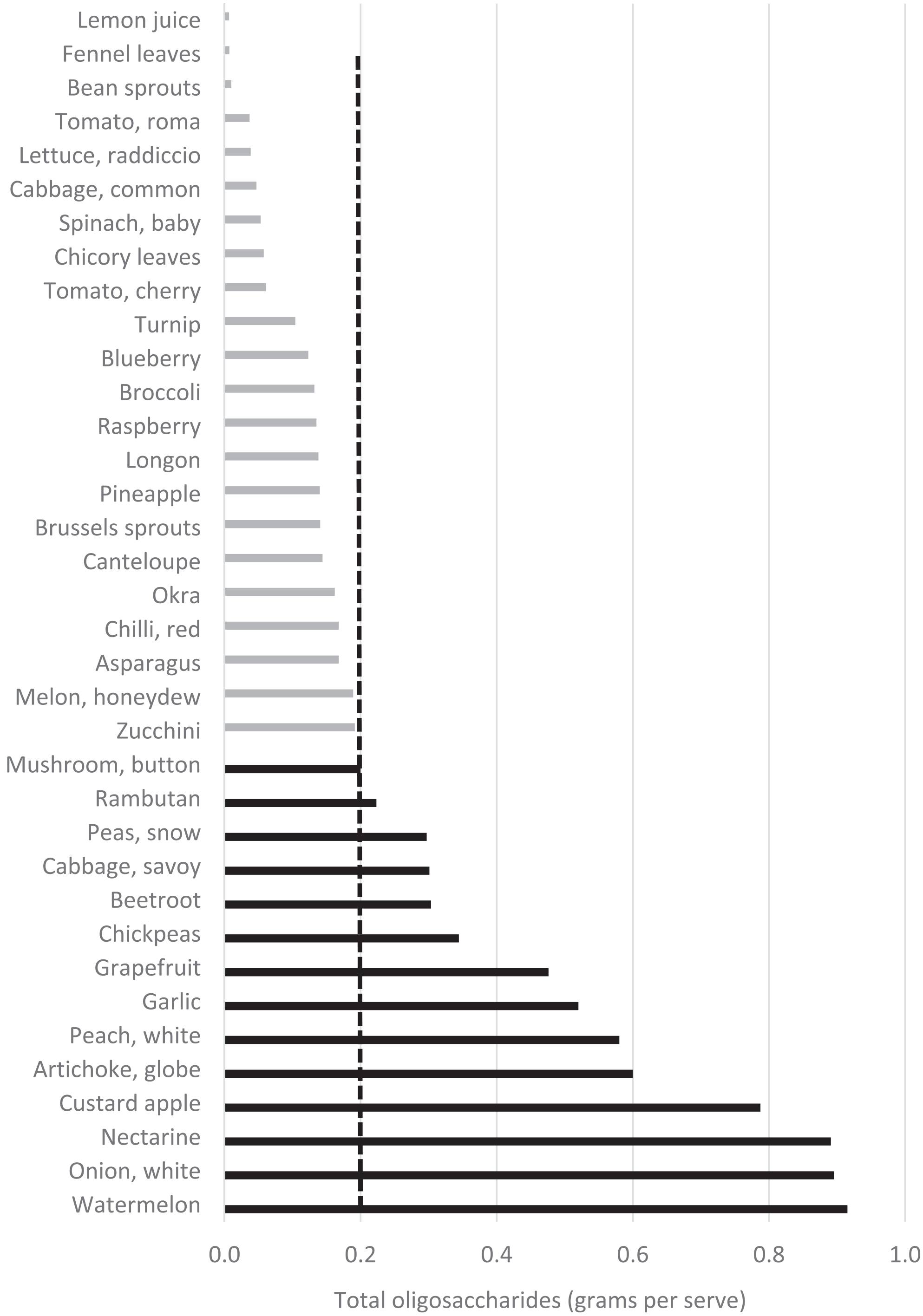

Figure 1 Oligosaccharide content of low-FODMAP (■) and high-FODMAP (■) fruits and vegetables.[12,13]

raffinose). The techniques for quantifying FODMAP levels in food have been discussed in detail and published previously.[12–14] Briefly, food sampling procedures are consistent with Food Standards Australia New Zealand protocols. For fruits and vegetables, this means collecting 500 g of samples from five different supermarkets and five different green grocers, and for grain and cereal products, it means collecting three samples of each packaged product (a popular brand, a generic homebrand, and one other) and preparing these as per packet directions. Equal quantities of each sample are then pooled (half the packet) and mixed to a homogenous consistency, before a 100 g of sample is frozen and then freeze-dried (Fig. 3). Samples of freeze-dried food (1 g) are then taken and extracted in hot (80°C) water, according to methods previously published.[12–14]

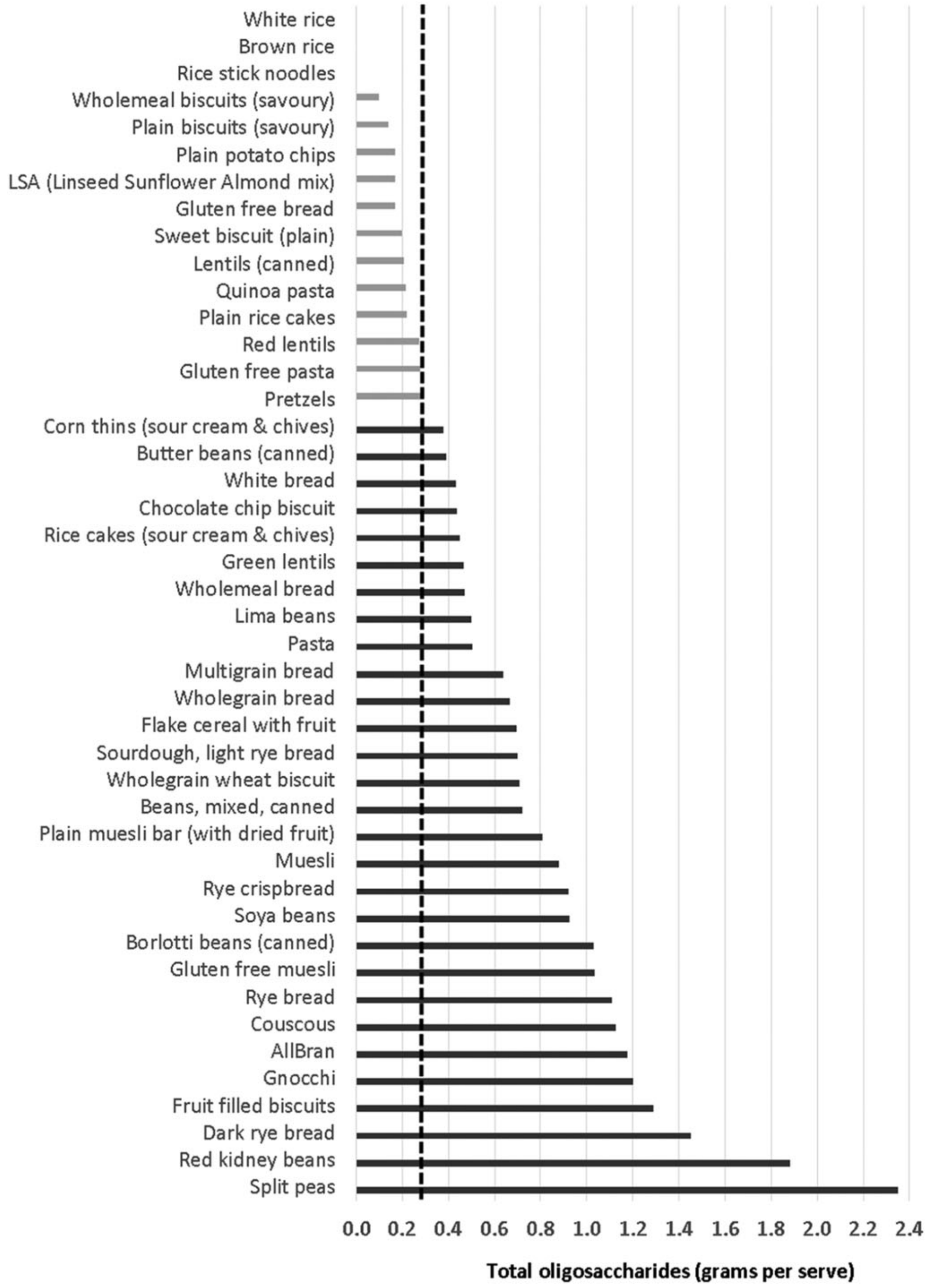

Figure 2 Oligosaccharide content of low-FODMAP (■) and high-FODMAP (■) breads, cereals, legumes, nuts, and seeds.[14]

Ultra-high-performance liquid chromatography is used to measure lactose and GOS (raffinose and stachyose) content, while high-performance liquid chromatography is used to measure fructose in excess of glucose, sugar polyols (sorbitol and mannitol), lactose, and GOS (raffinose and stachyose). Both instruments are fitted with evaporative light scattering detectors. Total fructan content is measured using the Megazyme Fructan HK Assay kit (Megazyme International Ireland Ltd, Wicklow, Ireland; AOAC Method 999.03 and AACC Method 32.32). As described previously,[12,13] sucrase and maltase are added to remove sucrose and short-chain maltosaccharides.[12] Fructanase is added to one sample to hydrolyse fructans into fructose, while the other duplicate sample receives no treatment.[12] Fructose content is determined by calculating absorbance following the addition of hexokinase/phosphoglucose isomerase/glucose-6-phosphate dehydrogenase. The total fructan content is determined by calculating the difference in absorbance and applying relative factors that convert absorbance to concentration of fructose and glucose produced.

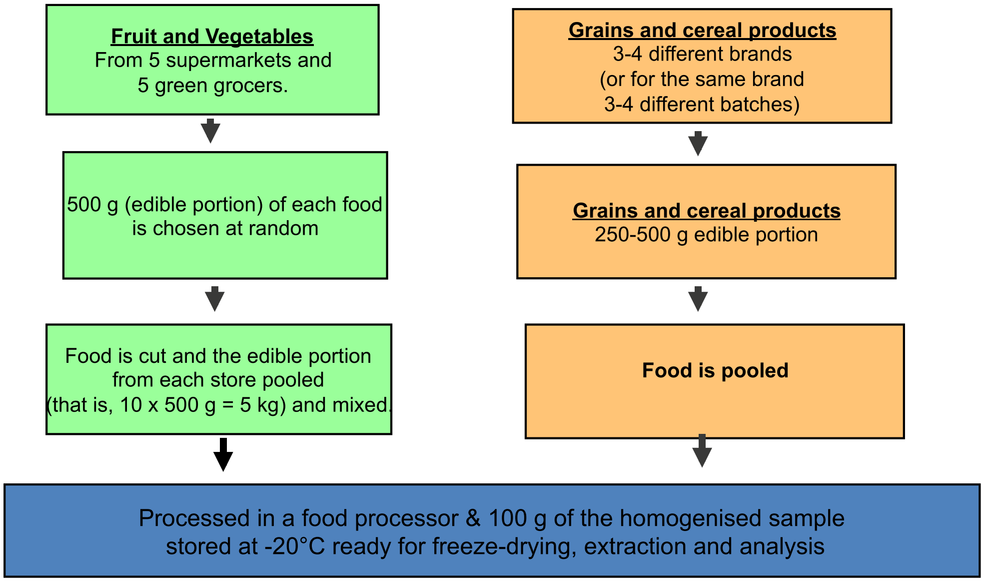

Figure 3 Food sampling protocol for FODMAP analysis.

Table 1 Low-FODMAP cutoff values for each FODMAP sugar (per serving of food per sitting) including oligosaccharides (total fructans plus galacto-oligosaccharides), polyols (sorbitol and mannitol), fructose in excess of glucose, and lactose

Individual FODMAPs	Grams per serve† (individual food)
Oligosaccharides‡ (core grain products, legumes, nuts, and seeds)	<0.30
Oligosaccharides‡ (vegetables, fruits, and all other products)	<0.20
Polyols—sorbitol or mannitol	<0.20
Total polyols	<0.40
Excess fructose§	<0.15
Excess fructose (for fresh fruit and vegetables when "fructose in excess of glucose" is the only FODMAP present)	<0.40
Lactose	<1.00

†Standard serve size.
‡Oligosaccharides = total fructans plus galacto-oligosaccharides (stachyose and raffinose).
§Excess fructose = fructose − glucose.

Fructans are present in different quantities and as different chain lengths in food samples. The Megazyme fructan assay quantifies all fructan (total fructan) present in food samples. It does not provide any information about the different chain lengths (degree of polymerization) present in a particular food. The FODMAP content of a large number of fruits, vegetables, grain, and cereals has been published previously.[12–14]

Establishment of "cutoff values". Developing a low-FODMAP diet has required not only extensive FODMAP composition data but also the establishment of "cutoff values" to classify foods as low FODMAP (Table 1). These cutoff values relate to each particular FODMAP sugar present in a food, including oligosaccharides (fructans and GOS), sugar polyols (mannitol and sorbitol), lactose, and fructose in excess of glucose.

Cutoff values were initially derived by considering (based on clinical experience) the FODMAP content and typical serving size of food, consumed in a single sitting or meal, that commonly triggered symptoms in individuals with IBS (e.g. onion, garlic, wheat bread, and apple). Foods that were generally well tolerated were also considered. This enabled the establishment of threshold levels for each FODMAP, above which most people experience symptoms. The levels were set conservatively to allow people to include a number of low-FODMAP foods at each sitting. Table 2 provides examples of how cutoff values are applied to individual food items, to classify them as low in FODMAPs.

The reliability of these FODMAP cutoff values was tested in a number of dietary studies.[2–4] An upper limit of 0.5 g of total FODMAPs (excluding lactose) per sitting was applied to the low-FODMAP arm of these studies, and this was generally well tolerated. The most recent of these studies was our landmark randomized controlled trial, which demonstrated that a low-FODMAP diet improved functional gastrointestinal symptoms in people with IBS.[2] This study utilized the low-FODMAP cutoff values included in Table 1 to design diets low and high in FODMAPs. Participants randomized to the low-FODMAP diet were provided low-FODMAP foods (according to these criteria) and limited to an intake of 0.5 g of FODMAPs per sitting. Table 3 provides an example meal plan, and Fig. 4 compares FODMAP intake on one day of the study diet. Examples of high-FODMAP foods omitted from the low-FODMAP diet included honey, apples, pears, watermelon, stone fruit, onion, leek, asparagus, artichokes, legumes, lentils, cabbage, Brussels sprouts, wheat-based and rye-based bread, pasta, breakfast cereals, cakes, and biscuits. Both diets were low in lactose to control for the effect of a large lactose load in lactose-intolerant participants. Having shown in this study that diets designed using these cutoff values led to clinically and statistically significant improvements in symptom control in people with IBS,

Table 2 Examples of how low FODMAP cutoff values are applied to a range of foods

Food (typical serve)	Oligosaccharides (oligos)		Polyols		Excess fructose	Lactose	FODMAP rating(using cutoff values†)
	GOS	Total Fructan	Sorbitol	Mannitol			
Fruit							
Apple, pink lady (165 g)	nd	nd	1.37	nd	10.6	nd	High FODMAP. Above cutoff for excess fructose (<0.15) and sorbitol (<0.20)
Orange (130 g)	nd	nd	nd	nd	—	nd	Low FODMAP. Below all cutoffs
Vegetable							
Mushroom, uncooked (74 g)	nd	nd	0.08	1.95	—	nd	High FODMAP. Above cutoff for total polyols (mannitol + sorbitol) (<0.40)
Onion, uncooked (36 g)	0.07	0.65	nd	nd	—	nd	High FODMAP. Above cutoff for total oligos (<0.20)
Zucchini/courgette, uncooked (66 g)	nd	0.19	nd	nd	—	nd	Low FODMAP. Below the cutoff for oligos (<0.20)
Grains/cereals							
Wheat bread (two slices, 49 g)	0.10	0.33	tr	tr	0.08	nd	High FODMAP. Above cutoff for total oligos for grains and cereals (<0.30) and below cutoff for excess fructose (<0.15). Overall rating is high FODMAP due to the high oligos
Gluten-free bread (two slices, 52 g)	0.07	0.10	tr	tr	0.12	nd	Low FODMAP. Below the cutoff for oligos (GOS + total fructan) for grains and cereals (<0.30) and below cutoff for excess fructose (<0.15)
Pasta, quinoa (155 g, cooked)	nd	0.22	nd	nd	—	nd	Low FODMAP. Below the cutoff for oligos for grains and cereals (<0.30)
Haricot beans (88 g, boiled)	0.96	0.23	nd	nd	—	nd	High FODMAP. Above cutoff for total oligos for grains and cereals (<0.30)

†See Table 1 for cutoff levels for the various FODMAPs. FODMAP composition data previously published.[12–14]
nd, not detected.

Table 3 Comparison of food intake on a study day of the high-FODMAP and low-FODMAP diets†

	Low-FODMAP diet	High-FODMAP diet
Breakfast	40-g oats 1/2 cup lactose free milk 200-g lactose-free yoghurt	2/3 cup muesli with fruit and nuts 1/2 cup lactose-free milk 200-g lactose-free yoghurt
Morning tea	1 slice cantaloupe 1 cup tea, black	1 slice watermelon 1/2 cup apple juice
Lunch	Chicken risotto, no onion/garlic 250-mL cordial	150-g mushroom risotto, with onion/garlic 1/2 cup apple juice
Afternoon tea	2 chocolate biscuits 1 cup tea, black	2 chocolate biscuits 1/2 cup apple juice
Dinner	1/2 cup ratatouille (low-FODMAP ingredients) 1 cup gluten-free pasta	1/2 cup ratatouille (high-FODMAP ingredients with onion/garlic) 1 cup wheat pasta
Supper	1 cup grapes 1 cup tea, black	1/2 cup cherries 1/2 cup apple juice

†Lactose-free products were used during both dietary periods.

we are confident that they provide a reliable means of classifying the FODMAP content of food and designing low-FODMAP diets to assist with IBS symptom control.

Determining cutoff values that classify food as low in FODMAPs has enabled us to make FODMAP composition data available to people with IBS worldwide, through our smartphone application.[15] The Monash University low-FODMAP diet app applies a green "traffic light" to low-FODMAP foods to indicate their suitability on a low-FODMAP diet. The app lists a large number of food items and is regularly updated with newly tested foods, allowing users to access the latest FODMAP composition data in a convenient, user friendly form and to follow a minimally restricted, evidence-based diet.

The coexistence of gluten and FODMAPs in foods. The development of the techniques to quantify the FODMAP content of foods has advanced our understanding of food composition. This knowledge has also contributed to a greater understanding of the entity of so-called, non-coeliac gluten sensitivity (NCGS) and the worldwide trend of gluten avoidance. This trend was highlighted in a recent Australian survey of 1184 participants, randomly selected from the electoral role.[16] The survey revealed that while less than 1% of the sample had formally diagnosed coeliac disease, 7.3% avoided wheat, and of the wheat avoiders, only 5.7% had a medically diagnosed allergy or intolerance that required them to do so. Wheat avoiders frequently reported adverse reactions to wheat-containing foods, such as bloating and cramps, symptoms commonly associated with IBS. Other theories proposing to explain the growing trend of wheat

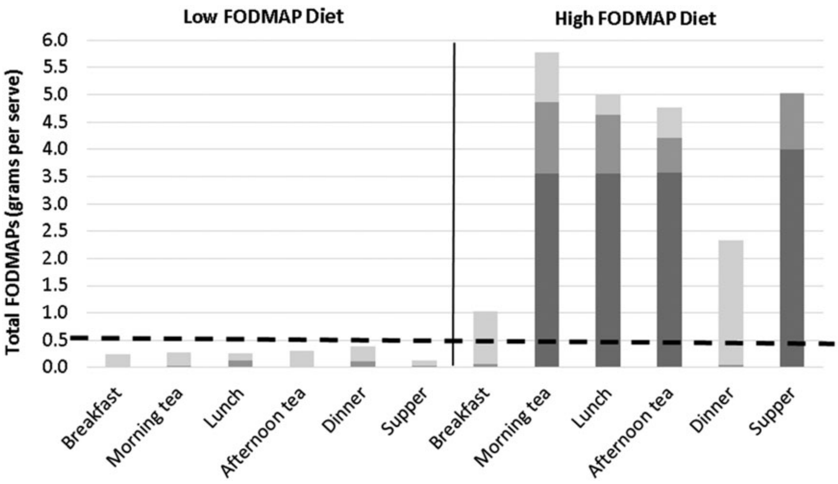

Figure 4 Comparison of FODMAP intake on a study day of the high-FODMAP and low-FODMAP diets. ■, total oligosaccharides; ■, total polyols; ■, excess fructose.[2]

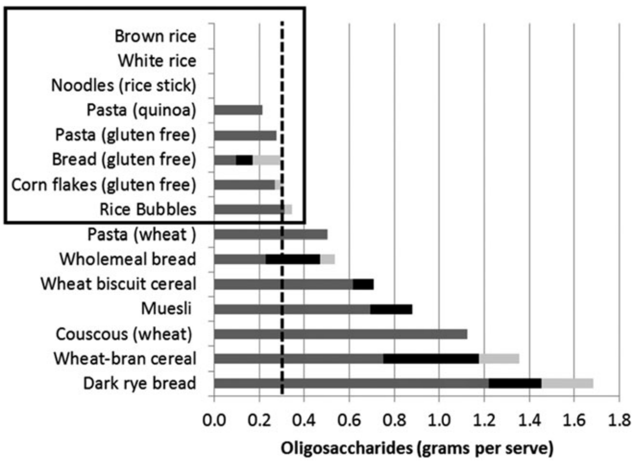

Figure 5 Oligosaccharide content of gluten-containing and gluten-free grains. □, gluten free; ■, fructan; ■, galacto-oligosaccharides; ■, excess fructose.[14]

and/or gluten avoidance include celebrity endorsements, the phenomenon of NCGS, increased availability of gluten-free foods, and perceived symptomatic improvements on a gluten-free and/or wheat-free diet. These perceived symptomatic improvements may be incorrectly attributed to gluten, with a number of other food components reduced and/or removed on a gluten-free diet, including amylase trypsin inhibitors and FODMAPs.

The coexistence of gluten and FODMAPs in grain and cereal foods is evident in Fig. 5, which shows that many gluten-containing cereal products are high in FODMAPs (mostly fructans), while most gluten-free grains are low in FODMAPs. This pattern might explain the symptomatic benefit that people report on a gluten-free diet, which may be wrongly attributed to the removal of gluten and more accurately attributed to a reduction in FODMAP intake. The notion that symptomatic improvements are attributed to the removal of dietary FODMAPs, not gluten, was highlighted in a placebo-controlled, crossover rechallenge study in 37 participants with NCGS and IBS. All participants experienced improvements in gastrointestinal symptoms on the initial low-FODMAP diet, which were greater than the improvements observed while following a strict gluten-free diet. Because no independent, gluten-specific effects were observed, it was suggested that FODMAPs, not gluten, were the major triggers of gastrointestinal symptoms in this population.[11]

Effect of ingredient selection and food processing techniques on FODMAP content. A number of ingredients and food processing techniques influence the final FODMAP composition of processed foods. Ingredients that commonly influence the final FODMAP content include flours (such as gluten free, wheat, and rye), grains (such as quinoa, rice, wheat, and barley), sweetening agents (such as sucrose, glucose, pear or apple concentrate, sugar polyols, high-fructose corn syrups, and dried fruit), and inulin, which is added to some processed foods to increase fiber content and improve texture. Highlighting the effect of ingredient selection on FODMAP content was a result of a recent analysis of gluten-free and wheat-containing breads from Australia, Norway, and the USA. This revealed that "gluten-free" breads were consistently lower in FODMAPs than wheat-containing breads (Fig. 6). The use of fructose-containing corn syrups in the USA may also affect bread composition and FODMAP content. This is highlighted in Fig. 7, which compares the FODMAP content of Australian and US breads and shows that many US breads are higher in FODMAPs than Australian breads. These inter-country differences in the FODMAP content of bread may also be attributed to international differences in the fructan content of wheat.

The effect of ingredients on final FODMAP content may be mediated by food processing techniques. Food processing techniques known to affect FODMAP levels include processes that involve heating and water, which can result in water-soluble FODMAPs (such as fructans and GOS) leaching into the surrounding liquid. For instance, canned lentils are lower in FODMAP, GOS, than boiled lentils. The lower FODMAP content of firm versus silken tofu is attributed to the former having undergone pressing, which removes the fructan- and GOS-containing liquid. In contrast, silken tofu, which is typically unpressed, has a higher water and GOS content.[17]

The mediating effect of food processing on final FODMAP content is highlighted in spelt-containing products. While spelt flour is typically lower in FODMAPs (mostly fructans) than modern

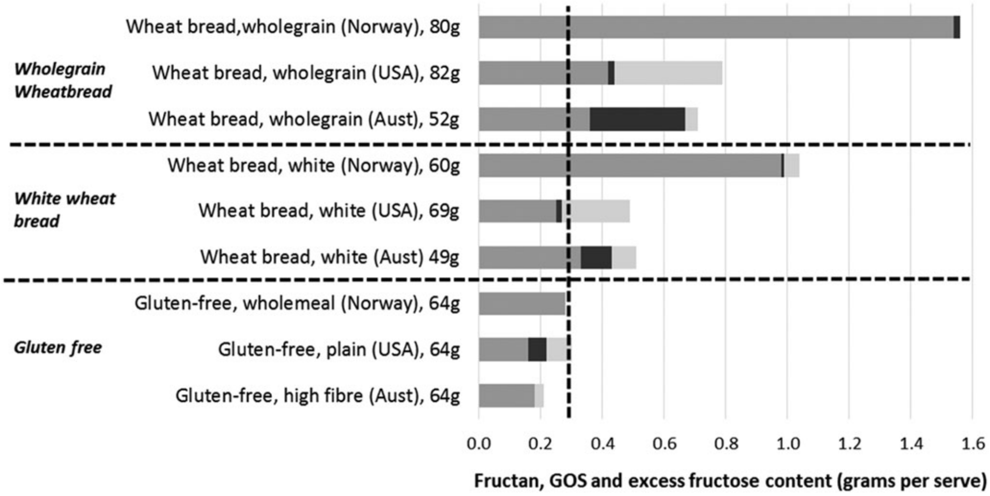

Figure 6 Comparison of excess fructose, GOS and fructan content in 1 serve (2 slices) of common breads from Australia, USA and Norway. ■, fructan; ■, galacto-oligosaccharides; ■, excess fructose.

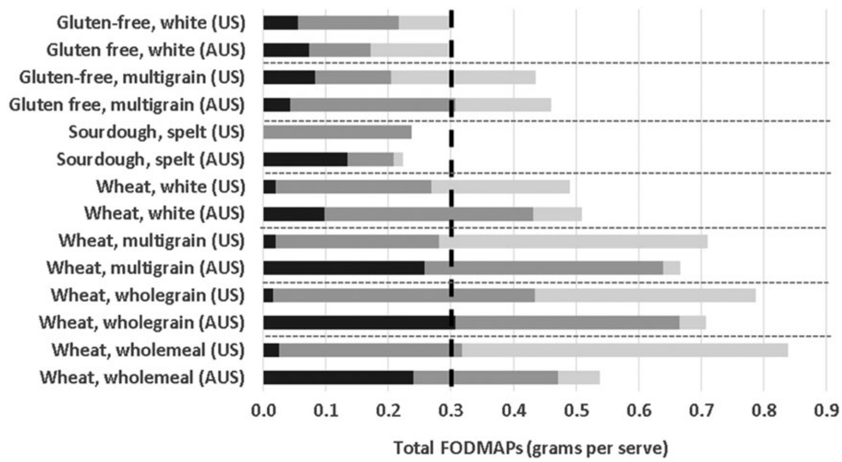

Figure 7 FODMAP content of Australian versus US breads. ■, galacto-oligosaccharides; ■, fructan; ■, excess fructose.

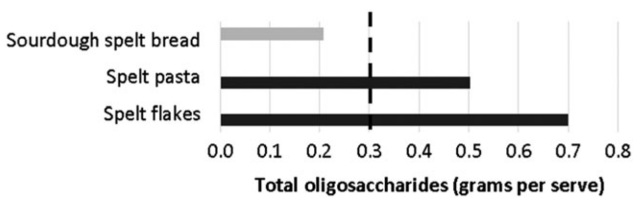

Figure 8 Oligosaccharide content of spelt products. ■, low-FODMAP; ■, high-FODMAP.

wheat, the use of spelt flour does not necessarily result in a low-FODMAP product. As shown in Fig. 8, while spelt flakes and spelt pasta are high in FODMAPs, sourdough spelt bread is low in FODMAPs. It appears that the spelt flour requires additional processing to lower the oligosaccharides (fructan) content. When a traditional sourdough culture (naturally high in lactobacilli) is used, together with a long proving time, bacteria metabolize the oligosaccharides (fructan) present in the spelt flour, thereby lowering fructan levels of the final product. Therefore, it can be inaccurate to predict whether a product will be low or high in FODMAPs based on the ingredient list. Instead, direct analysis of a food product is needed to determine the final FODMAP content. The effects of ingredients and food processing on FODMAP content provide food manufacturers with an opportunity to manipulate FODMAP composition through ingredient selection and food processing techniques.

Culturally specific FODMAP composition data. The strong evidence base supporting the efficacy of this diet and the expanding list of foods that have been tested for FODMAP content has driven worldwide uptake of this dietary approach among patients and health professionals. For this international uptake to be supported, more comprehensive country-specific FODMAP composition data are urgently required, with a number of country-specific factors known to affect FODMAP composition of food and FODMAP intake, including unique food processing techniques, food supply, food habits, and food culture. This aspect has been recently reviewed regarding East Asian countries.[18]

Implementing the low-FODMAP diet around the world: the US experience. Implementing a low-FODMAP diet in the USA presents unique challenges due to factors related to food supply and cultural trends. Local factors that impact on FODMAP composition include regional crop varieties[19] and a unique regulatory environment that influences permitted food ingredients, food additives, and labelling practices. For instance, high-fructose corn syrup is widely used as a sweetener in processed foods in the USA, with total fructose consumption increasing by almost 30% between 1970 and 2000, a trend which followed that of the intake of high-fructose corn syrup.[20] Highlighting the issue of food labelling in the USA, high-FODMAP ingredients such as onion and garlic are both prevalent in US processed foods, but not always clearly labelled on the ingredient list. The terms "flavoring" and "spices" are considered acceptable alternatives according to USDA regulations. For instance, US breads often contain more excess fructose than comparable Australian breads, which in part is likely due to the frequent addition of high-FODMAP ingredients, such as high-fructose corn syrup and honey (Fig. 7).

US cultural trends that may contribute to a higher FODMAP intake include large portion sizes that drive up intake of all dietary components, including FODMAPs. Similarly, heavy reliance on takeaway meals, restaurant meals, and pre-prepared and convenience foods[21–23] poses a problem for strict adherence to the low-FODMAP diet, as the FODMAP composition of these items is often unknown.

Popular commercial diet programs in the USA also promote a high-FODMAP intake, as these commonly provide and/or encourage the consumption of high-fiber breads, granola/muesli bars, yoghurt smoothies, shake mixes, unlimited quantities of fruit and vegetables, and "diet" varieties of processed foods that are often artificially sweetened with sugar polyols. Additionally, products marketed to US consumers, such as protein powders, shake mixes, probiotics, and vitamin and fiber supplements often contain inulin, fructooligosaccharides (FOS), fructose, and polyols. Despite these challenges, interest in the low-FODMAP approach continues to grow among American consumers, healthcare professionals, and researchers.

Dissemination of FODMAP composition data. The successful implementation of any dietary restriction hinges upon the availability of accurate and up-to-date food composition data. The Monash University low-FODMAP diet smartphone application is an effective tool for the dissemination of these data, delivering FODMAP composition data to users worldwide, using an easy-to-interpret, traffic light rating system. The app is regularly updated with the latest research findings and FODMAP composition data and was developed to overcome the challenges faced in disseminating this information to people with IBS.

Conclusion

There is now good evidence from a range of research centers confirming the efficacy of the low-FODMAP diet for the control of gastrointestinal symptoms associated with IBS. The methods for measuring FODMAPs in food are well described, and the cutoff values that define what is low in FODMAPs have been tested in a number of dietary studies. The challenge is now to successfully translate this diet therapy for health professionals and patients worldwide. International variations in food processing techniques, plant cultivars, and growing conditions all impact on FODMAP levels in food, so extending the program of food analysis to include more international food is required. The low-FODMAP diet is most effective when it is delivered by a trained dietitian who has knowledge and experienced in the area (see the article by O'Keefe and Lomer in this journal[24]). The guidance of an experienced dietitian is also required to ensure that patients only follow a strict low FODMAP diet for a 2- to 6-week period, followed by the reintroduction of foods.[25] Accordingly, future efforts must focus on improved training opportunities for dietitians worldwide, tasked with implementing this new diet therapy.

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