Jéssica Correia Pavão

FODMAPs in foods: Differences between food patterns and countries

Ciências da Nutrição

Faculdade das Ciências da Saúde

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(Jéssica Correia Pavão)

Trabalho apresentado à Universidade Fernando Pessoa como parte dos requisitos para obtenção do grau de licenciado em Ciências da Nutrição.

Orientadoras:

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I. Dedicatória

Aproveito esta oportunidade primeiramente para agradecer aos meus pais por todo o esforço e dedicação que depositaram em mim e na minha formação de forma a que hoje consiga alcançar esta conquista, e me torne licenciada.

Agradecer à minha família do Porto, Inês, Marta e Micael, por me terem acompanhado neste percurso e me mostrarem que família não é só de sangue.

Ao Henrique, por toda a paciência, compreensão, companheirismo e por sempre acreditar nas minhas capacidades.

Às minhas colegas de curso, agora amigas, Marta e Catarina, pelas divergências que se tornaram aprendizagens, pela cumplicidade que se tornou irmandade e pelo companheirismo que certamente será perpétuo.

Agradecer também a todas as pessoas que de alguma forma contactei ao longo do curso, tanto colegas como professores, por todo o crescimento e aprendizagem que me proporcionaram ao longo de todo o meu percurso.

Por fim, resta-me agradecer às minhas orientadoras, Professora Doutora Ana Sofia Sousa e Professora Doutora Catarina Simões, por toda a orientação, dedicação e empatia, não só durante a realização deste trabalho, mas ao longo de toda a licenciatura.

Obrigada.

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V. Abbreviations list

FODMAP - Fermentable Oligosaccharide, Disaccharide, Monosaccharide and Polyol

FOS – Fructooligosaccharides

GI - Gastrointestinal

GOS - Galactooligosaccharides

HFCS – High-fructose corn syrup

HPLC – High-Performance Liquid Chromatography

IBS - Irritable bowel syndrome

SCFAs – Short-chain fatty acids

UK – United Kingdom

US - United States

VAS – Visual Analogue Scale

FODMAPs in foods: Differences between food patterns and countries

FODMAPs nos alimentos: Diferenças entre padrões alimentares e países

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Contagem de palavras: 11056

Número de figuras/tabelas: 3

Número de referências bibliográficas: 46

Conflito de interesses: nada a declarar

VII. Abstract

Fermentable oligosaccharide, disaccharide, monosaccharide, and polyols (FODMAP) are poorly absorbed short-chain carbohydrates, that are rapidly fermented by the intestinal microbiota, with consequent gas production and water retention, leading to the distention of intestinal walls and symptoms associated with functional gut disorders. The low-FODMAP diet is an individualized dietary strategy design to reduce the FODMAP intake in order to achieve symptoms control. The knowledge about the FODMAP content of foods allows a more accurate implementation of the diet. Furthermore, there are factors capable of influencing the FODMAP content of foods that may present an opportunity to manipulate foods and reduce their FODMAP content. Regional crop varieties may also influence in the FODMAP intake since each country has their own food habits. Most of the information about FODMAP content of foods is prevenient from Australia. In North America and Europe, this approach is growing. In Eastern countries the limited knowledge may lead to other practicality challenges. This review of literature aims to identify the differences in the FODMAP content between different foods and dietary patterns of various countries. Also, it aims to verify whether other factors could influence the final FODMAP content. This review was elaborated through an online bibliographic search using electronic PubMed database. There is not much information about the FODMAP content of regions-specific foods. Nevertheless, it is possible to manipulate the FODMAP content and adapt the dietary pattern in order to reduce the FODMAP intake, but also, to acknowledge cultural differences.

Keywords: FODMAP, Low-FODMAP Diet, Dietary Patterns.

VIII. Resumo

Oligossacarídeos, dissacarídeos, monossacarídeos fermentáveis e polióis (FODMAP) são hidratos de carbono de cadeia curta mal absorvidos e rapidamente fermentáveis pelas bactérias intestinais, com consequente produção de gás e retenção de água, que distendem as paredes intestinais e induzem sintomas associados a desordens intestinais funcionais. A dieta pobre em FODMAPs é uma estratégia dietética individualizada formulada para reduzir o consumo de FODMAPs e controlar os sintomas. Conhecer o conteúdo em FODMAP dos alimentos leva à implementação mais precisa desta dieta. Existem ainda outros fatores capazes de influenciar o conteúdo em FODMAPs dos alimentos que podem ser uma oportunidade para manipular alimentos e reduzir o conteúdo em FODMAPs. Variedades culturais poderão também influenciar o consumo de FODMAPs pois cada país possui hábitos alimentares característicos. A informação acerca do conteúdo em FODMAP advém maioritariamente da Austrália. Na América do Norte e Europa esta abordagem está a crescer. Nos países Orientais o conhecimento limitado leva a desafios práticos. Esta revisão da literatura objetiva identificar as diferenças no conteúdo de FODMAP entre diferentes alimentos e padrões alimentares em vários países. Além disso, visa verificar a influência de outros fatores no conteúdo final de FODMAPs. Esta revisão foi elaborada através de uma pesquisa bibliográfica online com recurso à base de dados eletrónica PubMed. Existe pouca informação sobre o conteúdo em FODMAPs de alimentos específicos de cada região. No entanto, é possível manipular o conteúdo em FODMAP e adaptar os padrões alimentares de modo a reduzir a ingestão de FODMAPs e reconhecer diferenças culturais.

Palavras-chave: FODMAP, Dieta Pobre em FODMAPs, Padrões Alimentares.

1. Introduction

Fermentable oligo-, di-, mono-saccharides, and polyols (FODMAPs), have been investigated for their poor absorption in the small intestine and the rapid fermentation by colonic microorganisms, with effects on the gastrointestinal (GI) tract (1). FODMAPs are found in a wide range of foods and in varying amounts.

Oligosaccharides include fructans and galactooligosaccharides (GOS). Fructans are natural polymers, composed by a chain of fructose molecules and a glucose molecule at the end (2). These molecules can vary in size and structure. Fructans with a short-chain length (two to nine units) are referred as fructooligosaccharides (FOS), and with a longer chain (≥10 units) are called inulins (3). Fructans present several beneficial effects on health. As they are not absorbed in the small intestine, they are delivered in the large bowel and undergo rapid fermentation by bacteria. Consequently, bacteria populations expand, particularly bifidobacteria and lactobacilli (4). These bacteria promote a number of responses such as suppressing the growth of pathogens in the colon, increasing the absorption of calcium, and alleviating diarrhea (4). On the other hand, and as consequence of fermentation, fructans can also trigger GI symptoms such as flatulence, bloating and abdominal pain (3). Fructans and GOS are therefore considered prebiotics, as they are nondigestible food ingredients that selectively promote the growth of desirable bacteria in the gut (5). Fructans are usually presented as “total fructans”, *i.e.*, current methods of analyzing the fructan content in foods do not express differentiation regarding the type of fructans, as it is difficult to measure the exact mix of fructans in each food (4). The dietary sources of these polymers include wheat, rye, onions and garlic (5). GOS are also a family of molecules formed from galactose residues, with a fructose and a glucose molecule at the end. Raffinose and stachyose are the most common GOS present in foods. GOS are predominantly present in legumes, such as beans, lentils, and chickpeas (5).

Lactose is a **disaccharide** present in milk and other dairy products. Lactose is formed by two monomers, glucose and galactose, linked by a glycosidic bond (2). Lactase is the enzyme that breaks down lactose into its monosaccharide units so that it can be absorbed in the small bowel (2). When lactose is incompletely absorbed due to the absence or low production of this enzyme, there is lactose intolerance or hypolactasia. Undigested lactose is fermented by colonic bacteria which leads to symptoms such as bloating, diarrhea, and wind (6).

Fructose is a **monosaccharide** present in fruits, honey and high-fructose corn syrup (HFCS) (2) and this is a major FODMAP in the Western diet due to the daily use of these foods (5). Fructose can be absorbed across the villous epithelium via low capacity facilitated diffusion through GLUT5 transporters (5). Fructose may also be absorbed by high capacity, in a glucose-dependent fructose cotransport via GLUT2 as its absorption is greatly enhanced in the presence of glucose. Thus, the balance between fructose to glucose in a food may have great influence in fructose malabsorption because, if fructose is present in higher concentration than glucose (fructose in excess of glucose or free fructose), the absorption can be downregulated (5). Non absorbed fructose is then delivered to the large bowel where it will be rapidly fermented by colonic bacteria (5).

Polyols, such as sorbitol and mannitol, are sugar alcohols frequently used as sugar substitutes in food manufacturing to produce "low-calorie" products and as artificial sweeteners, often present in "sugar-free" chewing gums, mints and candies (2,7). It is commonly less recognized that polyols are also naturally present in a wide range of foods, as they are present in a variety of fruits (plums, apricots and cherries) and vegetables (mushrooms)(7). Polyols are partly absorbed in the small intestinal epithelium via passive diffusion. However, there is a high prevalence of malabsorption, which causes polyols to be directed to the large intestine and induce GI symptoms (7).

As described above, there are short-chain fermentable carbohydrates that can be absorbed. However, some are neither digested nor absorbed by humans. FODMAPs are rapidly fermented by the intestinal microbiota with consequent production of gas (hydrogen, carbon dioxide, and methane) (6,8,9) and short-chain fatty acids (SCFAs) such as acetate, propionate, butyrate, which promotes sodium and water absorption (4,9). In addition, the presence of FODMAPs in the large intestine lead to the increase of water retention due to their osmotic activity. Water retention and excess gas production cause the distention of the intestine walls, leading to functional GI symptoms such as bloating, abdominal discomfort or pain and altered bowel habits. These symptoms are often associated with irritable bowel syndrome and other functional gut disorders (4).

Functional GI disorders affect the function of the gut and symptoms are attributed to the middle or lower GI tract (2). The diagnosis relies upon the type of symptoms and their context, such as how long they have been experienced and when they occur (2). Irritable bowel syndrome (IBS) is a debilitating chronic condition that affects quality of life (6) and is characterized by several functional GI symptoms (10). IBS is associated with a significant burden to patients, health care systems and society (11). In those individuals who suffer from IBS and other functional GI disorders the subsequent rapid fermentation may lead to an exacerbation of symptoms (12). In healthy individuals, these GI effects are usually evident only at high doses of FODMAPs (2,3). The Monash University from Australia proposed, in 2005 a dietary strategy, the low-FODMAP diet, to reduce the quantity of FODMAPs in the diet (13). The strict adherence to this diet has been shown to improve symptoms, stool output, quality of life and overall well-being of patients with IBS (14–18).

The low-FODMAP diet is a three-phased intervention, that must be individualized for each patient, and should be implemented under the guidance of a dietitian (19). The first phase includes a short-term (two to eight weeks) reduction in FODMAP intake. The second phase involves a strategic reintroduction of those foods, to verify the patient's tolerance. Reintroduction should be individualized according to symptoms but also according to food preferences and nutritional requirements (20). Finally, the third phase is the long-term maintenance where foods are only avoided as identified during the second phase to maintain symptom control (21). Although a wide variety of foods are classified as high in FODMAPs, no food group is completely excluded from the diet, but a dose reduction in order to achieve symptom control (2). Therefore, when the diet is implemented with suitable alternatives, nutritional adequacy may be assured (22).

It has been well documented that dietary changes can improve GI symptoms (14–17) associated with IBS and other functional GI disorders, therefore, several western countries such as North America, Australia, New Zealand, and Western Europe, have had an increasing interest in using diet as a first line treatment rather than as an adjunct to pharmacological therapy (23,24). However, many issues about the low-FODMAP diet still need to be addressed, such as the exact type of foods to be used, the exact amount of this components present in foods and whether the FODMAP content varies according to countries and dietary patterns (24). FODMAP content of several food items has already been tested and the database addressing their composition has been growing, as they represent an array of categories. The current information is mostly based on Australian data (3–5,7,25).

FODMAP intake is increased in western societies (12). Urbanization has been associated with dietary modifications as the consequence of changes in food preferences and dietary patterns (12). For instance, the increase of fructose consumption results from the widespread use of HFCS as sweeteners in soft drinks and many packaged snacks (12,24). The use of fructans is also changing, as they offer technological benefits for food manufacturing. Fructans can improve palatability and stability of foods and allege to be "functional foods" (12). Also, the exposure of the population to polyols as food additives has increased, probably because of the widespread use of "sugar-free" products in an attempt to lower the energy intake (12).

Based on the current information, the present review of literature aims to identify the differences in FODMAP content between different foods and dietary patterns from various countries. This review also aims to verify whether other factors, such as the selection of ingredients in processed foods, food fermentation, food processing techniques or food regulations and labels, could influence the final FODMAP content of a food item. This information may contribute to a wider knowledge about FODMAP content in commonly consumed foods in different countries in order to improve the implementation of the low-FODMAP diet.

2. Methodology

For the present review, an online bibliographic search was carried out using electronic PubMed database, with a collection of articles that addressed the proposed subject. The search terms used were "FODMAP content". Meta-analyses, articles that did not respond to the main topics, studies in animals and articles in languages other than English were excluded.

As a result of the research, 82 articles were found and selected according to the relevance for the subject, and 56 of these articles were excluded after analysis of the titles and abstract. From this selection, 26 remained.

A snowball searching was also conducted to ensure that all potentially relevant papers were retrieved, and thus, 20 more articles were included. This search was made from the references of the selected articles resulted from the initial research. To carry out this review, a total of 46 articles were used.

A flow diagram with the search terms and the articles included in this study to fulfill the aim of this review is present in Figure 1.

3. FODMAPs in foods

3.1. Establishment of FODMAP content in foods: definition of cutoff values

Finding cutoff values capable of defining foods as high or low in FODMAPs, is determinant in the implementation of low-FODMAP diets. Due to the lack of information on values of the FODMAP content in food items from other countries, the cutoff values provided by Monash University, have been used as a reference. These cutoff values, represented in Table 1, refer to oligosaccharides (fructans, FOS and inulin, and GOS), lactose, excess fructose, and sugar polyols (mannitol and sorbitol) (24).

To establish these cutoff values, the typical serving size of food items recommended by Australian dietary guidelines was considered, in addition to the mean FODMAP content that commonly triggers symptoms in individuals with IBS when consumed in a single sitting or meal. Food items that are generally well tolerated were also considered, and this allows the establishment of threshold levels for each individual FODMAP, above which most people experience symptoms. These values were set in a manner to allow the inclusion of a number of low-FODMAP foods at each meal (24). The reliability of these FODMAP cutoffs has been tested (14). A generally well tolerated upper limit of 0.5g of total FODMAPs, excluding lactose, since lactose is present in higher concentrations than all other FODMAPs, per meal has been applied to low-FODMAP diets (24).

Halmos *et al.* (2014)(14) conducted a randomized controlled cross-over trial that analysed the effects of a diet low in FODMAPs when compared with a typical Australian diet in IBS patients (n=30), applying the low FODMAP cutoffs displayed in Table 1. When following a low-FODMAP diet, patients presented a clinically significant reduction of more than 13.0 mm on the Visual Analogue Scale (VAS), used to measure overall GI symptoms such as bloating and abdominal pain. With this reduction, it was demonstrated that a low-FODMAP diet effectively reduced functional GI symptoms, meaning that diets using these cutoffs led to symptom improvements in IBS patients (14).

Varney *et al.* (2016)(24) reported that these cutoff values (Table 1) are a reliable way to classify foods as high or low in FODMAPs and to plan low-FODMAP diets. Also, these values have already been used as reference in international studies (23,26). Despite that, more vigorous studies are required to validate the accuracy of these limits as well as being tested in other countries and dietary patterns, in order to obtain international validation.

3.2. FODMAP analysis in foods

Work has been done in order to analyse FODMAPs in foods in a more uniform manner and thus to obtain more reliable results. Lactose, excess fructose, sugar polyols (sorbitol and mannitol), total fructans and GOS (raffinose and stachyose) are FODMAPs that can be quantified.

Before the analysis itself, the preparation of food samples is required. Fresh food samples (fruits and vegetables) are collected from five different supermarkets and five different green groceries. Processed food samples are collected from three packaged products, from three different brands and prepared as the recommended instructions. Then, equal amounts of each sample are cut, pooled, mixed and a 100g homogenized sample is frozen and then freeze-dried at -20ºC, ready for extraction. The samples are then extracted in hot water at 80ºC (4,5,24,25).

To analyse colored beverages, the liquid food samples are previously decolorized (23). To analyse dairy products, a stabilizer and alkaline base is added to deproteinize the samples (23). High fat foods such as mayonnaise and peanut butter are heated above the melting point of the fat, then water is added. The samples are refrigerated and then filtrated (23).

The techniques to quantify FODMAP content includes high-performance liquid chromatography (HPLC), used to measure excess fructose, sugar polyols (sorbitol and mannitol), lactose and GOS (raffinose and stachyose)(5,7,25), and ultra-HPLC, used to quantify lactose and GOS (raffinose and stachyose). These chromatography types are equipped with evaporative light scattering detectors (24).

Alternatively, FODMAP composition in each food can be measured using commercially available enzymatic kits to obtain the content of fructose, glucose, lactose, mannitol, sorbitol, FOS and GOS (23).

Several foods have been tested for their FODMAP composition using the methods mentioned above. Foods analysed represent an array of categories, including fruits and vegetables; grains, cereals, legumes, nuts, and seeds; dairy products and dairy free alternatives; meat, fish, poultry, and eggs; fats and oils; beverages; and condiments and confectionary. The current database addressing the FODMAP content of foods are mostly prevenient from Australia (3–5,24,25), as briefly represented in Table 2.

Some of the analysed foods are common to both Western and to Eastern communities. But when it comes to utilize them in countries other than Australia, difficulties may arise. Firstly, not all foods are readily accessible in Australia and unique products, only available regionally, may have not been tested. Also, similar products may have different names, depending on the country. For instance, a leafy green salad vegetable is known in Australia as "rocket", is United States (US) as "arugula", and in Europe as "rucola" (20). Cooking methods, preservation techniques or ingredient selection might also affect the FODMAP content of specific food items (20).

3.3. Factors affecting FODMAP content in foods

3.3.1. Selection of ingredients in processed foods

The selection of ingredients during the development of processed foods can frequently influence the final FODMAP content of the product (24). Those ingredients may include flour (wheat, rye), grains (quinoa, rice, wheat and barley), sweetening agents (pear or apple concentrate, sugar polyols, HFCS and dried fruits) and inulin (added in some processed foods to increase fiber content and improve texture)(24).

Biesiekierski *et al.* (2011)(5), quantified the major FODMAPs present in a wide range of processed grain and cereal products commonly consumed in Australia. In this study, fructans were the major FODMAP present in wheat-based grains (pasta, breads, and breakfast cereals). The total fructans in cereal grain products were higher in couscous (1.12 g per portion), muesli (0.96 g per portion) and dark rye bread (0.6 g per portion) and lowest in rice and rice products (0g per portion).

The FODMAP composition of cereal grain products is dependent on the nature of the grain ingredients used in their production (5). For example, rice-based products tend to be low in FODMAP while wheat- and rye-based products tend to be high. Therefore, FODMAP levels can be manipulated in cereal grain product through choice of the grain ingredients to be used (5).

3.3.2. Food fermentation

Bread is a staple element of most individuals' diet. However, wheat or rye bread are not recommended in the low-FODMAP diet due to their high concentration of fructans (27). Notwithstanding this, whole grain cereals are also the major contributors to dietary fiber intake (27,28). Reduced dietary fiber intake may cause other risks to intestinal health of the patients, as it is a substrate for the gut microbiota (27,28). Apparently, the fermentation process, using varying sourdough cultures, allows the conversion or degradation of FODMAPs, without reducing the dietary fiber content of the bread (29).

The straight dough process evolves the addiction of baker's yeast as the sole fermentation organism (*Saccharomyces cerevisiae*) and achieves leavening after 2h or less (29). In sourdough process, lactic acid bacteria are utilized as the second group of organisms and the fermentation time is extended. Lactic acid bacteria increases the metabolic capacity of fermentation microbiota and the extended fermentation time boosts the contribution of flour enzymes to the conversion and degradation of dough components (29). Pejcz *et al.* (2020)(27) addresses that the decrease of FODMAP in sourdough bread, is dependent on the choice of bacterial cultures to use in sourdough bread making, the dough fermentation time and also the selection of production method, like the type of flour (27,30).

Li *et al.* (2020)(28) explored the fructan degradation in rye bread produced with sourdough fermented with *Lactobacillus crispatus* and compared with a straight dough process and conventional sourdough fermentation. Straight dough process reduced fructans in bread by less than 50%. In sourdough fermentation, the fructans in bread were reduced by 65-75%. The final product using sourdough with *L. crispatus* had their fructans content reduced by more than 90% and total FODMAPs by more than 70%, thus supporting the production of low-FODMAP breads by sourdough fermentation (28).

A clinical trial conducted by Pirkola *et al.* (2018)(31) with IBS patients (n=7) verified that low-FODMAP rye bread, made using sourdough, influences the GI symptoms associated with IBS, reducing colonic fermentation and flatulence values when compared with regular rye bread (31). This approach has increasingly been studied and has already been tested on other processed grain-based foods like baked goods (32) and bakery products (33). The sourdough bread making process shows an opportunity to develop natural low-FODMAP bakery products with increased dietary fiber content (28).

3.3.3. Food processing techniques

In a recent study conducted by Tuck *et al.* (2018)(25), the impact of food processing and cooking techniques in the FODMAP composition of a variety of plant-based foods was investigated. Within the methods analysed, pickling was the method that led to more substantial changes. Pickling vegetables like garlic, onion, and beetroot resulted in a sufficiently large decrease in total FODMAP content to change their classification from high to low (25). When comparing canned red kidney beans with its dried, soaked, and cooked form, canning method lowered GOS and fructan content (25).

Considering the cooking time, simmering red lentils for 5 minutes reduced the oligosaccharide content by 43% (25). Although longer simmering times did not cause any further decrease in oligosaccharides, straining the lentils after 30 minutes of simmering reduced the oligosaccharide content by 12% compared to unstained lentils (25). On that note, fructan content was also reduced, from raw form lentils (0.25g) to cooked and strained form (0.13g), and it remained higher in unstrained lentils (0.18g) (25). As with lentils, red kidney beans had their oligosaccharide content reduced when simmered, but its content continued to decline in times greater than 5 minutes. After 30 min of cooking, its content suffered a reduction of 32%. After that time, there was no further decrease. The differences in cooking time between red lentils and red kidney beans may be due to their size as red lentils are smaller and may allow the FODMAPs to leach out earlier (25).

3.3.4. Food regulations and labels

Ingredient lists on processed food labels do not always reflect the FODMAP content included in the final product (34). The presence of substrates used in manufacturing or changes in the content of FODMAPs due to the processing is not always notified (34). Integrating information on the label about the FODMAP content could facilitate the implementation of the low-FODMAP diet. Now that the cutoff values are established (24) and it is possible to classify foods as “low-FODMAP”, there needs to be a regulatory framework that allows for the communication of foods with low FODMAP content with their target population. For low FODMAP products meet the dietary supplement classification criteria, they would have to be present in a concentrated form like powders, tablets or capsules (34). General foods and dietary supplement products are not allowed to communicate health benefits through these products and limits those allegations to drug products (34). There is yet another category between those two, that include foods for special medical purposes. Still, these products do not meet one of the legal criteria for this category, as dietary management of the disease or medical condition can be achieved by simply modifying the normal diet (34).

Endorsements can also prompt the potential approvement of FODMAP related health claims through the support of medical or scientific organizations. For example, in Australia, a product could display in its label a logo with the statement “Monash University low FODMAP certified”, if it fulfilled the criteria (34). In regions where there are already established lists with nutritional and health claims, such as Europe, there may be accepted nutritional claims like “low in FODMAP” and health claims such as “A low FODMAP diet helps to improve gut comfort in subjects with digestive sensitivities” (34).

In brief, the factors affecting FODMAP content in foods offer an opportunity to food manufacturer to manipulate and to reduce the FODMAP content of foods (24,25). Also, food regulations and other regional cultural factors influence the permitted food ingredients, food additives and labelling systems and, therefore, affect the FODMAP composition of foods (24). Strategies that may reduce the burden of dietary restriction may improve adherence and nutritional adequacy for those who follow a low-FODMAP diet.

3.4. Effects of cultivation methods

Knowledge about possible changes in foods that may contribute to the decrease of FODMAP content may be highly relevant to the implementation of a low-FODMAP diet. It would be beneficial to know whether changes in the cultivation method could lead to beneficial variations in the FODMAP content of foods.

Onions are one of the most widely consumed vegetables worldwide (35) and one of the major contributors to total FODMAP intake as they are high in FODMAPs, specifically in fructans (36). A study by Pöhnl *et al.* (2018)(36) aimed to clarify the potential compositional differences between onion cultivar grown with identical cultivation methods (seed or set - bulbs partly formed), and between identical cultivars in seed and set grown onions. The results showed that total FOS concentrations in set grown onions were higher (65.8 ± 9.1 g/L FOS) than seed grown onions (42.2 ± 20.1 g/L FOS) in standard cultivars. Higher FOS levels in set grown onions might be due to their earlier seed emergence, thus resulting in an extended photosynthetically active period (12% more sunlight hours than the total for seeds). However, seed grown dehydrator onions (grown in FOS-rich onion cultivars), had higher FOS content (121.2 ± 37.8 g/L FOS) than the set grown onions in standard cultivars, indicating that both the cultivation method and cultivar selection have influence on the FODMAP content of onions (36). Thus, selecting “low FODMAP cultivars” and “seed growing” method may assist in the production of low FODMAP onions (36).

In another study, Call *et al.* (2021)(37) collected caryopses of common wheat at different grain developmental stages to study compositional changes in FODMAP content. Overall, the total FODMAP concentration decreased throughout grain development. Fructose concentration was at its maximum during cell division and expansion phase with 8.1g/100g and during grain development suffered a significant decrease to 0.05g/100g. Also, fructan concentration rapidly decreased during the milky stage (7 to 11 days after anthesis) from 1.3 to 0.6g/100g, resulting in an 80% reduction. The increase of starch concentration may justify the decrease of the soluble carbohydrates as they are progressively being converted into storage polysaccharides (37).

According to Muir *et al.* (2009)(4) ripeness may affect the FODMAP levels in fruits and vegetables (4). For instance, Packham pears, an Australian variety of pears, when is firm, contains higher levels of fructose (9.32g/100g) and sorbitol (5.99g) when compared with ripe Packham pear (3.40g of fructose and 2.29g of sorbitol) (4). Therefore, sugar levels in fruits will differ considerably depending on the variety, season, and climate but also in storage time and temperature (4,26).

In summary, the cultivation methods and the cultivar selection are related to changes in the FODMAP composition of foods. More studies are needed in order to make this evidence firmer and consider it in the manipulation of these and other food items to lower the FODMAP content of foods.

4. FODMAPs around the world

The food consumed all over the world on a daily basis varies markedly according to geographical regions and consequently, the FODMAP intake. In countries, such as Australia, the evidence of efficacy of the low-FODMAP diet is strong (14–17). Across US and other parts of Europe, this dietary intervention is increasing. In South America there are no references that indicate the FODMAP content of country-specific foods, although the interest in this approach in those countries is growing.

In East and Southeast Asia, health professionals may require additional knowledge to provide this treatment (20). In South Asia the scenario is similar. The limited knowledge of health professionals and a lack of dietitians lead to further challenges in the practicality of the diet (26). Although the use of low-FODMAP diets may be more limited in those populations rather than in westernized countries, it poses potential therapeutic opportunities, and the education resources can be translated to suit other communities (20,26). In African Continent there is no record of studies that addresses the FODMAP content of most consumed foods or their prediction, as well as the application of low-FODMAP diets.

In order to optimize the way the low-FODMAP diet is implemented in other countries and cultures, it is essential to expand the knowledge about the FODMAP content of the country-specific foods, but also of the way in which they are prepared, cooked and eaten (20). There is limited work about the FODMAP content of region-specific foods. However, since the low-FODMAP diet does not require the complete elimination of foods, but a dose reduction in order to achieve symptom control, it is possible to formulate strategies that can be useful in building a low FODMAP content diet for these countries, based on current food composition knowledge (20).

4.1. United States of America

Cultural trends and factors related to food supply represent a great influence in US diets, leading to unique challenges. Also, food regulations which influences the permitted food ingredients, and labelling practices, impacts on FODMAP composition (24).

Cultural trends that may contribute to increased FODMAP intake include, in addition to large portion sizes that lead to higher consumption of any dietary component, including FODMAPs, is the heavy reliance on fast foods, specifically take away meals, restaurant meals, and convenience foods (24). The FODMAP composition of this items is usually unknown, so the adherence to a low-FODMAP diet may be compromised (24).

Regarding food labeling in the US, food manufacturers have to declare certain nutrients on the product label. For carbohydrates, it is mandatory to include “total carbohydrate”, “dietary fiber” (may include FOS and GOS), “total sugars” (includes free mono- and disaccharides), and “added sugars” (added during processing or packaging of foods) (23). The “sugar alcohols” (may include polyols) are voluntary to include (23). Onion and garlic are prevalent in US processed foods, but they are not clearly labelled on the ingredient list. According to the US Department of Agriculture regulations, the terms “flavoring” and “spices” are acceptable alternatives (24).

It is also common that commercial diet plans encourage the consumption of products such as high fiber breads, unlimited quantities of fruits and vegetables, granola bars, yoghurt smoothies and “diet” foods, often artificially sweetened with sugar polyols, which leads to the increased consumption of FODMAPs (24). Advertised products like protein powders and vitamins supplements often include inulin, FOS, fructose, and polyols (24).

Fructose-containing syrups may also be a major contributor to a higher FODMAP intake, as it is commonly present, for example, in US breads composition. When comparing the FODMAP content of US and Australian breads, US breads usually contain higher concentrations of FODMAPs, specifically more excess fructose than the comparable Australian breads. This may be due to the addition of HFCS and honey (24).

Furthermore, the majority of the information about FODMAP content in foods are from Australia (23). The lack of clear US-specific guidelines on FODMAP content, may contribute to the disagreement found among low FODMAP food lists provided by the US academic centers (38). Parallel to this, is the increasing complexity of following a FODMAP diet and providing a FODMAP dietary intervention (38).

In 2018, Chumpitazi *et al.* (23) analysed the FODMAP content of several foods from USA, potentially low in FODMAPs. Of the analysed foods, it was found that most of the processed foods, such as gluten-free products and manufactured beverages, had a high FODMAP content, and until then were being considered for usage as low FODMAP items. Also, none of these foods had the FODMAP content discriminated in the nutritional label (23). This study highlights the importance of a further analysis of the FODMAP content of foods distributed in the US (23).

Despite the difficulties, the low-FODMAP approach has increasing interest among American consumers, healthcare professionals, and researchers (24). Therefore, studies that urge the knowledge about FODMAP content in foods are needed (24), as well as regulations that include these contents on food labels, in order to be accessible to the consumers (23).

4.2. Asia

All over the Asian continent, gastronomy have particular characteristics that can potentially contribute to a high FODMAP intake, such as the high consumption of onion, garlic, and wheat-based products. The information about FODMAP content of these country-specific foods is very limited. Therefore, some studies have predicted the possible FODMAP content of some traditional dishes, as well as the most consumed foods, with the support of the food composition information currently available (20,26). Although it may be a potential prediction, studies that directly analyse specific foods are needed. Several examples of these predictions are described below, so that more can be understood about the likely FODMAP content of the country-specific foods and traditional dishes.

4.2.1. South Asia (India, Pakistan, Bangladesh, Sri Lanka, and Nepal)

The high heterogeneity of dietary patterns and the diversity of food preparations throughout South Asia countries leads to a lower precision when it comes to defining foods as high or low in FODMAPs (26). Therefore, it may be questioned whether this diet is as useful in South Asia, as for other regions (26). Dietary patterns in South Asia are influenced by many factors, given the marked cultural, ethnical, and religious diversity (26). Those factors include religion (influences the type of animal protein consumed), ancient native medicinal systems (Ayurveda, a form of alternative medicine), food accessibility (food culture is influenced by the availability or exposure to specific foods) and economics (being the most economically deprived regions of the world) (26).

Rice is a staple food in South Asia, being the most consumed cereal (26). Cooked rice is commonly consumed mixed with curries and made into food balls by hand. Rice has a low FODMAP content but, the other components added, such as curries, may be high in FODMAPs, in this case due to its content in legumes. Moreover, rice-based foods are often fermented, and the fermentation effects on FODMAP content is widely unknown (26). Wheat is the second most consumed cereal in South Asia (26). Due to the high presence of oligosaccharides, wheat is high in FODMAPs. Wheat is frequently consumed in the form of leavened or unleavened homemade flat bread, along with various types of curry. Other cereal widely used is millet, especially in India. This cereal has a high nutritive value and provides a major portion of calories and protein to large segments of this population. Millet has low FODMAP content and could be a key food item for patients with IBS. General trends of the world, over the years, has had influence in the consumption of this region (26). The consumption of rice has declined, accompanied by an increase in the consumption of wheat, possibly leading to an rise of IBS incidence (26).

In Indian Subcontinent there is a huge variety of fruits and vegetables, many of them probably unfamiliar to the rest of the world. FODMAP content of those foods is practically unknown (26). Jackfruit, used in Sri Lanka, is consumed at various stages of maturity either as a vegetable or as a fruit, sometimes as a substitute for rice. Regarding the FODMAP content, it is only known that the fructose content increases with its maturation, in the first 6 days after harvesting, and when consumed in excess may cause abdominal bloating and discomfort (26). There is a high consumption of onions, shallots, and garlic among South Asians. These components are high in oligosaccharides (fructans) and therefore have a high FODMAP content. As these foods are so culturally characteristic, reducing them from the daily diet is very challenging (26).

Legumes are daily consumed in a variety of ways across this region, in some places as breakfast, in form of curry, accompanied by rice or flat bread. Despite being an important source of vegetable protein for this population, almost all legumes contain high

FODMAP content. Like the consumption of rice, the consumption of legumes has been decreasing, probably due to a westernization of the diet (26).

In India and Pakistan, the main animal protein sources are dairy products. Generally, dairy products are high in FODMAPs because of their high lactose content. Coconut is an important component of the diet in Sri Lanka and in some parts of India and coconut milk is commonly used as a milk substitute. It is usually used from fresh coconuts, but the canned form consumption has been increasing. Coconut milk is considered low in FODMAPs (25). However, the amount to be used is important to better classify their FODMAP content. From the analysis of a UHT coconut milk, a dose of 250 mL is classified as high in FODMAPs, 150 mL is moderate, and 120 mL is considered low (26).

Spices and condiments are commonly used, for example in curries. Only small amounts are added to food to add flavor, aroma, and color. Almost all has been tested, as they have a low FODMAP content (26). Black tea is a commonly consumed beverage. When compared with weak, strongly made black tea has a moderate-high FODMAP content. Coffee is low in FODMAPs, unless it has added milk. Other characteristic beverages, such as those made from flowers and herbs for medicinal purposes and alcohol beverages, has not been analysed (26).

There is a wide range of recipes and ingredients among countries, and ethnic and cultural groups, but there are also subtle variations in recipes between families, as their cooking traditions and techniques are transferred from mother to daughter (26). Likewise, measuring ingredients while cooking is not a common practice. Usually, they eat to their satisfaction. At the end of the meal, it is difficult to estimate how much of each dish is consumed by a person. These roots make reducing FODMAP content through recipes, based on portion size, more challenging (26).

Most of the foods consumed in the Indian Subcontinent are FODMAP-rich foods and portion sizes are unclear, which makes reducing FODMAP consumption more difficult. The exact FODMAP content of many South Asian foods is still limitedly known, as are suitable low-FODMAP alternatives. Until those issues are addressed, low-FODMAP diet implementation remains more limited than in Western countries (26).

4.2.2. East and Southeast Asia

Korea: "Kimchi" is a very known Korean side dish, consumed in almost every meal. Kimchi is made from a fermented and pickled Chinese cabbage, but it also may be made from radish, scallion (green onion) or cucumber. “Ssamjang” is a side dish, served with grilled meats or with a dish called ssambap (rice wrapped in leaf vegetables). SSamjag is made from “doenjang” (a fermented bean past that includes soybeans and brine, used to flavor foods), “gochujang” (a condiment made from red chili), garlic, onion, and sesame oil. Doenjang, gochujang and ssamjang includes garlic, onion, soybean and, in some of them, wheat flour. All of these dishes contain high FODMAP content foods, and it is likely that their final content is high in FODMAPs. However, it is necessary to have an analysis of this content, considering the amount of each ingested (20).

Japan: Aside from fish and sushi, Japan is also known for the consumption of noodles and gyozas (in other countries known as dumplings). The dough from both these dishes are generally made from wheat flour, which contains high FODMAP content. “Gyozas” are usually filed with chopped vegetables (traditionally includes cabbage, scallion, leek, and garlic) and minced meat. Practically all of the ingredients are high in FODMAPs (20).

Thailand: Dishes from Thailand are also noodle-based meals and clear broth-type soups with wontons (thin dough sell filled with meat and mixed vegetables). Curries and stews are commonly consumed as a compliment of any meal or as a dipping sauce. Curries and stews may contain legumes, onion, cabbage, and garlic, which are all high FODMAP ingredients. The curry paste itself includes high FODMAP ingredients like garlic, shallots, and soybeans, and is probably high in FODMAPs. The FODMAP content would be dependent on the amount of paste used, but for more accurate advices, a specific analysis is required (20).

China and Hong Kong: Traditional dishes from China and Hong Kong often include mushrooms, leeks, cabbage, and legumes (soya and mung). These dishes are typically accompanying with condiments, often containing garlic, onions, shallots, and honey. The most common grains used are rice and wheat, being wheat high in FODMAPs. Wheat is consumed as wontons (previously described), noodles, “bao” (filled and steamed wheat bun) and “man tou” (unfilled wheat bun). After a meal and like a dessert, in China and Hong Kong is common to eat a sweet soup. These soups include high FODMAP ingredients such as dried longan, dried dates, and mango. Hong Kong has also a western culture influence, having a fusion of British and Chinese gastronomy. This means that is common in Hong Kong to eat French toasts (contains wheat) with butter and sweetened condensed milk (contains lactose) and soupy macaroni (contains wheat). It is clear that several high FODMAP foods are included in the traditional gastronomy of those countries but serving sizes of each dish need to be clear and analysed before giving a definitive FODMAP classification (20).

Taiwan: Taiwanese street food is known all over the world, inclusively for its "stinky tofu". Tofu is low in FODMAPs but due to the sauces or condiments added, like gochujang (previously described), the final product is probably high in FODMAPs. Other street food from Taiwan is "youtiao", a deep-fried dough sticks (made from wheat flour). Some essential day-to-day product for a Taiwanese home comprises fried shallots, dried shitake mushrooms, fermented black beans, fermented chili bean sauce and "sha-cha" sauce (obtain from fish, shallots, garlic, and chilies). Drinks and desserts frequently include milk as the main ingredient, and for that are likely to have a high FODMAP content (20).

Vietnam: Some Vietnamese dishes include "Toi phi va ma toi" (fried garlic), "Nuoc man cham" (dipping fish sauce), and the traditional "Pho bo tai nam", well-known as "Pho" (beef noodle soup). All of these dishes include high FODMAP ingredients. White onion, for instance, is an essential ingredient to "pho", as it is finely sliced into rings and added fresh to it. Pho broth is also made with onions. Even though the broth is made separately from the main soup ingredients, oligosaccharides, in this case prevenient from the onion, are water soluble and are likely present. Vietnamese gastronomy has a French influence and due to that, there is consumption of wheat bread (high in fructans), including it in "Vietnamese pork rolls", for example (20).

Asian dishes clearly have a considerable proportion of high FODMAP ingredients included in their traditional gastronomy. Restricting FODMAP content in these countries leads to great uncertainties (20). The database of FODMAP content of these foods is very limited. On the other hand, there is uncertainty about the effects of preparation on FODMAP content and also, about the content of the final food portion that is eaten (20).

4.3. Europe

The current database addressing FODMAP content of foods is expanding and the interest in using the low-FODMAP approach to improve GI symptoms associated with IBS and other functional GI disorders is growing worldwide, especially in westernized countries, including some European Countries.

United Kingdom (UK) is the European country that has invested the most in the implementation of the low-FODMAP diet and the FODMAP content database. Although this diet is still considered a second-line treatment (39) the interest in expanding its knowledge is growing. McKenzie *et al.* (2016)(39) updated the British Dietetic Association for the dietary management of IBS, and Prichard *et al.* (2016)(40) determined the FODMAP content of commonly consumed foods by ethnic minority groups, as the heterogeneity in UK is vast. However, this direct analysis does not reflect the general population and for that, further research is needed. There are also articles that measure the fructan content of wheat, rye, and gluten-free UK breads (41), and it concludes that, from the breads analysed, rye bread was the richest source of fructans.

In Sweden there is no record of direct food analysis, but in a study led by Liljebo *et al.* (2020)(42) was calculated the FODMAP intake in healthy individuals from the general population and compare to previous research using direct analyses of FODMAPs. In a four-day food record, participants (n=117) registered their habitual food intake in order to understand which foods are most consumed by the Swedish population. From this record, the mean total of FODMAP intake was 19g per day. The most consumed food items containing FODMAPs in Sweden were products made from rye and wheat grains, as well as fruits and vegetables. Legumes are rich in GOS, but they are not commonly consumed among this population, so the average consumption was less than a gram per day. In this study was shown that the FODMAP intake can be calculated with information prevenient from the literature and the assistance of food diaries, to expand the FODMAP database (42).

In Portugal, the information on the implementation of the low-FODMAP diet is scarce, as well as information on the FODMAP content of Portuguese foods. The information found addresses the implementation of this diet in fibromyalgia patients, in an attempt to improve patients' quality of life (43–45). Also, there is only one article that addresses the effectiveness of the low-FODMAP diet as an approach to improve quality of life and GI symptoms in IBS patients (46). However, there is no reference to articles that registers the FODMAP content of Portugal-specific foods.

5. Discussion

FODMAPs are found in a wide range of foods in varying amounts. The methods to analyse them are set (3–5,20,23–25) and the cutoff values to classify them are established (24). FODMAP content of many foods has already been tested and the database addressing their composition has been growing (3–5,20,23–25), as they represent an array of categories.

The expanding lists that encompasses the FODMAP content of foods and the evidence base supporting the reliability of the low-FODMAP diet (14–17), boosted the worldwide acceptability of this dietary approach (18). In order to effectively implement the low-FODMAP diet worldwide, more comprehensive country-specific FODMAP composition data is needed. Furthermore, these data should consider a number of factors that affects the FODMAP composition of food and FODMAP intake, including the food processing techniques, food habits, and food culture (24).

Factors affecting FODMAP content such as food processing techniques and ingredient selection in processed foods provides an opportunity to manipulate and reduce the FODMAP content of foods (24,25). Food regulations should be aligned with those manipulations but also provide consumers with reliable information about the exact FODMAP content of processed foods (24,25). Cultivation methods and cultivar selection are associated with changes in FODMAP composition of foods and may be an opportunity to decrease the content of high FODMAP foods such as onions and wheat (36,37).

The current information on the FODMAP content of foods is mostly prevenient from Australia (3–5,7,25), and issues can arise when implementing this diet in countries other than Australia (20,23,26). Across other westernized countries, like North America and Europe, this therapy is growing (23). In Eastern countries the limited knowledge of health professionals and the lack of dietitians lead to a challenging practicality in the implementation of this approach (20,26). Nonetheless, this diet presents a potential therapeutic opportunity, and the education resources can be adapted to other communities (20,26). Also, the information about region-specific FODMAP content of foods is in its outset. The reduction of FODMAPs in the diet and the success of low-FODMAP diets greatly depends on the knowledge about the FODMAP content of the country-specific foods (20) and for that, more studies are needed. These analyses should also consider the way foods are prepared, cooked and eaten, as well as the serving sizes (20). Even so, some studies have predicted the possible FODMAP content of some of the traditional dishes with the information currently available. Perhaps this is the necessary push to open the door to a future analysis of more country-specific foods.

The limitation of this review is upon the fact that there is limited information about the FODMAP content of country-specific foods. Despite the lack of direct analyses, the strengths of this review are related to the fact that there are some studies that predict the estimated FODMAP content and leads to a better understanding of these foods. Also, cutoff values are established and the methods to analyse the FODMAP content of foods are set, which means that all the conditions are met so that there is an expansion of the current database in FODMAP content. Furthermore, the efficacy of the low-FODMAP diet is well proved, which imposes reliability to this approach and urges the interest in expanding its understanding. This study contributes to a wider knowledge about FODMAP content in commonly ingested foods in different countries in order to improve the implementation of the low-FODMAP diet.

The effectiveness of the low-FODMAP diet is well documented in certain countries but for others it is not. Thus, there is not sufficient information about the FODMAP content of those regions. Food is a characteristic of each country and represents the distinct culture of each region. This identity should not be removed. Despite the limitations, it is possible to manipulate the FODMAP content of foods and adapt the dietary pattern in order to reduce the FODMAP intake, but also, to acknowledge cultural differences.

In conclusion, differences between food patterns and countries may be overcomed, and the prescription of a diet low in FODMAPs can in fact be implemented, but currently its prescription in countries other than Australia is still very limited. Thus, more country-specific studies are needed.

As a future perspective, it would be advantageous to increase the database from each country in order to facilitate the implementation of the low-FODMAP diet, particularly in Portugal as this method is not much developed and has the potential to become a commonly used dietary approach. Studies where the FODMAP content are predicted could be a good starting point to encourage the direct analysis of country-specific foods.

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7. Tables and figures

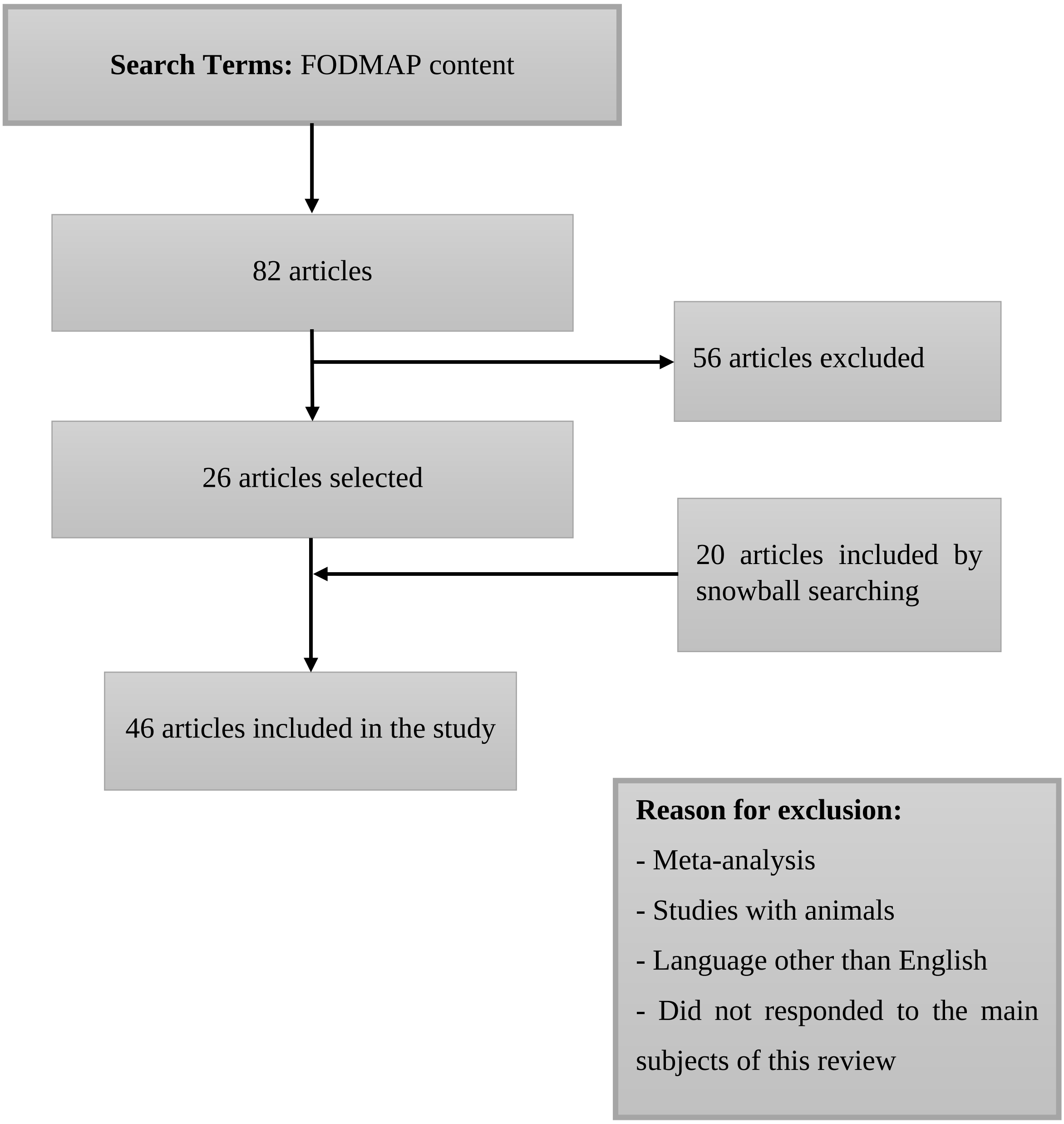

Figure 1. Flow diagram with the search terms and reasons for exclusion.

Table 1. FODMAP cutoff values defined by Monash University. Adapted from Varney J, Barrett J, Scarlata K, Catsos P, Gibson PR, Muir JG. FODMAPs: food composition, defining cutoff values and international application. J Gastroenterol Hepatol. 2017;32:53–61. (24).

FODMAPs	Grams per serve*
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 fruits and vegetables when “fructose in excess of glucose” is the only FODMAP present)	<0.40
Lactose	<1.00

*Standard serve size.
**Excess fructose = fructose – glucose.

Table 2. Foods with high and low FODMAP content. Adapted from Shepherd, S. and Gibson P. The Complete Low-FODMAP Diet: A Revolutionary Plan for Managing IBS and Other Digestive Disorders. The Experiment; 2013.(2).

		High	Low
Oligosaccharides	**Fructans**	**Fruits:** nectarines, persimmon, tamarillo, watermelon, white peaches. **Vegetables:** artichokes, garlic, leeks, onions, shallots. **Cereals, grains, and starches:** wheat-, rye-, and barley-based products. **Legumes:** chickpeas, lentils, and other beans. **Nuts:** pistachios, cashews. **Drinks:** chicory-based coffee substitutes	**Fruits:** blueberry, raspberry, longan, pineapple **Vegetables:** avocados, bell peppers, broccoli, cauliflower, green beans, lettuce, carrots, mushrooms, olives, potatoes, sweet potatoes, tomatoes. **Cereals, grains, and starches:** cornstarch, millet, oats, popcorn, potatoes, quinoa, rice, tapioca. **Legumes:** tempeh, tofu. **Drinks:** regular tea and coffee, many herbal teas, and infusions.
	GOS	**Legumes:** beans (kidney, black, butter, soy, mung, fava beans), chickpeas, lentils	
Disaccharides	**Lactose**	**Milk:** whole, low-fat, and skim cow's, goat's, or sheep's milk. **Yogurt:** full-fat, low-fat, and skim cow's, sheep's, and goat's yogurt. **Cheese:** soft cheeses (e.g., cottage cheese, cream cheese, mascarpone, ricotta).	**Milk:** whole, low-fat, and skim lactose-free milk; soy milk, rice, oat, almond, and quinoa milks. **Yogurt:** almond, soy, or rice yogurts (without inulin); lactose-free yogurts. **Cheese:** hard, formed, and ripened cheeses (blue, Brie, Cheddar, Emmental, Parmesan, mozzarella), soy cheese, soft cheeses (up to 2 ounces).
Monosaccharides	**Fructose**	**Fruits:** apples, Asian pears, boysenberries, cherries, figs, mangoes, pears, watermelon. **Vegetables:** asparagus, artichokes, sugar snap peas. **Sweeteners and condiments:** agave nectar, high-fructose corn syrup, fruit juice concentrate, honey.	**Fruits:** apricots, avocados, bananas, blackberries, durian, grapefruit, grapes, kiwi, longans, oranges, nectarines, oranges, passion fruit, papaya, peaches, pineapple, plums, strawberries, tangerines, tomatoes. **Vegetables:** cauliflower, mushrooms. **Sweeteners and condiments:** in moderation - sucrose, brown sugar, maple syrup, peanut butter.
Polyols		**Fruits:** apples, apricots, Asian pears, blackberries, nectarines, peaches, pears, plums, prunes, watermelon **Vegetables:** cauliflower, mushrooms, snow peas. **"Diet," "sugar-free," or "low-carb" foods**: gums, mints, candy, desserts. **Additives**: sorbitol, mannitol, maltitol, xylitol, polydextrose, isomalt.	**Fruits:** bananas, blueberries, cranberries, grapes, kiwi, lemons, limes, mangoes, oranges, passion fruit, papaya, pineapple, raspberries, strawberries **Vegetables:** bell peppers, broccoli, cauliflower, lettuce, tomatoes. **"Diet," "sugarfree," or "low-carb" foods:** chewing gum sweetened with sugar (sucrose), sugar-sweetened mints and candy. **Additives:** aspartame, saccharine, stevia.