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Review

Dietary Fibre for Health and Gastrointestinal Therapeutic Applications: A Review

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Abstract: Dietary fibre has been described as 'roughage' for many years, where it was often discarded as an unwanted mill by-product or combined into animal feed. As awareness of its beneficial role in the diet grew, it became increasingly regarded as a nutrient (family)—which could provide very significant health benefits in the gut and beyond. Transit through the digestive tract is supported by dietary fibre, as is a degree of regulation of other nutrient digestion/absorption and the provision of a fermentable substrate for the colonic microflora. However, not all fibre forms are equivalent, from either physicochemical or colonic fermentability perspectives. Apart from nutritional roles within food systems, dietary fibre is often used in supplements as a laxative. Most important in this respect is ispaghula (psyllium) husk, which is sold under many consumer health brand names. This review represents a 'walk-through' of dietary fibre(s) from food and clinical perspectives, with an inevitable focus on gut transit and constipation management.

***Keywords*:** dietary fibre, gut health, nutrient absorption, constipation, diarrhoea

1. Introduction

The portion of food indigestible in the small intestine of man is referred to as 'dietary fibre' and the constituents, all of plant origin, include oligosaccharides, polysaccharides, resistant starch, waxes, and lignin [1-5]. The bulk of the components, but not all, are carbohydrates, therefore. Polyols may also be included in the dietary fibre fraction of food depending on the definition [6] as reviewed recently [7]—who make the point that carbohydrates such as lactulose and polyols exhibit similar prebiotic effects to oligosaccharides/inulin, although they are not classed formally as dietary fibre. The Codex Alimentarius 2010, as reviewed by the Scientific Advisory Committee on Nutrition [8], and developments in thinking around this definition regarding dietary fibre definitions have been discussed in detail by others [7, 9, 10], where [9]:

'Dietary fibre means carbohydrate polymers with 10 or more monomeric units that are not hydrolysed by the endogenous enzymes in the small intestine of humans and belong to the following categories: (1) edible carbohydrate polymers naturally occurring in the food as consumed; (2) carbohydrate polymers, which have been obtained from food raw material by physical, enzymatic, or chemical means and which have been shown to have a physiological effect of benefit to health as demonstrated by generally accepted scientific evidence to competent authorities; and (3) synthetic carbohydrate polymers, which have been shown to have a physiological effect of benefit to health as demonstrated by

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generally accepted scientific evidence to competent authorities' (p.10). The overall definition includes two additional relevant footnotes (which continue to be subject of debate [7]) where 'Footnote 1' states that 'when derived from a plant origin, dietary fibre may include fractions of lignin and/or other compounds associated with polysaccharides in the plant cell walls. These compounds may also be measured by certain analytical method(s) for dietary fibre. However, such compounds are not included if they are added as isolated components' (p.10). In addition, 'Footnote 2' states that the 'decision on whether to include carbohydrates of 3 to 9 monomeric units should be left up to national authorities' (p.10).

Dietary fibre promotes the transit of food through the digestive tract and may be fermented in the large intestine by the colonic bacteria to Short-Chain Fatty Acids (SCFAs), which provide a number of potential health benefits as reviewed recently [11]. The diet should contain at least 30 g of dietary fibre per day [2-5, 8, 12-14], but many people are deficient in this respect [2-4, 13-14]. The inadequate intake of dietary fibre has been estimated in 2017 to be responsible for the death of around 100,000 people annually [13]. Higher figures have been reported for 2019, where [15] 348,850 deaths reported globally due to ischaemic heart disease may be linked to diets low in dietary fibre content—representing 3.82% of all ischaemic heart disease deaths worldwide. Dietary fibre is usually classified functionally as soluble or insoluble [2, 4], although this is a potentially limiting definition which does not encompass all aspects of functionality [5, 16, 17]. Different chemical structures and physical forms of dietary fibre make them function differently in the gut in terms of hydration, solubility, and fermentability, especially [18-19]. This is largely poorly understood by consumers.

2. Dietary fibre in food

2.1 *Types of polysaccharides in foods*

The polysaccharides found in foods commonly (see, for example, Lovegrove et al. [20] for more details) include:

(i) Starches (containing α-glucans, amylose and amylopectin, built from glucose alone which, if amorphous are readily digestible—although semi-crystalline and complexed (e.g., amylose-lipid) structures resist digestion);

(ii) Cellulose and mixed linkage glucans (β-glucans, built from glucose only, indigestible in the small intestine of man but fermentable in the large intestine);

(iii) Hemicelluloses (containing different sugar moieties and structures which include arabinoxylans, galactans, galactomannans, glucomannans, glucoronarabinoxylans, glucuronomannans, mannans, xylans, and xyloglucans) again, indigestible in the small intestine of man;

(iv) Pectins (homogalactans, rhamnogalacturans), once again, indigestible in the small intestine of man.

The starch and non-starch polysaccharides have been classified according to structure, extractability, and physicochemical properties over many decades, and the diversity provides complexity in classification.

The starches (i) are relatively easy to define anatomically, structurally, functionally and in digestive terms as α-(1-4) and α-(1-6) bonded glucans, comprising (in different ratios depending on botanical origin) amylose (~99% α-(1-4) and 1% α-(1-6) bonds) and amylopectin (~95% α-(1-4) and 5% α-(1-6) bonds) polymers.

Although amorphous forms of starch (e.g., damaged during milling or gelatinised during cooking) are readily digested by humans, resistant forms of starch (Types I-V) resist digestion, whether they are formed naturally in plants or generated during processing [21-23]. The forms represent [22]: Type I–Starch granules embedded in plant tissue and thus inaccessible to digestive amylases; Type II–Starch granules resistant to hydrolysis in their native form; Type III–Re-crystallised/retrograded starch α-glucans; Type IV–Chemically modified starch; and Type V–Amylose-fatty acid acyl chain complexes. The resistant starch functions in effect as dietary fibre (with prebiotic capacity too). High amylose starches are marketed as forms of dietary fibre in view of their resistance to gelatinisation during food processing.

In terms of (ii), cellulose is a β-(1-4) linked glucan (β-glucan). However, (in the nutrition literature especially), cellulose is not usually referred to as a 'β-glucan' but cellulose.

Nakashima et al. [24] have discussed this ambiguity: 'Typically β-glucans do not include cellulose, which is formed only from β-(1-4) bonds. So-called β-glucan is a polysaccharide formed mainly *via* β-(1-3) glycosidic bonds with varying numbers of β-(1-3) and β-(1-6) bonds' (p.8). EI Khoury et al. [25] have presented a similar definition: 'The simplest [β-]glucan is the linear and unbranched β-(1-3)-D-glucan, found among prokaryotes and eukaryotes. Another simple structural type occurs mostly in the nonlignified cell walls of cereal grains, and consists of linear β-(1-3, 1-4)-D-glucans' (p.5).

Hemicellulose molecules (iii) are comprised of β-(1-4)-linked monosaccharide backbones which include β-(1-3, 1-4)-glucans, galactomannans, α-(1-4)-D-galacturonic acid glucomannans, glucuronoarabinoxylan, glucuronoxylan, mannans, xylans and xyloglucans as discussed by Scheller and Ulvskov [26].

The pectins (iv) contain three major backbone configurations:

α-(1-4)-D-galacturonic acid-homogalacturonan (linear or 'smooth');

α-(1-4)-D-galacturonic acid with alternating α-(1-2)-L-rhamnose residues-rhamnogalacturonan I (branched due to side groups/chains, or 'hairy');

α-(1-4)-D-galacturonic acid with extensive branching at C2 and C3-rhamnogalacturonan II (branched, or 'hairy').

Xylogalacturonan and apiogalacturonan (both linear, 'smooth') may be additionally considered pectin-type molecules because they have the same backbone as homogalacturonan [27-28].

2.2 *Fibre equivalence*

Capuano [29] discussed in some detail how dietary fibre derived from different sources is not equivalent in the human digestive tract in terms of functionality. As an overview, Capuano identified three particular issues concerning dietary fibre that need greater consideration:

i. The structure-function relationship, which is key to defining how different sources of dietary fibre exert an effect in the gut;

ii. How dietary fibre sources interact with other nutrients and modify, for example, their bioavailability and;

iii. In which form the fibre source is consumed (especially with respect to liquid or solid).

2.3 *Fibre regulations in food*

In common with all nutrient claims for modern food packs, dietary fibre content claims are regulated. According to The Commission of the European Communities [30], a claim that a food is "high in fibre", or any claim that may reasonably be interpreted as having the same meaning by the consumer, is permitted only if the product contains at least 6 g of fibre per 100 g, or at least 3 g of fibre per 100 kcal. Although people eat a mixed diet, this is comparable to the fibre content of wholemeal (wholewheat) bread (~5%). It is assumed commonly and incorrectly that dietary fibre provides no calories in the diet. In fact, it does and this is recognised now in nutritional labelling. Dietary fibre is ascribed an energy value of 2 kcal/g [31].

2.4 *Claims permissible for foods*

In terms of EU-recognised clinically acceptable claims with respect to certain types of dietary fibre, they are presented in Table 1. Lactulose is included in the list, although it is made synthetically for clinical intervention. Also, the (synthetic) hydroxypropyl-methyl derivative of cellulose is added for completeness. The claims relate to helping manage blood glucose concentration, faecal bulk, concentrations of cholesterol in the blood, weight management, intestinal transit, and bowel function.

Table 1. Clinically acceptable claims with respect to dietary fibre sources

Origin	Claim
Arabinoxylan produced from wheat endosperm	Consumption of arabinoxylan as part of a meal contributes to a reduction of the blood glucose rise after that meal
Barley grain fibre	Barley grain fibre contributes to an increase in faecal bulk
β-glucans [From oats, oat bran, barley, barley bran, or from mixtures of these sources per quantified portion.]	β-glucans contribute to the maintenance of normal blood cholesterol level

Table 1. (cont.)

Origin	Claim
β-glucans from oats and barley	Consumption of β-glucans from oats or barley as part of a meal contributes to the reduction of the blood glucose rise after that meal
Glucomannan (konjac mannan)	Glucomannan contributes to the maintenance of normal blood cholesterol level
Glucomannan (konjac mannan)	Glucomannan in the context of an energy-restricted diet contributes to weight loss
Guar Gum	Guar gum contributes to the maintenance of normal blood cholesterol levels
Hydroxypropyl methylcellulose made by reacting alkali treated cellulose with methyl chloride then propylene oxide	Consumption of hydroxypropyl methylcellulose with a meal contributes to a reduction in the blood glucose rise after that meal
Hydroxypropyl methylcellulose	Hydroxypropyl methylcellulose contributes to the maintenance of normal blood cholesterol levels
Lactulose (isomerised lactose which may occur in heated milk, 4-O-β-D-Galactosyl-D-fructose)	Lactulose contributes to an acceleration of intestinal transit
Oat grain fibre	Oat grain fibre contributes to an increase in faecal bulk
Pectins	Pectins contribute to the maintenance of normal blood cholesterol levels
Pectins	Consumption of pectins with a meal contributes to the reduction of the blood glucose rise after that meal
Resistant starch	Replacing digestible starches with resistant starch in a meal contributes to a reduction in the blood glucose rise after that meal
Rye fibre	Rye fibre contributes to normal bowel function
Wheat bran fibre	Wheat bran fibre contributes to an acceleration of intestinal transit
Wheat bran fibre	Wheat bran fibre contributes to an increase in faecal bulk

Source: European Food Safety Authority [32], European Union Commission Regulation [33]

3. Characteristics of dietary fibre in the intestine

3.1 *Water holding capacity*

The swelling and water holding capacity of different forms of dietary fibre have been characterised by a number of authors [34-35]. An inverse relationship exists between dietary fibre water-holding capacity and faecal bulking, which suggests that dietary fibre does not control faecal weight by simply retaining water in the gut, independent of other factors [34]. Faecal weight impacts of dietary fibre may be more related to the specific nature of its water-holding properties rather than its absolute water-holding capacity [36]. Ispaghula husk is the most effective at binding and holding water, although other fibre sources, for example, glucomannans from konjac, also function well in this respect, whereas fibre produced from, for example, oats does not [34-35, 37]. This water binding capacity of, for example, ispaghula helps relieve constipation—by increasing the faecal mass, which in turn stimulates peristalsis.

3.2 *Transit time*

With respect to the 30 g dietary fibre recommended each day in the diet, people consuming above this amount in the diet have transit times of less than seventy-five hours (~three days) whereas thirty-eight percent of people eating less than this exhibits a transit time of up to one hundred and twenty-four hours (more than five days) according to Gear et al. [38]. Where gut transit time is less than forty-eight hours, dietary fibre consumption does not have a major impact, whilst for transit times of forty-eight hours or more, the time is reduced by thirty minutes per gram of fibre consumed, regardless of fermentability [39].

Transit time through the gut reflects the indigestible solid content of the food consumed [29]. Insoluble, poorly fermented dietary fibre has the most impact on faecal mass and consequently on reducing colon transit time [29, 39]. Particulate dietary fibre impacts on transit time are due to mechanical stimulation of gut secretion and peristalsis—enhanced by appropriately sized fibre particles [29]. Larger particles are more effective than smaller ones in this context. This 'particulate' dietary fibre impact on (reducing) transit times is unlike the impact of specific viscous gums such as ispaghula, however. Their efficacy in this respect is due to their ability to create a viscous, water-binding, largely unfermentable mass in the bowel.

4. Therapeutic application of dietary fibre

4.1 *Diarrhoea*

Although perhaps counterintuitive, plant polysaccharides—starch and non—starch-have the potential to be used to manage diarrhoea [40-41]. Applications include oral rehydration therapy products. People tend to consider that dietary fibre mass alone promotes defaecation—when in fact it has also the capacity to regulate intestinal luminal volume of faecal matter (as discussed in 3.2), both in health and disease [41]. These authors have discussed the mechanistic aspects of dietary fibre in the intestine with respect to diarrhoea management and concluded fibre may help manage diarrhoea by: (i) reducing the rate of gastric emptying, (ii) improving the gut barrier functions, (iii) increasing epithelial cell turnover, (iv) increasing colonic fluid and electrolyte absorption plus, through fermentation, to produce Short-Chain Fatty Acids (SCFAs), (v) reverse colonic water secretion, (vi) alter colonic motor activity, (vii) suppress pathogenic colonisation of the gut, (viii) regulate colonic fermentation, (ix) modulate immune function, (x) increase both colonic sodium and water absorption, (xi) improve stool consistency in diarrhoea by sequestering water from liquid stools where overall (xii) undigested dietary fibre contributes to faecal bulk.

4.2 *Constipation*

This condition affects about twelve-fourteen percent of the world's population [1-3, 42-43], although sometimes much higher figures are reported [44]. The condition causes severe distress and discomfort. Consequently, different types of laxatives are utilised to resolve constipation issues; some are sources of dietary fibre, although these tend not to be consumed in the diets of most people routinely. Prunes are a very efficient natural laxative in part because they are rich in sorbitol (14.7 g/100 g) in addition to the dietary fibre content [43].

Therapeutic approaches used to treat/manage constipation are presented in Table 2. Many products utilised for the management of constipation are available 'Over The Counter' (OTC) rather than requiring a prescription (Prescription Only Medicine (POM)).

Table 2. Therapies for constipation management

Therapy	Examples
Bulk forming laxatives (Dietary fibre)	See Table 3
Osmotic laxatives	Draw water into the colon. Lactulose, macrogol, and polyethylene glycol
Stimulant laxatives	Increase contractions in the colon. Bisacodyl, senna, and sodium pico-sulphate
Faecal softeners	Arachis oil and docusate
Prokinetic drugs	For example, serotonin 5-hydroxytryptamine 4 (5-HT4) receptor agonists that accelerate gastrointestinal and colonic transit
Secretagogues	Chloride channel activators which increase intestinal secretion. Guanylate cyclase C receptor agonists which increase intestinal secretion

See Basilisco and Coletta [42] for more details

Different authors [2, 5, 45-46] have discussed eloquently how all dietary fibre sources are not equivalent with respect to their capacity to provide a laxative effect. Indeed, some may lead to constipation (Table 3).

Table 3. Impact of different types of dietary fibre on laxation

Fibre type	Laxative effect
Cellulose	Potentially constipating
Guar gum	No
Inulin	No
Ispaghula husk (Psyllium)	Yes
Methyl-cellulose (chemically modified)	No
Oat bran	Potentially constipating
Polydextrose	No
Resistant starch	No
Wheat bran (coarse)	Coarse bran may provide laxation
Wheat bran (fine)	Potentially constipating
Wheat dextrin (chemically modified)	Maybe constipating
Soluble maize fibre	No

Source: McRorie and McKeown [46] and McRorie [2]

Wheat bran has been promoted as a component of the diet to optimise gut health, where, for example, it can promote gut transit and reduce transit times [47-48]. This is through mechanical impact on the gut mucosa. It can play a role in preventing and alleviating constipation [48], although it is insoluble.

In feeding trials comparing the impact of dietary fibre from different sources on gut transit, fibre supplementation overall (i) decreased gut transit times and (ii) increased both the daily number of defecations and the weight of stools [49]. In this study, wheat bran had a greater impact on gut transit time compared to ispaghula husk. However, the ispaghula husk had a greater effect on the amount of water (content) of the stools and the total stool weight.

McRorie and McKeown [46] have discussed the features they consider that are required for a dietary fibre to exert a laxative effect in the large intestine:

i. Presence of large/coarse insoluble fibre particles (such as wheat bran) which can irritate the gut mucosa by mechanical means, stimulating both water and mucous secretion;

ii. The presence of a high water-holding capacity gel-forming soluble fibre (such as ispaghula), which is able to resist dehydration;

iii. For both (i) and (ii), the fibre must resist fermentation.

In a subsequent publication, McRorie [2] emphasised that for a dietary fibre source to exert an appropriate laxative effect, it must meet two major prerequisites (which encompass i-iii, directly above):

Firstly, resist fermentation in the large bowel and arrive intact in the faecal matter;

Secondly, resist also the dehydrating effects of the large bowel and therefore increase the faecal water content.

These attributes are imperative for providing both faecal softening and output.

There is a lot of confusion with respect to dietary fibre consumption and the impact it has within the gut, mechanically and potential fermentability. Using the criteria above, this allows for a meaningful understanding of how non-digestible carbohydrates impact gut health with special focus on laxation.

4.3 *Dietary fibre as prebiotics*

A dietary prebiotic can be defined as 'a selectively fermented ingredient that results in specific changes in the composition and/or activity of the gastrointestinal microbiota, thus conferring benefit(s) upon host health' [50-51] within the gut (especially luminal cell health) and beyond (e.g potential immunomodulatory benefits). This functionality is thus more than a physical functionality within the intestine, promoting gut transit/peristalsis. A number of non-digestible carbohydrates (polysaccharides) fit this definition according to Wang et al. [52]. Most often, it is used in the context of specific fructans. In nature, these are synthesised as inulin-type with β-(2-1)-D-fructofuranosyl units or levan-type comprising β-(6-2)-D-fructofuranosyl units, as discussed elsewhere [53-54].

Native chicory inulin was granted prebiotic status in 2016 for a period of five years by the European Union [55] with the Claim 'Chicory inulin contributes to normal bowel function by increasing stool frequency'. Both fructooligosaccharides and galactooligosaccharides are receiving more attention with respect to their prebiotic activities [56]. As discussed in 2.1, resistant (to digestion) forms of starch can function as prebiotic material too.

4.4 *Systemic health roles of dietary fibre*

What is consumed, even if not digested and absorbed, impacts on the body beyond the gut. The main focus with respect to dietary fibre consumption is rightly gut health but this does have impact, indirectly, to other disease causing/disease states both physical such as cancer, cardiovascular disease, coronary heart disease, diabetes, elevated blood glucose and lipid/cholesterol concentrations, metabolic syndrome, obesity, satiety and psychological conditions such as depression [3, 25, 57-59].

5. Examples of dietary fibre

5.1 *Digestible and indigestible forms of starch*

Starch is classified (these days) by nutritionists as Rapidly Digestible Starch (RDS), Slowly Digestible Starch (SDS), and Resistant Starch (RS). Theoretically, [60] *in vitro* and *in vivo* assays of the starch forms are characterised as:

RDS: Hydrolysed within twenty minutes, equivalent to the mouth and small intestine;

SDS: Hydrolysed within twenty minutes to two hours, equivalent to the small intestine;

RS: Enters and is located within the large intestine and becomes thus fermentable to SCFAs, where it acts as a prebiotic as discussed by Topping and Clifton, [61] for example, where glucose would not be released from the colon and thus not into the blood stream (unlike for the small intestine).

In fact, the SDS fraction may be digested in the small intestine for many hours (not just two hours) and release glucose into the bloodstream during this period. Hence, the notion that starch residing for longer than two hours in the intestine is resistant starch (any dietary fibre therefore) is not correct physiologically [22-23, 62]. Thus, starch that resists digestion for more than two hours should not be considered as resistant starch and does not necessarily function as dietary fibre.

5.2 *Multi-functional glucomannans*

Glucomannan (especially that extracted from konjac, *Amorphophallus konjac* corms) is a relatively unusual permitted food ingredient (as konjac gum E 425i and konjac glucomannan E 425ii) in that many (albeit related) characteristics of the polysaccharide have been proposed for potential health-related application claims—with some granted and some not. The polysaccharide swells to many times its initial volume when hydrated—forming progressively less rigid gels as the hydration volume is increased. It has been consumed for centuries in Asia in the form of noodles, jellies, and tofu-type where it is associated with many health benefits [63]. In particular, when hydrated in the stomach, the glucomannan provides the sensation of feeling full, thus impacting food consumption patterns.

The European Commission Panel on Dietetic Products, Nutrition and Allergies was asked [32-33, 64] (Table 1) to consider the potential nutritional Claims of konjac glucomannan (fibre) and agreed that:

i. Body weight: A cause-and-effect relationship *has* been established between the consumption of glucomannan and the reduction of body weight in the context of an energy-restricted diet. The Panel considers that in order to obtain the claimed effect, at least 3 g of glucomannan should be consumed daily in three doses of at least 1 g each, together with 1-2 glasses of water before meals, in the context of an energy-restricted diet. The target population is overweight adults.

ii. Reduction of post-prandial glycaemic responses: A cause and effect relationship *has not* been established between the consumption of glucomannan and the reduction of post-prandial glycaemic responses.

iii. Maintenance of normal blood glucose concentrations: A cause and effect relationship *has not* been established between the consumption of glucomannan and the maintenance of normal blood glucose concentrations.

iv. Maintenance of normal (fasting) blood concentrations of triglycerides: A cause and effect relationship *has not* been established between the consumption of glucomannan and the maintenance of normal blood concentrations of triglycerides.

v. Maintenance of normal blood cholesterol concentrations: A claim on glucomannan and maintenance of normal blood cholesterol concentrations *has already been assessed with a favourable outcome*.

vi. Maintenance of normal bowel function: A cause and effect relationship *has not* been established between the consumption of glucomannan and the maintenance of normal bowel function.

vii. Decreasing potentially pathogenic gastrointestinal microorganisms: A cause and effect relationship *has not* been established between the consumption of glucomannan and decreasing potentially pathogenic gastrointestinal microorganisms.

Fang et al. [65] have reviewed in detail why they believe konjac glucomannan should be granted Claims as a meal for special medical purposes of type II diabetes.

5.3 *Ispaghula/psyllium husk*

Plantago represents a genus of approximately 200 species of flowering plants in the family *Plantaginaceae* (called plantains or fleaworts). Although most are herbaceous, a few are sub-shrubs. The genus has been discussed in detail by different authors [66-67]. The *Plantago ovata* seed husk (usually referred to as Psyllium or ispaghula husk) is very polysaccharide-rich, probably in the region of eighty-five percent [67].

The polysaccharides of ispaghula husk comprise primarily highly branched arabinoxylans with β-D-(1-4) linked xylopyranose backbones where α-L-arabinofuranose units are attached as side groups through α-(1-3) and α-(1-2) linkages [68-71]. Extraction can yield two fractions, one with a molecular weight of 7×10^6 D and a gelling fraction of 1-2 $\times 10^5$ D, according to Al-Assaf et al. [72]. Powdered ispaghula husk swells very rapidly [73]. Upon ingestion, ispaghula husk reaches the large intestine about four hours after consumption, in the most part intact [74]. The polysaccharide gels are not fermented extensively, making them a very effective dietary fibre source for constipation therapy [2, 44, 75-78]. However, changes to faecal microbiota as a consequence of ispaghula husk consumption have been reported, especially for constipated patients [79-80]. According to some authors, the gas production by dietary fibre sources such as ispaghula can be mitigated using microcrystalline cellulose as a dietary fibre source [81]. Bloating and gas production caused by consumption of ispaghula fibre can be short-lived, however [82-83].

The relatively unique properties that ispaghula husk brings with respect to issues of constipation management are presented in Figures 1 and 2. It is important that the polysaccharide does provide these properties to be effective and is used appropriately to optimise functionality whilst limiting side effects.

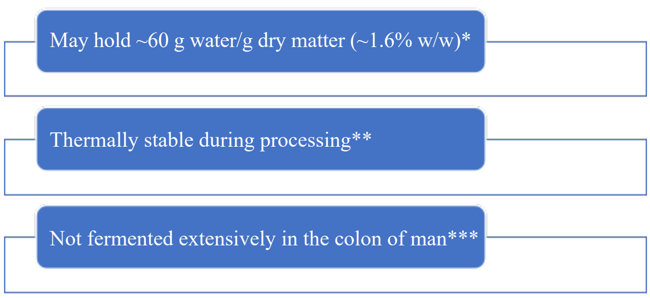

Figure 1. Ispaghula gel/gum properties at a glance
Source: Author's illustration using information from *[84]; ** [69]; *** [79-80]

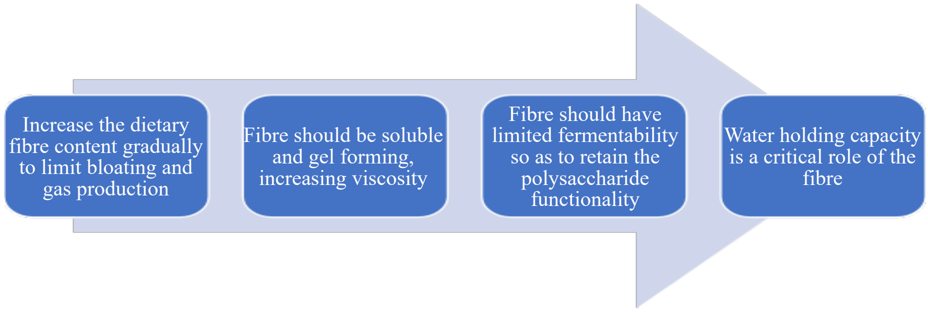

Figure 2. Increasing dietary fibre content to manage the incidence of constipation

There are many different brands of ispaghula products aimed at constipation therapy [70]. The ispaghula husk is used for a number of other therapies as indicated in Table 4.

Table 4. Clinical applications of ispaghula husk

Condition	Comment	Reference
Constipation	Facilitates laxation	See the main body of text
Diabetes	Helps blood glucose control management	[85-87]
Diarrhoea	By stabilising gut transit	[2, 46, 88]
Diverticulitis	Manages condition/discomfort	[89-90]
Glucose Homeostasis	Regulation of blood glucose concentration	[85, 91-92]
Haemorrhoids	Managing the discomfort	[76, 93-94]
Hypercholesterolaemia	Managing the absorption of cholesterol	[85, 95-96]
Hypertension	Management of cardiovascular risk factors	[97-99]
Irritable Bowel Disease (Crohn's Disease, Ulcerative Colitis)	Management of IBD symptoms (especially when in remission)	[100-102]
Irritable Bowel Syndrome	Improve bowel function	[2, 88, 103]

5.3.1 *Food containing ispaghula*

It is not an easy matter to construct food products containing ispaghula as the polysaccharide absorbs a great deal of water [104-105]. Products incorporating the polysaccharide can often have an adverse/gummy texture due to the water sequestration properties [71, 84]. To help overcome these limitations but retain dietary fibre benefits, hydrolysis of the polysaccharide with, for example, acids has been employed [104]. The problem then is that the product is modified from it regulated ingredient definition.

Ispaghula addition to baked goods can decrease the digestibility of the starch fraction [106] and the overall glycaemic index [71]. Although the polysaccharide may have a positive impact on baked goods structure, where it has been employed as a gluten replacer, the relatively high-water content of breads could lead to an issue with mould development [107].

Improperly hydrated ispaghula fibre can cause intestinal blockage, unfortunately [108]. Hence, products containing ispaghula need to be designed where a number of nutritional factors are taken into account.

Wiesner and Merz [109] have reported on potential negative health impacts from consuming ispagula, which are qualified as follows:

i. Flatulence.

ii. In granular form, ispaghula is banned by the U.S. Food and Drug Administration to avoid oesophageal obstruction.

iii. As ispaghula contains potent allergens, it is a possible cause of anaphylaxis. Thus, it should not be used by patients with hypersensitivity to the seed.

6. Conclusions

The utilisation of dietary fibre for gut transit support therapy is not as simple as it may seem, in view of the range of different sources available, physicochemical properties, amount consumed, form consumed, palatability, physiological functionality, and nature/extent of colonic microbiological transformations/fermentation. The need for a diet that promotes gut transit of 30 g or more fibre per day plays a role in avoiding constipation, but also helps to support laxation when constipated. Although dietary fibre particles play a major role in supporting gut transit to maintain health, ispaghula is the fibre of choice to manage gut transit when additional support is required. This is because it gels, holds water tightly, and is not fermented extensively in the large intestine—features that are all required to provide optimal efficacy. There might be an argument that by incorporating relatively large insoluble fibre particles into the ispaghula gum, such as wheat bran, an even more efficacious therapy could be developed. This proposed combination, providing both gelling and mucosal irritating components, is therefore relatively resistant to fermentation.

Conflict of interest

The authors report there are no competing interests to declare.

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