POLYDEXTROSE: HEALTH BENEFITS AND PRODUCT APPLICATIONS

Innovating to Meet Nutrition, Health, and Wellness Needs Every Day

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sta-lite® Polydextrose

MAKING FOOD EXTRAORDINARY

TATE & LYLE

- Despite the fact that many consumers say that they are making efforts to consume diets high in dietary fibre, current fibre intakes remain low.
- Research indicates that diets higher in fibre are associated with improved health and reduced risk of certain diseases such as coronary heart disease and type 2 diabetes.
- Added and functional fibres can help bridge the gap between actual intake and global dietary recommendations.
- The physio-chemical and functional properties of STA-LITE® Polydextrose make it a good candidate for manufacturers to use in developing new and innovative products to meet the fibre needs of the population without increasing energy intake.
- Research demonstrates that polydextrose provides several physiological benefits that include supporting gastrointestinal health, a low postprandial blood glucose response, and a satiety effect, thus potentially aiding in weight management.

FIBRE INTAKES AND RECOMMENDATIONS

Decades of research point to the health benefits of dietary fibre, including supporting cardiovascular health, tempering spikes in blood sugar, aiding healthy weight management and promoting a healthy gut.[1-3] Yet, across the globe, average intakes are well-below the recommended amount despite the widespread knowledge of its role in a healthy diet.[3]

While traditional sources of fibres like whole grains, fruits, and vegetables should be encouraged, fibres added to foods, also known as added fibres, are important contributors to dietary fibre intakes. An abundance of research continues to demonstrate that added fibres provide similar benefits as fibres inherent in whole foods.

Tate & Lyle's ingredient, STA-LITE® Polydextrose is a low-calorie bulking and texturing ingredient commonly added to foods to boost fibre content and to replace sugar and fat without sacrificing taste, texture, or enjoyment. Studies have also demonstrated the health benefits of this polydextrose.

Dietary fibre gap: Intakes vs. recommendations

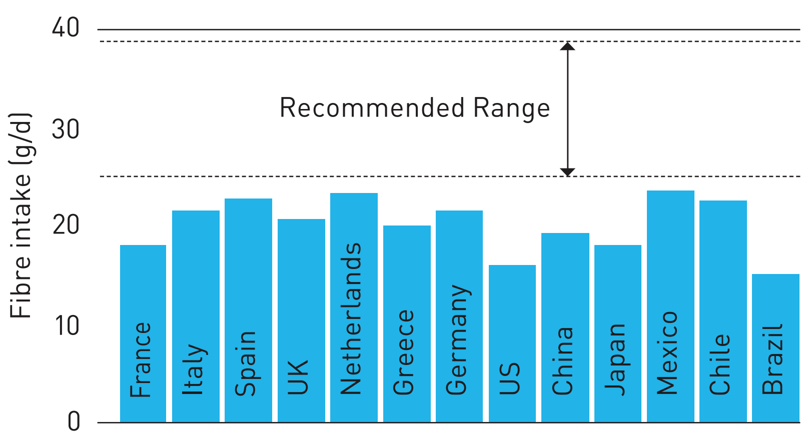
Recommendations for fibre intakes range from 25-38 g/day depending on country specific guidelines.[2, 3] The World Health Organization suggests worldwide recommendations of 25 g/day,[4] but fibre intakes in most countries are well below this level[5-11] (Figure 1). In the United States (US), for most age and gender groups, 5% or fewer of the population meet the dietary recommendations for fibre despite consistent messaging to the public to increase dietary fibre intake.[12, 13]

Fibre sources

Dietary fibres are non-digestible carbohydrates in the diet that, when consumed, pass through the small intestine into the large intestine where they may be partially or completely fermented by colonic microbiota.[2] Added fibres, also known as "functional fibres," are non-digestible carbohydrates that are isolated from a food source, or synthesized non-digestible carbohydrates, that have beneficial physiological effects in humans.[2]

Figure 1

Average adult fibre intakes by country[5-11]



HEALTH BENEFITS

Polydextrose has been tested by a number of independent researchers to validate its effectiveness and to demonstrate its physiological health benefits. The following are some highlights on the health benefits of polydextrose:

- Is well-tolerated,[18, 22, 34-37] even up to 90 g/day or 50 g as a single dose[18]
- Supports healthy blood glucose levels by eliciting a lower blood glucose response[37, 48, 49, 52, 58]
- May help promote regularity, as a result of its faecal bulking effect[35-37, 40, 45, 46]
- May support the growth of beneficial gut bacteria[23, 24, 37, 47]
- May support a healthy gut by producing short-chain fatty acids (SCFAs), which feed the beneficial bacteria in the colon[25, 36, 37]
- Is ideal for reduced-calorie foods and may assist with weight management by providing negligible calories (1 kcal/g)[19, 22, 26] and a satiety benefit, as suggested by emerging data[50, 53, 54]

These fibres can be extracted from one food source and added to another (e.g., bran added to grain-based foods); or they can be manufactured from grains like corn or wheat (e.g., STA-LITE® Polydextrose and PROMITOR® Soluble Fibre) or from fruit, vegetables, legumes, nuts, and seeds;[2] or the fibres can be modified forms of traditional fibres.[2] Adding fibre to new or commonly consumed foods is one strategy to increase the dietary fibre intake of target populations in order to bridge the gap between usual intakes and recommended intakes. Polydextrose (STA-LITE®) is a source of dietary fibre that can be added to reduce sugar content and increase the fiber content of a variety of foods such as sugar-free products, cereals, snacks, bakery items, beverages, dairy products, and sauces.

FIBRE INNOVATION FOR HEALTH

Physiological functions and benefits of fibre

The physical and chemical structure of a dietary fibre and its fermentation capacity are partially responsible for the many physiological benefits associated with dietary fibre consumption. Increased dietary fibre has been associated in epidemiological studies with the reduced risk of coronary heart disease, stroke, hypertension, obesity, prediabetes, type 2 diabetes, certain gastrointestinal disorders, and some cancers.[1] Evidence indicates that consumption patterns high in certain fibres are associated with lower total and LDL cholesterol, blood pressure, and blood glucose in healthy individuals and in those with prediabetes and type 2 diabetes; can help with both weight loss and maintenance; and can improve bowel regularity, laxation, and gastrointestinal health.[1-3, 14-17] While the breadth of scientific evidence supports these effects, science continues to build on other additional health benefits of fibre consumption such as fermentation by colonic microbiota and immunomodulation.[17]

STA-LITE® Polydextrose is an ingredient developed by Tate & Lyle as one of its solutions to help increase fibre intake. Polydextrose is approved as a food additive in the US (21 CFR 172.841), the European Union [(EC) No 1333/2008], and most other countries worldwide.

Characterization of STA-LITE® Polydextrose

Polydextrose is a highly branched, randomly bonded glucose polymer produced by the condensation of glucose in the presence of sorbitol and small amounts of food grade citric acid or phosphoric acid.[18]

Polydextrose has a broad molecular weight range (162-20,000 mw) with 90% of the molecules being between 504 and 5,000 mw. Its high stability in heat and acidic environments, low viscosity, high solubility in water, bulking and texturing properties, and bland taste lends itself to a wide-variety of food and beverage formulations.[19]

Polydextrose resists digestion and absorption and has the physiological effects of dietary fibre. In most countries, polydextrose is usually declared as a dietary fibre, and depending on its usage level, fibre claims can normally be made for foods containing polydextrose.*

STA-LITE® Polydextrose ingredient provides a minimum of 90% polydextrose and contains a maximum of 4% sugar with a caloric content of 1 kcal/g.

*Labeling varies by regional and country regulations.

Resists digestion and fermented in the gut

Polydextrose is minimally absorbed in the small intestine and is fermented in the large intestine by gut microbiota, leading to the production of the SCFAs propionate, butyrate, and acetate. Butyrate is a preferred energy source for colonocytes and has been studied for its anticarcinogenic properties.[20] Propionate is readily taken up by the liver and is linked with inhibiting cholesterol synthesis and enhancing satiety.[20-21] Acetate enters peripheral circulation and is metabolized, but may also increase cholesterol synthesis; hence it has been suggested that substrates that decrease the acetate to propionate ratio may help to decrease the risk of cardiovascular disease.[20]

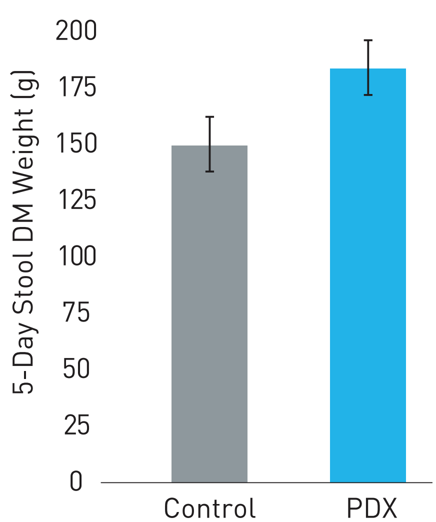
Polydextrose resists digestion due to the atypical linkages found between glucose units in its structure;[19] about 30-50% is excreted undigested.[19, 22] *In vitro* experiments that simulate human colon fermentation by using human faecal inoculum demonstrate that polydextrose is slowly fermented and produces less gas[25, 27] compared to many other dietary fibres. Most *in vitro* studies of polydextrose observe an increase in the production of the SCFA propionate [23-25, 27-29] followed by butyrate[23, 24, 28-30] and acetate.[23, 24, 28-30] Studies in rats and pigs also support an increase in propionate[31-33] and butyrate[31, 33] but not in acetate concentrations after polydextrose feeding. While some clinical evaluations[34-36] report no significant increase in faecal SCFAs, one study[37] observed a significant increase in faecal acetate and butyrate levels with the intake of 8 g/day and 12 g/day of polydextrose for 28 days. In the case of SCFAs production, *in vitro* and animal studies may be more indicative of fermentation patterns than human studies as SCFAs are readily absorbed from the colon.[20, 38, 39]

Products produced from the fermentation of protein by gut microbiota such as phenol, indole, iso-butyrate, iso-valerate, valerate, and ammonia are harmful to gut epithelia and may be potential promoters of colon cancer. Some clinical trials conducted in healthy adults report a reduction in these substances following polydextrose supplementation in the range of 8-21 g/day.[36, 40, 41]

Excellent digestive tolerance

Polydextrose is well-recognized as a fibre with excellent digestive tolerance. Several clinical studies have evaluated the gastrointestinal tolerance of polydextrose and have found that it is generally well tolerated.[18, 22, 34-37, 42] The fact that less gas[25, 27] is produced during fermentation is likely a contributing factor. The Joint FAO/WHO Expert Committee on Food Additives and the European Commission Scientific Committee for Food concluded that up to 90 g/day or 50 g as a single dose of polydextrose may be consumed without any detrimental effects (maximum laxative threshold).[18]

Figure 2
Faecal weight with 21 g/day polydextrose vs. control for 21 days in males[36]



Supports healthy laxation

Polydextrose has been shown to have positive bowel function benefits. In many developed countries, chronic constipation is a common condition among adults and children.[1] The European Food Safety Authority (EFSA) Panel on Dietetic Products, Nutrition, and Allergies has noted that changes in bowel function such as reduced transit time, more frequent bowel movements, increased faecal bulk, or softer stools may be considered beneficial physiological effects provided they do not result in diarrhea [in the context of the European Health Claims Regulation (Regulation EC 1924/2006)].[43] Increased faecal bulk and reduced intestinal transit time are also believed to reduce colon cancer risk by decreasing the exposure of colonocytes to potential gut carcinogens.[44] Clinical studies to date have demonstrated that polydextrose consumption increases faecal bulk/weight,[35-37, 40, 45, 46] faecal consistency,[34, 35, 45] ease of defecation,[37] and faecal frequency[35, 37] and decreases transit time[41] in healthy adults. Faecal bulk effects were shown to be effective between 8-30 g/day across studies from the US, Britain, Germany, China, and Japan. A randomized, double-blind, placebo-controlled study of 21 healthy, overweight men observed an increase of 29 g in faecal weight on a dry matter (DM) basis over a five-day period when 21 g of polydextrose was consumed compared to the control (Figure 2); an increase in faecal mass of 4.3 g was found per gram of fibre consumed.[36] The lowest effective dose was 8 g/day for improvements in faecal bulk[37] and faecal consistency,[34] whereas ease of defecation and faecal frequency was enhanced with a dose as low as 4 g/day.[37]

Prebiotic benefits

Polydextrose intake is associated with increased prebiotic activity. It is generally believed that a prebiotic should selectively increase the growth of beneficial gut bacteria such as lactic acid bacteria and/or bifidobacteria. 120 subjects consumed 4 g, 8 g, or 12 g of polydextrose for 28 days in a randomized, parallel-group, double-blind, placebo-controlled trial and significant increases of 0.84-1.64 x 10^9 per gram of faeces for *Lactobacillus* and 1.08-4.77 x 10^9 per gram of faeces for *Bifidobacterium* species were detected in their faeces compared to an increase of only 0.03 x 10^9 per gram of faeces for *Lactobacillus* and a decrease of 0.09 x 10^9 per gram of faeces for *Lactobacillus* and *Bifidobacterium*, respectively, for the control.[37] At the same time, concentrations of pathogenic species *Bacteroides fragilis*, *Bacteroides vulgutus*, and *Bacteroides intermedius* were significantly reduced by 0.96-1.13 x 10^9 per gram of faeces, 0.39-0.64 x 10^9 per gram of faeces, and 0.0-0.28 x 10^9 per gram of faeces, respectively, in the treatment groups compared to small to moderate increases in the control group.

Live bacteria, usually *Lactobacillus* and *Bifidobacterium* species, are often consumed as a dietary supplement (i.e., probiotics), but their survival in the gastrointestinal tract for extended periods has been questioned. Hence, one study evaluated whether the addition of prebiotics such as polydextrose to the live probiotic mixture would improve the survival of probiotics.[47] A sample of 20 healthy adults consumed 5 g of polydextrose with a probiotic mixture of lactic acid bacteria and bifidobacteria for two weeks. At baseline the faecal bifidobacteria count was 7.0 ± 2.2 $\log_{10}$ cfu per gram weight faeces, which increased, to 7.6 ± 2.0 $\log_{10}$ cfu per gram weight faeces with the supplementation of the probiotic mixture. The addition of polydextrose to the probiotic mixture significantly increased the count to 8.9 ± 2.5 $\log_{10}$ cfu per gram weight faeces compared to baseline, demonstrating an additive benefit of the polydextrose. *Lactobacillus* counts, on the other hand, did not increase with polydextrose intake. *In vitro* studies also support the increased growth of bifidobacteria with the addition of polydextrose.[23, 24]

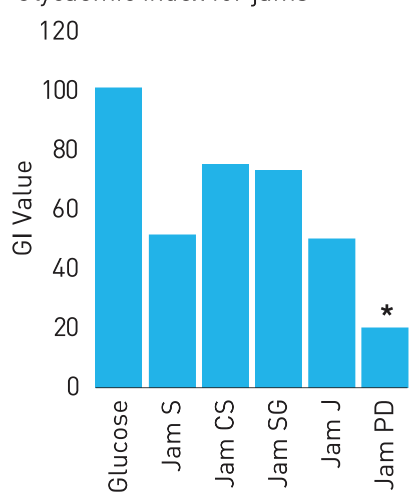
Favorable blood glucose and insulin response

There is increasing evidence that polydextrose decreases postprandial glycaemic and insulinaemic responses. Compared to glucose, which has a glycaemic index of 100, polydextrose has a glycaemic index of 7.[58] In their evaluation of multiple doses of polydextrose, Jie *et al*[37] reported that 12 g of polydextrose ingested with 50 g of glucose significantly lowered the glycaemic response compared to a 50 g glucose control in healthy adults. Kurotobi *et al*[48] compared the glycaemic index of five strawberry jams made with sugar (Jam S), corn syrup and sugar (Jam CS), sugar and glucose (Jam SG), apple juice (Jam J), and 40% polydextrose (Jam PD) in 30 healthy adults. The glycaemic index for the polydextrose jam was significantly lower than the glucose control and all the other jams[48] (Figure 3).

An EFSA Panel provided a positive scientific opinion on the replacement of sugar with polydextrose and the reduction of postprandial glycaemic responses.[49] The EFSA opinion noted that reducing postprandial glucose responses may be beneficial, particularly in those who have impaired glucose tolerance, as long as postprandial insulin responses are not disproportionately increased. The Panel concluded that a cause-and-effect relationship has been established between the consumption of foods/drinks containing polydextrose and the reduction of postprandial blood glucose responses as compared to sugar-containing foods/drinks.

Clinical studies have reported significantly lower blood glucose and insulin responses with polydextrose consumption. Konings *et al*[50] conducted a randomized, single-blind, crossover study in 18 overweight adults, finding a lower postprandial peak glucose response accompanied by a reduction in insulin following the consumption of 57 g of polydextrose split between two meals compared to similar full-calorie meals. The acute effects of a commercial fat- and lactose-free milk enriched with polydextrose was compared with a regular, fat-free milk or a fat- and lactose-free milk in the study by Lummela *et al*.[51] After an overnight fast, 26 healthy adults consumed the milks in a randomized block design. A significantly lower rise in blood insulin was observed after consumption of the polydextrose milk compared to the other

Figure 3
Glycaemic index for jams[48]



*Significant difference compared to all groups at P<0.01.

Research indicates that diets rich in fibre are associated with lower body weight and that dietary fibres may enhance satiety and decrease food intake thus reducing the risk of obesity.

two milks. The reduction in postprandial blood glucose and insulin responses has also been observed in individuals with type 2 diabetes when the consumption of sweetened, dried cranberries was compared to polydextrose-containing, reduced-sugar cranberries in a randomized, controlled, crossover study.[52]

Weight management

Research indicates that diets rich in fibre are associated with lower body weight and that dietary fibres may enhance satiety and decrease food intake thus reducing the risk of obesity.[1] Polydextrose may help support weight management strategies through its incorporation into lower calorie food formulations given that its calorie contribution is only 1 kcal/g. Further, research indicates a relationship between polydextrose consumption and appetite and reduced energy intake at a subsequent meal.[53, 54] There have been two meta-analyses and systematic reviews assessing polydextrose consumption and subjective appetite ratings and energy intake.[53, 54]

Ibarra *et al* (2016) conducted a meta-analysis and systematic review of seven studies assessing subjective feelings of appetite post-polydextrose consumption at levels between 6.25 g and 25.0 g in a single dose per day, which are within the commercial application range for foods and dietary supplements.[53] Some studies demonstrate that polydextrose consumption significantly impacts subjective feelings of appetite including reductions in desire to eat, which may explain reported reductions in energy intake at a subsequent meal. For other subjective feelings of appetite such as hunger, satisfaction, or fullness, this meta-analysis showed no significant differences with polydextrose consumption. When high doses of polydextrose have been tested (56.7 g over the duration of the day) as in a study by Konings *et al*, subjective feelings of appetite including hunger and desire to eat have been reduced while feelings of fullness and satisfaction have been increased.[50]

While subjective measures of appetite are important to understand, it is the reduction in energy intake that will potentially impact body weight and assist with weight management. Ibarra *et al* (2015) also conducted a meta-analysis and systematic review of studies assessing the effects of polydextrose consumption on energy intake.[54] All of the studies included in this meta-analyses provided the polydextrose dose at a mid-morning snack then assessed energy intake at the subsequent *ad libitum* lunch (six studies) or assessed energy intake for the remainder of the day (three studies). The meta-analysis demonstrated that the consumption of polydextrose is significantly associated with a reduction in energy intake at lunch but no significant effect on energy intake during the remainder of the day or daily energy intake. Ibarra *et al* concluded that consumption of polydextrose reduces voluntary energy intake at a subsequent meal and this energy intake reduction occurs in a dose-dependent manner. The timing and dose of polydextrose consumption is an important factor on impacting energy intake.

Polydextrose consumption may support weight management efforts through its low-calorie value and its potential effect on appetite and energy intake. Additional studies are needed to understand the effect of longer term consumption of polydextrose on energy intake over time and body weight.

sta-lite® Polydextrose

NUTRITIONAL IMPACT OF THE USE OF STALITE® POLYDEXTROSE

STA-LITE® Polydextrose is a source of dietary fibre that can be added to a variety of foods such as sugar-reduced, no-added sugar, and sugar-free cereals, snacks, bakery items, beverages, dairy products, and sauces. It can also be used in bakery items, beverages, dairy products, and sauces.

Globally, average fibre intakes fall well below recommended intakes.[5-11] Diets high in fibre have been associated with lower risk of heart disease, and improved blood glucose levels while also supporting digestive health, laxation, and aiding in healthy weight management.[1-3]

STA-LITE® Polydextrose is a soluble fibre used to provide body and texture in reduced-calorie and reduced-fat foods. Simple substitutions of similar foods made with STA-LITE® Polydextrose can help to close the fibre gap and may help to lower calorie intake. In this menu example, fibre increases by 12 g and total fat and saturated fat are lowered by 11% and 25%, respectively. STA-LITE® Polydextrose is well-tolerated and research to date suggests that it supports digestive health and laxation, may help decrease postprandial glycaemic response, may have prebiotic benefits, and may support weight management strategies by providing a satiety effect.

2,000-CALORIE MENU, BASELINE*	WITH STA-LITE® POLYDEXTROSE** SUBSTITUTIONS
Breakfast: 2 buttermilk waffles 1 tsp tub margarine 2 tbsp maple syrup 1 cup strawberries 1 cup fat-free milk	**Breakfast:** **2 buttermilk waffles, made with STA-LITE® Polydextrose**** 1 tsp tub margarine 2 tbsp maple syrup 1 cup strawberries 1 cup fat-free milk
Lunch: Grilled ham and Swiss sandwich: 2 slices wheat bread 1.5 oz lean ham 1.5 oz reduced-fat Swiss cheese 2 tsp tub margarine 1 cup garden vegetable soup 1 apple 1 cup water	**Lunch:** Grilled ham and Swiss sandwich: 2 slices wheat bread 1.5 oz lean ham 1.5 oz reduced-fat Swiss cheese 2 tsp tub margarine 1 cup garden vegetable soup 1 apple 1 cup water
Dinner: 4 oz broiled salmon 1 cup pasta w/pesto sauce 1 cup green beans 1 cup fat-free milk ½ cup cookies and cream ice cream	**Dinner:** 4 oz broiled salmon 1 cup pasta w/pesto sauce 1 cup green beans 1 cup fat-free milk **½ cup low-fat cookies and cream ice cream, made with STA-LITE® Polydextrose****
Snack: 1 cup low-fat fruit yogurt 2 graham crackers	**Snack:** 1 cup low-fat fruit yogurt **1 chewy granola bar, made with STA-LITE® Polydextrose****

NUTRITION FACTS				Change	% Change
Baseline menu		Menu with **STA-LITE®**			
Calories	2,040	**Calories**	1,950		
Total Fat **Saturated Fat**	61 g 20 g	**Total Fat** **Saturated Fat**	54 g 15 g	-7 g total fat -5 g sat fat	-11% -25%
Cholesterol	165 mg	**Cholesterol**	150 mg		
Sodium	2,370 mg	**Sodium**	2,220 mg		
Total Carbohydrate **Dietary Fibre** **Sugars**	280 g 21 g 140 g	**Total Carbohydrate** **Dietary Fibre** **Sugars**	280 g 33 g 133 g	+12 g fibre	+57 %
Protein	102 g	**Protein**	99 g		

* Menu based on Healthy US Style Eating Pattern, Dietary Guidelines for Americans, 2015-2020.
** These values reflect US labeling only. Labeling varies based on global regulations.

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To learn more about Tate & Lyle ingredients and innovations as well as health benefits and relevant research, please visit www.foodnutritionknowledge.info and www.tateandlyle.com.

Tate & Lyle's Global Commercial and Food Innovation Center, Hoffman Estates, Illinois, USA

INNOVATING TO MEET NUTRITION, HEALTH, AND WELLNESS NEEDS EVERY DAY

Nutrition professionals' opportunity to educate consumers

While many people acknowledge the added health benefits of fibre, only 25% of consumers around the world report daily consumption of fibre.[55]

Consumers want to consume more products with fibre, but struggle to find them. In fact, 33% of consumers claim they are not eating more fibre, because not enough products with fibre are available on the market.[55]

As people try to reach their recommended daily intake of fibre, they look to specific food and beverage categories to fill the gap. For example, an average of 68% of global consumers say they obtain fibre through cereals, 53% through baked goods, and 45% through dairy.[55]

Adding small amounts of fibre to foods that contain some dietary fibre or to foods traditionally low in dietary fibre could help individuals meet their fibre requirements without exceeding calorie needs, which is a practical way to help address global public health concerns.[56] Nutrition professionals can help to move consumers toward the goal of increasing fibre intake with education on benefits and sources of dietary fibre as consumers desire to make dietary changes.

CONCLUSIONS

While individuals should increase their consumption of naturally-occurring dietary fibre from legumes, other vegetables, fruits, and whole grains,[1] the consumption of foods with added fibres such as STA-LITE® Polydextrose is an additional strategy towards closing the gap between recommended and actual intakes. A recent comparison has shown that polydextrose has many similar functionalities as inherent plant cell wall-associated fibres, particularly in the gastrointestinal tract.[57] The physio-chemical and functional properties of STA-LITE® Polydextrose make it a good candidate for manufacturers to use in developing new and innovative products to meet the fibre needs of the population without increasing energy intake. Further, research to date suggests physiological benefits include supporting gastrointestinal health, promoting favorable postprandial blood glucose response, and potentially aiding in weight management via its satiety effect.

A commitment to innovation

Tate & Lyle, a global leader in wellness innovation, is committed to delivering innovative ingredients that can be incorporated into great-tasting foods to help consumers meet their nutrition, health, and wellness needs every day. That is because Tate & Lyle invests heavily in innovation and research and in developing ingredients that can be incorporated into a wide-variety of food and beverage solutions. Teams of food and nutrition scientists are continuously innovating, researching, and testing ingredients that will meet current and future health and nutrition needs.

At the same time, Tate & Lyle has a robust market research program designed to provide the necessary insights on market preferences around the world. The research program allows Tate & Lyle to customize its offerings and provide tailor-made solutions in local and regional markets.

Better-for-you ingredients for health and wellness

In response to global public health efforts calling for people to reduce calories and sodium and increase fibre intakes, Tate & Lyle offers a number of innovative ingredient solutions that meet these needs.

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