43 Polydextrose: Analysis and Physiological Benefits

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43.1 Introduction

Polydextrose (PDX) was invented at Pfizer Central Research during the late 1960s, and patented in 1973 (Rennhard 1973). It was originally developed as a reduced calorie (1 kcal/g) replacement for sugar, and partial replacer for fat, flour and starch. PDX is prepared by vacuum thermal polymerisation of glucose, using sorbitol and an approved food acid as catalyst. Random polymerisation and branching yield various types of glycosidic bonds in the structure (1,6 bonds predominate) (Rennhard 1973; Allingham 1982). A representative structure is shown in Fig. 43.1. Improved versions of PDX (Litesse®) have been patented that utilise ion exchange and hydrogenation, and provide even broader utility in foods (Borden et al. 1997; Guzek et al. 1997a, b).

The structural compactness and complexity of PDX prevents mammalian enzymes from hydrolysing the molecule. This imparts reduced caloric content, as the majority of PDX passes through the stomach and enters the large intestine, whereupon it behaves as a dietary fibre (Craig et al. 1998). This chapter discusses the physiological benefits and analytical measurement of PDX.

Fig. 43.1 Representative structure for polydextrose (PDX).
Bread
- improved shelf life
- less drying out of frozen doughs
- improved slicability

Biscuits
- improved mouthfeel
- better structure
- lower fat content
- higher fibre content

Convenience food
- less frying / cooking loss
- improved bite and texture
- better yield

FIBREX® is a natural, concentrated, dietary fibre with an excellent composition of soluble and insoluble fibre with a unique thermo stable water holding capacity
- on top of this FIBREX is free from gluten and phytic acid

FIBREX® works in YOUR application!

Danisco, the world’s pre-eminent supplier of functional ingredients to the food processing industry, presents Litesse® as a versatile dietary fiber. Litesse® has become established as a preferred source of dietary fiber in many parts of the world. Litesse® offers food processors a wide range of attributes including:

- 90% dietary fiber
- Neutral tasting
- Highly soluble
- Low calorie:
  1 kcal/gram
- Replaces sugar and fat
- Prebiotic

For more detailed information regarding the possible use of Litesse® as a dietary fiber in your formulation, or to receive a sample, please call 914.674.6565.

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43.2 Structure of PDX

The representative structure of PDX (Fig. 43.1) was determined from a variety of analyses, including methylation, periodate oxidation, acetolysis, $^{13}$C-NMR, chromatography and laser light scattering (Allingham 1982; Craig et al. 1996). The average degree of polymerisation (DP) is $\sim 12$ (weight average molecular weight of $\sim 2000\cdot \text{Da}$), although the range of molecular weights is from 162 to $\sim 20\,000\cdot \text{Da}$. The International Union of Pure and Applied Chemistry (IUPAC) defines oligosaccharides as carbohydrates with a DP of between 3 and 9, and polysaccharides as DP $\geq 10$ (Cummings & Englyst 1995). Therefore, PDX is most accurately defined as a polysaccharide. However, PDX does not analyse as a polysaccharide by a widely used technique – precipitation with aqueous (80%) ethanol. This is due to its highly branched structure and high water solubility, and this is therefore a significant issue with the determination of PDX as a dietary fibre. The aqueous ethanol step is part of the current Association of Official Analytical Chemists (AOAC) assay for dietary fibre; thus, PDX is not measured as dietary fibre.

43.3 Analysis of PDX

AOAC method 985.29 for determining total dietary fibre (TDF) in food is enzyme-gravimetric, and this is accepted in most countries as an official technique. It has been found that PDX provides no statistically significant TDF value by this method (Craig et al. 2000), although it has also been determined that PDX is not hydrolysed by the enzymes used in method 985.29, by analysing the aqueous ethanol supernatant (Craig et al. 2000). We have therefore developed a method for measuring PDX in foods that can be used as an adjunct to method 985.29 (and similar methods). This method has undergone a collaborative study, and was adopted by the AOAC as Official Methods℠ number 2000.11.

The first method developed to measure PDX in a food involved aqueous extraction of PDX, followed by a colorimetric assay (Dubois et al. 1956). The method uses acid hydrolysis to break the glycosidic bonds, followed by dehydration and derivatisation of the dextrose using phenol and sulphuric acid. The derivatised dextrose is measured spectrophotometrically at 490 nm. This method is cumbersome, and has only satisfactory precision. Moreover, the accuracy of this method can also be affected by other carbohydrates that may be present in a food system.

Several liquid chromatography (LC)-based methods have been published (Kobayashi et al. 1989; Arrigoni & Amado 1990; Noffsinger et al. 1990; Stumm & Baltes 1992). An assay currently used in Japan quantifies PDX as a fibre in foods (Kobayashi et al. 1989). As with the AOAC dietary fibre method, enzymes are used to degrade starch and maltodextrins in the food. The sample is then membrane-filtered, deionised and injected into the LC system (Ultron PS-80 N column, using refractive index detection). Noffsinger and co-workers (1990) used a sulphonated, polystyrene divinylbenzene (calcium form) column (Biorad Aminex HPX-87C) and refractive index detection, but no enzyme step. Arrigoni and Amado (1990) used a sulphonated polystyrene divinylbenzene (lead form) column (Biorad Aminex HPX-87P) and refractive index detection, but with a different enzyme. These methods work well for simple food systems (e.g. clear beverages), but the sample preparation does not remove many resistant oligomers or polymers, and this may lead to potential interference. In
addition, refractive index is a universal detection system that is non-specific to carbohydrates (including PDX).

Stumm and Baltes (1992) used an enzyme step followed by an anion exchange column (Dionex PA1), mobile phase gradient, and pulsed amperometric detection. This provides more selectivity for carbohydrates, but is a more complex technique. Our method (see below) is based on that of Stumm and Baltes, but uses an improved sample preparation step. PDX is extracted from food with hot water, and the extract is centrifuged. The supernatant then passes through a centrifugal ultrafilter to remove high-molecular weight interfering components. The filtrate is treated with an enzyme mix (isoamylase, amyloglucosidase and fructanase) to remove any oligosaccharide interference (mainly malto-oligomers and fructans). PDX standards undergo the same treatment. High-pressure anion exchange chromatography with electrochemical detection (HPAEC-ED) is used to detect and quantitate a high-molecular weight fraction of PDX. Internal validation of the method on various foods and PDX levels (Craig et al. 2000) demonstrated an average recovery of 95%, and average % relative standard deviation (RSD) of 3%. Calibration curves consistently gave a R² value of ≥0.998.

43.4 Physiological benefits of PDX

Several studies on PDX (human clinical, animal clinical and in vitro) have demonstrated physiological effects associated with dietary fibre (Polydextrose FAP 1978; Hamanaka 1987; Tomlin & Read 1988; Nakagawa et al. 1990; Endo et al. 1991; Oku et al. 1991; Wang & Gibson 1993; Achour et al. 1994; Harada et al. 1995). Upon reaching the lower intestine, PDX is partially fermented by colonic bacteria to short-chain fatty acids (SCFA). A qualitative measurement of SCFA produced from PDX gut fermentation was determined in a study using radiolabelled PDX (Polydextrose FAP 1978). The profile of acetate, propionate and butyrate was typical of that generated by dietary fibre. Another study measured the in-vitro production of SCFA from fermentation of 17 carbohydrates by slurries of mixed human faecal bacteria (Wang & Gibson 1993). PDX produced a molar ratio of acetate:propionate:butyrate of 61:25:14, which was the second highest proportion of propionate and the third highest proportion of butyrate of the carbohydrates studied. Butyrate is the preferred source of energy for colonocytes (Roediger 1980, 1982), being metabolised in preference to glucose and other substrates. SCFA were found to stimulate the proliferation of normal human caecal colonoocytes (Scheppach et al. 1991), with butyrate being more effective than either propionate or acetate. Butyrate has also been shown to slow the rate of cancer cell proliferation and to promote the expression of differentiation markers in vitro (Kim et al. 1980; Whitehead et al. 1986).

PDX ingestion leads to a lower faecal pH, increased faecal bulking, reduced transit time and softer stools (Polydextrose FAP 1978; Nakagawa et al. 1990; Endo et al. 1991; Oku et al. 1991; Wang & Gibson 1993; Achour et al. 1994; Harada et al. 1995). Intestinal infusion of PDX (Polydextrose FAP 1978) in humans resulted in a pH drop from 7.24 ± 0.45 to 6.44 ± 0.35 after 150 min (P < 0.05). Endo et al. (1991) found a similar drop in pH in another human trial. Oku et al. (1991) fed PDX to rats (3% of diet), and found an increased faecal volume and weight, decreased transit time, and increased faecal moisture content. Nakagawa et al. (1990) found that PDX fed to women led to softer stools, while Harada et al. (1995) showed PDX ingestion to stimulate a more rapid maturation of the gastrointestinal tract in weanling rats. Wang and Gibson (1993) measured the growth of colonic bacteria in batch fer-
menters with various carbohydrates added, and found that over 12 h, PDX led to an increase in total bacteria that was similar to that achieved with other carbohydrates (including pectin, starch, inulin, oligofructose and fructose). This is an important finding because bacteria form the majority of the weight of faeces.

The intestinal microflora are modulated by PDX, with an increase of beneficial bacteria (e.g. Lactobacillus and Bifidobacterium) and a decrease in detrimental species (e.g. Clostridium) (Endo et al. 1991). In addition, PDX fermentation reduced the concentration of certain putrefactive/carcinogenic substances (e.g. indole and p-cresol) in the colon (Endo et al. 1991). PDX also aids in blood glucose homeostasis as a result of its low glycemic index (15% compared with glucose at 100%) (Polydextrose FAP 1978).

**43.5 Conclusions**

PDX is a polysaccharide that is not measured as dietary fibre in foods by AOAC method 985.21 (and similar methods) due to its solubility in aqueous ethanol. We have developed a rugged method for measuring PDX in foods (AOAC method 2000.11) to be used as an adjunct to 985.29 (and similar methods), in foods where PDX is thought to be present. PDX is resistant to digestion in the small intestine, but is partially fermented in the large intestine by colonic microflora. This leads to a variety of beneficial physiological effects associated with dietary fibre.

**References**


Polydextrose Food Additive Petition (1978) #9A3441, Pfizer.


