POLISH JOURNAL OF FOOD AND NUTRITION SCIENCES
http://journal.pan.olsztyn.pl
e-mail: pjfns@pan.olsztyn.pl
Pol. J. Food Nutr. Sci.
2009, Vol. 59, No. 3, pp. 205-210

POTATO DIETARY FIBRE – PRELIMINARY CHARACTERIZATION OF THE PROPERTIES AND NUTRITIONAL EFFECTS – A REVIEW

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Key words: potato fibre, composition, properties, nutrients digestibility, fermentation, metabolism

A potential source of potato dietary fibre (PDF) is potato pulp, a waste product of the starch industry. The refined potato pulp (PDF preparation) contains 50-60% of DF, 10-20% of starch and 6% of protein (on dry matter basis). PDF consists of about 55% of insoluble (mainly cellulose) and 45% of soluble (mainly pectins) fraction; has low viscosity and relatively high water-holding capacity but lower fecal bulking properties than cellulose. It is intensively fermented in the large intestine, yielding a high amount of acetate and butyrate. Feeding PDF does not affect greatly morphology and morphometry of the intestinal tract. It delays the rate of passage of digesta (as compared with cellulose), reduces fat and protein digestibility in the whole digestive tract and does not affect ileal protein digestibility (as compared with cellulose and pectin). It seems to improve mineral absorption. Few experimental results do not allow to conclude whether PDF decreases blood concentration of triglycerides, total cholesterol or LDL fraction. Data on the effects of PDF on glucose and insulin levels are also scarce and insufficient.

INTRODUCTION

The epidemiological studies of Burkitt [1971; 1973] and the hypothesis of Burkitt & Trowell [1975] on an inverse relationship between the consumption of high-fibre diets and incidence of the so-called "Western" diseases, stimulated extensive studies on the properties of different types of dietary fibre and their implications for human health. Recently, it has been well recognized that DF consumption has protective effects against cardiovascular diseases as it decreases cholesterol level, it additionally reduces the incidence of type 2 diabetes owing to the reduction of a glycemic index, and decreases the risk of colonic cancer [Champ *et al*., 2003].

Some types of DF, including resistant starch and non-digestible oligosaccharides, are extensively utilized as energy substrates by the microbiological population in the large intestine, and due to the stimulation of beneficial microflora activity are claimed to have prebiotic properties. Short chain fatty acids (SCFA) synthesized by bacteria contribute to the energy balance and gut health of the host, with a particular role of butyric acid as the major energy source for colonic epithelial cells [Roediger, 1982]. The fermentability of DF is affected mainly by the source, solubility, degree of polymerization and lignification, and processing of DF, but also by the level of its inclusion in the diet, intestinal transit time, species, age and weight of organism, and the microflora composition [Montagne *et al*., 2003]. Soluble DF is generally more easily, rapidly and completely fermented than the insoluble DF [Nyman *et al*., 1986; Bach Knudsen & Hansen, 1991]. Soluble DF may also cause viscosity of digesta in the upper part of the gut and negatively affect digestive processes as observed both at the ileal and fecal level [Antoniou *et al*., 1981; Eggum, 1995; Buraczewska, 2001].

DF *in vitro* solubility provides an indication of its fermentability *in vivo,* however the physiological functions of DF depend to a large extent on physical properties that do not relate in any simple way to crude chemical composition [Oakenfull, 2001]. This means that we cannot assume that any material that falls within the definition of DF will necessarily be of health benefits to consumers, and the biological activity of any material proposed as a DF source should be extensively evaluated.

The accumulated knowledge on the beneficial health effects of DF leads to the progressively increasing demand for its native and processed forms, and stimulates a search for new DF sources. A rich source of DF are residues of the industrial processing of fruits and vegetables, one of them being potato pulp, a waste product of potato starch manufacturing. A refined potato pulp in the form of a potato fibre preparation is commercially produced under the brand name Potex. Data presented in the paper were obtained in the studies in which either unrefined or refined form of potato fibre (pulp or potato fibre preparation, respectively) were compared most often with cellulose and sometimes with pectin.

ORIGIN, COMPOSITION AND CHARACTERISTICS OF POTATO DIETARY FIBRE (PDF) PRODUCTS

The common initial steps of processing potatoes for starch, protein and fibre, involve cleaning, washing and grat-

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ing the tubers, and are followed by the separation of starch, extraction of protein from potato juice, and drying the remnants to obtain potato pulp.

The commercial potato fibre preparation is a refined potato pulp and has the form of a light-gray, flavor-free powder of fine granulation. The gross composition of potato pulp and of commercial potato fibre preparation is similar (Table 1). On dry matter basis, both products contain about 6% of protein, 3% of ash, traces of fat and considerable but variable amount of starch. Technically it is very difficult to remove starch from the potato products completely since a portion of starch granules in potato tubers is tightly bound to the storage parenchyma [McDougall *et al*., 1996]. Protein found in potato pulp [Serena & Bach Knudsen, 2007] contains similar proportions of essential amino acids as protein in potato tubers but differs from that of potato protein concentrate [Pastuszewska *et al*., 2007].

Taking into account the same origin, similar technology and proximate composition of the potato pulp and potato fibre preparation, it may be assumed that also the DF composition of both products does not differ to a great extent. Thus, data obtained from pulp analysis (Table 2) are considered to approximate those of the potato fibre preparation.

As shown in Table 2, PDF contains a small amount of lignin (less than 5% of total DF content) and a moderate level of cellulose (over 35%). The total content of insoluble PDF fraction comprising lignin, cellulose and insoluble non-cellulosic polysaccharides, accounts for about 55% of total DF while the rest belongs to the soluble DF fraction. This proportion is in agreement with data of Jorgensen [1997] who found that in potato fibre preparation 54% of total non-starch polysaccharides (NSP) belong to the insoluble and 46% to the soluble fraction. The high level of soluble non-cellulosic polysaccharides and a relatively high concentration of galactose and uronic acids in this fraction indicates that PDF is rich in pectic substances.

Viscosity of PDF is low and close to that of cellulose while its swelling and water binding capacity are quite high (Table 3). Due to these qualities, PDF was studied as a partial substitute of fat in low-fat processed meat products but was found to depress their texture and sensory parameters [Szczepaniak *et al*., 2007].

EFFECTS OF PDF IN THE DIGESTIVE TRACT

The mode of action of potato fibre in the gastrointestinal tract was studied mainly in rats and pigs as animal models and involved different aspects of gut physiology as transit time of digesta, function of pancreas, morphology and morphometry of intestines.

In pigs, potato fibre was found to reduce excretion of fecal fresh and dry matter and to delay passage of digesta, as compared with cellulose [Święch & Tuśnio, 2007], probably due to a greater content of the soluble fraction in PDF.

The effects of different sources of dietary fibre on exocrine pancreatic secretion are equivocal and indicate a greater stim-

TABLE 1. Chemical composition of a potato fibre preparation and potato pulp (% of DM).

Product	Protein (N x 6.25)	Ether extract	Ash	Crude fibre	ADF[6)]	NDF[7)]	Starch
Potato fibre[1)]	6.4	0.6	3.7	23.3	30.3	47.3	nd
Potato fibre[2)]	7.0	0.3	nd	24.0[4)]	nd	45.6[5)]	10.0
Potato pulp[3)]	6.5	0.4	3.3	nd	nd	nd	24.9
Potato pulp[1)]	5.1	0.7	2.7	20.5	26.2	46.2	nd

[1)] according to Antuszewicz [2006], [2)] according to Jakob *et al*. [1999], [3)] according to Serena & Bach Knudsen [2007], [4)] mainly cellulose + lignin, [5)] mainly pectin + hemicellulose, [6)] acid detergent fibre, [7)] neutral detergent fibre, nd – not determined.

TABLE 2. Potato pulp dietary fibre (DF) composition [according to Bach Knudsen, 2003, unpublished].

	Non-cellulosic polysaccharides (NCP)							Cellulose	Total NSP	Klason lignin	DF
	S-NCP[1)]	I-NCP[2)]	sugars				Uronic acids				
			ara	xyl	gal	glu					
as% DM	28.6	9.2	3.6	1.4	17.2	1.1	12.6	22.3	60.1	3.1	63.2
as% DF	45.2	14.5						35.3	95.1	4.9	100

[1)] soluble NCP, [2)] insoluble NCP.

TABLE 3. Physicochemical properties of potato dietary fibre.

Item	Viscosity[1)] (mPAS/sec)	Swelling[2)] (mL/g)	Water binding[2)] capacity (g/g)
Potato fibre	0.89	16.5	4.9
Cellulose	0.75	-	-
Apple pectin	43.2	-	-

[1)] according to Antuszewicz [2006], [2)] according to Bach Knudsen [2003, unpublished].

ulation of the secretion by native DF than by different added preparations. However, supplementation of a pig diet with 2% of PDF increased the volume of pancreatic juice, protein secretion and the total and specific trypsin, lipase and alfa-amylase activities as compared with the unsupplemented pre-fed diet [Jakob *et al*., 1999]. The stimulating effect of PDF on the pancreatic secretion was apparently confirmed by the increase in the relative mass of this organ found by Tuśnio [unpublished] in piglets but not in growing rats [Antuszewicz, 2006], (Table 4).

Dietary fibre affects gut structure, particularly morphology of intestinal mucosa, which is an important element of gut health [Bach Knudsen *et al*., 2008]. The effects of PDF on the relative mass and morphology of the digestive tract are of small magnitude (Table 4) and differ between the animal species. In growing rats, feeding PDF instead of cellulose increased the relative mass of the stomach, tended to increase the mass of the small intestine but did not affect morphology of duodenum [Antuszewicz, 2006]. In growing pigs, substitution of PDF for cellulose tended to decrease the relative mass of duodenum and slightly modified morphology of this part of the small intestine [Tuśnio *et al*., 2007]

Potato fibre is intensively fermented in the large intestine as indicated by a more than twofold increase of caecal concentration of the short chain fatty acids (SCFA) over that on low-fibre diet and on cellulose (Table 5) [Antuszewicz *et al*., 2005b]. As compared with cellulose, PDF stimulates the production of acetate and butyrate (6.72 *versus* 3.43 and 1.64 *versus* 1.01 mmol/100 g of digesta, respectively) but not of propionate. A high concentration of butyrate should be considered as particularly beneficial for the structure of intestine. Conformable to the stimulation of the production of SCFA, potato fibre lowers pH of digesta but, contrary to the effects of other intensively fermented DF [Berggren *et al*., 1993, Pastuszewska *et al*., 2000], it does not induce any increase in the mass of caecal tissue nor caecal digesta.

EFFECTS OF PDF ON NUTRIENT DIGESTIBILITY AND METABOLISM

The complex effects of dietary fibre on digestive processes depend greatly on its physicochemical properties. On general, viscous polysaccharides such as gums and pectins reduce the rate of nutrient absorption, whereas insoluble DF sources (*e.g.* wheat bran) have a smaller effect. Consequently, DF may modify and usually decreases digestibility of proteins, as well as lipids and certain minerals [Eggum, 1995].

In rats, the supplementation of a fibre-free casein-gluten diet or a low-fibre casein diet with PDF depressed digestibility of protein in the whole digestive tract [Gralak *et al*., 1996; Antuszewicz, 2006], the effect being similar to that of pectin and cellulose (Table 6). Also in pigs no significant differences were found in ileal digestibility of protein of casein-wheat diets supplemented either with PDF, cellulose or pectin at a 5% level [Antuszewicz & Święch, 2006]. This indicates that potato fibre impairs protein digestibility in the whole digestive tract to a similar extent as cellulose and pectin (rat experiment), and that its effects on protein digestion in the small intestine are also similar to those of pectin and cellulose (pig experiment).

Also digestibility of fat in the whole digestive tract of rats was considerably reduced by supplementation of a low fibre diet with PDF and pectin but not with cellulose (Table 6) [Antuszewicz, 2006].

It is generally assumed that dietary fibre negatively affects the absorption and bioavailability of minerals but mineral interactions with DF depend on many factors including the type of fibre [Harland & Narula, 2001]. Recent studies on

TABLE 4. Effects of feeding different dietary fibre (DF) sources on the mass of intestinal organs in growing rats (g/100 g body weight).

Source of DF	Stomach	Small intestine	Caecum	Pancreas	Liver
Potato fibre preparation	0.65[a]	2.52[b]	0.26[a]	0.37[b]	4.20[a]
Potato pulp	0.59[ba]	2.40[b]	0.25[a]	0.36[b]	4.37[a]
Cellulose	0.53[b]	2.29[b]	0.25[a]	0.39[ab]	4.52[a]
Pectin	0.55[b]	2.85[a]	0.48[b]	0.41[a]	4.81[b]

[1)] according to Antuszewicz [2006]

TABLE 5. Effects of different fibre sources fed at a 10% dietary level on the concentration of main short chain fatty acids (mmol/100 g) and pH of caecal digesta in rats.

Fibre source	Acetate	Propionate	Butyrate	Total SCFA	pH
Low-fibre diet[1)]	2.58	0.83	0.56	3.97	7.59
Potato fibre[1)]	6.72	1.01	1.64	9.37	6.81
Potato pulp[1)]	7.00	0.99	1.62	9.61	6.91
Cellulose[1)]	3.43	0.83	1.01	5.27	7.25
Cellulose[2)]	3.03	0.84	0.63	4.88	7.33
Potato starch[3)]	8.00	1.61	0.69	10.30	6.62

[1)] according to Antuszewicz [2006], [2)] according to Jurgoński *et al*. [2008], [3)] according to Pastuszewska *et al*. [2000].

TABLE 6. Effects of different DF sources on nutrients digestibility in rats (%) [according to Antuszewicz, 2006].

DF source	Coefficient of apparent digestibility (%)			
	Crude protein	Fat	Ash	Energy
Low-fibre control diet[1)]	93.7	96.3	53.7	94.1
Potato fibre[2)]	82.1	88.3	55.5	92.5
Cellulose[2)]	83.1	95.4	54.3	88.8
Pectin[2)]	82.5	85.0	50.5	93.8

[1)] supplemented with 4% cellulose, [2)] supplemented with 10% of DF under study.

the effects of inulin and oligofructose on mineral absorption and bone health reviewed by Caers [2007], have revealed that prebiotic fermentation of DF and acidification of the lumen of the colon results in an increased solubilisation and absorption of Ca and Mg. One can therefore expect that the intensive fermentation of potato fibre to SCFA and lowering effect on pH may induce similar positive effects.

This assumption was not confirmed by the results of rat experiment of Gralak *et al*. [1996] who found that the addition of a potato fibre preparation to a control unsupplemented diet tended to decrease apparent absorption of Ca, Mg, Fe and Mn while it significantly depressed that of Zn and Cu. The authors found that the apparent digestibility of minerals under study was more closely inversely correlated with insoluble than soluble fibre intake. In contrast to the results of Gralak *et al*. [1996], Antuszewicz [2006] did not show any negative slight effect of potato fibre on the apparent digestibility of mineral matter as compared with the low-fibre diet and cellulose, while a slightly positive effect was observed as compared with pectin (Table 6). A long-term study on male rats fed on diets containing potato fibre or cellulose showed that the concentration of ash in rat body tended to be higher in animals fed on the diet supplemented with potato fibre [Pastuszewska *et al*., 2009 in press].

In view of the scarcity and divergence of data, it is difficult to conclude on the effects of potato fibre on metabolism of particular minerals but it seems that feeding this source of fibre does not impair mineral status of the organism.

The effects of PDF on energy utilization were studied by Jorgensen [1997] in cannulated pigs. Increasing dietary levels of potato and soya fibre decreased ileal digestibility of energy in linear way while they had no effect on energy digestibility in the whole digestive tract. This indicates that both potato and soya fibre are not digested in the small intestine but are intensively fermented in the hind-gut. The calculated fermentability of potato fibre was greater than that of soya fibre (86 *versus* 71%). Only 15 and 6% of metabolizable energy contributed to energy retention from potato and soya fibre, respectively, whereas the remainder was metabolized and lost as heat.

In rats, the supplementation of a low-fibre diet with potato fibre and pectin decreased energy digestibility in the whole digestive tract to a small extent, while the supplementation with cellulose had a greater depressive effect (Table 6) [Antuszewicz, 2006]. These differences indicate a more intensive bacterial degradation of potato fibre than cellulose in the large intestine and comply with differences in their rate of fermentation.

The most important metabolic effects of some types of DF is the minimization of hyperglycemia and hyperinsulinemia due to slowed carbohydrate digestion, and their cholesterol-lowering effect attributed mainly to the inhibition of endogenous cholesterol synthesis. Two mechanisms have been proposed to explain the hypocholesterolemic properties of some DF: one is the inhibition of cholesterol synthesis by propionate, which is an important product of bacterial DF fermentation in the large intestine, and the second is restrained bile acid absorption due to the increased viscosity of digesta [Marlett, 2001].

Very limited data are available on the effects of PDF on lipid and glucose metabolism. In the study on adult rats fed for 12 or 24 weeks on diets containing 10% of either potato fibre or cellulose, the total cholesterol level was not affected by type of fibre in either of age groups [Pastuszewska *et al*., 2009 in press]. This can be explained by similar low viscosity of both DF sources and alike concentration of propionate in digesta. However, in younger, but not in older rats, the total lipids and VLDL fraction were significantly lower on PDF than on cellulose diet. Also in the experiment of Antuszewicz *et al*. [2005a] with growing pigs fed on casein-wheat diets supplemented with different sources of DF including cellulose and pectin, cholesterol level was not affected by PDF. In the same experiment, pigs fed on a diet with potato pulp had a higher postprandial peak of insulin (Figure 1), and also of glucose, than these on a diet with cellulose or pectin (Figure 1), but only immediately after the meal. Contrary to growing pigs, adult rats sacrificed after feeding a potato fibre diet for 24 weeks had a significantly lower glucose concentration than those fed on a cellulose diet (8.44 *versus* 11.46 mmol/L, respectively), [Pastuszewska *et al*., 2009 in press]. Such a difference was not, however, observed in younger rats fed on

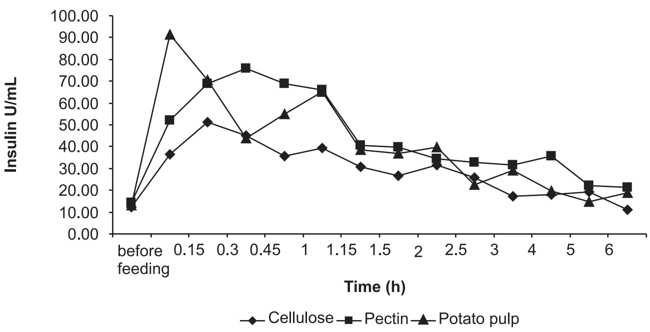

FIGURE 1. Profile of plasma insulin concentration in pigs fed on diets supplemented with cellulose, pectin or potato fibre.

the same diets for a shorter period (12 weeks).

These few and inconsistent results do not allow for drawing definite conclusions about health benefits of potato fibre but they indicate its biological activity which may have positive effects. They point also to a role of species and age as factors modifying animal response to DF.

CONCLUSIONS

Preliminary findings show that potato dietary fibre stimulates the microbial production of short chain fatty acids, mainly acetate and butyrate, in the large intestine, and positively affects mineral absorption. Results of investigations on the effects of PDF on lipid and glucose metabolism are inconclusive, they point, however, to a certain biological activity.

ACKNOWLEDGEMENTS

This work was supported by the State Committee for Scientific Research (KBN) project No. 2P06 Z 01830.

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Received May 2008. Revision received December 2008 and accepted February 2009.