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Digestible and Undigestible Carbohydrates in Autoclaved Legumes, Potatoes and Corn

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ABSTRACT

The formation of a type of undigestible starch (so-called resistant starch, RS) in autoclaved infant purées and canned foods was studied. The products studied were peas, beans, potatoes and corn.

The formation of RS in autoclaved infant purées ranged from 2 to 8% of the total starch content. The formation of RS was more prominent in the product which included peas. Autoclaved infant purées may thus be a significant source of undigestible carbohydrates for infants.

In canned legume seeds, the RS content ranged from 1·5 to 3·2% (dwb), thus amounting to approximately 6% of the total starch. The amount of RS was also higher in canned potatoes than in reconstituted mashed potato products. For corn, however, autoclaving resulted in only minor amounts of RS, while the RS content in cornflakes was 1·1% (dwb).

INTRODUCTION

Interest in the digestion and absorption of starch has increased dramatically during the last decade. Earlier, starch was regarded as a completely digestible carbohydrate. This assumption was based on the observation that no starch remnants could be detected in faeces after a meal. Evidence of starch malabsorption from common food items, such as bread, potatoes and legumes, is now available (Anderson *et al.*, 1981; Levitt, 1983; Stephen *et al.*, 1983; Englyst & Cummings, 1985, 1987). The mechanisms to an incomplete digestion of starch may be several. However, malabsorbed starch reaching the colon will constitute an easily available substrate for fermentation by the colonic microflora. The significance *in vivo* of malabsorbed starch is not yet clear. The Volatile Fatty Acids that are produced when carbohydrates are fermented in the colon have, however, been suggested to have positive effects on cholesterol and carbohydrate metabolism (Jenkins *et al.*, 1987). The decrease in faecal pH, due to production of acids, has also been suggested to be a preventive factor against cancer in the large bowel (Thornton *et al.*, 1985). However, for infants, who do not have a fully developed faecal microflora, an excessive intake of undigestible carbohydrates may cause diarrhea.

The discovery of starch being malabsorbed introduced a new dimension in the division of carbohydrates into digestible (starch) and non-digestible (dietary fibre). Englyst and Cummings (1987) have suggested that starch should be classified as 'readily digestible, partially resistant, or resistant starch'. Partially resistant includes physically inaccessible starch as well as naturally crystalline and recrystallized (i.e. retrograded) amylopectin, while resistant starch is mainly retrograded amylose. However, the value of this classification is limited as long as no techniques to differentiate all these starch fractions in food products are available.

Resistant starch (RS), however, represents one starch fraction that can be determined separately from the others. RS is, in this study, defined analytically as 'starch resistant to amylases unless solubilized 2M KOH or DMSO'. RS will appear analytically as dietary fibre, unless solubilized by chemical means. This starch fraction was first observed in bread as an increase in dietary fibre content after baking (1–2% dwb) (Englyst *et al.*, 1983; Johansson *et al.*, 1984). All available data today show that RS consists of relatively short recrystallized amylose fragments (Berry *et al.*, 1988; Sievert & Pomeranz, 1989; Siljeström *et al.*, 1989). Also, RS was shown to be resistant to enzymic degradation in the small intestine of rats, but easily fermented by colonic bacteria (Björck *et al.*, 1987). Today, there is considerable debate whether RS should be classified as starch or as dietary fibre. When a nutritional definition of dietary fibre is advocated it is more natural to also include RS than when a chemical approach is preferred.

RS has been reported to be formed after heat treatment of starch and starchy products at high moisture contents (Englyst *et al.*, 1983; Siljeström & Asp, 1985; Berry, 1986; Björck *et al.*, 1987). Thus, wet autoclaving of wheat starch resulted in considerable formation of RS, especially when the heating was repeated in cycles with intermittent cooling (Berry, 1986; Björck *et al.*, 1987; Sievert & Pomeranz, 1989). Also, in autoclaved barley flour suspensions, RS was formed, particularly in genotypes with higher amylose content (Björck *et al.*, 1989). Hence, the possibility of formation of RS in canned starchy products must be considered. Legumes are particularly interesting in this respect, since they generally have a higher amylose/amylopectin ratio than cereals.

The purpose of this investigation was to study the extent of RS formation in commercially available autoclaved corn, potato and leguminous products. A special interest has been focused on potato and vegetable purées intended for infants from 3–8 months of age.

The following definitions are used in the text:

> *Digestible starch:* starch content according to the enzymic method of Holm *et al.* (1986), i.e. total in-vitro digestible starch.
> *Resistant starch (RS):* starch that is totally resistant to digestion by amylases unless prior solubilized in alkali or DMSO.
> *Total starch:* in-vitro digestible starch + RS.

MATERIALS AND METHODS

The materials were commercially available canned corn, potato and leguminous products and autoclaved purées intended for infants. For comparison, two dried mashed potato products and cornflakes were also analyzed. The dried potato products were a granulate powder and a drum-dried flaked sample. The materials, except for cornflakes, were all purchased in a local Swedish supermarket. The samples of cornflakes and corn grits were supplied by Finax AB, Helsingborg, Sweden.

The whole canned samples were thoroughly homogenized before analysis. The dry matter content was determined after drying the samples at 105°C overnight. Dietary fibre was analyzed with an enzymic-gravimetric method according to Asp *et al.* (1983). Digestible starch was analyzed with the method of Holm *et al.* (1986).

Residual starch and RS contents were analyzed essentially as described by Siljeström *et al.* (1989). The dietary fibre residue was divided into quarters, and suspended in water. For residual starch analysis, Termamyl (5 μl) was added before heating in a boiling water bath. Glucose was determined with a glucose oxidase peroxidase reagent after digestion with amyloglucosidase, and starch content was calculated as glucose $\times 0{\cdot}9$. The amount of RS was determined by digestion with amyloglucosidase after solubilization in 2M KOH. Released glucose was determined as for residual starch and RS is calculated as the difference between starch values with KOH-solubilization and residual starch. The precisions of the residual and resistant starch analyses were calculated according to the following equation:

$$s = \sqrt{\frac{1}{2k}\sum_{i=1}^{k}(x_{i1} - x_{i2})^2}$$

where s = standard deviation, k = number of samples and x_{i1} and x_{i2} = duplicate values for sample No. i. The standard deviations were found to be 0·03 for the residual and 0·07 for the resistant starch analysis.

RESULTS AND DISCUSSION

Autoclaved infant products

In Table 1, the contents of dietary fibre, digestible starch and RS in some autoclaved infant purées are shown. The total carbohydrate content (= dietary fibre + digestible starch + RS) in the purées was approximately 50% of the dry matter, which was consistent with the declared amount. The content of dietary fibre was 6–8% (dwb) in the full-meal purées (containing meat or fish and potato), and almost three times higher in the pea/potato product (ratio peas/potatoes: 60/18). When expressed in percentage of total starch content, RS content ranged from approximately 2 to 8% (Table 1). Hence, a considerable fraction of the starch was not available to enzymic digestion unless solubilized in alkali. The RS contributed to approximately 10% of the dietary fibre in these purées (Table 1).

The product with the lowest amount of digestible starch—pea/potato purée—also had the highest content of RS (Table 1). The full-meal products are based on potatoes and contain from 40 to 55% potatoes (w/w). Thus, it seems that the starch in peas has a structure, which is more favourable to the formation of RS than that in potatoes.

Successive heating/cooling cycles have been shown to increase the formation of RS (Berry, 1986; Björck *et al.*, 1987; Sievert & Pomeranz, 1989).

TABLE 1
Dietary Fibre, Digestible Starch and RS in Various Autoclaved Infant Purées

Puréed product	*Dietary fibre*[a] *(g/100 g dry matter)*	*Digestible starch (g/100 g dry matter)*	*RS (g/100 g dry matter)*	*RS as % of total starch*[b]	*Intake of RS/can (g)*[c]
Green peas/potatoes	21·6	29·1	2·4	7·6	0·58
Calf with potatoes	7·3	47·9	1·3	2·6	0·28
Chicken with potatoes and vegetables	8·5	43·2	0·8	1·8	0·19
Salmon with potatoes	8·5	45·3	0·8	1·7	0·19

[a] Dietary fibre including RS.
[b] Total starch = digestible starch + RS.
[c] Total amount of one can is 135 g.

However, reheating and cooling of the infant purées in this study in a 'household manner' (heating to 50°C and cooling to 'eating temperature') had no effect on the RS content.

At present, there is a debate concerning the optimal intake of undigestible carbohydrates during infancy (Asp, 1988). It is known that a high intake of dietary fibre may produce diarrhea. In this connection it is also important to consider possible effects of RS. The potato-based purées studied are intended as complete meals for infants from 5 to 8 months of age and are supplied in cans containing 135 g. Thus, supposing that a meal consists of one can of potato-based purée and 1/3 can of the pea purée, the total intake of RS would be about 0·4 g. This is a considerable amount, especially in relation to the daily intake of RS for adults, recently reported to range from 1·5 to 5 g (Karlström *et al.*, 1989). However, in the present investigation only a few infant purées have been analyzed and more extensive studies need to be performed before the results can be generalized.

Whole canned products

The RS content in canned legumes (peas and beans) was found to be, on average, 2·4% ± 0·6 (dwb) (Table 2). The influence of the botanical origin of starches on the formation of RS was also noted in the canned whole products. The content of RS was higher in leguminous products than in potatoes, 1·9% (dwb) (Table 3). However, a considerable difference in RS content was also observed between two brands of canned peas (Table 2). RS amounted to, on average, 6% of the total starch for the legumes and 2·6% for the potato product.

TABLE 2
Dietary Fibre, Digestible Starch and RS in Various Canned Leguminous Products

Product	*Dietary fibre*[a] *(g/100 g dry matter)*	*Digestible starch (g/100 g dry matter)*	*RS (g/100 g dry matter)*	*RS in % of total starch*[b]
Green peas				
brand No. 1	27·4	20·7	1·5	6·8
brand No. 2	26·5	ND	3·2	
Red kidney beans	19·8	35·8	2·5	6·5
White beans	22·0	ND	2·5	
Chickpeas	19·2	43·8	2·2	4·8
Haricot beans	30·1	ND	0·2	

ND, not determined
[a] Dietary fibre including RS.
[b] Total starch = digestible starch + RS.

TABLE 3
Dietary Fibre, Digestible Starch and RS Contents. Comparison between Canned and Dried Mashed Potatoes

Product	*Dietary fibre*[a] *(g/100 g dry matter)*	*Digestible starch (g100 g dry matter)*	*RS (g/100 g dry matter)*	*RS in % of total starch*[b]
Potatoes				
canned	10·1	70·0	1·9	2·6
mashed—brand No. 1[c]	6·3	62·2	0·5	0·8
mashed—brand No. 2[c]	7·4	70·1	0·9	1·3

[a] Dietary fibre including RS.
[b] Total starch = digestible starch + RS.
[c] Brand No. 1 was a granular powdered product and brand No. 2 consisted of drum-dried flakes.

The content of dietary fibre varied among the autoclaved products, from 10% (dwb) for potatoes to 30% (dwb) for haricot beans (Tables 2 and 3). RS constituted between 5 and 12% of the undigestible carbohydrates in the leguminous products, versus almost 19% in canned potatoes.

The intake per portion of RS from canned legumes or potatoes was estimated to range from 0·2 to 0·6 g.

Comparison between canning and other treatments for potatoes and corn

The amount of RS was considerably higher in the canned potatoes than in the reconstituted mashed potato products (Table 3). A small difference in the contents of digestible starch and RS was also noted between the two reconstituted mashed products. Product No. 1 was a granular powder, manufactured in an 'add-back' process, where part of the material is rehydrated and dried. The other (No. 2) was a flaked, drum-dried product. It has been suggested that starch in reconstituted mashed potato made from flakes would be more easily digested *in vivo* than that made from granules (Hellendoorn *et al.*, 1970). However, in our study, the in-vitro digestibility was somewhat lower in the flaked product, as judged from RS contents.

In canned corn, the formation of RS was negligible (<0·1% dwb). However, a high content of RS (about 3% dwb) has been observed earlier in cornflakes (Englyst *et al.*, 1983). The RS content in cornflakes, in this study, was found to be, on average, 1·1% (dwb). The corresponding raw material (corn grits) had a very low RS content (<0·2% dwb). The increase in RS in cornflakes was accompanied by a 5% decrease in the content of digestible starch. Also, the amount of digestible starch in canned corn was lower than in cornflakes, 53% and 76% (dwb), respectively, suggesting differences in corn varieties. These results further emphasize the importance of the processing conditions and/or the botanical origin of the starch for the RS formation.

Although RS is analyzed as the starch residue digestible only after solubilization in 2M KOH, further studies are needed to establish the true nature of RS from cornflakes and legumes. RS from wheat has been shown to consist of short recrystallized amylose fragments, and there is reason to believe that RS from other sources also have a similar structure. Although the analyses were performed on homogenized samples, the possibility of, for instance, physically entrapped starch interfering with the determination of RS cannot be ignored.

In conclusion, the formation of RS in wet autoclaved products is quite considerable, especially when these products contain appreciable amounts of legumes. The nutritional impact of RS in autoclaved infant products needs to be evaluated.

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