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ORIGINAL COMMUNICATION

Resistant starch content in a selection of starchy foods on the Swedish market

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Objective: The objective was to determine the resistant starch (RS) content in a selection of typical starchy foods on the Swedish market. In addition, the daily RS intake was estimated from Swedish food consumption data.
Design: The major forms of RS, including physically encapsulated starch, were determined with an *in vitro* method using chewing as a pre-step before enzymatic incubation.
Setting: The study was performed at the Department of Applied Nutrition and Food Chemistry, Lund University, Sweden.
Subjects: Six healthy subjects were used to chew the food products before enzymatic incubation of the samples.
Results: Twenty-five cereal, potato and legume products were included in the study. The highest RS concentration was noted in the legume group (9.5 – 11.1% total starch basis). Commercially processed potato products were found to have a higher RS content (4.8 – 5.9%), compared with boiled potatoes (2.0%). Among the cereal products, bread with enclosure of intact rye grains, barley flakes and semolina porridge, respectively, were identified to have a RS level in the higher range (4.5 – 6.0%). The daily RS intake was estimated to be 3.2 g.
Conclusions: The main RS sources in the Swedish diet are bread and potato products, which contribute approximately 1.3 and 1.2 g RS per day, respectively. Based on food habits the RS intake may vary considerably, thus when added to dietary fibre intake, the contribution of RS may be of nutritional importance for certain individuals.
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Introduction

In publications by Anderson *et al* (1981), Van der Westhuizen *et al* (1972) and Wolf *et al* (1977), it was questioned for the first time whether starch was completely digested and absorbed in the human small intestine. In further studies by Englyst & Cummings (1985, 1986, 1987), it was demonstrated that a part of the ingested starch in, for example, cereals, bananas and potatoes, could be recovered in ileostomy effluents. Such starch, ie the sum of starch and starch degradation products not absorbed in the small intestine of healthy individuals, is commonly referred to as resistant starch (RS) (Asp, 1992). Three main forms of RS have been differentiated: (1) starch that is physically inaccessible to digestive enzymes owing to enclosure in food structures such as intact cells or partly milled or whole grains or seeds; (2) resistant B-type starch granules occurring in, for example, raw potatoes and green bananas; and (3) retrograded starch formed during processing of foods (Englyst & Cummings, 1990; Englyst & Kingman, 1990).

The recent increased interest in RS is related to its effects in the gastrointestinal tract, which in many ways are similar to these of dietary fibre. Like soluble fibre, RS is a substrate for the colonic microflora, forming metabolites including the short-chain fatty acids (SCFA), ie mainly acetic, propionic and butyric acid. According to Scheppach *et al* (1988), starch that escapes digestion in the small intestine increases the production of, in particular, butyric acid in man. However, the type of SCFA generated during fermentation of starch may vary depending on the amylose – amylopectin ratio (Andrieux *et al*, 1992). Butyric acid is largely metabo-

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lised by the colonocyte, and is the most import energy source for the cell (Roedinger, 1990). Thus, this SCFA appears to be of special relevance in relation to the welfare of the colonic epithelium. It is possible that butyric acid has a role in the pathophysiology of colonic disturbances such as ulcerative colitis (Scheppach *et al*, 1992), the key feature of this disease being a diminished capacity of the colonocytes to utilise butyric acid (Roedinger, 1990).

Acetic acid and propionic acid have been discussed in relation to glucose and lipid metabolism. In a study by Thorburn *et al* (1993), it was reported that an evening meal high in fermentable carbohydrates lowered hepatic glucose output the following morning in healthy subjects, hence emphasising a potential influence of SCFA on glucose metabolism.

Until recently, no *in vitro* method has been capable of quantifying all RS fractions likely to be present in food. Thus, RS has been estimated from analysis of starch output in ileostomy effluents (Englyst & Cummings, 1985, 1987; Muir *et al*, 1995a; Silvester *et al*, 1995), and by ileal intubation of healthy subjects (Stephen *et al*, 1983; Faisant *et al*, 1995), or indirectly by measurement of breath H_2 (Wolever *et al*, 1986; Levitt *et al*, 1987) or blood acetate (Cummings & Englyst, 1989; Muir *et al*, 1995b). Newly developed *in vitro* methods which mimic the physiologic conditions in human have simplified the determination of RS in food (Englyst *et al*, 1992; Muir & O'Dea 1992; Åkerberg *et al*, 1998). However, data concerning RS content in common food products are still scarce, which limits reliable estimations of daily RS intake. The RS intake in 10 different European countries have been evaluated from national consumption statistics (Dysseler & Hoffem, 1994a). According to these calculations the RS intake varied from 3.2 to 5.7 g/day between different countries. However, this survey did not allow any detailed comparison between countries due to the shortage of characterised domestic food products. In a recently published study by Brighenti *et al* (1998); the estimated intake of RS in a range of foods representing the main sources of starch intake in the Italian diet was found to be 8.5 g/day.

The aim of the present study was to determine the RS content in a selection of typical starchy foods available on the Swedish market. The major forms of RS, including physically encapsulated starch, were determined with an *in vitro* method using chewing as a pre-step before enzymatic incubation (Åkerberg *et al*, 1998). The daily RS intake was estimated from Swedish food consumption data from 1997 to 1998 (Becker, 1999).

Materials and methods

Test products

Twenty-five cereal, potato and legume products were included in the study (Table 1). Test products were analysed 'as eaten'. Thus, cooked foods were prepared according to the instruction on the packages, and analysed immediately after cooling to room temperature.

Chemical analysis

Total starch was analysed in milled test products by using sequential incubations with termamyl and amyloglucosidase after solubilisation in KOH (Siljeström *et al*, 1988). Separation of total starch into available starch and RS was performed according to Åkerberg *et al* (1998), and is described as follows. An amount of product, corresponding to 1 g total starch, was chewed 15 times for $\sim$15 s (six subjects participated in the study). Products that had been cooked were allowed to reach room temperature before chewing to obtain stable weight. After chewing, the product was expectorated into a beaker containing 5 ml of distilled water and 1 ml pepsin solution (pepsin = 50 g/l, 2000 FIB-U/g, Merck, Darmstadt, Germany). The subjects rinsed their mouths with another 5 ml of distilled water for 60 s, and expectorated the rinsing solution into the beaker. The pH was adjusted to 1.5 with 2 mol/l HCl and the samples were incubated at 37°C for 30 min. During the incubation, the samples were stirred every 10 min. Ten millilitres of a sodium acetate buffer (pH 5.0, 0.5 mol/l) were added and pH adjusted to 5.0 with 1 mol/l NaOH. The following were added to the beakers: 125 μl of a $MgCl_2$–$CaCl_2$ solution ($MgCl_2$, 0.06 mol/l; $CaCl_2$, 0.3 mol/l), 125 μl pancreatin (pancreatin, 40 g/l, 8*x* USP, Sigma, St Louis, USA), 400 μl amyloglucosidase (amyloglucosidase, 1.4×10^5 U/l special quality for starch analysis, 3500 U Boehringer, Mannheim, Germany) and 100 μl isopropanol. Each beaker was equipped with a magnet (floating stir bar). Distilled water was then added to a final volume of 0.05 l. The beakers were covered with para-film, held into place with a rubber band, and incubated for 16 h at 40°C with constant stirring.

Further, the samples were precipitated with ethanol and filtrated. The filtrates were collected for analysis of the potentially available starch fraction. The RS fraction in the crucibles were washed with ethanol and dried overnight. Finally, the filter residue was ground and used for determination of total starch after solubilisation in KOH.

Results and discussion

In Table 1, the RS and potentially available starch contents are listed for the different food products.

Cereal products

Bread products. Among cereal products, bread is the most important source of starch in the Swedish diet, and the daily intake was recently estimated at 100 g/day (Becker, 1999). The RS content in the six bread products (one crisp bread, one flat bread and four loaves) included in the present study varied from 0.6% RS (total starch basis) in the flat bread based on white wheat flour (*Hällakaka*), to 6.0% RS in the rye bread made with inclusion of intact or partly cracked rye grains (*Fullkorns rågbröd*). The high RS level in the rye bread was probably due to the fact that a part of the starch remained encapsulated in the grain structure. The

Table 1 RS and potentially available starch contents in a selection of starchy food products on the Swedish market

	Product description	*RS*[a] *(%)*	*Potentially available starch*[a] *(%)*
Cereal products			
Bread products			
Crisp bread	*Husman* (whole-meal rye flour). Wasabröd AB, Sweden	1.4±0.1	91.8±2.1
Flat bread	*Hällakaka* (white wheat flour). Polarbröd, Sweden	0.6±0.1	99.0±6.3
Loaf	*Lockarps fullkorn* (wholemeal rye flour, cut rye kernels, white wheat flour, sourdough). Lockarps Bageri AB, Sweden	1.0±0.4	88.0±2.3
Loaf	*Delikatesslimpa* (rye flour/white wheat flour). Skogaholms Bröd AB, Sweden	1.9±0.1	96.0±3.7
Loaf	*Södervidinge hård kavring* (scalded whole-meal rye flour, white wheat flour, sourdough). Södervidinge Bröd AB, Sweden	2.5±0.3	87.2±1.3
Loaf	*Fullkorns rågbröd* (wholemeal rye flour, intact/cracked rye kernels, white wheat flour, sourdough). F-gruppen, Albertslund, Denmark	6.0±1.2	89.5±3.0
Breakfast cereals			
Extruded cereals	*Havrefras* (oats, maize). Nakskov Mill Foods A/S, Denmark	0.2±0.0	101.4±1.3
Puffed wheat	*Kalaspuffar* (roasted puffed wheat grains). Quaker Oats Ltd, UK	1.2±0.2	99.9±1.7
Oat flakes	*Havregryn*. Kungsörnen AB, Sweden	0.3±0.1	95.1±7.7
Barley flakes	*Kornflingor*. Saltå Kvarn, Sweden	4.5±0.8	94.3±0.2
Porridges			
Oat porridge	*Havregrynsgröt*. Oat flakes boiled with water for 2 min. Kungsörnen AB, Sweden	0.3±0.0	96.8±6.5
Rice porridge	*Risgrynsgröt*. Round-grain rice boiled with milk for 40 min. ICA Handlarnas AB, Sweden	1.2±0.1	102.0±1.8
Semolina porridge	*Mannagrynsgröt*. Semolina boiled with milk for 4 min. Kungsörnen AB, Sweden	4.8±0.5	90.5±5.2
Rice and pasta products			
Rice	Long-grain parboiled rice boiled for 20 min. Uncle Ben's Inc, USA	3.7±0.4	96.9±1.6
Spaghetti	Dried spaghetti with added monoglycerides boiled for 12 min. Kungsörnen AB, Sweden	0.9±0.4	93.2±2.4
Spaghetti	Dried spaghetti boiled for 9 min. Kungsörnen AB, Sweden	2.9±0.4	101.0±3.4
Macaroni	Dried macaroni boiled for 3 min. Kungsörnen AB, Sweden	1.2±0.2	97.2±0.8
Potato products			
Potatoes	Boiled potatoes (*Bintje*)	2.0±0.4	98.2±3.5
Mashed potatoes	Instant potato powder reconstituted with water. Procordia Food AB, Sweden	2.4±0.2	101.3±1.0
Deep fried potatoes	Pommes Frites. Procordia Food AB, Sweden	4.8±0.4	93.8±4.8
Deep fried potatoes	*Potatiskroketter* (mashed potatoes formed as balls). Procordia Food AB, Sweden	5.2±0.4	90.3±3.5
Potato salad	Cold boiled potatoes in cream/mayonnaise sauce. Denja AB, Sweden	5.9±1.5	92.4±3.4
Legume products	...		
Yellow pea soup	*Artsoppa*. Boiled yellow peas. Goman, Sweden	9.5±0.7	74.6±2.9
Brown beans	*Bruna bönor*. Boiled brown beans. Scan, Sweden	10.1±1.2	80.3±6.4
White beans	Autoclaved white beans in tomato sauce. Heinz Co Ltd, UK	11.1±1.2	90.5±1.8

[a]Values are means±s.d. (total starch basis) of six replicates.

contribution of RS from intact cereal grains has been emphasised in a previous study (Åkerberg *et al*, 1998). Consequently, in a bread made from 80% barley kernels and 20% white wheat flour as much as 26% RS (total starch basis) was found. In contrast, corresponding wholemeal bread contained only 1.5% RS.

Breakfast cereals. The extruded and puffed breakfast cereals were found to have a low RS content, 0.2% RS, total starch basis, (*Havrefras*) and 1.2% RS (*Kalaspuffar*), respectively. Also, the oat flakes contained only minor amounts of RS (0.3%). In contrast, a considerable amount of RS was registered in the barley flakes, or 4.5%. In a study in ileostomists, Livesey *et al* (1995) reported that as much as 17% of the starch in barley flakes remained indigested. The differences in RS content between oat and barley flakes, respectively, could probably be explained by the fact that the products were subjected to different heat treatments during the flaking process. Before the flaking procedure, it is known that the oat grains are steamed at high temperature to inhibit the lipase enzyme, suggesting a high degree of starch gelatinisation.

Porridges. Three different porridges based on oat flakes, rice or semolina were examined. The RS content in the oat porridge was similar to the uncooked oat flakes, ie 0.3% (total starch basis), which is comparable with *in vitro* data (0.8% total starch basis) reported by Englyst *et al* (1996). A somewhat higher RS level was found in the rice porridge (1.2%), whereas the RS fraction in the semolina porridge was surprisingly high (4.8%). Semolina is made from the grain endosperm of protein-rich wheat. The high RS content could be due to interactions between proteins and starch. Another possible explanation is that the porridge-making process (semolina and milk are boiled for 4 min) is too short to allow the starch to be completely gelatinised.

Rice and pasta products. The boiled long-grain rice contained 3.7% RS (total starch basis). Compared with the sticky rice that was used in the porridge, this rice product was parboiled. The parboiling process may affect the rice structure in such a way that the starch will be more restricted in swelling, which may be the cause for the higher RS level in boiled rice compared with rice porridge. In an *in vitro* study by Brighenti *et al* (1998), the mean RS content of six boiled rice varieties was found to be 5.4% (dry weight basis), which is significantly higher compared with the concentration (3.0% dry weight basis) found in the rice examined in the present study.

One macaroni and two spaghetti products were included in the study. A low concentration of RS was noted in the macaroni product (1.2% total starch basis). Englyst *et al* (1996) have reported a higher RS level in macaroni analysed *in vitro* (2.7% total starch basis). This discrepancy might be due to differences in the products *per se*. The Swedish macaroni product was made with thin walls in order to reduce the boiling time (3 min).

The RS fraction in the spaghetti without addition of monoglycerides was higher (2.9% total starch basis) than in the spaghetti where monoglycerides were included (0.9%). Thus, it seems like the addition of lipids may interfere with the retrogradation process of amylose. Consequently, gelatinisation and heat-cycling of starch in the presence of mono-palmitic acid was shown to generate a considerably lower level of RS, suggesting a competitive mechanism between amylose crystallites and amylose–lipid complexes (Tufvesson *et al*, 2001).

Potato products

Potato products are an important source of starch in the Swedish diet. In a recent dietary survey (Becker, 1999) the daily intake was estimated to be 142 g. The RS concentration in boiled potatoes and mashed potatoes (instant potato powder reconstituted with water) was found to be similar, ie 2.0% (total starch basis) and 2.4%, respectively. Higher RS levels were found in the deep-fried products, 4.8% (*Pommes Frites*) and 5.2% (*Potatis kroketter*). An even higher amount of RS (9% total starch basis) has previously been reported in potato crisps (Englyst *et al*, 1996), suggesting an influence of the deep-frying process on RS formation.

The highest RS content among the potato products tested, was registered in the cold potato salad (5.9% total starch basis). According to Åkerberg *et al* (1998), storage of boiled potatoes in a refrigerator may influence the formation of retrograded starch considerably. Thus, when boiled potatoes were stored at 5°C for 24 h, the RS content increased from 3.7% (total starch basis) to 7.0%. The nature of the RS formed is probably retrograded amylopectin, since retrogradation of amylose is favoured around 100°C (Eerlingen *et al*, 1993).

Legume products

Traditionally cooked brown beans, yellow pea soup and autoclaved white beans in tomato sauce contained 9.5–11.1% RS (total starch basis). Values in a similar range have been reported for legume products by other laboratories using ileostomists (Jenkins *et al*, 1987; Steinhart *et al*, 1992). However, recently published *in vitro* data on legume products in the Italian diet (Brighenti *et al*, 1998) was found to be significantly higher (11.7% dry weight basis) than the mean value obtained in the present study (4.0% dry weight basis). Although the mean legume intake in the Swedish population is limited, 10 g/day (Becker, 1999), legume products might contribute an important amount of RS in certain subjects.

Conclusions

This is the first study where a selection of starchy foods on the Swedish market have been examined regarding the content of RS. Since RS is considered to have implications for colonic health and to improve the glucose and lipid metabolism, an increased intake of this starch fraction is probably desirable. Among the cereal products examined in the present study, bread with enclosure of intact rye grains, barley flakes and semolina porridge, respectively, were identified to have a RS content in the higher range (4.5–6.0% total starch basis). Obviously RS intake may vary considerably among individuals. By exchange of the traditional Swedish loaf for bread with inclusion of intact grains, the daily RS intake would increase from 0.8 to 2.0 g (based on a daily intake of 100 g bread). A breakfast based on, for instance, yoghurt with muesli made from barley flakes instead of oat flakes may increase the RS intake from <0.1 to 1.1 g (based on 40 g flakes). Commercially processed potato products were found to have a higher RS content (4.8–5.9%), compared with boiled potatoes (2.0%). However, it should be emphasised that deep-fried products and potato salad also usually have a high fat content. Hence, an increased intake of such products cannot be encouraged. The highest RS concentration was noted in the legume group (mean = 10.2%). If the daily intake of boiled potatoes (142 g) is exchanged for legumes, the RS intake would increase by an additional 1.5 g per day.

In order to estimate the daily RS intake in the Swedish diet, food consumption data from 1997–1998 was used (Becker, 1999). A mean RS value was calculated from the analysed individual products in each food group (bread products, breakfast cereals, porridges, pasta, potato products and legumes). Consequently, the daily RS intake was estimated to be 3.2 g. The main RS sources in the diet are bread and potato products, which contribute with approximately 1.3 and 1.2 g RS per day, respectively. Other sources of importance are pasta products (0.2 g/day) and rice (0.2 g/day), followed by legumes (0.1 g/day), porridges (0.1 g/day), cereal flakes and muesli (0.1 g/day). Any potential RS from pizza dough and pie is not included in the estimated daily intake. The intake of 3.2 g RS estimated in the present study is comparable with 3.4 g/day previously calculated for the Swedish diet for a limited number of starchy products (Dysseler & Hoffem, 1994a). The products were analysed according to the *in vitro* method by Englyst *et al* (1992). A previous study from our laboratory (Åkerberg *et al*, 1998) has shown a good agreement between the RS method used in the present study and the method described by Englyst *et al* (1992).

Another RS source not studied in the present study is banana. A ripe banana has been found to contain 5.1% RS, dry weight (Dysseler & Hoffem, 1994b). Thus, considering the annual high intake in Sweden (21 kg/person) this fruit may contribute 0.8 g RS/day. When including RS from banana, the estimated daily intake of RS in the Swedish diet reaches 4.0 g. A comparable average value was previously estimated for 10 countries in Europe, where consumption of banana was included for seven of the countries (Dysseler & Hoffem, 1994a). However, in a study by Brighenti *et al* (1998), the RS intake in the Italian diet was found to be much higher, ie 8.5 g/day, compared with the average intake in Europe. One reason for the higher RS intake in Italy could be the higher daily intake of bread (Italy (I) = 158 g, Sweden (S) = 100 g), pasta (I = 80 g, S = 40 g) and legumes (I = 26 g, S = 10 g). However, in addition to the various consumption data for certain products, it should be emphasised that the RS content in the food products included in the Italian and present study, respectively, were determined by different *in vitro* methods (Champ, 1992 *vs* Åkerberg *et al*, 1998).

In conclusion, based on 25 cereal, potato and legume products, the estimated average intake of RS in the Swedish diet was found to be 3.2 g/day. When including the consumption of banana, the value reached 4 g/day. However, based on food habits the RS intake may vary considerably. Consequently, when added to the dietary fibre intake, the contribution of RS may be of nutritional importance for certain individuals.

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