



Union Européenne du Commerce des Pommes de Terre
European Union of the Potato Trade
Europäische Union des Kartoffelhandels

Potatoes compared to other carbohydrate sources like rice and pasta

This study was made possible thanks to the following sponsors of Europatat:



Prof. John Van Camp
Ghent University
Dept. Food Safety and Food Quality
Research group Food Chemistry and Human Nutrition



FACULTY OF AGRICULTURAL
AND APPLIED BIOLOGICAL SCIENCES

The nutritional properties of starch in potato products: Impact on glycaemia and satiety

1 Introduction

General characteristics of potato tubers

Potatoes are an important staple food in many countries in Europe. Quantitatively the main nutrient in potatoes, as in cereals, is the storage-carbohydrate starch. The potato is also a source of good-quality protein and energy. It contains vitamins and minerals such as calcium, potassium, and phosphorus, and its value within the human diet is often underestimated or ignored, particularly as a source of ascorbic acid (vitamin C) (Table 1).

Table 1: Nutrients in a portion of boiled potatoes in comparison with rice and pasta.

	Potatoes, boiled, per portion (200 g)	Pasta, boiled, per portion (200 g)	Pasta, wholemeal, boiled, per portion (200 g)	Rice, boiled, per portion (200 g)	Rice, brown, boiled, per portion (200 g)
Energy (kcal)	152	250	242	250	284
Protein (g)	4,6	8	9	6,2	6
Fat (g)	0	0,4	0,4	0,8	2,8
Carbohydrate (g)	33,6	53,6	50,8	54,4	58,6
Fibre (g)	6,2	3,2	6	3,6	3,8
Water (g)	158	146	146	136	130
Sodium (mg)	4	10	46	6	2
Potassium (mg)	868	44	146	34	198
Calcium (mg)	18	16	42	28	8
Phosphorus (mg)	114	100	230	80	240
Magnesium (mg)	38	24	88	14	86
Iron (mg)	1.2	1.4	2.2	0.8	1
Zinc (mg)	0.8	0.6	1.6	1	1.4
Vitamin A activity (µg)	0	-	-	0	0
Vitamin B1 (mg)	0,18	0,1	0,26	0,04	0,28
Vitamin B2 (mg)	0,1	0,08	0,04	0	0,04
Vitamin B6 (mg)	0,38	-	-	-	-
Vitamin C (mg)	28	0	0	0	0

(Belgische voedingsmiddelentabel, Nubel, 1999)

Characteristics of potato starch

Starch is the main food reserve in plants and in the human diet. It is a mixture of two large polymers: amylose, which comprises mainly linear chains (200-2000 glucose units), and amylopectin, which is a highly branched polymer with a higher molecular weight (10000-100000 glucose units). Both molecules are composed of glucose residues mainly linked with α -1,4-glucosidic bonds. Amylopectin, and to a smaller extent amylose, also contain α -1,6-glucosidic bonds, providing a branched like structure.

Starch is produced during photosynthesis and stored as partially crystalline granules in specific locations, such as tubers, grains and kernels. The shape and size of the granules and

their physical characteristics, notably the temperature at which starch gelatinises, are dependent on the relative amount of amylose and amylopectin present.

The potato tuber contains approximately 20% dry matter (DM). Starch is the main component and comprises about 70-80% on DM basis. In potatoes, amylose content is normally around 20-30% of the total starch content, the figure depending on variety and method for determination.

Gelatinisation

Gelatinisation, i.e. heating in the presence of water, includes loss of crystallinity, swelling of the granules, disruption and finally solubilisation of the polymer molecules. Gelatinisation properties are dependent on factors such as botanical origin and available water content. The gelatinisation temperature for potatoes is within the range of 60-65°C.

The crystalline structure present in native potato starch granules is highly resistant towards digestive enzymes, and the digestibility increases as a result of gelatinisation. In parallel, the rate of starch digestion is also affected and gelatinisation of potato starch also increases glycaemic response.

Retrogradation / resistant starch

A starch solution obtained after heating is not stable and almost immediately upon cooling structural changes occur, where the starch molecules re-associate into an ordered structure retrieving a crystalline order. These structural transformations are termed retrogradation. During retrogradation, the starch fraction becomes more crystalline and thereby more resistant to amylolytic enzymes (resistant starch). The retrogradation procedure needs a minimum of water and first affects amylose, then linear fractions of amylopectin.

Resistant starch (RS) is the sum of starch and the products of starch degradation not absorbed in the small intestine of healthy individuals. RS is divided into three main fractions: (1) starch that is physically enclosed and thereby inaccessible for digestive enzymes (2) raw starch granules and (3) retrograded starch, e.g. in cooked and cooled potatoes. Sometimes a fourth group is included covering some chemically modified starches.

2 Glycaemic index

Definition, methodology, impact on health

Definitions

Carbohydrate containing foods differ in their effects on postprandial blood glucose levels. The **glycaemic index** (GI) concept was introduced in 1981 by Jenkins and colleagues in order to rank starchy foods regarding their effects on postprandial blood glucose levels (Jenkins et al., 1981). The glycaemic index is defined as “the incremental area under the blood glucose response curve of a 50g carbohydrate portion of a test food expressed as a percent of the response to the same amount of carbohydrate from a reference food taken by the same subject”. Both white bread and glucose have been used as the reference food for glycaemic index calculations. Because it is confusing to have two different sets of glycaemic index values, it has been recommended that glycaemic index values should be expressed on the glucose scale. If white bread is used as the reference food, conversion to glucose-based glycaemic index values (ie, glycaemic index of glucose = 100) is achieved by dividing the bread-based glycaemic index values by 1,43, because white bread elicits a glycaemic response 29% less than that of oral glucose (FAO/WHO, 1998; Wolever et al., 2003). All GI values in

this review have been converted to the glucose scale. A GI value ≥ 70 is considered high, a GI value 56-69 is medium and a GI value ≤ 55 is low, where glucose = 100 (Brand-Miller et al., 2003a).

Both the quantity and quality (ie., nature or source) of carbohydrate influence the glycaemic response. By definition, the GI compares equal quantities of carbohydrate and provides a measure of carbohydrate quality but not quantity. In 1997 the concept of **glycaemic load** (GL) was introduced by researchers at Harvard University to quantify the overall glycaemic effect of a portion of food. Thus, the GL of a typical serving of food is “the product of the amount of available carbohydrate in that serving and the GI of the food”. The higher the GL, the greater the expected elevation in blood glucose and in the insulinogenic effect of the food (Foster-Powell, 2002).

Methodological aspects of glycaemic index (in vivo-method):

- subject number?
- test number?
- subject status?
- what should be the reference food?
- meal volume, composition and consumption time?
- carbohydrate basis for glycaemic index determination (available CHO)?
- what should be the carbohydrate dose?
- when should the test take place?
- subject preparation?
- how should the randomisation be done?
- should we include as many males as females?
- how many foods in one batch of tests?
- how should blood be sampled?
- blood-sampling time schedule?
- glucose analysis?
- washout period between two consecutive tests?
- which type of calculation of AUC should be applied?
- interlaboratory values and variation?

Based on the currently available science described in the review of Brouns et al. (2005), the following conclusions and recommendations are made:

- (1) At least ten test subjects should be tested to obtain a sufficient statistical power;
- (2) Inclusion of both sexes in a study is acceptable;
- (3) For GI measurement the CHO portion should be based on available CHO;
- (4) A test dose of 50 g available CHO is recommended;
- (5) For foods with a low CHO content it is justified to lower the test dose to 25 g;
- (6) The reference food should be measured at least twice;
- (7) The use of healthy human volunteers is recommended;
- (8) Fluid ingestion, 250 ml, should take place within 5-10 min;
- (9) Solids and semi-solids ingestion within 10-15 min;
- (10) Glucose or white bread are recommended as reference foods;
- (11) The evening before a test each subject should consume a meal of choice and repeat that meal before each subsequent test. Unusual vigorous physical activity should be avoided;
- (12) Test foods should be randomised in blocks of maximal 6;
- (13) The total duration of tests should not exceed 4 months;

- (14) In the case of testing multiple foods, a reference test should be done at the beginning and a repetition should take place after every 6-8 weeks;
- (15) Glucose measurement alone is appropriate;
- (16) For more mechanistic and/or metabolic studies, measurement of both glucose and insulin is recommended;
- (17) Blood sampling times should be at 0 min (baseline sample), followed by 15, 30, 45, 60, 90 and 120 min after starting to eat the test meal;
- (18) AUC calculation should be based on incremental AUC, ignoring area under the baseline;
- (19) It is recommended to calculate GI as the mean of the individual ratios.

Hätönen et al. (2006) studied the effect of methodologic choices on GI values. Comparisons were made between venous and capillary blood sampling and between glucose and white bread as the reference food. The number of tests needed for the reference food was assessed. Rye bread, oatmeal porridge, and instant mashed potato were used as the test foods (See table 1).

Table 1: Glycaemic indexes for rye bread, oatmeal porridge, and mashed potato on the basis of capillary and venous blood sampling and 1,2, or 3 measurements of the reference foods (Hätönen et al., 2006)

Test food and blood sample	Number of reference tests	Glucose solution		White bread		Ratio of the white bread GI to the glucose GI
		Mean \pm SD	CV	Mean \pm SD	CV	
			%		%	
Rye bread						
Venous	1	153 \pm 183	120	144 \pm 119	83	0.94
	2	77 \pm 16	21	164 \pm 197	121	2.13
	3	82 \pm 18	22	128 \pm 80	63	1.56
<i>P</i>		0.31		0.68		
Capillary	1	85 \pm 39	45	99 \pm 46	46	1.16
	2	78 \pm 38	48	96 \pm 37	39	1.23
	3	77 \pm 31	40	102 \pm 40	39	1.32
<i>P</i>		0.48		0.15		
Oatmeal porridge						
Venous	1	221 \pm 362	164	153 \pm 141	92	0.69
	2	91 \pm 37	40	177 \pm 232	131	1.95
	3	95 \pm 41	43	134 \pm 97	73	1.14
<i>P</i>		0.44		0.75		
Capillary	1	82 \pm 38	46	97 \pm 51	53	1.18
	2	74 \pm 26	35	92 \pm 35	38	1.24
	3	74 \pm 23	31	98 \pm 36	36	1.32
<i>P</i>		0.48		0.12		
Mashed potato						
Venous	1	182 \pm 247	135	148 \pm 117	79	0.81
	2	86 \pm 35	41	164 \pm 186	113	1.91
	3	92 \pm 40	44	134 \pm 84	63	1.46
<i>P</i>		0.31		0.75		
Capillary	1	90 \pm 40	44	108 \pm 58	53	1.20
	2	79 \pm 21	27	102 \pm 42	41	1.29
	3	80 \pm 21	26	108 \pm 45	41	1.35
<i>P</i>		0.42		0.18		

² *n* = 11 for glucose solution and *n* = 11 and 9 for capillary and venous samples for white bread, respectively. A repeated-measures ANOVA was used to test the differences between GIs of 1, 2, or 3 reference tests.

The GI values were significantly lower when based on capillary blood than when based on venous blood, especially when white bread was used as the reference. The capillary GI values were significantly lower and had significantly smaller CVs with 2 or 3 tests of the reference food than with 1 test.

In vitro method

The relationship between the rate of digestion and absorption and glycaemic response is also shown using various *in vitro* digestion models that mimic the *in vivo* situation.

However it is possible that some factors that significantly affect glycemia *in vivo*, such as the rate of gastric emptying, will not change the rate of carbohydrate digestion *in vitro*. For example, high osmolality and high acidity or soluble fibre slow down the gastric emptying rate and reduce glycemia *in vivo*, but they may not alter the rate of carbohydrate digestion *in vitro*. It is difficult to mimic all of the human digestive processes in a test tube.

Foster-Powell et al. (2002) stated that results from their laboratory have shown that GI values measured *in vivo* can differ significantly from the same foods tested *in vitro*.

On the contrary, Englyst et al. (2003) found a very high correlation between the rate of *in vitro* glucose release from cereal products, using pancreatic and brush-border enzymes, and the glycaemic response *in vivo*. The amount of rapidly available glucose (RAG) was positively ($r^2 = 0,54$; $P < 0,001$), and the amount of slowly available glucose (SAG) was negatively ($r^2 = 0,63$; $P < 0,001$) correlated with GI.

Impact on health

Diabetes mellitus (DM) and cardiovascular diseases (CVD) are some of the leading causes of mortality and morbidity. Accumulating data indicate that a diet characterized by low-glycaemic index foods may improve the management of diabetes or lipid profiles. Opperman et al. (2004) conducted a meta-analysis to critically analyse the scientific evidence that low-GI diets have beneficial effects on carbohydrate and lipid metabolism compared with high-GI diets. The low-GI diets significantly improved blood glucose control in type 2 DM subjects. These findings were in accordance with other meta-analyses conducted on markers of carbohydrate metabolism (Brand-Miller, 1994; Brand-Miller et al., 2003b; Wolever, 2003). Regarding lipid metabolism, a significant improvement in LDL-cholesterol and TC was observed for type 2 DM subjects, while TG and HDL-cholesterol concentrations were not influenced. Only two randomised controlled trials were performed: CHD patients and healthy subjects. No notable effects of a low-GI diet on lipid and carbohydrate metabolism were observed in these patients. It is therefore difficult to draw a final conclusion. More studies should therefore be conducted in non-DM subjects to investigate the effect of low-GI diets on HDL-cholesterol, LDL-cholesterol and TC concentrations. Furthermore, many of the studies included in this meta-analysis involved only small numbers of subjects and were of short duration: it is recommended that more long-term studies should be conducted.

Raben (2002) performed a systematic review of published human intervention studies comparing the effects of high- and low-GI food diets on appetite, food intake, energy expenditure and body weight. In a total of 31 short-term studies (< 1 d), low-GI foods were associated with greater satiety or reduced hunger in 15 studies, whereas reduced satiety or no differences were seen in 16 other studies. Low-GI foods reduced *ad libitum* food intake in seven studies, but not in eight other studies. In 20 longer-term studies (< 6 months), a weight loss on a low-GI diet was seen in four and on a high-GI diet in two, with no difference recorded in 14. The average weight loss was 1,5 kg on a low-GI diet and 1,6 kg on a high-GI diet. To conclude, there is no evidence at present that low-GI foods are superior to high-GI foods in regard to long-term body weight control. However, the ideal long-term study where *ad libitum* intake and fluctuations in body weight are permitted, and the diets are similar in all aspects except GI, has not yet been performed.

GI of potatoes in relation to other carbohydrate sources

Potatoes generally have one of the highest GI values of any food (Table 2), although some varieties appear to be lower than others. Published GI values are highly variable (Foster-Powell et al., 2002); however, it can be difficult to compare values as the variety of potato is

rarely specified, leading to some confusion over the impact of variety versus preparation method. It is necessary to clarify the GI of different varieties of potatoes as they are a major staple in Europe, contributing approximately 7 % of total carbohydrate intake (Wirfält et al., 2002).

Table 2: Table of glycaemic index (Bjorck et al., 2000)

	Starchy foods	Fruits	Dairy
Potato products	58, 71-87		
Breakfast cereals	54, 70-95		
Common bread	65-95		
Ripened banana		57-67	
Rice	43-60, 87		
Pasta products	29-51		
Apples, oranges		33-54	
Milk, yoghurt			11-44
Legumes	9-51		

Effect of variety and maturity on glycaemic index

The hypothesis that new potatoes may have a relatively lower GI than mature potatoes was made by Soh and Brand-Miller (1999). To study this, 10 healthy volunteers were recruited. Equal (50 g) carbohydrate portions of potato meals (three varieties, two states of maturity) and two reference bread meals were fed in random order to each of the subjects over a period of 10 weeks. Capillary blood samples were taken in fasting state and then at 15, 30, 45, 60, 90 and 120 min from the start of each meal. Samples were analysed for plasma glucose concentration and incremental areas under the plasma glucose curves were calculated. The GI of the potato was calculated as the AUC of the potato expressed as a percentage of the individual's average AUC of the white bread and then converted to glucose as a reference. The GI of the products tested is shown in Table 3, no statistically significant difference was found among the GI of the different varieties of potato (Sebago, Pontiac and Desiree) ($P = 0,38$). The only significant difference was between the canned new potato and boiled Desiree potato ($P = 0,047$). The GI of the three mature varieties and two 'new' potato products correlated with their average tuber weight ($r = 0,83$, $P < 0,05$).

Table 3: GI values of test foods \pm s.e.m. ($n = 10$, except $n = 9$ for new potatoes, canned and microwave-heated)

<i>Food</i>	<i>GI \pm s.e.m.</i> <i>(white bread = 100)</i>	<i>GI \pm s.e.m.</i> <i>(glucose = 100)</i>
Variety		
Sebago, peeled and boiled	124 \pm 10	87 \pm 7
Desiree, peeled and boiled	144 \pm 22	101 \pm 15
Pontiac, peeled and boiled	125 \pm 13	88 \pm 9
Maturity		
New, unpeeled and boiled	112 \pm 17	78 \pm 12
New, canned and microwave heated	93 \pm 13	65 \pm 9

The same hypothesis was made by Leeman et al. (2005). They studied the *in vitro* availability of starch in heat-treated potatoes as related to genotype, weight and storage time. Six varieties of potato were used in the tests. Each variety was bought at one occasion to minimise sources of variation. The storage temperature used for the raw potato tubers was 6°C in all cases. *In vitro* prediction of GI of boiled potato products included all six varieties, whereas the effect of size and storage time were evaluated in Asterix, Bintje and King Edward. The influence of

storage was studied by analysing tubers of similar weight in autumn and spring, 1-3 and 8-10 months after harvest, respectively. The tubers were boiled unpeeled. Boiling always took place immediately before starting the analyses to exclude possibilities that the extent of retrogradation could differ depending on the time the boiled potatoes were kept before analysis. Evaluation of the rate of starch hydrolysis was performed according to a previously described method by Granfeldt (1992). The hydrolysis index (HI) for a test product is calculated as the area under the hydrolysis curve (0-180 min) as a percentage of the corresponding area for white bread.

Table 4: Hydrolysis index (HI) values and predicted glycaemic index (GI) values for boiled potatoes of different weight, variety and storage time (Leeman et al., 2005)

Storage time (months)	Variety	Weight \pm SD (g)	HI \pm SEM (White bread = 100)	Predicted GI (White bread = 100)	Predicted GI (Glucose = 100)
0	'Early' King Edward	46 \pm 11	130 \pm 4	125	88
0	Platina	90 \pm 9	143 \pm 5	137	96
0	Frieslander	100 \pm 5	126 \pm 3	121	85
0	Rocket	131 \pm 11	137 \pm 6	131	92
1-3	King Edward	63 \pm 8	141 \pm 4	135	94
1-3	King Edward	309 \pm 47	144 \pm 4	138	97
1-3	Bintje	63 \pm 11	128 \pm 4	123	86
1-3	Bintje	359 \pm 78	126 \pm 3	121	85
1-3	Asterix	90 \pm 8	124 \pm 4	119	83
1-3	Asterix	389 \pm 12	122 \pm 2	118	83
8-10	King Edward	41 \pm 4	130 \pm 6	125	88
8-10	King Edward	297 \pm 36	135 \pm 4	129	90
8-10	Bintje	41 \pm 12	139 \pm 10	133	93
8-10	Bintje	285 \pm 16	135 \pm 4	129	90
8-10	Asterix	52 \pm 9	133 \pm 9	128	90
8-10	Asterix	322 \pm 17	127 \pm 3	122	85

HI for white bread = 100, n=6. GI = 6.272 + 0.912 x HI (based on the equation stated in Granfeldt (1992), extended and including both low- and high-GI products, n=36)

All potatoes gave high HI values (Table 4). GI values (glucose=100) calculated from HI values ranged from 83-97. No differences were found between potatoes stored 1-3 months or 8-10 months, nor between winter and early potato varieties. Moreover, no significant correlation was noted between HI and average weight of the tubers analysed. When the four varieties of early potatoes (storage time 0 months) were compared, small but significant differences were found in HI between Frieslander (126) and Platina (143) ($P < 0,05$) (Leeman et al., 2005).

Henry et al. (2005) compared the glycaemic response to eight potato varieties commercially available in Great-Britain against a glucose standard in a non-blind, randomised, repeated measure, crossover design trial. Seventeen healthy subjects (3 males, 14 females), mean age 32 (SD 13) years and mean BMI 22,3 (SD 3,6) kg/m², were recruited for the study. Subjects were served portions of eight potato varieties (boiled potatoes) and a standard food (glucose), on separate occasions, each containing 50 g carbohydrate. Capillary blood glucose was measured from finger-prick samples in fasted subjects (0 min) and at 15, 30, 45, 60, 90 and 120 min after the consumption of each test food. For each potato variety, the glycaemic index value was calculated geometrically by expressing the incremental area under the blood glucose curve (IAUC) as a percentage of each subject's average IAUC for the standard food (See table 5).

Table 5: Incremental area under the blood glucose curves (IAUC) and glycaemic index (GI) values for each potato variety (mean values with their standard errors) (Henry, 2005).

Potato variety	IAUC		GI value	
	Mean	SEM	Mean	SEM
Maris Peer	182	33	94	16
Maris Piper	167	17	85	4
Desiree	133	18	77	17
Estima	143	13	66	5
Charlotte	134	30	66	5
Marfona	93	21	56	3
King Edward	166	10	75	10
Nicola	130	10	59	7

Table 6: Glycaemic index (GI) classification and characteristics of each potato variety (Henry, 2005).

Potato variety	GI classification	Crop type	Texture†	Texture rating*
Maris Peer	High	Second early	Firm	5
Maris Piper	High	Main crop	Floury	5
Desiree	High	Main crop	Firm	5
Estima	Medium	Second early	Firm, moist	4
Charlotte	Medium	Salad	Firm, waxy	4
Marfona	Medium	Second early	Waxy	3
King Edward	High	Main crop	Floury	6
Nicola	Medium	Salad	Firm	4

* Information obtained from the British Potato Council website www.potato.org.uk. Texture ratings are measured on a scale from 1 to 9 (1 being most waxy and 9 being the most floury).

The potatoes exhibited a large variation in GI values ranging from 56 (Marfona) to 94 (Maris Peer), although the differences in GI were not statistically significant ($P = 0,330$). There was a strong positive correlation between the GI value and the texture rating (See table 6). In general, potatoes with floury textures (low in moisture, low in sugar with high starch) were in the high-GI category, whilst those with firm to waxy textures (high in moisture, low starch) were in the medium-GI category. Generally, the earlier crop varieties of potato (second early) and the salad potatoes tend to have waxy textures while the main crop varieties tend to have floury textures (Henry, 2005). Changes in the nature of the starch, predominantly an increase in the amount of amylopectin (Soh & Brand-Miller, 1999), may be partly responsible for the difference in glycaemic response seen with floury, more mature potatoes. Amylopectin has a branched structure that makes it more readily digestible than linear chain starch leading to a higher glycaemic response (Van Amelsvoort & Westrate, 1992).

Fernandes et al. (2005) studied the GI of potatoes commonly consumed in North America. The subjects (11 men and 1 woman, aged 18 to 50) consumed 50 g carbohydrate portions of white bread or potatoes. The meals were consumed after a 10- to 12-hour overnight fast and fingerprick capillary-blood glucose was measured before and at intervals for 2 hours after consumption. Glycaemic index values were calculated. The GI for baked Russet potato and baked Prince Edward Island white potato was $76,5 \pm 8,7$ and $72,8 \pm 4,5$ respectively (glucose = 100). These GI values did not differ significantly.

To state that “all potatoes have a high glycaemic index” is an unjustified generalisation. While mature varieties prevail in the USA, Canada, Australia and the UK, varieties commonly consumed in Central European countries are characterised by a lower starch content, an indication of smaller, less mature potatoes with reduced amylopectin branching. This is also reflected in the lower GI values reported by studies that have examined European potatoes (Buyken & Kroke, 2005; Chantelau, 2000; Foster-Powell, 2002).

Effect of processing on glycaemic index

The carbohydrates of potatoes are mainly starch which gelatinizes in the cooking process. Starch digestibility improves during processing and is affected by cooking methods. During cooling the gelatinized food starch molecules begin to crystallize and resistant starch is formed. All these factors could affect the GI-values of processed potatoes.

Buyken et al. (2005) collected data from different studies (fig. 2) to compare the influence of different cooking methods on GI-values.

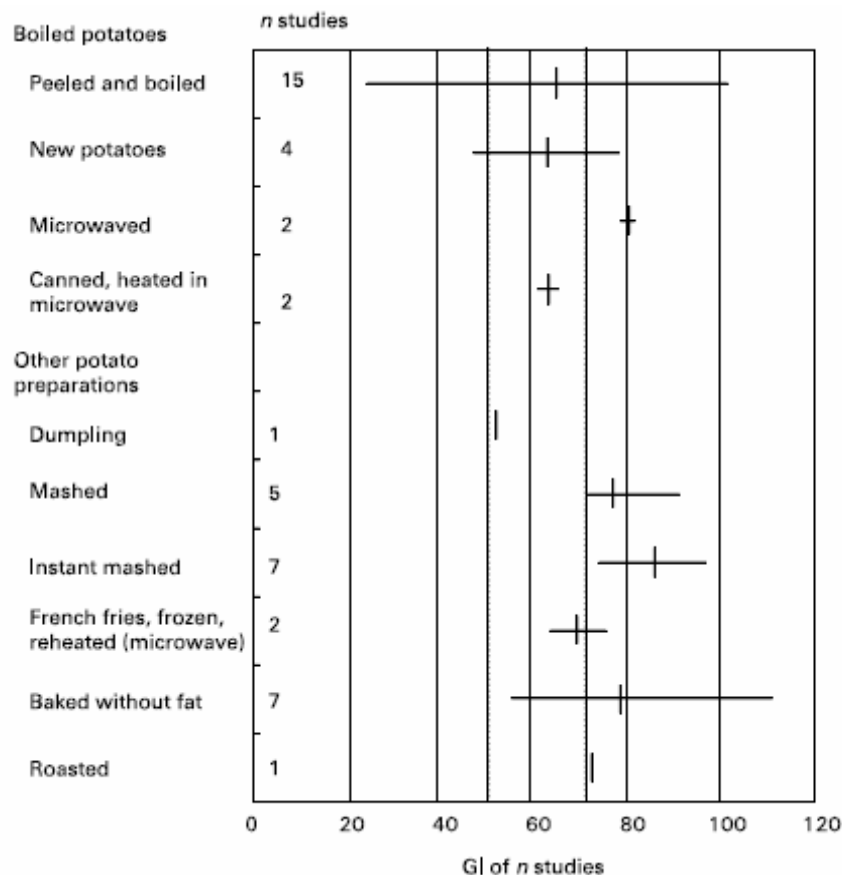


Fig. 2: Glycaemic index values (glucose reference) for potatoes by different cooking methods (Chantelau, 2000; Foster-Powell, 2002). Values are means with the range (minimum to maximum) depicted by horizontal bars. Dotted vertical lines represent the cut-off levels proposed for a low GI (≤ 55) and a high GI (≥ 70) of a food.

These data suggest a very large range of GI-values for the same cooking method, but since the variety is rarely identified, a comparison between different studies is not appropriate. In this review only comparisons within the same study are considered to discuss possible statistical significant influences of processing on the GI-values of potatoes.

In the same study as mentioned in section 2.3, Soh and Brand-Miller (1999), also studied the effect of cooking method on GI-values. Results are given in table 7.

Table 7: GI values of test foods \pm s.e.m. ($n = 10$)

<i>Food</i>	<i>GI \pm s.e.m. (white bread = 100)</i>	<i>GI \pm s.e.m. (glucose = 100)</i>
Cooking method		
Pontiac, peeled and boiled	125 \pm 13	88 \pm 9
Pontiac, peeled, boiled and mashed	130 \pm 13	91 \pm 9
Pontiac, peeled and microwaved	112 \pm 13	79 \pm 9
Pontiac, peeled and baked	133 \pm 15	93 \pm 11

In this study there were no significant differences in GI of Pontiac potatoes whether they were boiled, oven-baked, microwaved or mashed. ($P = 0,55$).

According to Kingman and Englyst (1994), potato tubers contain sufficient water in the natural state to allow full gelatinization of their starch content during heat treatment. Thus only minor differences should be expected between conventionally processed potato products, if served soon after cooking.

In contrast, Lunetta et al. (1995) found that baked potatoes produced a significantly lower incremental glycaemic response compared with boiled potatoes, even when the same amounts of fat were added to each. They concluded that the baking process led to less cooking of the internal part of the potato and reduced the potato's digestibility.

Fernandes et al. (2005) also determined the effect of cooking method on the glycaemic index (study design, see section 2.3). The results are listed in table 8.

Table 8: Glycaemic index for 50 g available carbohydrate portions of potatoes tested by 12 subjects (adapted from Fernandes et al., 2005).

Potatoes tested	Serving size (g)	Fat (g)	Total carbohydrates (g)	Available carbohydrates (g)	Glycaemic index (glucose = 100)
Baked Russet potato	298	0,2	53,8	50,0	76,5 \pm 8,7 ^{xyz}
Instant mashed potato (Russet)	67,3	0,6	54,2	50,0	87,7 \pm 8,0 ^{xy}
French fried potatoes (Russet)	233	9,7	55,5	50,0	63,6 \pm 5,5 ^{yz}
Boiled red potato (hot)	352	0,5	56,0	50,0	89,4 \pm 7,2 ^x
Boiled red potato (cold)	352	0,5	56,0	50,0	56,2 \pm 5,3 ^z

^{xyz}Means in the same column not sharing the same letter superscript differ significantly ($P < 0,05$)

Instant mashed potatoes and French fries were both made from Russet potatoes but their glycaemic index values differed significantly. The relative low glycaemic index value of French fries might be due to the 9,7 g fat they contained, because fat delays gastric emptying. However, blood glucose concentrations after French fries rose as quickly and reached a peak as high as that after baked Russet potatoes, which was not compatible with a reduced rate of gastric emptying. The relatively low glycaemic index of French fries could be due to the fact that they were precooked, frozen, and reheated before consumption. Consuming cold versus hot red potatoes had a substantial effect on postprandial glucose, with cold potatoes eliciting nearly a 40% lower response.

Because the share of processed potato products is growing, Tahvonen et al. (2006) conducted a study to determine the effects of processing on the glycaemic indices of industrially processed potato products (variety Nicola). Two groups (11 and 10 volunteer subjects) attended a glucose tolerance test and glycaemic response test of 4 and 3 processed potato products, respectively. GI values of different potato products were calculated for each subject using their own glucose tolerance test and glycaemic responses for test meals and averages calculated for each product. GI values of freshly prepared potato products were high: steam boiled potatoes 104 ± 39 , oven-baked casserole 95 ± 30 (carbo-peeled sliced potato) and mashed potatoes 106 ± 42 . GI values of cooled and stored potato products were intermediate, potato cubes served cold 76 ± 32 and cooled, reheated oven-baked casseroles 73 ± 25 (carbo-peeled sliced potato), 75 ± 17 (carbo-peeled mashed potato) and 81 ± 28 steam-peeled mashed potato). Cooling and cold storage decreased GI values significantly ($P = 0.01$). In conclusion: cooking method, peeling method, or slicing or mashing did not affect the GI values. Cooling and cold storage despite reheating lowered GI values of potato products by about 25%. These results indicate significant changes in the starch during cooling and cold storage.

A part of gelatinized starch is known to crystallize (retrogradation) during storage, this phenomenon being faster at low temperatures. Retrogradation of amylose is known to be fast near 0°C , and about 20% of potato starch is usually amylose. Amylopectin shows less retrogradation at conventional food processing conditions. Akerberg et al. (1998) found an increase in resistant starch content when boiled potatoes were stored at 5°C for 24h. Successive cooling and reheating cycles increase the amount of resistant starch in *in vitro* tests (Kingman & Englyst, 1994). Leeman et al. (2005), also found a significant increase of resistant starch in potatoes after extended time periods of temperature cycling at conditions known to favour amylose retrogradation. *In vitro* tests have also shown lower digestibility for cooled potato products (Kingman & Englyst, 1994) and for temperature-cycled potatoes (Leeman et al., 2005). These all suggest the formation of type-3 resistant starch, when potatoes are stored at refrigerator temperatures after baking or boiling.

3 Satiety

Rapid progress is being made in understanding the brain-processing and related psychology of the sensory properties of food, and how the satiety (fullness) signals produced during and after eating regulate appetite (Rolls, 2007). A conceptual diagram to show how the sensory signals produced by food interact in the brain with satiety signals in order to produce an output that represents the reward, hedonic or appetitive value of the food, and which leads to eating, is shown in figure 3.

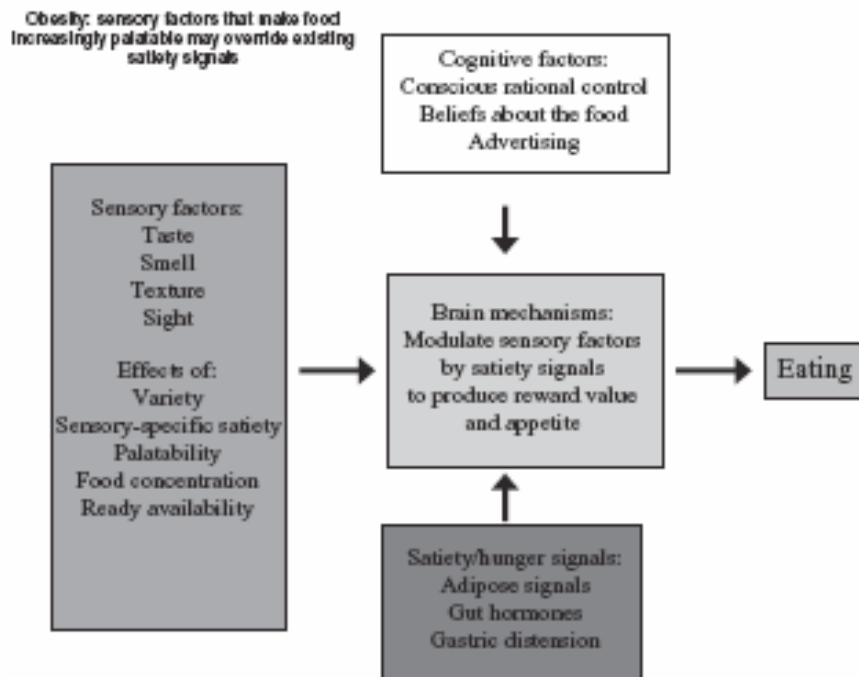


Fig. 3: Schematic diagram to show how sensory factors interact in the brain with satiety signals to produce the hedonic, rewarding value of food, which leads to appetite and eating (Rolls, 2007).

Definition, methodology

Experiments indicate that exposure to high-carbohydrate foods can give rise to a clear modulation of the expression of human appetite. The potency and time course of the effects of various carbohydrates on satiety vary with the amount consumed and the chemical structure. There is evidence that this biological effect can modulate the temporal profile of hunger and the eating pattern of meals and snacks. One important issue is the action of carbohydrate foods on **satiation** (within meals) and **satiety** (after meals). Technically, satiety can be defined as the inhibition of hunger and eating that arises as a consequence of food consumption. It can be distinguished from satiation that is the process that brings a period of eating to a halt. The physiological mechanisms through which carbohydrates exert an action on appetite are not completely identified, although plasma glucose values are likely to play a role (Blundell et al., 1994).

To determine the **satiety index**, a subjective rating scale is used (ie. Fig. 4).

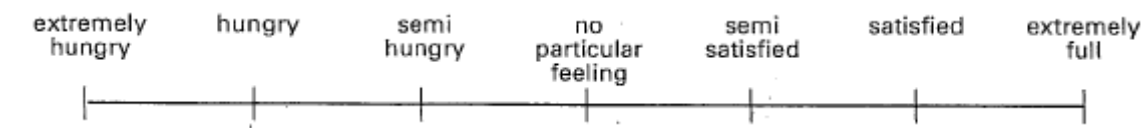


Fig. 4: The rating scale used to assess subjective satiety (Holt et al., 1995)

After eating a portion of a certain food, the subjects are asked to assess their feelings of hunger/satiety using an equilateral seven-point rating scale. This scale is anchored at -3 ('extremely hungry') with a midpoint at 0 (no 'particular feeling') through to +3 ('extremely full'). These data points are then plotted in function of the time after eating (fig.5).

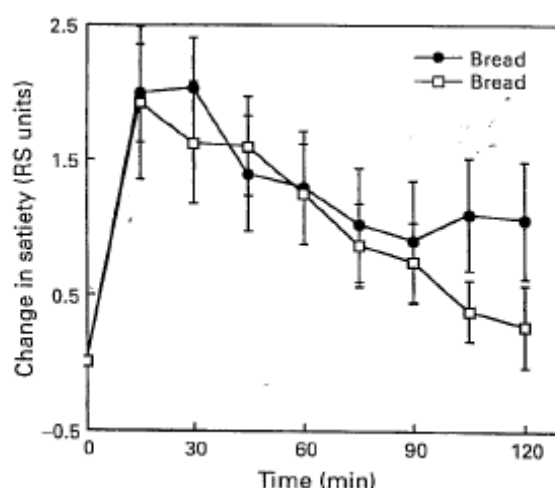


Fig 5: The mean changes in satiety responses over 120 min to white bread on two separate occasions (n=9)

The satiety response to a food is quantified as the incremental area under the 120 min response curve (AUC), calculated using the trapezoidal rule with fasting levels as the baseline and truncated at zero. Any negative area is ignored. Satiety index scores (SI%) are obtained by dividing the satiety AUC value for the test food by the mean of the group's response to white bread and expressed as a percentage (Holt, 1995).

Satiety of potatoes in relation to other carbohydrate sources

In 1995, Holt et al. conducted a study to produce a validated satiety index of common foods. Iso-energetic 1000 kJ servings of 38 foods separated into six food categories (fruits, bakery products, snack foods, carbohydrate-rich foods, protein-rich foods, breakfast cereals) were fed to groups of 11-13 subjects. Satiety ratings were obtained every 15 min over 120 min after which subjects were free to eat *ad libitum* from a standard range of foods and drinks. A satiety index (SI) score was calculated by dividing the area under the satiety response curve (AUC) for the test food by the group mean satiety AUC for white bread and multiplying by 100. Thus, white bread had a SI score of 100% and the SI scores of the other foods were expressed as a percentage of white bread.

There were significant differences in satiety both within and between the six food categories. The highest SI score was produced by boiled potatoes ($323 \pm 51\%$) which was seven-fold higher than the lowest SI score of the croissant ($47 \pm 17\%$). Most foods (76%) had an SI score greater than or equal to white bread. The amount of energy eaten immediately after 120 min correlated negatively with the mean satiety AUC responses ($r = -0,37, P < 0,05, n = 43$) thereby supporting the subjective satiety ratings. SI scores correlated positively with the serving weight of the foods ($r = 0,66, P < 0,01, n = 38$) and negatively with palatability ratings ($r = -0,64, P < 0,001, n = 38$). Fat content was negatively associated ($r = -0,43, P < 0,01$) (Table 9).

Table 9: The nutritional composition of the test foods per 1000 kJ and their satiety index scores (adapted from Holt et al., 1995)

Carbohydrate-rich foods	Serving size (g)	Fat (g)	Starch (g)	SI score (%)
White bread	94	2,1	44,1	100 ± 0
French fries	93	8,7	35,4	116 ± 35
White pasta	201	0,8	47,1	119 ± 35

Brown rice	148	2,1	52,6	132 ± 35
White rice	203	0,5	56,0	138 ± 31
Grainy bread	108	5,4	37,6	154 ± 40
Wholemeal bread	101	2,6	43,7	157 ± 29
Brown pasta	218	1,6	47,8	188 ± 45
Potatoes	368	1,0	45,9	323 ± 51

The high bulkiness of the potato meal was suggested as a plausible explanation for the high SI% of the boiled potatoes. However also low-energy items such as orange and apples were included in the test and these meals had higher meal weights without exerting the satiating benefits of boiled potatoes. Higher RS content, or decreased palatability when ingested in the form of a breakfast meal are other hypothetical reasons for the substantial satiating capacity of boiled potatoes. Satiety ratings were registered during 120 min, and thus it remains to be shown if the satiating capacity of potatoes remain long enough to affect also the voluntary intake at the subsequent meal.

In elderly, mashed potatoes (high-GI) induced significantly higher satiety (36% higher fullness sensation) compared with a barley meal (low-GI) containing the same amount of available carbohydrates as measured during 120 min (Kaplan and Greenwood, 2002).

In the study of Westrate and Amelsvoort (1992) the ratio of amylose to amylopectin in the starch fraction of a meal was examined. Blood indices and satiety were measured for up to 6 h. Subjects ate four different meals, each containing 62% carbohydrate in which 57% was polysaccharides and 5% mono- and disaccharides. The amylose-amylopectin ratios were manipulated by using different types of rice and maize starch. The high amylose meals showed lower postprandial blood glucose curves and gave rise to stronger suppression of subjective willingness to eat and more intense reports of fullness for up to 6 h after consumption. The differences between high-amylose and high-amylopectin meals were not large and may turn out to be not very meaningful.

Effect of processing of potatoes on satiety

Leeman et al. (2007) investigated the glycaemic and satiating properties of potato products in healthy subjects using energy-equivalent (study 1) or carbohydrate-equivalent (study 2) test meals, respectively. Thirteen healthy subjects volunteered for the first study, and 14 for the second. All meals were served as breakfast in random order after an overnight fast. Study 1 included four energy-equivalent (1000 kJ) meals of boiled potatoes, French fries, or mashed potatoes; the latter varying in portion size by use of different amounts of water. The available carbohydrate content varied between 32,5 and 50,3 g/portion. Capillary blood samples were collected during 240 min for analysis of glucose, and satiety was measured with a subjective rating scale. Study 2 included four carbohydrate-equivalent meals (50 g available carbohydrates) of French fries, boiled potatoes served with and without addition of oil, and white wheat bread (reference). The energy content varied between 963 and 1534 kJ/portion. Capillary blood samples were collected during 180 min for analysis of glucose, and satiety was measured using a subjective rating scale.

In study 1 the boiled potatoes induced a higher subjective satiety than French fries when compared on an energy-equivalent basis. The French fries elicited the lowest early glycaemic response and were less satiating in the early postprandial phase (area under the curve (AUC) 0-45 min). No differences were found in glycaemic or satiety response between boiled or mashed potatoes.

In study 2 the French fries resulted in a significantly lower glycaemic response than boiled potatoes either with or without addition of oil. No differences were found in subjective satiety response between the products served on a carbohydrate-equivalent basis.

In conclusion: Boiled potatoes were more satiating than French fries on an energy-equivalent basis, the effect being most prominent in the early postprandial phase, whereas no difference in satiety could be seen on a carbohydrate-equivalent basis.

4 Conclusions and recommendations

The glycaemic index is proposed as a tool to evaluate carbohydrate rich-foods, but is highly variable and influenced by the methodology used. Potatoes and potato products mostly show a high GI but with large variability. The effect of processing is not consistent. Cooling and cold storage can reduce the GI values. Potatoes show a high satiety index (SI) which changes upon processing. It is difficult to relate GI to SI, and to apply this in current practice.

There is no need to exclude potatoes from the daily diet because of their (mostly) high GI. Potato products can make part of a healthy diet if there is enough variation and if dietary guidelines are followed.

References:

Akerberg, A.K.E., Liljeberg, H.G.M., Granfeldt, Y.E., Drews, A.W., Bjorck, I.M.E. (1998). An in vitro method, based on chewing, to predict resistant starch content in foods allows parallel determination of potentially available starch and dietary fibre. *Journal of Nutrition*, 128: 651-660.

Bjorck, I., Liljeberg, H., & Ostman, E. (2000) Low glycaemic-index foods. *British Journal of Nutrition*, 83: S149-S155.

Blundell, J.E., Green, S., & Burley, V. (1994) Carbohydrates and human appetite. *The American Journal of Clinical Nutrition*, 59: 728S-734S.

Brand-Miller, J. (1994) Importance of glycaemic index in diabetes. *American Journal of Clinical Nutrition*, 59: 747S-752S.

Brand-Miller, J., Foster-Powell, K., Colagiuri, S. (2003a) The new glucose revolution. New York: Marlowe and Company.

Brand-Miller, J., Hayne, S., Petocz, P., & Colaiuri, S. (2003b) Low-glycaemic index diets in the management of diabetes. A meta-analysis of randomized controlled trials. *Diabetes Care*, 26: 2261-2267.

Brouns, F., Bjorck, I., Frayn, K.N., Gibbs, A.L., Lang, V., Slama, G., & Wolever, T.M.S. (2005) Glycaemic index methodology. *Nutrition Research Reviews*, 18: 145-171.

- Buyken, A.E., & Kroke, A. (2005) Glycaemic index of potatoes: myth and reality from a European perspective. *British Journal of Nutrition*, 94: 1035-1037.
- Chantelau, E. (2000) The glycaemic index of carbohydrate foods: an update from a diabetologist's perspective. *Aktuel Ernaehr Med.*, 25: 176-185.
- Englyst, K.N., Vinoy, S., Englyst, H.N., & Lang, V. (2003) Glycaemic index of cereal products explained by their content of rapidly and slowly available glucose. *British Journal of Nutrition*, 89, 329-340.
- FAO/WHO (1998) Carbohydrates in human nutrition. Report of an FAO/WHO expert consultation on carbohydrates, April 14-18 1997, Rome, Italy.
- Fernandes, G., Velangi, A., & Wolever, T. (2005) Glycaemic index of potatoes commonly consumed in North America. *Journal of the American dietetic association*, 105: 557-562.
- Foster-Powell, K., Holt, S.H.A., & Brand-Miller, J.C. (2002) International table of glycaemic index and glycaemic load values: 2002. *American Journal of Clinical Nutrition*, 76: 5-56.
- Jenkins, D.J.A., Wolever, T.M.S., Taylor, R.H., Barker, H., Fielden, H., Baldwin, J.M., Bowling, A.C., Newman, H.C., Jenkins, A.L., & Goff, D.V. (1981) Glycaemic index of foods: a physiological basis for carbohydrate exchange. *American Journal of Clinical Nutrition*, 34: 362-366.
- Granfeldt, Y., Bjorck, I., Drews, A., & Tovar, J. (1992) An in vitro procedure based on chewing to predict metabolic response to starch in cereal and legume products. *European Journal of Clinical Nutrition*, 46: 649-660.
- Gray, J. (1991) Starches and sugars: a comparison of their metabolism in man. ILSI Europe Concise Monograph Series. Springer-Verlag, London, UK.
- Hätönen, K.A., Simila, M.E., Virtamo, J.R., Eriksson, J.G., Hannila, M.-L., Sinkko, H.K., Sundvall, J.E., Mykkanen, H.M., & Valsta, L.M. (2006) Methodologic considerations in the measurement of glycaemic index: glycaemic response to rye bread, oatmeal porridge, and mashed potato. *American Journal of Clinical Nutrition*, 84: 1055-1061.
- Henry, C.J.K., Lightowler, H.J., Strik, C.M., & Storey, M. (2005) Glycaemic index values for commercially available potatoes in Great Britain. *British Journal of Nutrition*, 94: 917-921.
- Holt, S.H.A., Brand-Miller, J.C., Petocz, P., & Farmakalidis, E. (1995) A satiety index of common foods. *European Journal of Clinical Nutrition*, 49: 675-690.
- Kaplan, R.J., & Greenwood, C.E. (2002) Influence of dietary carbohydrates and glycaemic response on subjective appetite and food intake in healthy elderly persons. *International Journal of Food Sciences and Nutrition*, 53: 305-316.
- Kingman, S.M., & Englyst, H.M. (1994) The influence of food preparation methods on the in vitro digestibility of starch in potatoes. *Food Chemistry*, 49: 181-186.

- Leeman, A.M., Barstrom, L.M., & Bjorck, I.M.E. (2005) In vitro availability of starch in heat-treated potatoes as related to genotype, weight and storage time. *Journal of the Science of Food and Agriculture*, 85: 751-756.
- Leeman, M., Ostman, E., & Björck, I. (2007) Glycaemic and satiating properties of potato products. *European Journal of Clinical Nutrition*, advance online publication, 28 february 2007, doi: 10.1038/sj.ejcn.1602677
- Lunetta, M., Di Mauro, M., Crimi, S., & Mughini, L. (1995) Influence of different cooking processes on the glycaemic response to potatoes in non-insulin dependent diabetic patients. *Diabetes Nutrition Metabolism*, 8: 49-53.
- Opperman, A.M., Venter, C.S., Oosthuizen, W., Thompson, R.L., & Vorster, H.H. (2004) Meta-analysis of the health effects of using the glycaemic index in meal-planning. *British Journal of Nutrition*, 92: 367-381.
- Raben, A. (2002) Should obese patients be counselled to follow a low-glycaemic index diet? *Obesity Reviews*, 3: 245-256.
- Rolls, E.T. (2007) Understanding the mechanisms of food intake and obesity. *Obesity Reviews*, 8: S67-S72.
- Soh, N.L., & Brand-Miller, J. (1999) The glycaemic index of potatoes: the effect of variety, cooking method and maturity. *European Journal of Clinical Nutrition*, 53: 249-254.
- Tahvonen, R., Hietanen, R.M., Sihvonen, J., & Salminen, E. (2006) Influence of different processing methods on the glycaemic index of potato (Nicola). *Journal of Food Composition and Analysis*, 19: 372-378.
- Wirfält et al. (2002) Food sources of carbohydrates in a European cohort of adults. *Public Health Nutrition*, 5: 1197-1215.
- Wolever, T.M.S. (2003) Carbohydrate and the regulation of blood glucose and metabolism. *Nutrition Reviews*, 61: S40-S48.
- Wolever, T.M.S., Bjorck, I., Brand-Miller, J., Brighenti, F., Holt, S., Mann, J., Perry, T.L., Venter, C., Granfeldt, Y., Xaomei, W., & Vorster, H. (2003) Determination of the glycaemic index of foods: interlaboratory study. *European Journal of Clinical Nutrition*, 57: 475-482.
- Van Amelsvoort, J.M., & Westrate, J.A. (1992) Amylose-amylopectin ratio in a meal affects postprandial variables in male volunteers. *American Journal of Clinical Nutrition*, 55: 712-718.