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Review

Impact of food processing on the glycemic index (GI) of potato products

Balunkeswar Nayak [a,*], Jose De J. Berrios [b], Juming Tang [c]

[a] School of Food and Agriculture, University of Maine, Orono, ME 04469, USA
[b] Processed Foods Research Unit, USDA-ARS-WRRC, Albany, CA 94710, USA
[c] Department of Biological Systems Engineering, Washington State University, Pullman, WA 99164, USA

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ABSTRACT

Potatoes are one of the most popular carbohydrate foods in industrialized and some developing countries. However, contradicting arguments and misconceptions on potatoes as a high glycemic index (GI) food is directly affecting potato consumption during the past years. Potato varieties, maturity level, starch structure, food processing techniques and composition of the meal contribute to the GI of potatoes. Domestic boiling, baking, microwave cooking, oven cooking, extrusion and frying result in different degrees of gelatinization, and the crystallinity of starch in potato. French fried potatoes contain more resistant starch whereas boiled and mashed potatoes contribute to significant digestible starch. Extrusion processing conditions could affect the starch physicochemical structure and resulting nutritional value. Extrusion cooking makes more gelatinized starch than conventional cooking methods. Cooling or storing after processing of potatoes significantly reduces the GI due to retrogradation of starch molecules. This review provides a brief idea about the glycemic index, glycemic load, and their importance to human diseases, and detail information on the effect of food cooking methods on the glycemic index of potatoes.

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* Corresponding author. Tel.: +1 207 581 1687.
E-mail address: Balunkeswar.nayak@maine.edu (B. Nayak).

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1. Introduction

Potatoes are one of the most popular vegetables used as food in the USA. Per capita consumption of potato in the US was approximately 110.3 lb/person/year. Nearly 80% of consumers eat potatoes in some or other way 3.6 times in every two weeks (National Potato Council, USA, 2013).

According to National Potato Council of United States (2013) processed potatoes account for major consumption since 2011 in the USA (Table 1). Among all potatoes, 26% were consumed as fresh or without processing, whereas the remaining 74% were utilized in some or other forms of processing. Frozen potatoes (40%) were the most consumed processed potato product in the processed category in the USA. However, a decline in potato consumption is observed in recent years in all age groups (USDA, Economic Research Service, 2013). Foods with high GI values are considered potential contributors to mainly the type 2 diabetes (American Diabetes Association, 2002). This conclusion could be misleading as the perception was based on the studies published before the GI of potatoes was well studied.

Potatoes and potato-products yield variable glycemic responses. For example, the published GI values of potato range from very low (23 for an unspecified cultivar) to very high (144 for boiled Desiree) (Foster-Powell, Holt, & Brand-Miller, 2002; Soh & Brand-Miller, 1999). The variation in the GI values of potato-products may be due to a number of factors such as potato cultivar, maturity, starch structure, processing, and storage conditions. Lynch et al. (2007) reviewed the glycemic index of potato focusing some of the above factors and their importance to industry. Among all other factors, processing plays a major role influencing the final GI values of potato products (Fig. 1). The importance of physical activity and its relation to improving human health and reducing risk of chronic diseases by preventing obesity and insulin resistance has been reported (Solomon & Thyfault, 2013; Welty, 2013). This paper aims to provide a general overview of basic information about GI, glycemic load (GL), and the effect of processing on the GI values of potato and potato-products.

2. Glycemic index and human health issues

2.1. Glycemic index determination

Current dietary guidelines recommend that carbohydrates in human diet comprise 45–65% of total calories; and dietary carbohydrate intake come primarily from complex carbohydrates or starches (Institute of Medicine, 2005). The nutritional properties of carbohydrate in foods may be described on the basis of physiological effects: availability for digestion and/or absorption in the gastrointestinal tract, i.e. ability to raise blood glucose. Such classification of the blood glucose raising potential of carbohydrates is referred to as the GI of the food. The GI was introduced by Jenkins and co-workers in the early 1980s, and is a quantitive concept of ranking carbohydrate foods based on the effects of postprandial glycaemia (Jenkins et al., 1981). Venn and Green (2007) reviewed on the issues related to measurement of GI, GL and their effect on diet-disease relationships.

The GI is defined as the incremental blood glucose area following the test food, expressed as a percentage of the response to an equivalent carbohydrate portion of a reference food taken by the same subject (Wolever, Jenkins, Jenkins, & Josse, 1991) as shown in Fig. 2. The World Health Organization (WHO) provides GI methodology guidelines for classifying food according to GI ratings (Table 2) with the protocol stating "to determine the GI of the food, the tests illustrated in Table 3 would be repeated in six more subjects and the resulting GI values averaged. Normally, the GI for more than one food would be determined in one series of tests, for example, each subject might test four foods once each and the standard food three times for a total of seven tests in random order on separate days. Subjects are studied on separate days in the morning after a 10–12 h overnight fast. A standard drink of water, tea or coffee should be given with each test meal". The area under curve (AUC) is calculated according to the trapezoidal rule in geometry. The standard or reference food usually taken is glucose or white bread. The GI rating in percentage is calculated as follows:

$$GI\ rating\ (\%) = \frac{Area\ under\ curve\ (AUC)\ for\ the\ test\ food}{Area\ under\ curve\ (AUC) for\ the\ reference\ food} \times 100$$

Based on the above methodology, GI values of test foods using white bread are approximately 1.4 times than those calculated based on glucose as reference food. The differences in GI could be attributed to the differences in the rate of absorption of the carbohydrates i.e. the slower the rate of carbohydrate absorption, the lower the increase of blood glucose and hence, lower the GI value. For example, carbohydrate foods consumed in isoglucidic amounts produce different glycemic responses (Jenkins et al., 1981).

The postprandial blood glucose response is influenced not only by the GI of the food, but also by the amount of ingested carbohydrate. Therefore, glycemic load (GL) is another parameter to understand the impact of blood sugar upon the carbohydrates and calculated as the GI of the test food multiplied by grams of carbohydrate per serving size. Glycemic index is based on a specific quantity and carbohydrate content of a test food. GL is calculated by multiplying the weighted mean of the dietary GI by the percentage total energy from the test food or grams of carbohydrate per serving. In other words, each unit of dietary GL represents the equivalent glycemic effect of 1 g carbohydrate from a reference food such as white bread (Willett, Manson, & Liu, 2002). A hypothesis on the potential mechanism linking glycemic load with the development of type 2 diabetes is illustrated in Fig. 3. Investigating on the long-term effect of varying the source or amount of dietary carbohydrate on postprandial plasma glucose, insulin, triacylglycerol, and free fatty acid concentrations in subjects with impaired glucose tolerance, however, Wolever and Mehling (2003) reported that reducing the glycemic index or amount of carbohydrate intake in food has no change on postprandial plasma glucose. The same investigators also reported that the observations based on GI and GL separately have a different effect on postprandial insulin, triacylglycerols and free fatty acids.

2.2. In vitro methods

In vitro studies are designed to simulate digestion in the small intestine and measure the rate of starch digestion as an alternative to in vivo testing of the glycemic response to carbohydrate foods. Basically, three classifications of starch most starchy foods contain i.e. (i) rapidly digestible starch (RDS), (ii) slowly digestible starch (SDS), and (iii) resistant starch (RS) was introduced for nutritional purposes (Englyst, Liu, & Englyst, 2007). RDS consists mainly of amorphous and dispersed starch, found in high amounts in starchy foods cooked by moist heat. SDS is expected to be completely digested in the small intestine, but for one reason or another, it is digested more slowly. RS is indigestible by body enzymes. In an in vitro method, the physico-chemical properties of a carbohydrate food are described by measuring the rate and extent of glucose release by enzymatic digestion under controlled conditions (Englyst, Englyst, Hudson, Cole, & Cummings, 1999). Additional tests in an in vitro method might include chewing of test foods by subjects

Table 1
Share of potato utilization in 2011 in USA (National Potato Council, 2013).

	Forms of utilization	% Potato crop
i.	Fresh potatoes (table potatoes)	26.0
ii.	Frozen potatoes (frozen fries, tater tot, spiral fries, home fries, wedges and frozen whole potatoes)	40.0
iii.	Potato chips (including canned shoestring potatoes)	15.0
iv.	Dehydrated potatoes (including extruded potato chips)	11.0

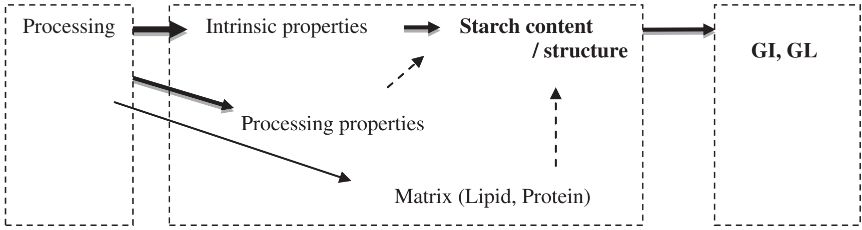

Fig. 1. Mechanism of processing that effect glycemic Index (GI) and glycemic load (GL).

rather than mechanical homogenisation of foods (Akerberg, Liljeberg, Granfeldt, Drews, & Bjorck, 1998; Granfeldt, Bjorck, Drews, & Tovar, 1992), the use of proteolytic enzymes in addition to amylases (Goni, Garcia-Alonso, & Saura-Calixto, 1997) and dialysis tubing to imitate the small intestine (Granfeldt et al., 1992). Investigating on a chemically modified corn, Chunga, Shinb, and Limc (2008) reported that both the in vitro digestibility and estimated glycemic index of starch could be changed by the chemical modifications which are currently practiced for the preparation of food starches, such as oxidation, acetylation, hydroxypropylation, and cross-linking. While cross-linking induced substantial changes in pasting characteristics of starch, it did not affect starch digestibility as much as oxidation or substitutions. The substitution (hydroxypropylation and acetylation) and oxidation contribute in raising the amount of resistant starch (RS) content by decreasing SDS content in prime starch, and decreasing RDS content in gelatinized starch.

Granfeldt et al. (1992) derived a hydrolysis index (HI) by calculating the area under a hydrolysis curve from plotting the rate of glucose released over a period of 180 min using white-wheat bread as a reference. Using the HI method of Granfeldt et al. (1992) to predict the GI of six different potato varieties (Asterix, Bintje, King Edward, Frieslander, Platina and Rocket), which were boiled, Leeman, Barstroem, and Bjoerck (2005) found that the predicted GI was high for all of the varieties irrespective of tuber size. In another method using the techniques of Englyst, Kingman, and Cummings (1992), Kingman and Englyst (1994) reported that digestion rates after processing by different cooking methods (boiling, frying, oven and microwave baking) showed no differences between potato varieties (Marfona, Maris Piper, Belle de Fontenay and Desiree) and between processing methods. Another in vitro study tested a variety of potato products, fresh potatoes, instant mash, crisps and potato flour and all gave a high estimate for the GI value (Garcia-Alonso & Goni, 2000).

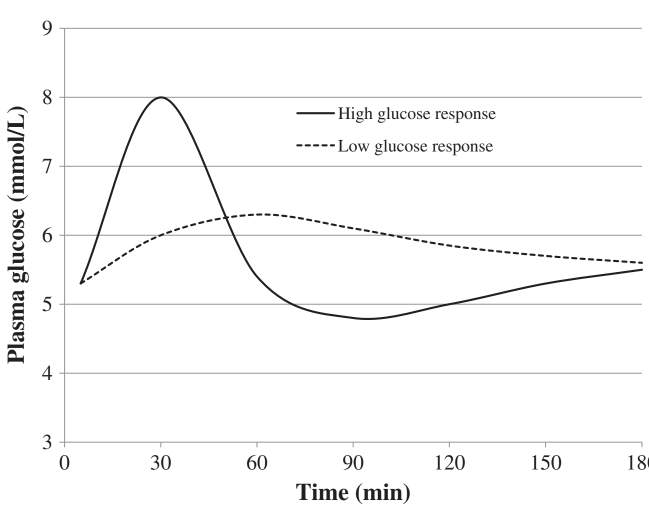

Fig. 2. The area under the curve (AUC) is calculated to reflect the total rise in plasma glucose levels over the time after eating the test food. The GI rating (%) of high or low GI food is calculated by dividing the AUC for the test food by the AUC for the reference food (same amount of glucose) and multiplying by 100 (Wolever et al., 1991).

Recently, an artificial neural network has been designed to predict the GI of unknown food samples. The method used foods with known GI values and tested them using an in vitro method simulating human digestion under both stomach and small intestine conditions. The digestate was analyzed for glucose, fructose, sucrose, lactose, galactose, and maltitol using HPLC. These results were combined with nutritional information (protein, fat and total dietary fiber content) of the test food, and reported or tested in vivo GI values were used as the calibration set of data. The sample set consisted of 72 food types and a correlation of $r^2 = 0.93$ was obtained, indicating a good predictive ability of the method (Magaletta et al., 2010).

Although the in vitro method has been proposed as an alternative method for classifying carbohydrates and correlated with some studies for in vivo GI testing, there are only a few foods that have been subjected to both testing methods for comparison (Araya, Contreras, Alvina, Vera, & Pak, 2002; Englyst et al., 1999; Granfeldt et al., 1992). However, it is noteworthy to mention that all potatoes tested had a high HI, and consequently the predicted GI values were high, regardless of variety, preparation and cold storage time in the above studies. Although in vitro studies may not be a replacement for in vivo studies, they offer considerable benefits in the speed of testing, the potential to use controlled conditions and the freedom to test novel foods and ingredients. The complementary application of these two approaches should provide a clearer understanding of potato digestibility and GI.

2.3. Human health issues

Several health benefits exist for reducing the rate of carbohydrate digestion and absorption by means of a low GI diet. These include: improved blood glucose control (Amano et al., 2007; Brand, Nicholson, Thorburn, & Truswell, 1985; Gilbertson et al., 2001), reduced insulin demand (Frost, Keogh, Smith, Leeds, & Dornhorst, 1998), reduced blood lipid levels in healthy adults (Ma et al., 2006) and patients with diabetes and hypertriglyceridaemia (Jenkins, Wolever, Kalmusky et al., 1987), improved satiety (Raben, Kiens, & Richter, 1994) and increased colonic fermentation (Jenkins, Wolever, & Collier, 1987; Regina et al., 2006). All factors may play important roles in the prevention of several chronic diseases, such as obesity, type-2 diabetes, coronary heart disease and several forms of cancer.

The health benefits of a low GI diet are supported by a number of semi-long-term and long-term studies which suggest that diets characterized by low-GI starchy foods improve factors related to glucose and lipid metabolism in humans (Brand-Miller, 1994). In diabetics, low-GI diet can improve glucose tolerance (Brand et al., 1985; Brand-Miller, 1994). In hyperlipidemic patients, low GI diets can substantially lower the levels of total serum cholesterol and, in particular, of serum triacylglyceride. However, the mechanisms are still unclear. A possible biological mechanism could involve the regulation of insulin sensitivity and glucose levels by low-GI diets. In general, rapidly absorbed carbohydrates trigger a large insulin rise and strongly inhibit glucagon release, followed by a rapid blood glucose fall, often less than fasting levels. This could result in a counter-regulatory response with the release of free fatty acids, creating an insulin-resistant environment and reducing glucose tolerance (Boden et al., 1991; Piatti, Monti, Pacchioni, Pontiroli, & Pozza, 1991). Ingestion of a slow release carbohydrate food produces

Table 2
Examples of comparison of glycemic index and glycemic load of some common foods (The American Journal of Clinical Nutrition, July 2002; International table of glycemic index and glycemic load, University of Sydney (Australia) GI index, Foster-Powell et al., 2002). Reference food: glucose.

		Glycemic index		
		Low (≤55)	Medium (56–69)	High (≥70)
Glycemic load	Low (≤10)	Apples (6, 38)	Beets (5, 84)	Popcorn (8, 72)
		All bran cereal (8, 42)	Cantaloupe (4, 65)	Watermelon (4, 72)
		Carrots (3, 47)	Pineapple (7, 65)	Whole wheat flour bread (9, 71)
		Peanuts (1, 14)	Table sugar (7, 68)	
	Medium (11–19)	Apple juice (11, 40)	Life cereal (16, 66)	Cherrios (15, 74)
		Bananas (12, 52)	Wild rice (18, 57)	Shredded wheat (15, 75)
		Orange juice (12, 50)		
		Sourdough wheat bread (15, 54)		
	High (≥20)	Macaroni (23, 47)	White rice (23, 64)	Baked russet potatoes (26, 85)
		Spaghetti (20, 42)	Couscous (23, 65)	Cornflakes (21, 81)

an attenuated glucose response, so the resulting hormone responses and effects are less dramatic.

Another physiological effect observed is a prolonged satiety following the consumption of low-GI starchy foods, which may contribute to long-term weight loss by reducing the food intake (Ludwig, 2002; Maki, Rains, Kaden, Raneri, & Davidson, 2007). An inverse relationship was noted between the satiety ranking and GI for six cereal products. For example, as a result of high insulin response following a high-GI meal, the hormone environment reduces the availability of two major metabolic fuels (glucose and fatty acids), triggering a rapid return of hunger (Aston, 2006). Many low-GI foods are high in fiber, which slows gastric emptying. This will also increase and prolong the secretion of some gut peptides suggested as potential satiety factors (Burton-Freeman, Davis, & Schneeman, 2002; Pawlak, Ebbeling, & Ludwig, 2002).

Evidence is also emerging of a possible link between the prevention of bowel cancer with low GI foods containing indigestible carbohydrates, such as resistant starch. Such low GI foods can increase the amount of indigestible carbohydrates reaching the large bowel for fermentation by colonic microflora. The fermentation of starch and other indigestible carbohydrates yields short chain fatty acids such as propionic and butyric acids, preferred source of energy for the cells lining the colon shown to inhibit the proliferation of colonic cancer cells in vitro, suggesting a preventive effect against colonic cancers (Scheppach, Fabian, Ahrens, Spengler, & Kasper, 1988).

Several case control and prospective cohort studies suggested a direct association between the GI of diet and incidence of breast cancer (Augustin et al., 2001) and endometrial cancer (Augustin, Franceschi, Jenkins, Kendall, & La Vecchia, 2002; Folsom, Demissie, & Harnack, 2003; Silvera et al., 2005). Carbohydrate intake may influence breast cancer risk by affecting insulin resistance and plasma levels of insulin and glucose (Michels, Mohllajee, Roset-bahmanyar, Beehler, & Moysich, 2007). The associations between GI and endometrial cancer risk are stronger in older women, in overweight women with low physical activity, and in hormone replacement therapy users. These women had greater insulin response to their diet compared with lean and active women. Insulin acts as a cancer promoting agent in vitro and animal studies (Bjork, Nilsson, Hultcrantz, & Johansson, 1993; Tran, Medline, & Bruce, 1996). High GI diets may also increase oxidative stress which may contribute to cancer risk (Augustin et al., 2003; Collins, Duthie, & Ross, 1994). Low GI foods are often high in fiber and rich in antioxidants and other micronutrients that may be protective in carcinogenesis.

Table 3
Sample blood glucose responses to the ingestion of 50 g carbohydrate.

Minute								
	0	15	30	45	60	90	120	IAUC*
Standard #1	4.3	6.3	7.9	5.3	4.1	4.6	4.9	114
Standard #2	4.0	6.0	6.7	5.5	5.3	5.0	4.2	155
Standard #3	4.1	5.8	8.0	6.5	5.9	4.8	3.9	179
Test food	4.0	5.0	5.8	5.4	4.8	4.2	4.4	93

* IAUC: incremental area under curve; IAUC is calculated as the incremental area under the blood glucose response curve.

3. General strategy for producing low GI potato food products

Because of the health benefit of low GI foods, increased consumption is recommended by several health organizations in the management of type 2 diabetes (European Association for the Study of Diabetes, Canadian diabetes Association and Dietitian Association of Australia) and as part of the healthy diet for the general population (FAO/WHO report, 1998). Potatoes are one of the major food items in developed countries, so producing potato-products with low GI would help to reduce the overall GI of the diet in these counties. The development of low GI potato products is a challenge for the potato and food industries.

3.1. Potato cultivar and maturity

Starch is the most abundant constituent in potatoes after water content. The total starch content will determine the true available carbohydrate content in potatoes. Depending on the botanical cultivars, the total starch in potato varies from 70 to 90% on dry basis, leading to the variation in GIs of potato products. Monro, Mishra, Blandford, Anderson, and Genet (2009) reported detailed differences in the rapidly digested, slow digested and resistance starch in New Zealand potato varieties when processed and refrigerated depending on their genotype (Table 4). GI values of peeled and boiled potatoes are reported in the range of 56 (Pontiac) to 101 (Desiree). Very low GI values (23–41) are reported for unspecified cultivars of potatoes grown in Africa, India and Romania (Foster-Powell et al., 2002). Some wild cultivars exhibit smaller GI values than common commercial cultivars grown in Western countries. For example, bush potatoes, pencil yams and cheeky yams grown in Australian Aboriginal regions are slowly digested in vitro and exhibit smaller plasma glucose and insulin responses than commercial potato cultivars (Thorburn, Brand, O'Dea, et al., 1987; Thorburn, Brand, & Truswell, 1987). It may be possible to develop new commercially available low GI potato cultivars by exploring and manipulating the genotype of commercially exotic wild potato cultivars (Soh & Brand-Miller, 1999).

Evaluation of eight selected cultivars of potatoes commonly consumed in the UK presented a strong positive correlation between GI value and texture rating: potatoes with floury textures (low in moisture, low in sugar with high starch) were in the high GI category, while potatoes with firm to waxy (virtually no amylose) textures (high in moisture, low starch) were in the medium category (Henry, Lightowler, Strik, & Storey, 2005). Generally, the earlier crop varieties of potato

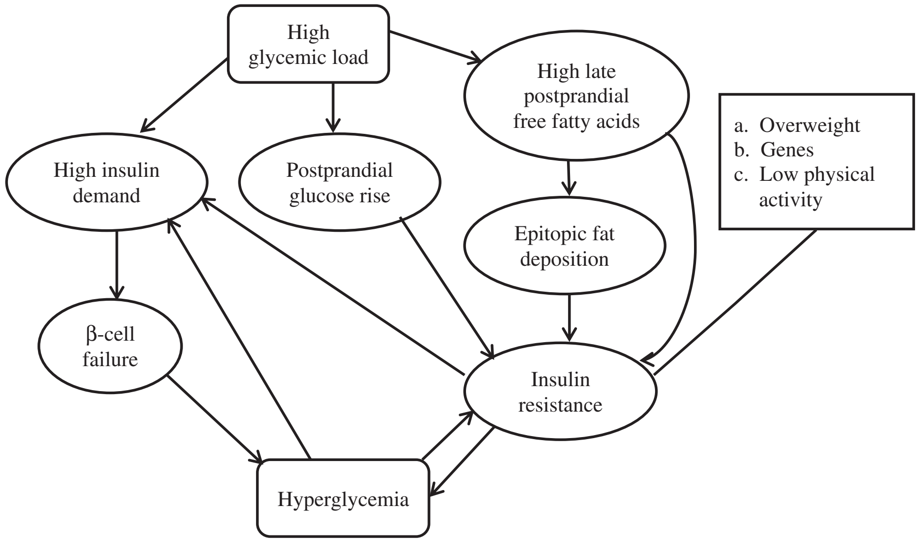

Fig. 3. Potential mechanisms linking a high glycemic load with the development of type 2 diabetes (adapted and modified from Riccardi, Rivellese, & Giacco, 2008).

(second early) and the salad potatoes tend to exhibit waxy textures while the main crop varieties tend to have floury textures.

Potato maturity will also affect the GI of potato products. Small and less mature potatoes tend to have lower GI values than large and mature potatoes. As potatoes mature, the quantity of amylose increases slightly but the degree of amylopectin branching increases significantly. The lower degree of branching in the amylopectin of less mature potatoes may be associated to greater resistance to starch gelatinization, hence resulting in a slower rate of starch hydrolysis in the gastrointestinal tract and to lower GI values (Soh & Brand-Miller, 1999).

3.2. Starch structure

The glycemic index of boiled or baked potatoes in Russet, some Australian, English and Canadian varieties ranges from intermediate to very high i.e. 59–111 (Foster-Powell et al., 2002; Jenkins et al., 1981; Soh & Brand-Miller, 1999; Wolever et al., 1994). Although some investigators argue on possible random error (Wolever and Mehling, 2003), some suggest that the differences could be due to the differences in their starch structures (Brand-Miller, Pang, & Bramall, 1992). Compared to most cereal starches, potato starches in native uncooked granules are poorly digested in the human small intestine and reach the large bowel in considerable amounts. In raw state, 87% of starch in potatoes resist digestion, whereas most cereal starches are slowly but virtually completely digested and absorbed in vivo (Holm, Lundquist, Bjoerck, Eliasson, & Asp, 1988). The crystallinity in granules, smaller surface-to-volume ratio of the large potato granules, and a layer of non-starch barrier material such as polysaccharides on the surface of starch granules result in potato granules less susceptible to digestion enzymes (Bednar et al., 2001).

Another feature of the starch molecule which may influence nutritional properties of starches is the amylose: amylopectin ratio. Under commonly used food processing conditions, linear amylose molecules tend to retrograde and recrystallize, resulting in extensively ordered regions resistant to enzyme digestion and absorption in the small intestine. In addition, enzyme accessibility of high amylose starch is further hindered by incomplete gelatinization and limited swelling of starch granules during processing. Amylose concentration in potato varies little from 24 to 32% with effects of genotype and growing conditions. The simultaneous "antisense" inhibition of two isoforms of starch branching enzyme resulted in a significant increase of apparent amylose content to 60–89%, comparable to commercial available high amylose maize starches (Schwall et al., 2000). The development of potato genotypes with high amylose content opens possibilities to significantly decrease the glycemic response of potato products.

Table 4
Effect of cooking on starch fractions of New Zealand potatoes. Bulked sample of three tubers analyzed in duplicate. Values are expressed in wet weight basis. Adapted from Monro et al. (2009).

Cultivar	Freshly cooked			Cooked and refrigerated		
	RDS	SDS	RS	RDS	SDS	RS
Draga	128	0.0	5.8	80	37	16.6
Frisia	149	10.2	10.5	75	77	14.4
Nadine	90	9.9	9.3	73	24	15.7
Desiree	149	0.5	6.3	92	51	14.0
Karaka	138	2.4	7.6	73	55	19.6
Moonlight	145	2.5	7.0	105	32	16.4
Agria	138	6.8	6.7	89	53	9.6
Fronika	132	17.2	8.1	80	67	10.7
White delight	150	0.0	6.3	111	32	13.8
Mean	135	5.5	7.5	86	47	14.5
S.E.M.	4.4	4.8	0.64	2.8	4.3	2.5
Range	90–150	0–17	5.8–10.5	73–111	20–77	9.6–19.6

RDS: rapidly digested starch; SDS: slowly digested starch; RS: resistance starch.

3.3. Dietary fiber content

Lightowler and Henry (2009) investigated mashed potatoes containing 1, 2 or 3% levels of high-viscosity hydroxypropylmethylcellulose, a modified cellulose dietary fiber and observed significant reduction in glycemic responses in all samples than the standard mashed potato. One of the first food components observed to reduce the glycemic response was dietary fiber (Bjoerck & Asp, 1994; Haber, Heaton, Murphy, & Burroughs, 1977). In 2009, the Codex Alimentarius Commission adopted a definition of dietary fiber which divided dietary fiber into 3 categories: "naturally occurring in the food as consumed"; "obtained from food raw material by physical, enzymatic or chemical means…"; and "synthetic carbohydrate polymers".

A portion of dietary fiber is fermented to volatile fatty acids in the gastrointestinal tract. The addition of viscous dietary fiber to a carbohydrate meal may reduce the glycemic response (Braaten et al., 1991). By forming viscous solutions, soluble fiber delays the rate of gastric emptying, reduces the mixing and diffusion in the small intestinal lumen, and thus reduces the rate of digestion and glucose absorption by the intestine (Fig. 4).

3.4. Lipid

Lipids in potato may also affect the digestibility of starch by the formation of a complex of lipid with amylose. Amylose–lipid can be formed in the presence of both endogenous and added lipids during food processing. Contradictory conclusions were reached by researchers on the effect of complex formation on the digestibility of starch. Holm et al. (1983) reported that amylose–lipid complexes were fully digested and absorbed in the small intestine of rats, whereas Eggum, Juliano, Perez, and Khush (1993) reported that the complexes were not digestible in the small intestine of rats. A possible explanation for such contradictory results was proposed by Larsen et al. (2000). There are two types of amylose–lipid complexes: complex I and complex II. Complex I melts just below 100 °C in the DSC and exhibits little crystalline structure, whereas complex II exhibits a melting temperature well above 100 °C and consists of more crystallites (Biliaderis & Galloway, 1989). The more complete crystal structure of complex II possibly renders it less susceptible to enzymatic degradation. Mercier, Charbonniere, Grebaut, and De la Gueriviere (1980) observed that pure potato amylose and oleic acid formed complexes highly resistant to enzymatic degradation.

3.5. Processing condition

GIs of potato starch can be significantly reduced by chemical modification during processing. Numerous chemically modified food starches are available as ingredients for processed foods. Chemical reactions currently allowed and used to produce modified starches for food use in the United States include esterification, etherification, acid modification, cross-linking and oxidation. Chemical modification may affect the rate and extent of starch digestion in the small intestine. For most modified starches, the level of indigestible starch increases as the degree of modification increases.

Raw potato starch granules have a slower digestion rate as compared with gelatinized starch. When potatoes are processed, potato starch becomes digestible, and the digestibility of starch and resulting glycemic response of potato foods can be affected by the type and extend of processing. For example, the GI of some potatoes were not affected after boiling, microwaving and baking compared with raw/fresh ones, whereas canning of immature potatoes decreased the GI value compared to boiled matured potato (Desiree *cv*) (Lynch et al., 2007). When subjected to thermal treatments such as heating in an aqueous environment, crystallinity within the starch granule melts, and the starch granules swell to a high degree (Cooke & Gidley, 1992) and eventually bursts, especially if shear force is applied. The transition from crystalline to a continuous amorphous or gel phase of starch is called gelatinization. Gelatinized starch is susceptible to enzymatic degradation. Gelatinization helps in digestion and absorption in the small intestine. The metabolic mechanism is well supported by reported increase in blood glucose and insulin by consuming processed foods containing potatoes or potato starch (Brand et al., 1985; Vaaler, Hanssen, & Aagenaes, 1984).

During cooling, some starch molecules partially reassociate to form a network by association of the linear starch fractions, eventually leading to the starch retrogradation. During retrogradation, starch molecules begin to crystallize and resistant starch is formed. Retrograded amylose in potatoes is highly resistant to amylolysis (Ring, Gee, Whittam, Orford, & Johnson, 1988). Repeated cycles of cooling and reheating form progressively more-resistant starch, delaying digestion and absorption, thus reducing the glycemic response. Therefore, reducing GIs of processed potato products can be achieved by controlling the degree of gelatinization and retrogradation through optimizing the food processing techniques.

3.6. Annealing and hydrothermal conditions

Heating starches above their gelatinization temperature results in the simultaneous loss of granular, lamellar, crystalline and double helical order. Heating at sub-gelatinization temperatures preserves granular structures, while other levels of organization are affected (Jacobs & Delcour, 1998; Tester & Debon, 2000). Annealing (ANN) and heat-moisture treatment (HMT) are two hydrothermal methods that have been used to modify starch digestibility. ANN is performed on starch granules in excess (>60% w/w) or at intermediate water content (40% w/w) and held at a temperature above the glass transition temperature (Tg) but below the onset (To) temperature of gelatinization for a set period of time (Hoover & Vasanthan, 1994; Tester & Debon, 2000). HMT is also a physical modification technique that involves the treatment of starch granules at low moisture levels (<35% moisture w/w) for a certain time period (15 min–16 h) and at temperatures (84–120 °C) above Tg but below the gelatinization temperature. ANN

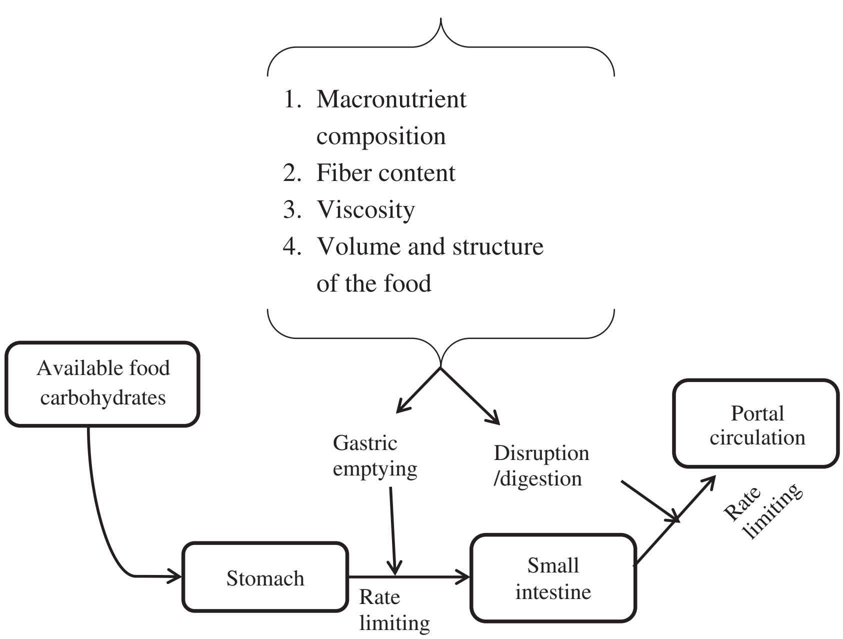

Fig. 4. Factors influencing the rate of digestible carbohydrate availability in the gastrointestinal tract (modified from Riccardi et al., 2008).

can modify starches by narrowing of the gelatinization temperature range, increasing gelatinization temperatures, increasing granule stability, crystalline perfection, decreasing granular swelling, starch chain interactions within the amorphous and crystalline domains of the granule, formation of double helices, and decreasing amylose leaching (Hoover & Vasanthan, 1994; Jacobs & Delcour, 1998; Tester & Debon, 2000). HMT also increases gelatinization temperatures, widens the gelatinization temperature range, decrease granular swelling and amylose leaching, and increase in thermal stability in all starches (Gunaratne & Hoover, 2002; Hoover & Manuel, 1996).

Several attempts to generate RS by ANN and HMT have been reported in the literatures (Brumovsky & Thompson, 2001; Haralampu, 2000; Lehmann & Robin, 2007; Sajilata, Singhal, & Kulkarni, 2006; Vasanthan & Bhatty, 1998). Both treatments increase gelatinization temperatures of potato starches. Annealing narrows gelatinization ranges, while HMT increases the temperature range over which gelatinization is observed (Jacobs & Delcour, 1998; Tester & Debon, 2000). Annealing of potato starch does not (Karlsson & Eliasson, 2003) or only moderately (Nakazawa & Wang, 2003) increase enthalpy of gelatinization. HMT reduced the gelatinization endotherms and lowered total crystallinity of potato starch (Gunaratne & Hoover, 2002; Hoover & Vasanthan, 1994). Shin, Kim, Ha, Lee, and Moon (2005) showed that the hydrothermal treatment (50% moisture at 55 °C for 12 h) of sweet potato starch increased the SDS level from 15.6% to 31.0%. Chung, Liu, and Hoover (2009) have investigated the impact of annealing (ANN) and heat-moisture treatment (HMT) on rapidly digestible starch (RDS), slowly digestible starch (SDS), resistant starch (RS), and expected glycemic index of corn, pea, and lentil starches in their native and gelatinized states. ANN was performed at 70% moisture at temperatures 10 and 15 °C below the onset (T_o) temperature of gelatinization for 24 h, while HMT was done at 30% moisture at 100 and 120 °C for 2 h. The same investigated and observed that amylopectin structure and interactions formed during ANN and HMT had a significant impact on RDS, SDS, RS and expected GI levels of starches. In the above study, ANN and HMT increased RDS, RS and expected GI levels and decreased SDS levels in granular starches. In gelatinized starches, ANN and HMT decreased RDS and expected GI, but increased SDS and RS levels.

3.7. Food matrix and additives

Several studies suggest that different GI values are obtained from a food when eaten alone or included in a mixed meal (Calle-Pascual, Gomez, Leon, & Bordiu, 1988; Hollenbeck & Coulston, 1991), while Wolever (1990) reports that in a mixed meal with bread, rice and pasta the relative rankings of the index remained the same and explained 90% of the observed glucose and insulin response. Sugiyama, Tang, Wakaki, and Koyama (2003) found that the ingestion of milk with rice resulted in a significantly lower GI than when rice was eaten alone. Schafer, Schenk, Ritzel, Ranmdori, and Leonhardt (2003) demonstrate a significant ($P < 0.05$) reduction in the glucose response in a mixed meal with potato and peas compared with a potato only meal. Both fat and protein in a meal have been shown to moderate the influence of carbohydrate on the glucose response (Gullfford, Bicknell, & Scarpello, 1989). A study using common toppings on baked potatoes found that the co-ingestion of fat lowered the GI of potatoes (Estima) by 58%, changing the GI classification from high GI to low GI whereas co-ingestion of protein only lowered the GI of potatoes by 18% with the classification remaining as high GI (Henry et al., 2005). Glycemic index is also affected by food consumed at prior meals. Legumes consumed at a preceding meal lower the GI of carbohydrates consumed in a subsequent meal (Wolever, Jenkins, Ocana, Rao, & Comer, 1988). It is clear that combining foods does influence GI and that the addition of protein and fat to a carbohydrate containing meal can appreciably reduce the glycemic response (Collier & O'Dea, 1983).

The presence of some additives has influenced the GI of potato products. For example, Leeman et al. (2005) reported that the addition of vinegar and olive oil in the form of a vinaigrette dressing to cooked and cooled Sava potatoes in a salad reduced the GI by 43% compared to the boiled potatoes served hot, whereas refrigeration alone reduced the GI by 26%. In a separate study, acetic acid (vinegar) in the test meal reduced postprandial glycemia by reducing the rate of gastric emptying (Liljeberg & Bjorck, 1998). Thus, aggregating the GIs of individual components of a meal does not reliably predict the observed GI of the meal as a whole.

4. Food properties related to GI as affected by processing

4.1. Processing/cooking

Processing conditions alter postprandial glucose responses of starch by disrupting the cell wall and structure of the granule and gelatinization increases the glycemic index (Fernandes, Velangi, & Wolever, 2005). Minimizing or controlling the degree of gelatinization may increase the degree of crystallinity within the starch granules. Minimal roasting instead of extensive steaming prior to flaking will also maintain high crystallinity in finished products. For example, the glycemic response of roasted flaked product was similar to the glycemic response of raw wheat flakes (Bjorck, Liljeberg, & Ostman, 2000).

Garcia-Alonso and Goni (2000) conducted a detailed study on selected starch quantities of potatoes exposed to various processing conditions (Table 5). Obviously, raw fresh potatoes contain the least digestible starch (10%), whereas boiled and mashed potatoes are more digestible with 78 and 70% of digestible starch. However, French fries contain around seven percent of resistant starch. The resistant starch of fried potatoes may be partly attributed to the formation of amylose–lipid complexes resistant to amylolysis.

The degree of gelatinization and starch digestibility are determined by the initial moisture content in raw foods and the amount of water added during heat treatment. Quantitative changes in various starches during selected processing conditions depend on the availability of water. Baking and deep fat frying limit the water availability and thus fried and baked potatoes exhibit lesser quantity of total starch compared to the raw and boiled potatoes. Simultaneously, the amount of resistant starch also decreases in frying potatoes immediately after frying and increases thereafter during cooling with the retrogradation (Goni, Bravo, Larrauri, & Saura-Calixto, 1997). Quantitatively, raw potatoes exhibit high resistant starch that decreases with the increase in degree of gelatinization. The presence of sufficient water for complete gelatinization of starch during boiling improves digestibility reducing the RS. Highest digestibility was observed in boiled and mashed potatoes compared to other processed potatoes (Garcia-Alonso & Goni, 2000). This was well supported by Lunetta, Di Mauro, Crimi, and Mughini (1995) who observed a much lower incremental glycemic response with baked potatoes than with boiled one. Three varieties of boiled Australian potatoes had glycemic index ranging from 87 to 101 (Soh & Brand-Miller, 1999), some baked Russet potatoes had higher glycemic index of 111 (Foster-Powell et al., 2002), whereas glycemic index of boiled English new potatoes and boiled or baked Canadian potatoes had intermediate values ranging from 59 to 70 (Jenkins et al., 1981; Wolever et al., 1994).

In contrast, Wolever et al. (1994) found no significant difference in boiled, baked or canned potatoes and Soh and Brand-Miller (1999) as well as Tahvonen, Hietanen, Sihvonen, and Salminen (2006) also supported the fact and could also not significantly differentiate the GI in boiled, baked, microwaved or mashed potatoes (Table 6). In addition, Table 7 provides brief GI values of various processed potatoes as reported by various investigators. The variation in the GI could be due to botanical differences, time of measurement after cooking and consideration of different reference foods. Different peeling, cubing, slicing or mashing methods had not affected the GI value of potato in various processing conditions (Tahvonen et al., 2006).

Table 5
Different starch quantities in various process conditions. Adapted from Garcia-Alonso and Goni (2000).

Potato	Total starch (%)	Resistible starch		Digestible starch*		Moisture (%)
		Absolute %	% w.r.t TS	Absolute %	% w.r.t TS	
Raw	79.36	69.05	86.9	10.31	13.0	81.25
Boiled	79.36	1.18	1.5	78.18	98.5	81.25
Boiled and cooled	75.18	4.63	6.2	70.55	93.8	79.43
Raw flakes	71.97	2.80	3.9	68.57	95.3	8.59
Mashed	71.97	2.08	2.9	69.89	97.1	86.23
Oven-cooked	65.91	3.70	5.6	62.20	94.4	79.63
French fries	59.34	6.64	11.2	52.70	88.8	17.69
Crisps	65.42	3.27	5.0	65.15	99.6	2.57
Retrograded potato flour	79.36	10.38	13.1	68.98	86.9	4.32

Total starch, resistible starch and digestible starch are in expressed on dry basis.
NB: whole potatoes, instant mash potatoes, potato crisps and retrograded potato flours were purchased separately from the supermarket.
* Digestible starch is the difference between total starch and resistible starch.

4.2. Extrusion process conditions and GI of potato products

Extrusion cooking has been used for the fabrication of breakfast cereals, pasta products, snack foods, baby foods, flat breads, and pre-cooked flours. Among all components in potato flour, starch plays a key role during extrusion. Upon heating and shearing during the extrusion process, the starch granules are fragmented, the granular crystallinity is decreased and partial depolymerisation occurs, which result in a uniform viscous starch fluid which can be described as a concentrated suspension of fractured granules embedded in a continuous and deformable matrix (Barron, Buléon, Colonna, & Della Valle, 2000). Extrusion processing conditions of temperatures, moisture addition (starch to water ratio) and screw speed, among others, will affect the changes in starch physical and chemical structure, and subsequently the GIs of the final extruded products.

4.2.1. Gelatinization of starch granules

Due to the high temperatures and pressures applied during the process, extrusion cooking makes starch granules in potato more damaged and gelatinized, thus more digestible than conventional-cooking methods such as boiling or baking (Brand et al., 1985). Although the degree of starch gelatinization of extruded products is normally large, variations in degree of gelatinization were observed when processing at selected extrusion conditions.

Extrusion conditions that increase barrel temperature, shear and pressure tends to enhance the degree of gelatinization. The effect of feed moisture content on the degree of starch gelatinization is more complicated than the previously indicated extrusion conditions. Increasing the moisture content in the low moisture range (<40%) or decreasing the moisture content in the high moisture range (>40%) led to increase in the degree of gelatinization of sago starch (Govindasamy, Campanella, & Oates, 1996). Extruding starch at low moisture content may restrict the material flow inside the extruder barrel, increase the viscosity and residence time, subsequently increasing the degree of gelatinization. At high moisture content, with excess water acting as a lubricant, the viscosity of the starch is low, allowing for extensive internal mixing and uniform heating, accounting for enhanced gelatinization.

A similar effect of screw speed on the degree of starch gelatinization has been reported. Increasing extruder screw speed above 410 rpm resulted in a rise in the degree of starch gelatinization (Govindasamy et al., 1996). The possible reason for this observation tends to be related to the swelling of the starch granule. The authors indicated that the swollen granules were increasingly susceptible to disintegration by the high shear developed in the extruder during processing. Raising the screw speed above 410 rpm tends to increase the shear rate and lower the residence time of the material under process. Moreover, the shearing action presumably predominates over residence time accounting for starch swelling and enhanced gelatinization of the starch observed under this condition. Parada and Aguilera (2009) investigated on in-vitro digestibility and glycemic response of isolated potato starch in relation to granular size and degree of gelatinization and observed that the degree of gelatinization of starch strongly affects its digestibility in vitro and influences postprandial glycemic response.

Table 6
Effect if variety, cooking method and maturity on the glycemic index values of potatoes compared to reference foods as tested with 10 subjects. Adapted from Soh and Brand-Miller (1999).

Item	Glycemic index (mean ± s.e.m.)	
	White bread = 100	Glucose = 100
Variety		
Sebago, peeled and boiled	124 ± 10	87 ± 7
Desiree, peeled and boiled	144 ± 22	101 ± 15
Pontiac, peeled and boiled	125 ± 13	88 ± 9
Cooking method		
Pontiac, peeled and boiled	125 ± 13	88 ± 9
Pontiac, peeled, boiled and mashed	130 ± 13	91 ± 9
Pontiac, peeled and microwaved	112 ± 13	79 ± 9
Pontiac, peeled and baked	133 ± 15	93 ± 11
Maturity		
New, unpeeled and boiled	112 ± 17	78 ± 12
New, canned and microwave heated	93 ± 13	65 ± 9

4.2.2. Molecular weight degradation

Starch molecules are also depolymerized during extrusion processing. Therefore, extrusion cooking of potato starch provides an alternative to enzymatic methods for production of linear maltodextrins for infant foods. Both amylose and amylopectin molecules are susceptible to molecular weight degradation, with the larger and branched amylopectin being the more susceptible. The molecular degradation of the linear (alpha 1–4 glucose polymer) amylose occurs during extrusion mainly at a consequence of high shear effect (Sagar & Merrill, 1995).

The molecular weight degradation of starch influences many properties of starch-based products, including nutritional values, but the mechanisms are not well understood. Among low molecular weight carbohydrates produced from thermal degradation are highly reactive anhydro-compounds, e.g. 1, 6-anhydrosaccharides, which may react with starch or fragmented starch through transglycosidation reactions to form branched glucans which are partly resistant to amylolytic enzymes (Theander & Westerlund, 1987). The formation of indigestible starch fragments may contribute to the increase of dietary fiber after the extrusion of cereal grains (Theander & Westerlund, 1987) but this finding was not corroborated by Politz, Timpa, and Wasserman (1994).

Strong positive correlation between specific mechanical energy (SME) and starch molecular weight degradation during extrusion was observed (van den Einde, Akkermans, van der Goot, & Boom, 2004). In general, decreasing the moisture content, increasing the mechanical shearing and increasing the temperature resulted in an increase in degradation. The decrease in intrinsic viscosity at low temperatures and moisture contents was only dependent on the maximal shear stress.

Table 7
Glycemic index* of potato with different conventional processing conditions.

Reference	Boiled	Baked	Roasted	Mashed	French fries	Microwave
Foster-Powell & Brand-Miller, 1995	64	53	55	74	38	–
Garcia-Alonso & Goni, 2000	71	48	53 (crisped)	77	40	–
Fernandes et al., 2005	–	72	73	88	64	–
Tahvonen et al., 2006	74 ± 28 (fresh)	68 ± 21 (fresh)		76 ± 30 (fresh)	–	–
Wolever et al., 1994	59–64	–	–	88	76	–
Soh & Brand-Miller, 1999	88 ± 9	93 ± 11		91 ± 9		79 ± 9
Foster-Powell et al., 2002	–	–	–	74–97	–	–

* Glucose as reference food.

At higher temperatures, thermo mechanical breakdown could be split into mechanical breakdown depending on maximal shear stress and thermal breakdown. Greater moisture content during thermo mechanical treatment resulted in more thermal breakdown and decreased the shear stresses required for mechanical breakdown. A model for the mechanical degradation of starch during single-screw extrusion was developed by Davidson, Paton, Diosady, and Rubin (1984). A first-order relationship between the extent of degradation and the product of the residence time and the nominal shear stress was given. Pretreatment of starch by steeping the cereal grains to achieve 20% moisture level resulted in small losses of starch through molecular degradation during extrusion.

4.2.3. Retrogradation

An increase in resistant starch content in extruded products can also be promoted by retrogradation. However, the literature on formation of resistant starch during extrusion presents contrasting results (Huth et al., 2000; Parchure and Kulkarni, 1997; Unlu & Faller, 1998). Generally, increasing amylose content of starch can promote the formation of resistant starch, supported by observation of the increase in resistant starch in extruded high-amylose barley flour, but not in low-amylose barley flour. Unlu and Faller (1998) also reported formation of resistant starch during extrusion of corn meal blended with high amylose maize starch.

The shearing action of the extruder screw, which results in degradation of amylose into smaller molecules that were not incorporated into a crystalline structure, resulted in less formation of resistant starch (Gidley et al., 1995). A negative correlation between formation of resistant starch and screw speed was reported by Unlu and Faller (1998).

4.2.4. Amylose–lipid complex

The formation of a complex between amylose and fatty acids in extruded material was suggested by NMR, differential scanning calorimeter, Iodine Spectrum and X-ray diffraction (Mercier, Charbonniere, Gallant, & Guilbot, 1979). Such interaction leads to structural reorganization of amylose chains from spiral to helix, resulting from the fatty acids penetrating the helical cavity of the amylose and forming a complex. The amylose–lipid complex was only detected in starch containing both amylose and lipid, but not in extruded potato starch free of lipid or waxy starch free of amylose (Mercier et al., 1979). This formation results in thermally stable and water-insoluble starch, and reduces starch digestibility. The amylose complex was resistant to a-amylase in vitro. With increasing amylose content, there was a decrease in the rate of amylolysis after extrusion. When added to high amylose starch, monoglycerides and linear free fatty acids are more likely to form complexes than do triglycerides and phosphatides (Bhatnagar & Hanna, 1994; Mercier et al., 1980). In general, conditions of low moisture content, high temperature, high viscosity and longer residence time favor complex formation in the extruder (Ho & Izzo, 1992).

4.3. Effect of cooling and storage on GI

The amount of resistant starch was increased when boiled potatoes were stored in a refrigerator (Akerberg et al., 1998). Cold storage of potatoes has been demonstrated to affect the starch bioavailability in vivo (Garcia-Alonso & Goni, 2000; Leeman et al., 2005). Fernandes et al. (2005) observed that the consumption of hot red potatoes (GI = 89) released more blood (40%) glucose than that of cold red potatoes (GI = 56) and pre-cooked, frozen and reheated before consumption, French fries gave less GI value than when consumed immediately after cooking (Table 8). GI of Baked (GI = 72) and roasted white potatoes (GI = 73) that were consumed immediately after cooking (Wolever et al., 1994) were more than the baked and boiled white potatoes (GI = 59–64) that were pre-cooked and reheated (Fernandes et al., 2005). Similarly, reduction in rapidly digested starch compared to slowly digested starch is observed when cooked and refrigerated compared to freshly cooked in some varieties of New Zealand potatoes (Table 4). So precooking and reheating potatoes before consumption will produce a smaller glycemic response compared with potatoes consumed immediately after cooking. Englyst and Cummings (1987) also suggested that recurrent heating and cooling result in more resistant starch that directly impacts the glycemic response by slowing digestion and absorption. Tahvonen et al. (2006) reported a significantly smaller GI in cold potatoes than the GI of hot-steamed boiled potatoes. The quantity of total

Table 8
Incremental area under curve and glycemic index values for 50 g available carbohydrate portions of white bread and seven potatoes tested in 12 subjects. Adapted from Fernandes et al. (2005).

Potato tested	Area under curve (mmol × min/L)	Glycemic index	
		White bread = 100	Glucose = 100
White bread	174 ± 18^{xy}	100^{xyz}	71^{xyz}
Baked Russet potato	178 ± 25^{xy}	107.7 ± 12.3^{xyz}	76.5 ± 8.7^{xyz}
Instant mashed potato	206 ± 23^{x}	123.5 ± 11.3^{xy}	87.7 ± 8.0^{xy}
Roasted California white potato	165 ± 20^{xy}	101.8 ± 11.6^{xyz}	72.3 ± 8.2^{xyz}
Baked PEI white potato	178 ± 21^{xy}	102.5 ± 6.4^{xyz}	72.8 ± 4.5^{xyz}
Boiled red potato (hot)	208 ± 20^{x}	125.9 ± 10.1^{x}	89.4 ± 7.2^{x}
Boiled red potato (cold)	135 ± 18^{y}	79.2 ± 7.4^{z}	56.2 ± 5.3^{z}
French fried potatoes	155 ± 19^{xy}	89.6 ± 7.7^{yz}	63.6 ± 5.5^{yz}

^{xyz}Means in the same column with different superscript are significantly different ($P < 0.05$).
PEI—Prince Edward Island.

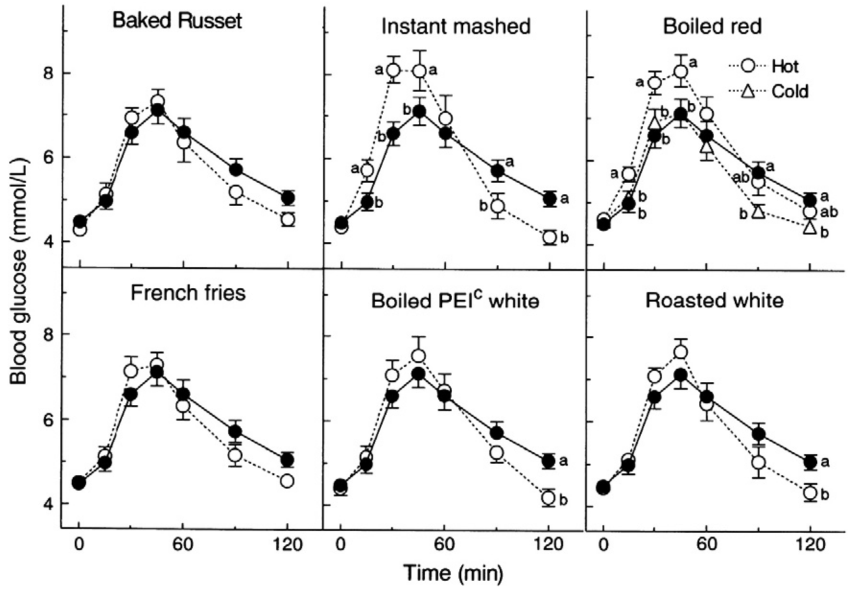

Fig. 5. Blood glucose response of different varieties of potatoes (open symbols, dotted lines) calculated from 50 g available carbohydrate portions present compared to white bread (closed circle, solid lines). Adapted from Fernandes et al., 2005. [ab]Means at the same time point with different letters are significantly different (P < 0.05). [c]PEI—Prince Edward island.

digestible starch in the consumable food is responsible for the release of glucose into blood (Fernandes et al., 2005).

With cooling or storing of potatoes for 24 h, the quantity of initial resistant starch (1.18%) in boiled potatoes increased to 4.63%. Cooling the outer portion of French fries also affected the overall resistant starch. Resistant starch observed in the whole sample of French fries (5.16%) was more than the resistant starch (1.17%) in the internal part only (Garcia-Alonso & Goni, 2000). The investigator also observed a high RS content in retrograded potato flours. A comparison of cold vs. hot red potato consumption on postprandial glucose level (Fig. 5) showed that cold potatoes elicited nearly a 405 lower response than that of hot potatoes (Fernandes et al., 2005). For example, 7% resistance starch in cooked potato increases to about 13% upon cooling (Englyst et al., 1992). Therefore, cooling boiled potatoes forms resistance starch that is not digested in the small intestine and does not contribute to blood glucose response.

5. Summary

The benefits of a low GI food in reducing insulin demand, improving satiety, improving blood glucose control with diabetic people, reducing blood lipid level and increasing colonic fermentation are well documented. Potatoes are a major food item in developed countries, and producing potato food products with low GI will help to reduce the overall GI of the diet in these countries. Potato and its products produced variable glycemic responses, depending on potato cultivars, maturity, starch structure, processing method and extend. GI of potatoes may be significantly reduced by manipulating the genotype of exotic potato cultivars and the development of potato genotypes with high amylose content. Food processing plays an important role in the control of the GI of potato products. The GI of potato products can be reduced by optimizing the food processing conditions. For example, precooking and reheating or consuming processed potatoes in cold condition may result in reduced glycemic responses. Conditions known to decrease the digestibility of potato starch and subsequent GI responses are those which decrease the starch granule damage and gelatinization, increase lipid–amylose formation and increase starch retro-gradation during cooling and storage. Human lifestyle and daily activities effect on the type 2 diabetes. In future, studies on the interactions between exercise, diet, timing of consumption, conditions of foods and type 2 diabetes related diseases would be needed to understand the mechanism of glycemic index in health.

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