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Technological treatments of cereals. Repercussions on the physiological properties of starch

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The structural and physicochemical properties of starches in cereal food vary continuously according to the starch characteristics (botanical origin, amylopectin/amylose ratio, etc.), the food water content, the temperature and the other food components (fibres, proteins, lipids, etc.). The starch characteristics, digestibility (rate of available starch fraction) and thus nutritional properties (transit time, food glycaemic and insulinaemic indexes) can be modified by industrial hydrothermic processing (i.e. panification, pastification, extrusion cooking, etc.). In cereal products, one fraction — the 'resistant starch' (RS) fraction — is not digestible, whether *in vitro* or *in vivo*. Four different RS fractions have been identified in the cereal products; they are the native starch, the retrograded amylose, the amylo-lipid complex and the encapsulated gelatinized starch. The amount and quality of the RS fractions in cereal food can be modulated by industrial processing. After reaching the large intestine, the RS fractions are fermented by the colonic flora, resulting in short chain fatty acids (SCFA). In SCFA, the RS profiles, compared to that of the conventional fibres, are lower in acetate and higher in butyrate. The SCFAs are an energetic fuel to the colonic cells (butyrate) and to the body as a whole (acetate and propionate). Further studies on human nutrition are needed to appreciate the nutritional consequences (insulin sensitivity and glucose tolerance, lipid metabolisms and impact of colonic cell) of industrial processing and its impact on starch availability.

INTRODUCTION

For centuries, wheat (*Triticum aestivum* and *Triticum durum*) in the West and Middle East, rice (*Oriza sativa*) in Asia, corn (*Zea mays*) in America, and Sorghum (*Sorghum vulgare*) and millet (*Panicum* L.) in Africa, have formed the major staple food. Originally, the climatic conditions were accountable for the geographical distribution of cereals. Specific varieties can now be used and all the cereals can be acclimatized anywhere in the world. Starch is the major component of cereal (40–90% dry matter); its main nutritional property is to provide energy (4·4 kcal/g).

Starch consists of two glucose polymers: amylose and amylopectin. The physical arrangement of amylose and amylopectin in food and the interrelation and interaction between starch molecules and other food components (protein, fibres, lipids, etc.) determine the physicochemical and functional properties of starch and thus its susceptibility to α-amylase and its bioavailability. Hydrothermic food processing has a major impact on starch availability. The arrangement of starch components changes continuously under the influence of the hydrothermic parameters, during both food processing and storage. The main role of food starch physicochemical characteristics is to determine the nutritional properties of starchy food.

The fraction of starch digested in the small intestine provides glucose and thus energy (4 kcal/g) to the whole body. The clear-cut differences between glycaemic or insulinaemic starchy food indexes are essentially the result of a specific digestive behaviour of starch. Moreover, in the long term, the absorption rate of the dietary carbohydrate glucose seems to play a decisive

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role on the glucose and lipid metabolisms of both healthy and unhealthy subjects. The rate at which starch glucose is absorbed by the small intestine depends on the gastric emptying and starch digestibility rates. Both digestive phenomena vary greatly according to food starch characteristics, i.e. solid/liquid form of starchy food, size of particle, starch paste viscosity, α-amylase susceptibility, etc.

The fraction of starch which reaches the large intestine, or the resistant starch (RS) fraction, has a digestive fate similar to that of the dietary fibre components. The RS fraction is completely or partially fermented by the colonic microflora. This colonic metabolism produces gas (hydrogen, methane, carbon dioxide) and short-chain fatty acids, or SCFAs (acetate, propionate, butyrate). Short chain fatty acids are readily absorbed by the colonic mucosa and can affect nutrition. Butyrate has a trophic effect on colonic mucosa and constitutes the fuel of the colonic cell. Acetate and propionate are believed to affect glucose and human cholesterol metabolisms. The different natures of RS that have been identified in starchy food are all the consequence of some specific food processing.

THE STARCH GRANULE AND ITS MODIFICATION ACCORDING TO HYDROTHERMIC FOOD PROCESSING (FIG. 1)

Native starch (Fig. 2)

Starch consists of two glucose homopolymers — amylose and amylopectin. Amylose contains $\alpha(1 \rightarrow 4)$ linked glucose units. Its structure is linear. The polymerization degree of starch ranges, according to starch origin, from 600 to 6000 units of glucose. Amylopectin has a branched structure with $\alpha(1 \rightarrow 6)$ linked glucose units at the branch point and $\alpha(1 \rightarrow 4)$

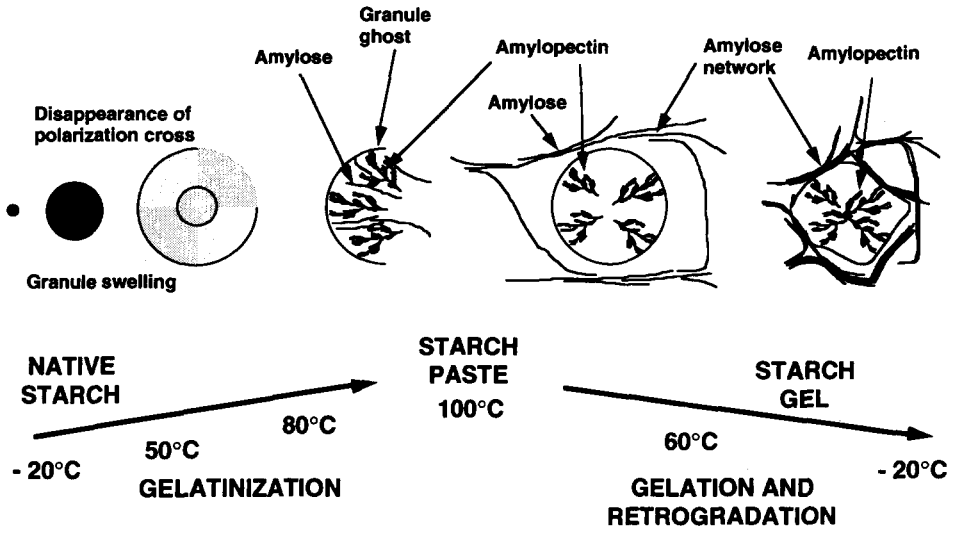


Fig. 1. Influence of hydrothermic processing on physical starch characteristics.

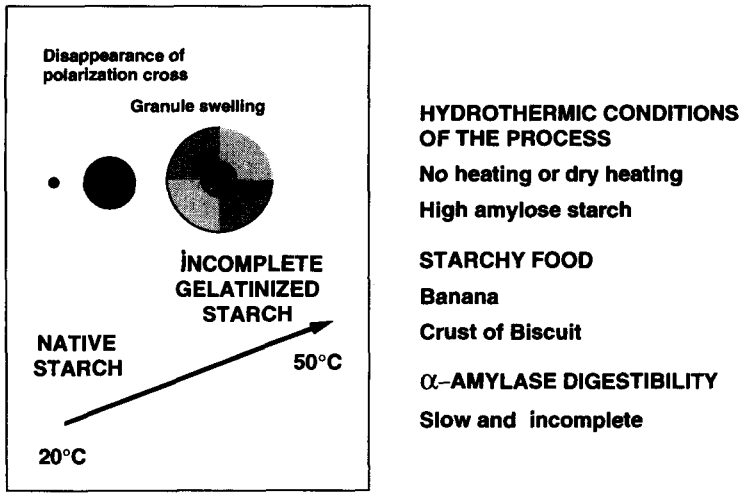


Fig. 2. Native starch or partial gelatinized starch.

links in linear parts. The proportion of $\alpha(1 \rightarrow 6)$ links in the amylopectin is 5-6%. A macromolecule of amylopectin may consist of up to 10^6 glucose units. Starch granules contain different ratios of amylose and amylopectin, depending on their botanical origin. Cereal starches have an amylose content ranging from 15 to 28%. The amylopectin content in waxy maize reaches nearly 100%. The amylose content of some high amylose maize starches ranges from 50 to 70-80%. Native starch in the granule form is insoluble in cold water. When observed under polarized light, an aqueous suspension of starch gives rise to a characteristic polarization cross, proving its microcrystalline structure. The crystalline structure can also be observed using X-ray diffractometry and differential scanning calorimetry (DSC). The X-ray diffractometry of cereal starch granules leads to an A-type spectrum when the amylose content is normal and to a B-type when the amylose content is high (50-70%) (Gallant *et al.*, 1992). The structure is maintained by hydrogen bonds between the starch chains. Under dry heat conditions, starch granules are not disrupted and the polarization cross remains unchanged. Native starch granules are slowly attacked by salivary and pancreatic amylases. All the mechanical processes that cause fissures to appear on the starch surface increase the starch susceptibility to α-amylase.

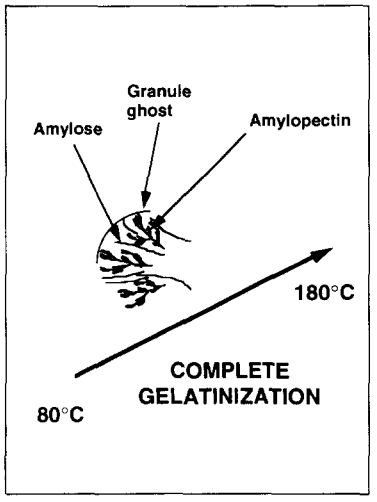
In the cereal biscuit, a significant amount of starch granule is not gelatinized in the crust because of the dry heat at the surface of the biscuit during cooking. High levels of native starch are also found in the most commonly consumed raw banana, particularly when it is still green.

Gelatinization of starch and starch paste (Fig. 3)

Starch is not usually eaten in its native state; it normally undergoes an initial step of gelatinization. Dramatic changes occur in the structure of the starch granule when it is heated in the presence of water (Colonna *et al.*, 1992). The first change is the loss of the polarized cross. As temperature increases, hydrogen bonds are disrupted and water is absorbed by the starch granules. This swelling is followed by a step of amylose leaching. The starch is progressively solubilized, gradually increasing the solution viscosity. The gelatinization step leads to the formation of a starch paste. This state of utmost disorganization is a function of the gelatinization temperature, which varies according to the starch origin (Guilbot & Mercer, 1985) from 65 to 85°C. Usually, the gelatinization temperature of the cereal starches is higher than that of the tuber starches (potato, tapioca). The gelatinization temperature of high amylose maize starches rise above 100°C. At the same time, starch α-amylase susceptibility increases dramatically.

Starch gel and retrograded starch (Fig. 4)

As temperature decreases, a gel forms progressively, under the action of the system, consisting of the remaining wrapping of the starch granules (ghost particle) enriched in amylopectin, following immersion in a high amylose content solution: this is called the gelification step. A rearrangement between starch chains occurs and a tridimensional network is rapidly constituted. The higher the starch amylose content, the harder the starch gel. Hardness is indicated by Young's modulus which is determined on an Instron testing machine. The starch α-amylase susceptibility of a gel is lower than that of a paste. As starch chains rearrange, hydrogen bonds between the chains reappear and a new crystalline structure is created: this is the retrogradation phenomenon. Whatever the initial starch, the new crystalline structure gives a B-type spectrum in X-ray diffractometry.



PROCESSES

Baking, Extrusion Cooking, Drum Drying,...

STARCHY FOOD

Mashed potatoes, Crumb of bread

Instant flour cereals, Breakfast cereals

HYDROTHERMIC CONDITIONS OF THE PROCESS

T°C > 100 - 180 °C - High moisture

STARCH CHARACTERISTICS

Disrupted starch structure

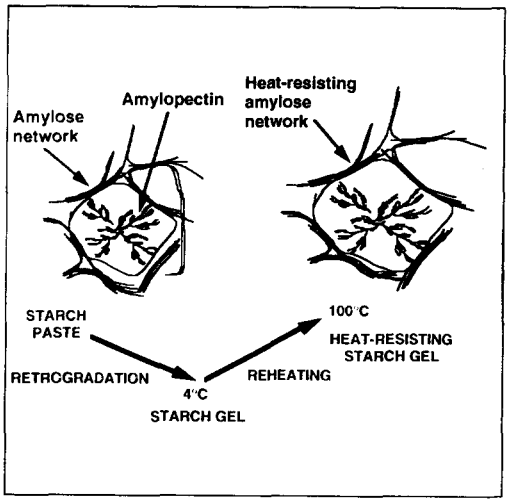
Dextrinized starch

High solubility

α-AMYLASE DIGESTIBILITY

Rapid, high and complete

Fig. 3. Gelatinized starch with disrupted structure.



PROCESS
Pastification
STARCHY FOOD
Mung bean noodles
HYDROTHERMIC CONDITIONS OF THE PROCESS
1° step : Gelatinization (T °C > 100 - High moisture)
2° step : Cooling
STARCH CHARACTERISTICS
High amylose starch
Heat-resisting amylose network
Low solubility and swelling
α–AMYLASE DIGESTIBILITY
Slow but nearly complete

Fig. 4. Heat-resisting starch gel.

In the process of time, starch gel retrogradation increases. It is all the more marked if the gelatinization of the starch has been conducted well, i.e. at high temperatures and high moisture conditions and under prolonged and effective stirring. The other factors that promote retrogradation are the high amylose content, the low starch gel moisture and the low storage temperature (4°C). In the case of starch paste, the retrogradation phenomenon is, however, delayed when mono- or triglycerides are added, whereas all the factors preventing the dehydration of a starch gel encourage is retrogradation. The crystalline structure of retrograded amylose is acid- and heat-resistant. Its melting-point is above 120°C.

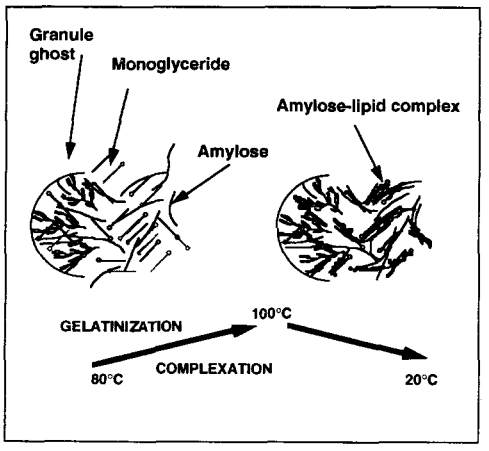
In vitro, the retrograded starch and retrograded amylose fraction are highly resistant to α-amylase.

Lipid-starch complexes (Fig. 5)

During gelatinization, constitutive monoglycerides of cereal starch or added monoglycerides melt and merge with amylose to create a new crystalline structure — the amylo-lipid complex. This complex is identified in X-ray diffractometry by its V-type spectrum. The amylo-lipid complex digestion by α-amylase is slower than that of the native amylose. The longer the monoglyceride chain, the slower the amylo-lipid complex digestibility.

FOOD PROCESSING, DIGESTIBLE STARCH FRACTION AND METABOLIC EFFECTS

The starch fraction digested in the small intestine provides glucose to the whole body. Glucose is disposed of, via the insulin secreted by the pancreas. Over the years, it has often been found that the ingestion of different types of starchy food induces various glycaemic and insulinaemic responses, in both healthy and diabetic subjects (Spaethe *et al.*, 1972; Crapo *et al.*, 1976, 1977; Jenkins, 1982; Jenkins *et al.*,



PROCESSES
Baking, Extrusion-cooking...
STARCHY FOOD
Bread, Corn Flakes
HYDROTHERMIC CONDITIONS OF THE PROCESS
Gelatinization in the presence of monoacyl lipids (constitutive or added)
STARCH CHARACTERISTICS
Amylose lipid complex
Crystalline structure
Low thermal stability
α–AMYLASE DIGESTIBILITY
Slow and incomplete

Fig. 5. Amylose-lipid complexes.

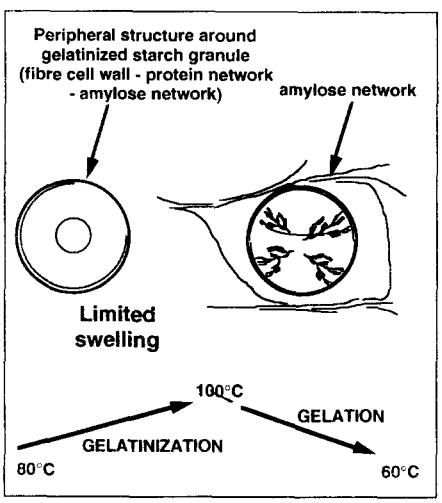
1980, 1981; Slama *et al.*, 1981; Nuttall *et al.*, 1983). These observations led to the development of glycaemic or insulinaemic indexes, defined as the ratio of the GI mean plasma glucose/insulin response area of test food to the blood glucose/insulin response area of reference food (glucose or white bread) by the same individual, multiplied by 100 (Jenkins *et al.*, 1981). When glucose is the reference carbohydrate, white bread and potatoes have a high GI (90–70%), white rice and pasta a moderate GI (50–60%), and legumes a low GI (20–40%).

Food processing and starch α-amylase susceptibility

Numerous studies (O'Dea *et al.*, 1980; Jenkins *et al.*, 1981, 1982; Björck *et al.*, 1984) have emphasized the role of food processing, which is considered a factor capable of modifying both the food starch α-amylase susceptibility *in vitro* and the starch bio-availability *in vivo*. The digestion of food starch by pancreatic amylase can be increased by a more disorganized state of the starch molecule, which is, for this purpose, heated or sheared in excess water. The food processes that lead to gelatinized, highly viscous and soluble starches result in high GI starchy food. This is the case for bread made of soft wheat flour, dextrinized starch, pre-cooked drum-dried starches and starches of high water content extruded at high temperatures.

On the contrary, food processes that limit the swelling of starch result in low GI food (Fig. 6). Several studies have shown that the digestion of durum wheat pasta by diabetics and healthy subjects is characterized by a reduced plasma glucose and by reduced insulin responses (Anderson *et al.*, 1981; Jenkins *et al.*, 1983). Colonna *et al.* (1990) have shown, by X-ray diffractometry and by the DSC analysis, that starch is completely gelatinized after only 11 min cooking in boiling water. Furthermore, the starch pasta α-amylase performed *in vitro* at 37°C (600 nkat of α-amylase) underlines the increase in starch susceptibility to amylase, as a result of cooking. Overcooking, however, has little effect: when spaghetti is cooked for 5 or 15 min, its glycaemic index remains unchanged, as has been reported by Wolever and Jenkins (1986) in diabetics and by Bornet *et al.* (1990*a*) in healthy subjects. When α-amylase concentration is the limiting factor (activity < 600 nkat), pasta of different sizes and/or different cooking times can be differentiated *in vitro* for their susceptibility to hydrolysis by α-amylase. This differentiation would be significant *in vivo* in subjects with low levels of amylase secretion, such as infants, old people or patients with intraluminal pancreatic enzyme deficiency. Colonna *et al.* (1990) have shown that the preincubation of pasta with protease (pronase containing <0·1% amylase activity) enhanced the starch pasta α-amylolysis. Similar results have been reported by Holm *et al.* (1983) with wheat starch, suggesting that a large fraction of the starch is encapsulated in a protein matrix. Scanning electron microscopy using freeze-fracturing and thin-sectioning have confirmed that during pasta cooking, proteins coagulate to form a continuous network surrounding each starch granule, thus limiting its swelling and thereby providing a structural explanation for the low plasma responses of pasta. Recently, Jenkins *et al.* (1987*a*) have shown the same reduced glycaemic effect of the starch–gluten interaction in bread.

The industrial heat processing of food which respects the cell structure of the starch granule wrapping, as in leguminous seeds, leads to a low food glycaemic index (Golay *et al.*, 1986), but the industrial canning of leguminous seeds can induce a pronounced postprandial metabolic response and a high in-vitro digestion rate, by disrupting the structure of the



PROCESSES

Pastification, Controlled boiling

STARCHY FOOD

Pasta, boiled rice, leguminous seeds

HYDROTHERMIC CONDITIONS OF THE PROCESS

T°C > 100 °C - High moisture

STARCH CHARACTERISTICS

Persistent starch structure

Limited swelling

Gelatinized starch, low solubility

α-AMYLASE DIGESTIBILITY

Slow but nearly complete

Fig. 6. Gelatinized starch with limited swelling.

product and thus making the starch more readily digestible (Wolever *et al.*, 1987).

The existing relationship between the starchy food amylose content and the metabolic responses that have been observed in leguminous seeds and in rice (Goddard *et al.*, 1984) could be explained by the high tendency of amylose starch to produce hard gels, retrograded amylose and amylo-lipid complexes. Mung bean noodles, which are made of high amylose leguminous seeds, are based on a constitutive retrograded amylose network (Mestres *et al.*, 1989). This network being heat-resistant, the cooked noodles have slow metabolic effects (Bornet *et al.*, 1989).

To reduce the digestibility of starch, fibres must have highly viscous properties (guar gum, pectins, etc.) and be largely distributed throughout the meal. If the starch granule is insoluble, as in the leguminous seed, insoluble fibres may delay starch digestion. The addition of wheat bran to cereal products has no effect on the glycaemic response of the starch fraction (O'Dea *et al.*, 1980). Jenkins *et al.* (1981) have shown no correlation between the crude fibre content of food and its glycaemic responses. These results illustrate the importance of space relationship between all the starchy food components, leading to specific starch availability and metabolic responses.

Food processing and gastric emptying of starchy food

The gastric emptying rate of starchy food is the digestive phenomenon which controls the rate of starch appearance in the small intestine. Thus, in association with hydrolysis, the gastric emptying of starchy food controls the glucose production rate in the small intestine. The faster the gastric emptying of starchy food, the higher the amount of available starch for pancreatic α-amylase hydrolysis. Several studies have been conducted to determine the respective role of gastric emptying and α-amylolysis in the metabolic effect of starchy food. The results are not unequivocal. Mourot *et al.* (1988) have studied the glycaemic and insulinaemic responses to four starchy products (white bread, mashed potatoes, rice and spaghetti) in healthy subjects. The gastric emptying of the different meals was estimated using the isotope tracer and the gamma camera records. A significant negative linear regression was found between the maximum incremental values of glucose and the different times of half gastric emptying ($r = 0{\cdot}60$; $p < 0{\cdot}001$). Torsdottir *et al.* (1990) have recently compared six healthy subjects on two iso-volumic and iso-energetic meals, in which the starch fraction was either mashed potatoes or white beans. The meals were labelled with ^{51}Cr and the gastric emptying of the tracer measured by external gamma counting. The glycaemic and insulinaemic responses to the meals were very different, but the kinetics of the gastric emptying were similar. The relationship between starch α-amylase susceptibility, plasma responses and gastric emptying rates was recently studied in nine healthy subjects on three carbohydrate test meals (25 g starch or glucose units equivalent (Bornet *et al.*, 1990*b*). The two maize starch pastes that had been chosen (24% and 50% amylose content) differed *in vitro* by their viscosity and their α-amylase susceptibility. The higher the amylose content of the maize, the lower the viscosity and the α-amylase susceptibility of the starch paste. The carbohydrate loads were labelled with ^{99m}Tc and the isotope gastric emptying was measured by external gamma counting. The time of the half gastric emptying was significantly ($P < 0{\cdot}05$) shorter for the starch paste made of high amylose maize (SP50: 19 ± 2 min) than for the glucose solution (GS: 29 ± 2 min). No correlation was found between the different times of half gastric emptying and the plasma response values. The values of peak insulin (mmol/litre; mean ± SD) were significantly ($P < 0{\cdot}05$) different: GS: 306 ± 11 mmol/litre, SP24: 227 ± 11 mmol/litre, SP50: 187 ± 11 mmol/litre. The tested carbohydrate α-amylase susceptibility was therefore a determining factor in the insulin responses of healthy subjects, while the viscosity of the test meals and the gastric emptying rate had no effect.

Food processing and metabolic effects of starchy food

The differences between the glycaemic and insulinaemic indexes of starchy food persist primarily when the food is ingested in a mixed meal by healthy or IDDM patients (Wolever & Jenkins, 1986, Bornet *et al.*, 1987). Moreover, in the carbohydrate diet, the rate of glucose absorption seems to play, in the long term, a decisive role on the glucose and lipid metabolisms of both healthy and unhealthy subjects. Recently, Fontvieille *et al.* (1988) have demonstrated that a moderate switch from high to low glycaemic food indexes (the mean glycaemic indexes being respectively 60·1 and 46·5) could improve, in 6 weeks, the plasma fructosamine, which is a reference plasma glucose index, and at the same time cause a significant (but moderate) decrease in the daily insulin needs of IDDM patients. Interestingly enough, the total fibre content of the meal was lower during the low rather than the high glycaemic index period and therefore was not accountable for the observed improvement.

Fontvieille *et al.* (1992) have drawn the same conclusion in a more recent study on IDDM and NIDDM subjects tested during 5 and 10 weeks. Similar observations have been made by other groups (Andersén *et al.*, 1984; Jenkins *et al.*, 1987*b*; Brand *et al.*, 1991). All studies have shown an improvement in fructosamine or glucosylated haemoglobin and a decrease in fasting plasma glucose and in mean daily blood glucose, during low GI diet. These results suggest that a low GI diet improves the action of insulin. This could be the

consequence of the slow glucose concentration rate in response to low GI food, resulting in a reduced insulin secretion (O'Connor *et al.*, 1977). The development of hyperinsulinaemia diminishes the number of insulin-receptors and impairs the insulin action, exacerbating its resistance. This mechanism is the downregulation phenomenon. An emerging concept, developed by a number of authors (De Fronzo, 1988), suggests that the glucose *per se* (i.e. hyperglycaemia) is a cellular toxin to both β-cell and peripheral tissues. The results of several studies (Ullrey *et al.*, 1975; Kletzien & Perdue, 1985; Haspal *et al.*, 1986) have shown that the development of a chronic hyperglycaemia can end in insulin resistance through the downregulation of the glucose transport system.

RESISTANT STARCH FRACTION AND METABOLIC IMPACT

Since low GI food (pasta, biscuits, leguminous seeds) has a highly resistant starch fraction and/or a high fibre content (leguminous seeds), the SCFA hyptheses cannot be ruled out. All these products are fermented in the colon.

No studies have been published so far about the metabolic state of the RS fractions reaching the colon and thus behaving like dietary fibres. Their characteristics are still only hypothetical.

Due to their crystalline physical structure, these fractions are insoluble and develop no tendency towards viscosity. Their physicochemical properties are fairly close to those of the cellulose fibres. Therefore, no marked impact on the upper gastrointestinal trace should be expected from these fractions and hardly any measurable metabolic effects, after an occasional food intake, such as those observed when soluble fibres have been consumed (pectin, guar gum, etc.).

On the other hand, an impact on the glucidic and lipidic metabolisms of these fractions may be observed during chronic food intake, as is the case with chronic intake of dietary cellulose fibres. As far as we know, the potential effects have nothing to do with the upper gastrointestinal tract, but are due to the volatile fatty acids (SCFA), which are products of the starchy fraction fermented by colonic bacteria.

Recently, a number of authors (Cummings & Branch, 1986; Wolever *et al.*, 1989) have suggested that SCFAs might be involved in some metabolic changes induced by fibres (reduction of plasma cholesterol, improvement in glucose tolerance).

The daily production of SCFAs by man is estimated at between 200 and 500 mmol, the mole ratios for acetate, propionate and butyrate being 60, 25 and 15, respectively (Cummings & Branch, 1986).

These are theoretical figures derived from stoichiometric equations based on the rumen metabolism and adapted to the human colon:

$$10\text{ g fermented hexose} \rightarrow 100\text{ mmols SCFA} + 850\text{ ml } CH_4 + 1200\text{ ml } CO_2$$

The characteristic of resistant starches, as has been shown in the early studies about their in-vitro fermentability, is their high butyrate-acetate production ratio (Englyst *et al.*, 1987). This may be due to the fast fermentation kinetics of the starchy fractions compared to that of the dietary cellulose fibres.

Butyrate and colonic trophicity

Butyrate is principally used by the colonocytes as an energetic substrate (Roediger, 1982). In the case of colorectal cancer, butyrate is of great interest because of its effects on the nucleic acid metabolism. It represents indeed a factor of cellular differentiation in this epithelium and especially as far as human cloned colorectal cells are concerned (Tsao *et al.*, 1983). A number of works on colonic cancer mention the colon butyrate deficiency as an element enhancing cancer (Clausen *et al.*, 1991).

SCFA and glucidic metabolism

Propionate is metabolized by the liver and is present in small quantities in the peripheral blood circulation (Pomare *et al.*, 1985). Acetate, on the other hand, is not entirely metabolized by the liver. The fraction of acetate which can be detected in the peripheral blood is metabolized by the muscle.

An increasing number of data suggest that SCFAs may interact in the glucidic metabolism. They may be the factors modulating both the glucose production by the liver and the peripheral susceptibility to insulin.

Anderson & Bridges (1984) have shown on isolated liver cells that propionate inhibits the conversion of lactate into glucose and activates the glycolysis. Its effect would therefore be to diminish the production of glucose (neoglycogenesis) and to activate its utilization (glycolysis). This effect might result in an increase in the glucose uptake of the liver and a decrease in the sus-hepatic glucose flow. Propionate is, however, with its three carbon atoms, the only neoglycogenerator SCFA. It can stimulate the insulin secretion, as has been shown in animals. The global effects of SCFA on neoglycogenesis in humans are still to be demonstrated.

The in-vitro effects of acetate and butyrate have opposite effects to those of propionate (Demigné *et al.*, 1986). The results of a number of experiments on animals suggest that acetate reduces glycaemia. Wolever *et al.* (1989) have recently shown that a rectal perfusion of SCFA decreases free peripheral fatty acids. High concentrations of free fatty acids are known to alter the

susceptibility of muscular cells to insulin and to inhibit the glucose utilization (Randle *et al.*, 1963).

SCFA and cholesterol metabolism

Chen and Anderson (1986) have shown that on isolated liver cells, the propionate, in physiological quantities, inhibits the cholesterol synthesis. *In vivo*, the ingestion of propionate by rats is shown to diminish the liver and serum cholesterolaemia (Ruppin *et al.*, 1980). A reduction in the cholesterol synthesis would enhance the LDL lipoprotein receptors' capacity and, consequently, increas their metabolic clearance, which might explain why a decrease in total plasma cholesterol is to the detriment of LDLs.

Acetate, contrary to propionate, is a cholesterol precursor. Jenkins *et al.* (1991) have suggested that the increase in total cholesterol and in LDL plasma fractions following a high lactulose diet (18–25 g/day) could be due to a significant production of colonic acetate.

The profile of SCFA production from a given substrate, i.e. the balance of the various SCFAs, appears to play a major role in the substrate effects on the metabolism of cholesterol.

CONCLUSIONS

The latest nutritional data about the 'starch' fractions in starchy food have revealed:

- the kinetics of the varying starchy food glucose assimilation, which is highly dependent on the starch digestibility, varies with the botanical origin of the product and especially with the industrial and culinary hydrothermic treatments prior to consumption;
- the physiological ill-absorption of a starch fraction in cooked food. This RS fraction is very heterogeneous and varies in size according to the food product. It depends on the botanical nature of the starch and especially on its hydrothermic history.

Future studies on resistant starch should try to determine the physicochemical mechanisms promoting or limiting the amount of RS fractions in the product. They should also evaluate the desirable proportion of RS in the daily intake of dietary fibres and explain the RS role in the genesis of potential functional digestive disorders or determine their impact on the mechanisms of colonic cancerogenesis and their effects on the glucidic and lipidic metabolisms, in both healthy and unhealthy patients.

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