INDUSTRIAL TECHNOLOGIES USED TO MODIFY DIGESTIBILITY OF STARCHY FOODSTUFFS

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The nutritional importance of available carbohydrate currently extends far beyond its role as a major source of sustenance for humans. Thanks to modern agriculture, transport, food technology, and to the market-driven economy in which appetite-driven food wants, rather than nutritional needs and survival, have come to determine the types of foods available to consumers.

As a result, the "developed" world is now facing an obesity crisis. Carbohydrate digestibility has gained new importance, not only because of its contribution to obesity, but also because a secondary consequence of obesity is the metabolic syndrome for which a defining feature is glucose intolerance – an impaired ability to control blood glucose concentrations after a carbohydrate meal.

Reduction in postprandial glucose release is an up-to-date issue in research. In Brazil, data from the Epidemiology Research Group at the Federal University of Pelotas indicates that 70% of people older than 60 years are overweighed or even obese. Allied to the requirement of older people for food with slow rate of glucose release are the changes of young consumers' mind. Several metabolic syndromes may be avoided by adjusting the components of there dairy diet, and they know it.

Published in 2010, the FIESP/IBOPE research of Brazilians food consumers' group demonstrated that more than 20% of Brazilians select foods according to "healthy and welfare" benefits. Therefore, in recent years, research on starch digestibility has been developed.

Figure 1 shows the number of publications available in the *ScienceDirect* database on starch digestibility in recent years. It can be verified that from 2013 the number of publications increased significantly.

Most of the carbohydrates that we commonly consume are complex carbs essentially made up of starches belonging to the amylose category which is divided into four families: cereals, tubers, pulses and fruits.

In order to be absorbed and enter into the bloodstream, these carbohydrates have to be broken down into glucose. This decomposing process is performed by digestive enzymes (more precisely, of alpha-amylases).

Digestion of starch normally begins in the mouth, where a salivary amylase is secreted, catalyzing the breakup of the starch by hydrolysis. After a quick passage through the stomachs, additional breakdown of starch occurs in the small intestine with amylases secreted from the pancreas.

The glycemic index scale measures starch digestibility through comparison. Researches shows that, for similar portions of carbohydrates from one foodstuff to another, the postprandial glycemic response can vary immensely since there are fractions of starches which cannot be digested or are slowly digested (resistant starch and/or slowly digestible starch), and this is what determines their absorption rate.

Several factors can cause these variations and the purpose of glycemic indexes is precisely to classify starches according to the variation in their digestibility.

As previously stated, the digestibility (glycemic index and resistant starch) can vary greatly from one to another food (Table 1). The following factors that affect digestibility will be detailed: proportion of amylose and amylopectin, thermal processing, gelatinization *versus* retrogradation, effect of fiber and protein, and effect of particle size on glycemic index.

"Hydrothermal, industrial or culinary processing change characteristics of food and alter its digestibility"

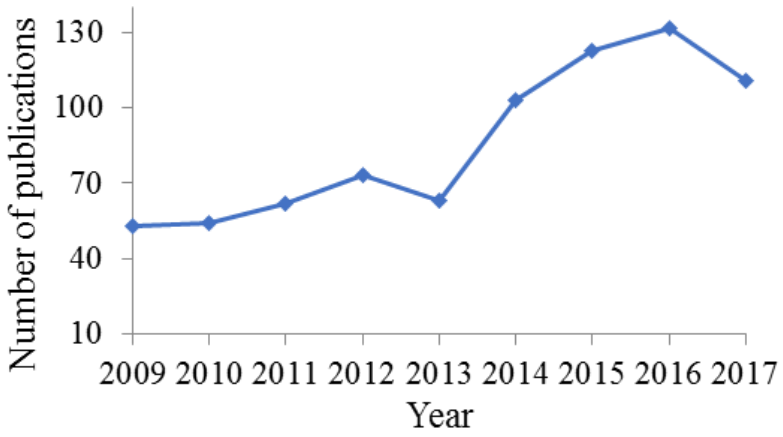

Figure 1. Publications on starch digestibility in recent years.

Digestibility variations

Proportion of amylose and amylopectin

High temperatures modify the amylose and amylopectin structure. When an aqueous suspension of starch is heated, water is absorbed, and the starch granules swell and a fraction of the amylopectin becomes part of the substance.

When the heating process is prolonged, a fraction of amylose also becomes component of the substance. The degree of gelatinization is proportional to the amount of amylose; the less amylose there is, the greater the degree of gelatinization and vice-versa.

It is reported that the greater the degree of gelatinization exhibited by starches, the greater will be the chances of starch be hydrolyzed by alpha-amylase (starch digestive enzymes), as well as the greater will be its propensity to become glucose and, naturally, the greater its tendency to raise blood sugar levels. In other words, starches with lower amylose content have higher glycemic indexes. Inversely, starches with a higher amylose content will be less susceptible to gelatinization, that is, to breaking down into glucose. This is why potatoes, that exhibit a low amylose level, have a high glycemic index, while lentils, which have high amylose, have a low glycemic index.

Another important factor to mention related to the amylose content is the susceptibility to modification with consequent changes in digestibility.

As example, researchers at Labgrãos carried out a study using the heat-moisture treatment modification in rice starch from different levels of amylose and verified that the HMT-induced effects depend on the amylose content. The HMT increased the resistant starch and slowly digestible starch content for all amylose levels of the rice starches, and this increase became more pronounced with increasing rice amylose content.

Thermal processing

Hydration and heat raise glycemic index of food. Certain industrial processes take gelatinization to the extreme. This is true for mashed potatoes and cornflakes, as well as for binding agents, such as modified starches and dextrinized starches. These processes noticeably increase foodstuffs glycemic indexes (80 for cornflakes, 95 for mashed potatoes, 100 for modified starches).

Table 1. Comparison of resistant starch content and glycemic index for commonly consumed starchy foods.

Source	Resistant starch g/100 g	Glycemic index
Grain and cereal products		
Buckwheat	1.8	51
Bread (white)	1.2	69
Bread (whole meal)	1.0	72
Millet	1.7	71
Rice (brown)	1.7	66
Rice (white)	1.2	72
Spaghetti (whole meal)	1.4	42
Spaghetti (white)	1.1	50
Breakfast cereals		
All-Bran (Kellogg's)	0.7	51
Cornflakes	3.2	80
Muesli	3.3	66
Porridge oats	0.2	49
Shredded wheat	1.2	67
Wheatabix	0.1	75

Adapted from Birt et al., Journal advances in nutrition, v. 4, p. 587-601, 2013.

Likewise, exploding corn grains to make pop-corn or rice grains to make puffed rice increases the original glycemic indexes by 15% to 20%. But there are also thermal treatments used to reduce glycemic indexes.

As example, another study conducted by Labgrãos research group, who aimed to apply heat-moisture treatment (HMT) in paddy rice grain prior to processing, revealed a reduction in starch digestibility and confirmed that HMT affect starch digestibility of rice flour, suggesting that HMT can be used as a new application for production of foods with slow digestion rate and a low glycemic index.

Gelatinization versus retrogradation

Gelatinized starch, when getting cold, is subjected to further modifications. While cooling, gelatinized starch gradually begins to reorganize its amylose and amylopectin macromolecules. This is what is known as retrogradation, a return to its former molecular structure.

Retrogradation becomes more intense as time passes and temperatures go down. Dry bread, for example, loses its humidity and stimulates starch retrogradation, as in the case of toasted bread. Although retrogradation does not wholly reverse food gelatinization, it does contribute to lowering foodstuffs' glycemic indexes. Spaghetti (even white refined), for example, exhibits a 35 glycemic index if cooked al dente and eaten cold (in salads). Whilst fully cooked it can present values close to 50.

As we can see, the same bread (made from the same flour) may exhibit a different glycemic index depending on how it is prepared: freshly baked and still oven hot, dried or toasted. Fresh bread when frozen and thawed out at room temperature will also present a much lower glycemic index.

Also, it is important to point out that starches (in their raw and natural form) are not only presented in raw foods. Raw starches can also be found after cooking when water contents are not sufficient to produce starch gelatinization. For this, some studies aimed to verify the influence of the amount of water in the gelatinization and its effect on *in vitro* starch digestibility. It was verified that the lower the concentration of water during cooking, the higher is the formation of slowly digestible starch and resistant starch.

Processes using non-thermal treatments, such as high hydrostatic pressure (HHP), for starch gelatinization also have been used for decreasing starch digestibility. This modification is quite interesting, because when controlled it can promote the gelatinization of the starch granule without breaking it, making starch granule difficult to be accessed by enzymes.

Several studies report the effects of HHP on the physicochemical properties of numerous starches, including those from wheat, corn, rice, barley, mung bean, rye, tapioca and buckwheat. However, only few of these studies reported the effect of the HHP on the starch digestibility.

Those studies who reports show large reductions in the levels of rapidly digestible starch followed by the increase of the slowly digestible starch and resistant starch. This decrease in digestibility is allied to the immediate retrogradation that occurs in the starch after the modification process.

Effect of fiber and protein on glycemic index

The natural protein content of certain carbohydrates might be the reason why their starches are not digested as much as others and why they have lower glycemic indexes. This is what happens with cereals.

The phenomenon is particularly evident in the case of pasta. The presence of gluten slows the action of digestive amylases which limits glucose absorption. The fiber contained in starches can also serve to block the amylase action contributing to reducing glucose absorption.

Basically, the fibers that directly or indirectly contribute to reducing intestinal glucose absorption and, thus, lowering the corresponding starches glycemic indexes, are soluble fibers.

Another example reported by Berg et al. (2012) shows the role of cotyledon cell structure during *in vitro* digestion of starch in navy beans. The cotyledon cell walls of navy beans impose restrictions on swelling and gelatinization of bean starch during cooking. This incomplete gelatinization of starch granules reduces the rate and extent of starch hydrolysis measured as glucose release during 120 min of *in vitro* digestion with simulated gastric and small intestinal fluids.

The stability of cotyledon cells and the small surface area of the starch granules which are tightly packed inside the cells also appear to restrict the free access of amylolytic enzymes during *in vitro* digestion of beans.

Effect of particle size on hydrolysis and glycemic index

When starchy foods are ground, their particles become much finer, which naturally raises their glycemic index. This is what happens to cereals when they are ground into flour.

Rice flour, accordingly, has a higher glycemic index than rice itself. Now, thinking of whole grains, *in vitro* digestibility studies show that even consuming cooked rice grains in its integral form, the process of size reduction promoted by chewing significantly increases the rate of glucose release.

To reverse this situation, modifications such as HMT and HPP or chemical treatments are suggested to decrease the digestibility or even making the digestion slow without loose the characteristics of the original product.

Final considerations

Carbohydrates' nutritional characteristics deserve special attention. Starches differ due to their original molecular structure and also because of the nature of the additional nutrients they contain (proteins, fibers) apart from modifications that can be made.

Starches and starchy grains physical-chemical properties evolve when they come in contact with water, undergo temperature variations and as time passes. Hydrothermal, industrial or culinary processing transforms our food and change its properties and digestibility.

The most diverse types of treatments affect intestinal absorption rates and, as a result, our bodies' corresponding glycemic and insulin responses. A foodstuffs glycemic index is then the result of several parameters which we must keep in mind when choosing what we eat.

"The natural protein content of grains might be the reason why their starches are not digested as much as isolated starch, and why they have lower glycemic indexes"

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