Starch: the best and worst of nutrients

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The link between diet and health has been long known, as well as the fact that an increase in saturated fats and simple, refined carbohydrates in the diet, combined with our modern sedentary lifestyle, is contributing to an epidemic of diseases such as obesity and diet-related metabolic conditions. Although these can be multi-factorial disorders, simple lifestyle changes such as eating more fruit and vegetables in the diet and physical activity are known to be major factors in decreasing their prevalence. This has led to a focus on how dietary habits are affecting our overall health and how this information can be utilized to provide dietary solutions to combat the obesity epidemic. Of particular interest is the relationship between the digestion of starchy foods, which comprise 55–75% of dietary energy intake, and the subsequent effects on health.

The availability of cooked starch is thought to have been crucial in providing the extra energy required by our brains during development from early to modern day humans. While the ability to improve the digestibility of starch through cooking, and thus access glucose to feed our growing brains, has been suggested to be key to the development of modern humans, it is now a major problem. We have become too adept at processing starchy foods to maximize starch digestibility.

Physical chemistry in the kitchen

Currently, we are learning more about the links between starch structure at the molecular level and its digestion. Raw starch has a complex crystalline structure that reduces the accessibility of α-amylase to the chains of glucose which make up the starch molecule. This limits the ability of the enzyme to digest the starch, hence, the effectiveness of cooking for increasing digestibility. In some cases (for example, bananas), we do eat starch in its raw form, but we generally want to cook food before eating it. Research suggests several ways that the physical structure of cooked starch can be influenced to control its digestion.

Starch digestion

Starch digestion begins the moment you bite the cookie, with the oral release of salivary α-amylase (the enzyme in our digestive tract that breaks down starch to sugars) as well as mechanical shearing when the food is chewed and swallowed, enzymic breakdown is slowed in the stomach by low pH and started again in the duodenum with the release of pancreatic α-amylase.

The nutritional properties of starch are reliant on its digestibility and not all starch is created equal. Starch differs depending on source, structure and processing, as well as intrinsic factors including granule size and arrangement and the amylose-to-amylopectin ratio (high amylose starches tend to be more resistant to digestion). Historically, it was thought that all starch was rapidly digested in the upper digestive tract to simple sugars, or monosaccharides, but research in the 70s and 80s demonstrated that some starch is much more slowly digested or completely resistant to digestion.
by cooling and reheating starch-containing foods, we can retain the crystallized amylose, which is highly resistant to digestion, while maintain the texture of the food through melting the amylopectin crystals. This effect has been understood since the work of Berry and others in the 1980s, but it is only recently that it has become more widely acknowledged in dietary advice.

**High-tech starches**

While there are simple methods that can be used in the kitchen, there are also more advanced technological approaches to reducing the digestibility of starches. One option is to alter the processing parameters of staple foods, such as biscuits, in order to render starch less accessible to digestive enzymes. This can be achieved through an understanding of the factors which control the loss of crystallinity during starch cooking. The key factors are moisture and temperature, with the temperature required to melt starch crystals being dependent on the amount of water available during cooking. Some food manufacturers therefore use a combination of low moisture, low temperature cooking to control starch crystallinity, and therefore digestibility, but this is only possible in a narrow range of products.

An alternative strategy is the use of advanced plant breeding methods to produce starches with structures which are inherently resistant to digestion, either through increasing the melting temperature of the starch, or increasing the amount of amylose that can recrystallize following cooking and cooling. Starch biosynthesis is a complex process involving enzymes which catalyse chain elongation, chain branching and chain debranching, with several isoforms of each enzyme required to synthesize a starch granule. By using targeted genetic approaches, plant breeders are able to knock-out specific isoforms of starch-branching enzymes in common crops such as wheat and pea. Using this approach, in the future it will be possible to breed crops with starches which are inherently resistant to digestion.

**Into the colon**

When we eat food, it spends around 5–30 seconds in the mouth, during which time it is chewed and mixed with salivary amylase, initiating starch digestion. After swallowing, the food then spends around 30 minutes to an hour in the stomach. Although the environment of the stomach is highly acid, the buffering effect of the food is such that starch digestion continues in the stomach, before the food then moves into the small intestine. Here, it mixes with pancreatic amylase and the starch is further digested to maltose and highly branched dextrins, which are degraded to glucose by enzymes in the brush border of the small intestine and adsorbed. Foods take around 2 hours to pass through the small intestine. Given this time limitation, any starch which is so slowly digested that its digestion is not fully complete after this 3-hour process will pass into the colon. The colon is home to trillions of bacteria, from between 400 and 800 different species, many of which are evolved to degrade highly crystalline forms of starch. The bacteria in our colon ferment starch to produce short chain fatty acids (SCFAs), which are absorbed by the host (that’s us) and which helps recover energy from our diet, but also provide a range of other potential health benefits.

The most abundant SCFAs, acetate, propionate and butyrate (which together comprise around 95% of all SCFAs...
in the colon), have been linked with multiple benefits, including providing dietary energy and suppressing the growth of pathogens by decreasing the pH of the intestinal lumen. Acetate has a major role in the ability of beneficial *Bifidobacteria* to inhibit toxicity from gut pathogens by blocking the transport of toxins from the gut lumen to the blood. Propionate can help to lower cholesterol levels by inhibiting the synthesis and reuptake of LDL cholesterol. Butyrate is the preferred energy substrate for the colonic epithelium. Butyrate has been linked with protection from initiation of colon cancer by many different pathways including promoting cell differentiation, cell-cycle arrest and apoptosis of transformed colonocytes.

Besides digestion and fermentation, the interaction between starchy food and the gut microbiota has recently been found to be important in sending and receiving signals from the brain, known as the gut–brain axis. Changes to the composition of gut bacteria and subsequent changes to the release of SCFAs as signalling molecules can have great effects in the body, from influencing mood and behaviour to altering immune responses. For example, SCFAs can activate the free fatty acid receptor FFAR3, which then activates a signalling cascade. This signalling can result in changes to intestinal immunity by mediating inflammatory responses by gut immune cells, acting to reduce inflammation and protect the gut lining. These signals can also have wider effects on energy homeostasis and appetite, signalling to our brains that we feel full (Figure 1).

In regulation of the appetite, the composition of our gut microbiota can be very important – some microbes produce metabolites small enough to pass through the blood–brain barrier during fermentation, including the amino acids tryptophan and tyrosine. These amino acids are converted into the neurotransmitters serotonin and dopamine, providing a mood-boosting reward for the
Further reading

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