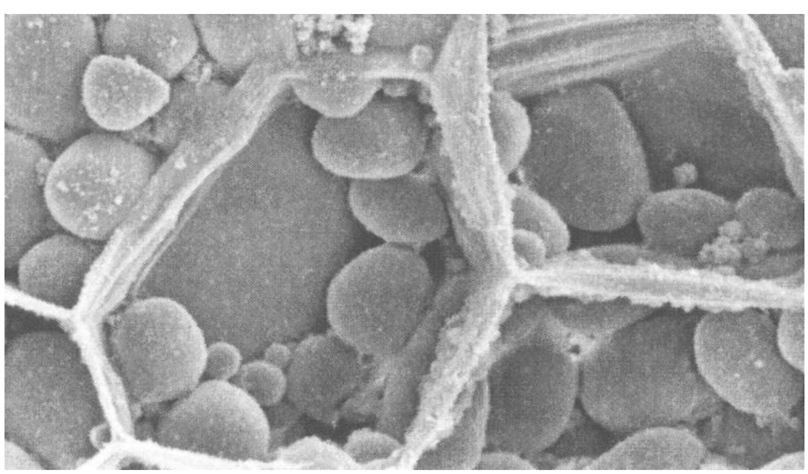
Starch in Food: What Makes Rice Sticky, Why Does Bread Stale, and Eat Your Beans!

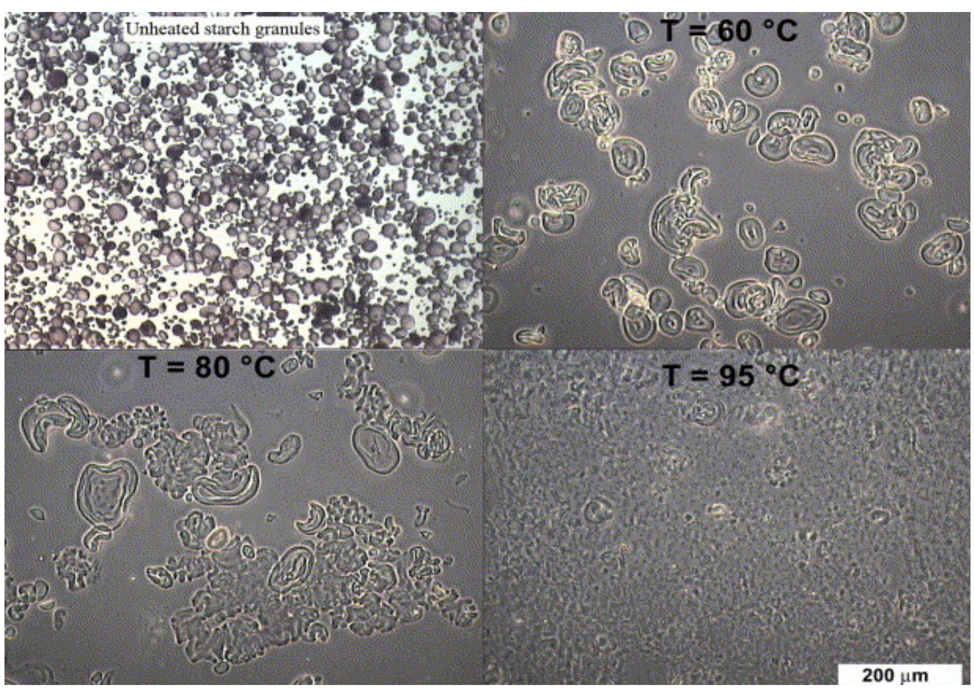
Starch is one of the most common forms of carbohydrates in food. All plants produce glucose from carbon dioxide and water by photosynthesis. As glucose is produced it is converted to starch, a polymer composed of thousands of glucose molecules linked together end to end, which is then stored in plant cells for use as a source of energy. Starch is thus an efficient way of storing lots of glucose in a minimal amount of space. Mammals also store glucose as a giant polymer called glycogen, which has a structure that is similar to starch. But starch and glycogen differ in one important aspect: Plants store glucose in two forms. One is a smaller linear molecule called *amylose*, and the other is a much larger branched molecule called *amylopectin,* that is shaped like a tree with both short and long branches attached to a trunk. It is most common for plants to produce amylose and amylopectin in a weight ratio of about 1:4, although some plants produce starch containing almost no amylose. This is commonly referred to as *waxy* starch (see the science note on waxy versus mealy potatoes). For whatever reason, mammals evolved to produce only the highly branched polymer of glucose, and none of the smaller linear form.

The amylose and amylopectin molecules produced by plants are organized into microscopic particles called *starch granules* stored within plant cells until needed for energy. The amylopectin molecules are arranged in alternating layers of organized crystalline structures and amorphous non-crystalline structures, with the amylose molecules randomly dispersed throughout. The linear molecules of amylose, and the ends of the long branches of amylopectin, form helical structures, both alone and entwined together. When the helical structures pack together they create the ordered crystalline regions within the granules. The size and shapes of the granules vary with each plant, but are consistent within each type of plant. Figure 1 below shows a photomicrograph of starch granules within empty potato cells. Potatoes contain the largest starch granules of the commonly consumed vegetables. They also contain a large number of granules per cell.



When starch granules are heated in water they begin to absorb some of the water and swell, like blowing air into a balloon. As the temperature rises the granules continue to absorb more water until they reach their maximum volume and viscosity, called the *gelatinization temperature*. This temperature is quite specific for each type of starch, whether it is in corn, wheat, potato, rice, or sorghum. The gelatinization temperature depends on the type of starch and the ratio of amylose to amylopectin in the starch granules. Higher amylose delays swelling and increases the gelatinization temperature. A good example is the starch in rice. The starches in short, medium, and long-grain rice vary in their ratio of amylose to amylopectin. Long-grain rice contains about 22-28% amylose by weight, medium-grain contains about 16-18% by weight amylose, while short-grain contains less than 15%, to almost no amylose (waxy starch). Varieties of long-grain rice have a gelatinization temperature above 158°F (70°C), while waxy short-grain rice gelatinizes at 144°F (62°C). The gelatinization temperature of the starch greatly affects the texture of cooked rice. This largely explains why long-grain rice is fluffy, and short-grain rice is sticky. Granules in short-grain rice burst at a much lower temperature releasing starch molecules that cause rice grains to stick together, while the granules in long-grain rice tend to remain intact.

Figure 2 below shows how granules of pure cornstarch absorb water and swell when heated. Notice at 60°C the granules have started to swell, and at 95°C (203°F) have swollen so much that they are difficult to see, and eventually burst and release amylose and amylopectin creating an infinite network of entwined molecules that trap water and thicken to a gel on cooling. This is how cornstarch thickens gravies and sauces, and turns them to solid gels when refrigerated. Starch granules do not have to reach the bursting point before they start to thicken a sauce, as even well swollen granules trap enough water to thicken it.



The reason bread stales and turns firm and dry is also explained by the behavior of the starch molecules in bread. Fresh baked bread contains about 35% water by weight with the wheat starch granules swollen and gelatinized. At this level the large starch and protein molecules are hydrated and flexible, and able to move about to a certain degree, making the bread soft and tender. But after a few days the bread becomes firm and appears to dry out. Most people assume it is because much of the moisture has evaporated, when in fact it really hasn't. As bread ages the amylose molecules form helices, which pack together like a box of pencils, forming crystalline structures that trap water molecules inside the crystalline regions. This makes the bread appear to be dry, when in fact it has not lost any significant amount of water. The crystalline structures also make the bread feel firm. The ends of long branches of amylopectin behave in a similar way, but these crystalline regions are relatively short and not as strong as those formed by longer chains of amylose, and will reverse with mild heat. If stale, dry, firm bread is briefly heated in the microwave these less stable crystalline regions of amylopectin are disrupted, releasing the trapped molecules of water making the bread appear softer and more moist, at least temporarily. The process of gelatinized starch molecules forming crystalline regions with time is called *retrogradation.* Starch molecules will retrograde (crystallize) at room temperature, but undergo this process at a much faster rate in the refrigerator. So don't place bread in the refrigerator to keep it from staling, as this hastens the process. Fortunately, refrigerated bread can be revived by brief microwaving. Bread can also be stored in the freezer. Once the water molecules are frozen the starch molecules are also frozen in space curtailing retrogradation. Frozen bread can be thawed to yield soft, moist bread.

One final point about starch in food. Most starch, especially if it has been heated and gelatinized, is rapidly digested to glucose, which is quickly absorbed into the body, elevating the level of glucose and insulin in the blood. The amount of glucose absorbed over a period of several hours following consumption of a food is called the *glycemic index* of the food. Foods with a higher glycemic index cause the release of more insulin into the blood system, which impacts the amount of fat stored in fat cells. Retrograded starch is very poorly digested by digestive enzymes, so much of it passes into the large intestine where it is digested by the gut bacteria which convert it into *short-chain fatty acids*, such as butyric and propionic acids. The cells lining the large intestine use these short-chain fatty acids for energy. Retrograded starch, also called *resistant starch* because it is resistant to digestion, functions as a prebiotic and is beneficial for the colonic cells. Since retrograded starch is not digested to glucose the calorie content of foods containing retrograded resistant starch is lower than cooked high starch foods like rice, potatoes, and fresh white bread. The amount of retrograded starch is directly related to the amylose content of the starch. Legumes are especially high in amylose, and therefore resistant starch, which is a major reason why they are a healthy food. Eat beans for resistant starch!

Some Helpful References

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