Golden Rice

Golden Rice was engineered from normal rice by Ingo Potrykus and Peter Beyer in the 1990s to help improve human health. Golden Rice has an engineered multi-gene biochemical pathway in its genome. This pathway produces beta-carotene, a molecule that becomes vitamin A when metabolized by humans. Ingo Potrykus worked at the Swiss Federal Institute of Technology in Zurich, Switzerland, and Peter Beyer worked at University of Freiburg, in Freiburg, Germany. The US Rockefeller Foundation supported their collaboration. The scientists and their collaborators first succeeded in expressing beta-carotene in rice in 1999, and they published the results in 2000. Since then, scientists have improved Golden Rice through laboratory and field trials, but as of 2013 no countries have grown it commercially. Golden Rice is a technology that intersects scientific and ethical debates that extend beyond a grain of rice.

Golden Rice is named for its golden color, which is caused by beta-carotene. Normal rice, Oryza sativa, does not express beta-carotene in its endosperm—the starchy and biggest part of the rice seed, which is usually an off-white color. Beta-carotene is part of a class of molecules called carotenoids, one of hundreds that plants naturally produce, and it has a yellow-orange hue. Carotenoids are essential nutrients for humans, because they are precursors to molecules needed in metabolism. The human body transforms beta-carotene, also known as pro-vitamin A, into vitamin A, which is necessary to produce retinal and retinoic acid. When people lack access to foods containing beta-carotene, because they eat mostly cereal crops such as rice, wheat, or sorghum, they are at risk of blindness and disease.

The creation of much plant biotechnology involves at least three steps: 1) researchers transfer related genes into the plant embryos; 2) the embryos incorporate the new genes into their DNA, produce the desired proteins, and grow and produce seeds; and 3) the successful heritability of the new genes, meaning that the modified plants pass on the inserted genes to their offspring. Potrykus was an early proponent of scientific rigor in biotechnology, maintaining that scientists must show that the engineered plants pass all three steps. In the development of Golden Rice, there was one further step: researchers had to get all three of the inserted genes to work in concert. By coordinating the different genes, rice endosperm can create beta-carotene.

The strategy of using recombinant DNA to create vitamin A-enriched rice had percolated within the Rockefeller Foundation since the mid 1980s. The Rockefeller Foundation, headquartered in New York, New York, had a history of investing in the International Rice Research Institute (IRRI) in Los Baños, Philippines. The Rockefeller Foundation viewed engineering rice as a good mechanism to help improve the health of many. They chose to focus on rice because they argued that, although it feeds over half of the world's population, private companies hesitated to invest in rice research, and instead focused on crops like corn, soybean, and cotton. Unlike previous innovations in rice, the Rockefeller project would focus on micronutrient fortification, or increasing the quantity of biological nutrients in edible plants for human health. After the advent of agricultural biotechnology in the 1970s, rice biotechnology became a focus of the Rockefeller Foundation's humanitarian efforts in the 1980s.

In 1993 Potrykus, a plant biotechnologist, and Beyer, a biochemist, started the Golden Rice project with support from the Rockefeller Foundation, the European Union, and the Swiss Federal Office for Education and Science. Seven years later, members of Potrykus' lab in Zurich, Switzerland, finally worked through all of the necessary steps to successfully express not one, but three unique genes in rice embryos—two genes from daffodils and one from bacteria.

Because no one had previously successfully expressed three genes in a food crop, Potrykus' lab at-

tempted multiple methods for the transformation. The first step was to insert the genes into the rice embryo, through particle bombardment or bacterial transfer. Potrykus' lab used an Agrobacterium-mediated transformation, where engineered bacteria inserted its DNA into the targeted rice plant embryos. This DNA contained all three genes—phytoene synthase (psy, from daffodil), phytoene desaturase (crtI from bacteria), and lycopene beta-cyclase (lcy, from daffodil). Scientists also inserted other pieces of DNA that the genes needed to function in the cell, and they inserted marker genes to help them track the inserted DNA. Then the scientists grew, selected, and tested the embryos for beta-carotene. When full-grown, the rice plants produced and stored beta-carotene in their starch.

With the backing of Peter Raven of the Missouri Botanical Garden in Saint Louis, Missouri, the US popular media and scientific press widely promoted the creation of Golden Rice. The resulting paper in 2000, “Engineering the Provitamin A (beta-Carotene) Biosynthetic Pathway into (Carotenoid-Free) Rice Endosperm,” had greater than 1300 citations as of 2013. Since the initial experiments with rice, scientists have engineered other crops, including maize and potato, to produce beta-carotene using different biochemical pathways.

Rather than commercializing their invention, the inventors, especially Potrykus, worked to legally secure Golden Rice as a humanitarian project. They licensed Golden Rice to Syngenta (formerly Zeneca), a biopharmaceutical company headquartered in Basel, Switzerland. Potrykus and Beyer then established a “Golden Rice Humanitarian Board” to oversee the development of the technology and grant noncommercial licenses to public research institutes. These national and international research organizations would adapt Golden Rice to local environmental and climate conditions. The International Rice Research Institute (IRRI) gained a license for non-commercial use from the Golden Rice project in 2001, aiming to spread the use of Golden Rice throughout Asia. Golden Rice Humanitarian Board oversees that these research institutes can acquire their licenses at low costs and in short periods to better promote the development of Golden Rice.

Both inventors credit Syngenta's Adrian Dubock with helping them navigate the complex intellectual property legal system around agricultural biotechnology. Potrykus and Beyer said they never anticipated the Intellectual and Technological Property Rights and material transfer agreements required for the production of Golden Rice. These licenses protect inventors' rights to genetic material, scientific techniques, and exchange of seeds for research. A legal assessment of Golden Rice in 2000 showed that it contained material protected by greater than seventy patents, but patents vary country to country. Many of the patents do not apply in developing countries, which are the target markets for Golden Rice.

Critics of Golden Rice include the environmental group Greenpeace, headquartered in Amsterdam, the Netherlands. Greenpeace has staged public protests against Golden Rice, and it opposes all genetically modified organisms. Greenpeace claimed that the amount of beta-carotene in Golden Rice was so small that one would need to consume massive quantities of rice to reach an effective dose. While it can be difficult to measure the ingestion of vitamins, a team of scientists from Syngenta in 2005 introduced Golden Rice 2, which produced increased levels of beta-carotene by substituting the original daffodil genes with corn genes.

As of 2013, tests of Golden Rice remained in field trials. IRRI, partnered with Helen Keller International, plans to introduce Golden Rice in Bangladesh and in the Philippines by crossing it with local, high-yielding rice varieties. While IRRI has participated in the Golden Rice project nearly since its invention, Helen Keller International, headquartered in New York, New York, joined the project in 2011 to support the public health benefits of vitamin A, which can prevent blindness. In the US, the Rockefeller Foundation, the United States Agency for International Development, and the Bill & Melinda Gates Foundation supported the Golden Rice project at IRRI. The Bill & Melinda Gates Foundation, headquartered in Seattle, Washington, became a supporter of the Golden Rice project in 2011. Furthermore, the government of Bangladesh approved field trials of Golden Rice, and in 2012 estimated that varieties would be available for consumption by 2015.

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