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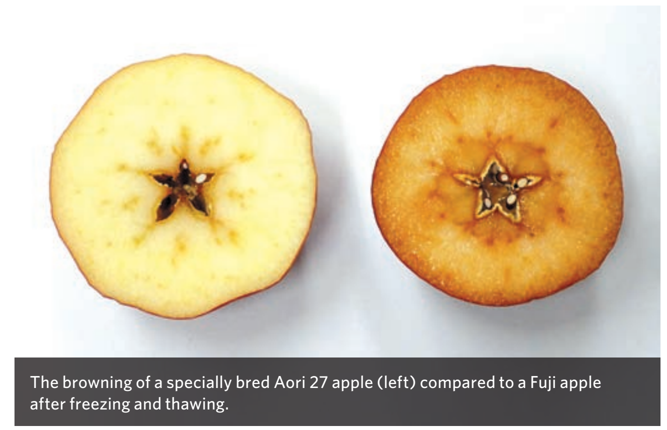
Crops 2.0: seeds of change in improved breeding

Farmers' yields will soon be easier to predict as DATA-DRIVEN BREEDING AND CULTIVATION PRODUCES more reliable and productive new crop varieties.

Japanese researchers are anticipating a surge in grain demand from Asia.

DNA extracted from seedlings can help predict characteristics, cutting out the long wait for a plant to mature.



The browning of a specially bred Aori 27 apple (left) compared to a Fuji apple after freezing and thawing.

Apple Research Institute, Aomori Prefectural Industrial Technology Research Center

Fuji, one of the most cultivated apple varieties in the world, is in need of an update. While popular for its flavour and long-lasting shelf life, the surface of a cut Fuji apple browns in minutes. As supermarkets are opting to sell more cut fruit in recent years, this is affecting sales.

Fuji is also susceptible to fungal diseases. "Many other fruit and vegetable varieties are also at a very risky state, and we don't have similar alternatives with stronger resilience if these varieties are hard-hit by climate change," says Masao Ishimoto, a research director at Japan's National Agriculture and Food Research Organization (NARO).

Crop breeders have been tackling these characteristics for decades with little success. "Crop improvement still depends on chance, and the roles of plant genes are still largely wrapped in mystery," explains Ishimoto. This is one of the reasons why breeders have been unable to produce a variety to rival Fuji's place in the market since it was bred in the 1960s. Ishimoto's team are advancing data-driven breeding to make this process more efficient.

Data driven decisions

Ishimoto says that data-driven breeding essentially "increases the chance to win big in a lottery". Traditionally, breeding starts by crossing two varieties and selecting offspring with desired traits. Breeding fruit varieties could take more than a decade, as trees take years to mature and bear fruit.

THEY HAVE ALREADY SEEN SUCCESS IN OPTIMIZING STRAWBERRIES, DOUBLING THE AVERAGE WEIGHT.

But where breeders would have drawn largely on experience to make this cross-breeding selection, the team under Ishimoto inputs genomic and phenotypic information into a database to model their relationships. "When seeds sprout, we extract DNA from seedlings and analyze their genotypes so that we can then predict the characteristics that a seedling will have when it matures, without needing to wait until the plant bears fruit," he says. With breeders only able to grow a limited number of saplings, the technique enables them to choose seedlings with the highest potential out of the tens of thousands of offspring.

Today the team is creating a special population of Aori 27 apple, one of the only two varieties to maintain a fresh yellow colour when cut. With data-driven breeding, they improved the prediction accuracy of the colour-changing trait 10-fold compared with breeder experience. In addition to apples, the team is using data-driven breeding for other crops, such as citrus, grapes, pears, strawberries, onions, and rice. They have already seen success in optimizing strawberries, doubling the average weight of a piece in single selection cycle of the breeding base population.

Genome editing for crops

Another project running simultaneously is developing new varieties through genome editing. Project members under Toshihiko Komari, a senior scientific advisor for Japan Tobacco Inc., are working to upgrade the CRISPR-Cas9 editing system to better edit plant varieties.

Target crops include cereal grains, a demand for which, Komari says, will spike in the coming years. "The world's population, currently at 7.7 billion, is projected to cross the 9.7 billion mark at about 2050," he says. "When the living standards of these people improve, they'll also be after a more varied diet, including meat. That in turn means a surge in demand for grains, to use for feed."

While CRISPR-Cas9 can target a specific part of the genome, says Komari, "it's not perfect at making replacements. We rely on errors that the cell makes when repairing DNA, and hope that one of the error patterns will work for us." His team is developing a new system that uses structure-based protein engineering to fine-tune Cas9 enzymes to edit single bases more precisely. The researchers are also developing plant-specific delivery methods, and were the first to modify a plant virus to carry editing tools into plant cell with little risk of unintended modification.

New plant varieties are also in the pipeline through the use of well-established genome editing techniques. These include tomatoes that are higher in nutritional value, melons that stay fresh for longer, and morning glories with more attractive flowering displays.

Environmental modelling

Meanwhile, other teams linked to the project are digitalizing the complex interactions between plants, microbes and soil. These include the effect of environmental factors, such as soil condition, on the effect of nutrient additives.

A RIKEN team is using this data to compare soil and plant metabolomes, distributions of elements, microbiomes, transcriptomes and phenotypes. Initial data was collected from an agricultural field in 2019, and the effects of adding nutrients and several farming methods are being tested under a variety of conditions.

The hope across the board, says Komari, is to apply state-of-the-art informatics technology to speed up processes that would normally take a farmer a lifetime. "This is about turning 'farmer's intuition' into digital data," he says.

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