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CREATING NEW TYPES OF PLANTS—THE ART OF PLANT BREEDING

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YOUNG REVIEWERS:

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AGE: 13

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We eat or interact with crops every day for food (tomatoes, lettuce, apples, rice, etc.), for feeding animals (hay, corn), or for a wide variety of other uses (wood, cotton). All crops come from wild plants that do not look anything like the ones we buy at the store. That is because they have been selected to look and behave in very specific ways that fit the needs of farmers, sellers, and us—the consumers. The process of developing new varieties is called breeding. Plant breeding is a complicated and lengthy process. Why do we need to breed plants? Because climate and environmental conditions are changing quickly and breeding new varieties that can survive in these new conditions or meet new needs is even more critical than before. In this article, we explain why breeding takes so long, and we discuss recent scientific findings that might help speed up the process.

WHY DO SPECIFIC FRUITS AND VEGETABLES END UP IN THE SUPERMARKET AND NOT OTHERS?

Have you ever stopped to wonder why your favorite fruit or vegetable looks and tastes the same every year? For example, a Roma tomato always tastes like a Roma tomato and never like a cherry tomato; and green peppers are always green, while yellow peppers are always yellow. All crops come from wild plant species that do not look anything like the types you buy at the store. They have been specially selected to have uniform qualities, so that the fruits and vegetables a farmer plants and harvests to sell at the local grocery store are fairly standard.

These fruits and vegetables have been selected for two types of characteristics: consumer traits and **agronomic traits**. Consumer traits are characteristics that appeal to the people who buy the products, such as taste, color, size, smell, or cooking properties. Agronomic traits are important for the farmer, to grow and harvest the plants easily and efficiently. The process of creating new plant varieties is called **plant breeding**. Breeding is complicated and can take more than 10 years for annual crops (crops that grow from seed every year, like maize and tomatoes), and even longer for tree crops (like oranges and apples)!

AGRONOMIC TRAIT

A characteristic of a plant that is useful to grow and harvest the plant. These are typically chosen by the farmers and growers.

PLANT BREEDING

The production of new types of plant using different parents chosen because of how they look, grow, taste, etc.

WHY DO WE NEED TO BREED NEW VARIETIES?

Imagine a farmer who has grown sweet corn for decades but recently, due to climate change, the plants are struggling because of higher temperatures. The higher temperatures are also making pests and diseases a bigger problem on the farm.

The farmer turns to a local seed company, or to plant breeders at a local university, for advice. These breeders know of another kind of maize, a variety called tough corn, that does well in high temperatures and is resistant to the pests that have invaded the farm. But this variety produces corn that is not sweet. Ideally, the breeders would make a new variety of maize with all the traits that are suitable for the new climate... but that also produces corn consumers want to eat. In other words, a combination of the old, sweet corn and the variety that can survive better in the new conditions.

HOW DO WE CREATE NEW VARIETIES?

The goal of breeding is to produce new varieties that are better than the current ones in some way. All new varieties start with **crossing** (mating) two varieties with each other. This involves bringing pollen from one flower to another, very much like what bees, other insects, or wind can do in nature, but in a much more controlled way (Figure 1).

CROSSING

The process of plant breeding involving producing progeny (baby plants) from two specific parent plants, by bringing pollen from one flower to another.

F1 GENERATION

The result of a first cross between two different varieties. F1 individuals are often different from both of their parents.

In the corn example, breeders would start by crossing the sweet corn with the tough corn. The progeny (baby plants) from a cross between two varieties is called the **F1 generation**. In corn, if you cross two varieties with each other, the F1 plants do not look like either parent. This is similar to mating two dog breeds: a pinscher and a poodle will have puppies that do not look like either of their parents. This is because the two parents carry different versions of each of their genes. Bringing the different genes together creates a new combination of genes and a unique puppy.

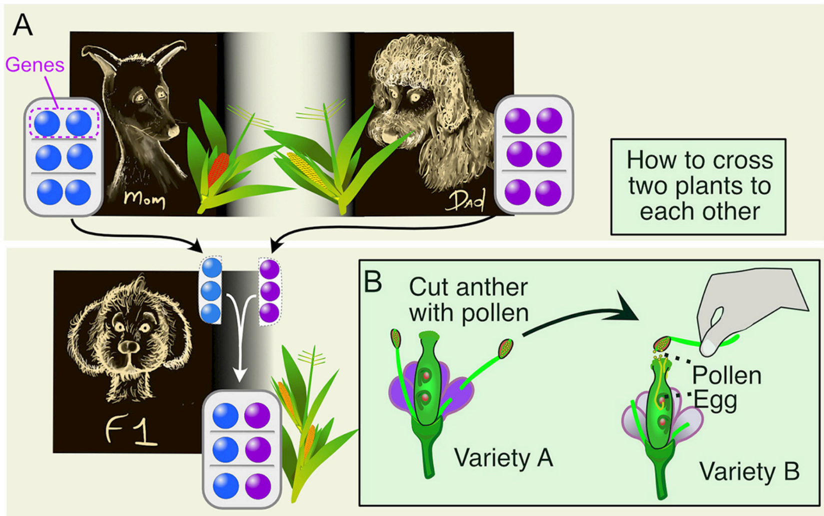

Figure 1

Figure 1

(A) If two different-looking dogs breed, the puppies usually look different from both parents. This is because the parents have different versions of each gene (blue/purple dots). Each parent passes one copy to their puppies. The same is true for corn. **(B)** Crossing two plants involves transferring pollen from one flower (variety A) to another (variety B), like bees do in nature, except that in this case, the two flowers are carefully selected ahead of time. This results in the fruit or seeds that can form new, unique plants.

New combinations are great, but if we find the one we want, how do we make lots of them? Farmers do not want just one plant, they want a whole field of them. The problem, both for plants and puppies, is that in the next generation (the "grandchildren"), all the genes are shuffled into millions of combinations that are all different from each other (Figure 2). To produce a lot of the exact same plant, breeders need a plant that carries two identical copies of each gene so that, when it randomly passes its genes on to the next generation, the result is always the same (Figure 2). In plants, this is called an inbred variety, in animals, it is called a purebred.

HOW DO WE CREATE A NEW INBRED VARIETY?

SELFING

Crossing a plant with itself. In other words, the plant is used as both the mother and the father in a cross.

Unfortunately, it takes many generations to make a new inbred variety. Coming back to our corn example, here is how it works. The sweet variety is crossed with the tough corn variety to start the process of breeding a new corn that is both sweet and tough. The characteristics of the F1 are in between those of the two parents, so it is not good enough for farming yet. The breeders take the F1 plants and cross them to themselves, which is called **selfing**, to make the next generation. Like the litter of puppies from our example, the next

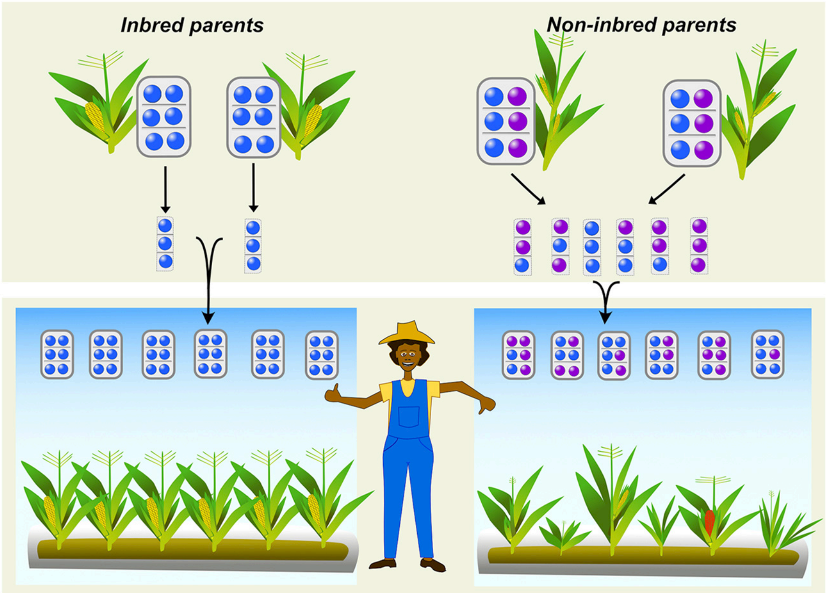

Figure 2

Figure 2

How do we make fruit and vegetables that all look and taste the same? Inbred varieties carry two identical copies of each gene. This means all their progeny get identical copies, too. Plants that are not inbred carry two different versions of each gene (blue and purple). That means their progeny all contain different combinations of blue and purple genes. Therefore, the progeny look different from each other and from the parent plants, just like we look different from our siblings and our parents. The farmer likes the inbred corn because all plants are the same.

generation of plants do not look like each other. But some are closer to what the farmer needs. So, the best plants—those that can tolerate the new climate, make sweet corn ears, and are resistant to new pests/diseases—are selected and selfed again. The others are discarded.

This selection process is repeated for nine generations! At the end, the new plants that have been selected are both sweet and tough and they have identical pairs of each gene. So, no matter which of the two genes is passed on to the next generation, the result is always the same. As a result, the progeny are all identical to each other and to the parents. That is what the farmers and growers wanted all along: a corn that is sweet and tough and produces progeny that are all sweet and tough too! This new variety is now ready to be planted in the field.

BREEDING TAKES A LONG TIME—CAN WE SPEED UP THE PROCESS?

Producing a new inbred variety of plants takes a very long time. Most plants (including cultivated crops) reproduce once a year. If breeders need 9 generations to produce a new corn variety, it will take more than 10 years! That is a long time for farmers to wait!

Breeders have come up with crafty ways of speeding up the process. Inbred plants are obtained after many selfing crosses because the goal is to obtain plants that carry the same versions of each gene (Figure 3). Can we obtain the same result faster? Most plants (and humans) are **diploid**, which means they carry two sets of each gene. There is a trick

DIPLOID

An individual with two sets of genes. Most species are diploid, including humans. We receive one set of genes from our mothers and one from our fathers.

HAPLOID INDUCTION

Creating a haploid plant from a diploid plant.

HAPLOIDS

An individual with only one set of genes. Haploids only received one copy either because only one parent contributed, or one parent's contribution was lost.

Figure 3

Plant breeders try to find new combinations of genes (colored balls) that produce plants with certain useful characteristics. These plants need to be inbred, so they can produce progeny with the same characteristics. With traditional breeding **(top path)**, this process takes many years. However, with haploid induction **(bottom path)**, breeders can create plants that carry the same copy for all genes, in a single step! The plants resulting from these two methods are almost exactly the same, and they both produce identical, uniform progeny, as desired by farmers and consumers.

called **haploid induction** that allows breeders to produce plants with only one copy of each gene instead of two. Plants (or animals) with half the normal number of genes are called **haploids**. If breeders take a haploid plant and double each gene (with a drug), they get a plant with the correct number of genes but all pairs are identical copies. Those plants are perfectly inbred in a single generation! As a result, all of their progeny are exactly the same. Haploid induction is remarkable because it allows breeders to breed new varieties in 2–3 years instead of the decade-long traditional method.

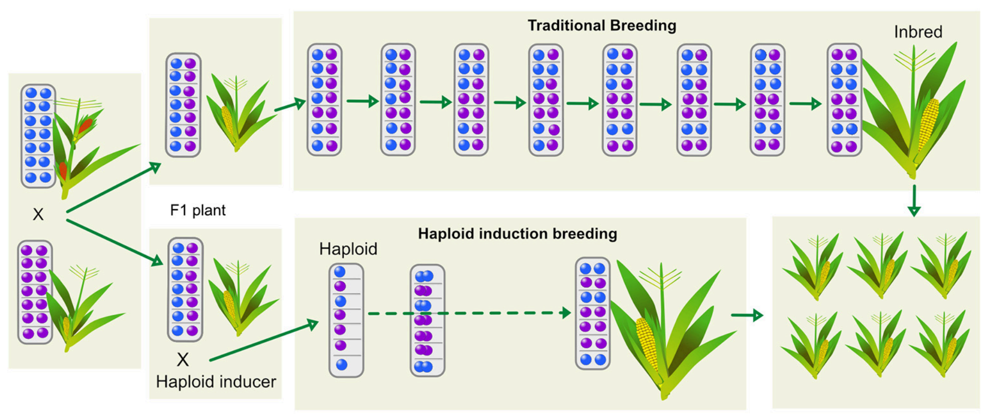

Figure 3

HOW ARE HAPLOID PLANTS PRODUCED?

Until very recently, creating haploid plants was not easy because it required a long and difficult process that involved dissecting tiny unopened flowers. A few years ago, a new method of haploid induction was developed in which special plants, called haploid inducers, do all the work: they produce haploids when crossed to a variety of interest! This new method could make breeding much faster and less expensive. Currently this new method works only for certain crops like potatoes and maize [1–3], but researchers are working to understand how to improve the process [4, 5]. This will allow the development of haploid inducers for other crops, and hopefully allow for faster development of new varieties.

GOOD TIMING!

New types of plants are needed because we constantly need new crops that fit our needs better or grow more efficiently. Developing new crops is the work of plant breeders, who cross existing plants to make new ones. After they have chosen which plants they like best, it can take years to produce them on a large enough scale that they can be found in the supermarket. Luckily, the process of haploid induction could speed up this process. This is great news because, with the growing world population and changing climate, new types of plants are needed now more than ever!

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REFERENCES

1. Ordoñez, B., Santayana, M., Aponte, M., Henry, I. M., Comai, L., Eyzaguirre, R., et al. 2021. PL-4 (CIP596131. 4): an improved potato haploid inducer. *Am. J. Potato Res.* 98:255–262. doi: 10.1007/s12230-021-09839-y
2. Ulyanov, A. V., Karlov, A. V., Khatefov, E. B. 2022. The use of maize haploidy inducers as a tool in agricultural plant biotechnology. *Vavilovskii Zhurnal Genet Selektsii* 26:704–713. doi: 10.18699/VJGB-22-85
3. Coe, E. H. 1959. A line of maize with high haploid frequency. *Am. Nat.* 93:381–382. doi: 10.1086/282098
4. Amundson, K. R., Ordoñez, B., Santayana, M., Tan, E. H., Henry, I. M., Mihovilovich, E., et al. 2020. Genomic outcomes of haploid induction crosses in potato (*Solanum tuberosum* L.). *Genetics* 214:369–380. doi: 10.1534/genetics.119.302843
5. Amundson, K. R., Ordoñez, B., Santayana, M., Nganga, M. L., Henry, I. M., Bonierbale, M., et al. 2021. Rare instances of haploid inducer DNA in potato dihaploids and ploidy-dependent genome instability. *Plant Cell.* 33:2149–2163. doi: 10.1093/plcell/koab100

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CONFLICT OF INTEREST: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

YOUNG REVIEWERS

AYA, AGE: 13

Hi, my name is Aya. I am 13 years old and enjoy crocheting, drawing, reading, and music. I love school. I am very interested in conlangs (constructed languages), and learning how to make my own languages.

VIHAS, AGE: 10

I live in India. I love playing cricket and reading adventurous books. I am fond of animals and find it interesting to communicate with them.

AUTHORS

VICTORIA STEWART

Victoria graduated from the University of California, Davis with a major in biology and a minor in English. While studying at the university, she started working at the Comai Laboratory. During her 2 years in the lab, she helped other researchers in trying to understand how haploid induction works in potatoes. She is currently studying at the same university to learn how to be a science teacher. She is interested in making science more accessible to the public and educating the next generation of citizen scientists.

MWAURA LIVINGSTONE NGANGA

Mwaura graduated from University of Missouri - St. Louis in St. Louis, Missouri in 2014, where he studied biochemistry and biotechnology. He then earned a Ph.D. in plant biology from UC Davis, where he studied how haploid induction works in potato. Mwaura is interested in the intersection of research, agriculture, and technology. During his Ph.D., he explored various opportunities to combine his research training with building agriculture technology businesses. Currently, he is a venture capital fellow at BioGenerator Ventures in St. Louis, Missouri. His day-to-day tasks consist of working with many startup companies to identify good investment opportunities that have to do with agriculture. He is also working on starting his own company to commercialize haploid induction. He loves hiking, working in the yard, and traveling in Kenya, his native country, and listening to African music.

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Isabelle is originally from Belgium, where she first studied biology and biochemistry as an undergraduate student. She moved to the US for graduate school and received

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LUCA COMAI

Luca is a professor at the University of California, Davis. He leads a research group that studies how plant DNA is organized. He grew up in Italy, where he studied towards his bachelor's degree in agriculture from the University of Bologna. He moved to the US to attend graduate school and obtained his Ph.D. in 1980, studying plant diseases. Since then, he has worked on a wide variety of projects and many different plant species, always interested in understanding how they function and particularly what happens when their chromosomes change. Amongst other hobbies, he enjoys drawing, as exemplified by the figures included in this article. *lcomai@ucdavis.edu