Plant Breeding Basics

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Plant breeding is the art and science of manipulating plants for the benefit of humans. Throughout history, humans have selected specimens for improved characteristics such as yield, quality, and flavor. The seeds of these selected plants formed the next year's crop, and repetition of this process over many generations resulted in improved, locally adapted populations that are often referred to as landraces.

Critical Need for Plant Breeding in Addressing Global Challenges

Plant breeding offers a mechanism for helping to address some of the world's most pressing and current concerns. One of the greatest challenges facing modern plant breeders is ensuring global food security in the face of a host of global and local obstacles. The current food supply is expected to be insufficient to support projected population growth, both in quantity and nutritional quality, thus necessitating plant breeding efforts that can increase production while using less land and fewer resources. Doing more with less will undoubtedly be a mantra of the plant breeding community moving forward.

Climate Change and Resource Limitations

Natural adaptation and selection are unable to keep up with the rate at which climates are changing. Resource limitations and environmental concerns are increasing global pressure to reduce agronomic inputs such as nitrogen, phosphorus, and water. Artificial selection within breeding programs for traits such as water use efficiency (WUE) and nitrogen use efficiency (NUE) may effectively respond to climate change and accelerate our efforts to feed current and future human populations and reduce agricultural inputs.

Monoculture and Improving Nutritional Quality

Low-diversity cropping systems (i.e., monocultures), along with the introduction of plant and insect species to non-native environments, have exacerbated the propagation of plant pathogens. Breeding to improve crops with natural adaptive capacity, as well as disease and pest resistance, can reduce threats associated with the systemic spread and propagation of plant pathogens. Furthermore, the growing focus on concurrent improvement of yield and nutritional quality of edible plant tissues emphasizes a critical role for well-trained plant breeders as human populations move from calorie-dense to nutrient-balanced diets.

Biomass Supply and Adapting to Cultural Practices

Plant biomass (grain and stover) is the substrate for not only food production but also fiber, feed, and fuel production. There is a growing need to balance the end use of plant biomass in a way that satisfies consumer needs. Plant breeders can play a role by developing new crops to fill a niche for various needs or by adding new priority traits for improvement within their existing programs. As another important consideration, cultural practices in agriculture vary widely across geographic regions. Different realities exist for smallholder farms that save seed from open-pollinated varieties or purchase from local markets or vendors versus large-scale, mechanized farming endeavors using hybrid crop varieties. The latter situation is more amenable to current breeding methodologies given the more stable performance of hybrid varieties, but such a focus will leave smallholder farmers in need.

Considerations for Improvement of Crops

Before beginning the breeding process, a trait must be defined, along with a system to measure phenotypes (a plant's performance for that trait). The diversity and range of phenotypic values must also be considered. For example, in biofortification the trait of interest is micronutrient content, and phenotypes are analyzed through various assays such as liquid chromatography and spectroscopy. The crossing type and propagation system must also be considered: is a crop propagated by seed or by tuber? Is the plant self-pollinating (such as beans) or does it depend on cross-pollination (such as maize)? How will success be defined, and what are the relevant measures of performance? What other traits are important for consumer acceptance (e.g., appearance, flavor, yield potential)? Should breeders seek adaptability to different environments or stability across all environments? How will genetic and phenotypic diversity be maintained to reduce disease susceptibility (as highly related lines risk being wiped out by the same strain), preserve plants' abilities to adapt, and maximize future gains from breeding?

Methodology

Breeders must consider the heritability of a trait—the proportion of phenotypic variance explained by genetic factors—and how this factors into selection of breeding methods and outcomes. Conventional breeding is phenotype-driven, meaning that selections are made based on visible traits. Typically breeding populations are developed by crossing a small number of parental lines together, which allows the development of families that can be tracked and selected upon through the breeding process.

Breeding can use a strategy termed backcrossing, in which lines showing favorable phenotypes for the trait of interest are crossed back to one of the parents to regain some of the parent's superior phenotypes for other traits of interest. In the case of self-pollinating crops, the conventional goal is to make selections through multiple cycles of inbreeding until a stable, superior family or line is identified and released as a variety. For outcrossing species, the goal may be to inbreed families while testing their ability to complement families from other populations, such that the hybrid progeny resulting from a single cross is superior to the inbred counterparts of the parental populations.

Conventional breeding can easily become complicated and is further muddled by the population development procedure, which mixes different strands of DNA and swaps multiple genes at one time—the effects of which might not be immediately visible. Because even promising new lines must be tested over multiple generations, conventional breeding is a lengthy process. Marker-assisted selection, in which particular genes of interest are identified and selected upon, is by contrast genotype-driven. Using this method, scientists can analyze plant tissue from experimental crosses to see if it contains the genes of interest—cutting down on the time required to identify promising lines.

An extension of marker-assisted selection is genomic selection, in which genome-wide markers are each assigned particular weights based on their influence on a trait's phenotype across the whole plant population being studied. This methodology allows trait phenotypes and breeding values to be assigned to an individual plant based on its genotype alone, greatly reducing the cost and rigor of field trials and saving time by allowing individuals to be assessed early on during the breeding cycle.

The Future of Plant Breeding

Innovations such as high-throughput phenotyping and combining molecular genetics with crop models offer new frontiers for improvement of plant breeding science. High-throughput phenotyping offers an improved capacity to rapidly quantify phenotypic traits—especially whole-plant physiological traits (e.g., responses to low water status) in the field—providing valuable information on plant and environmental effects and their interactions, as well as a prognosis for plant performance. Advances in methods and techniques for understanding epigenomics, or the regulatory patterns underlying gene expression, are allowing breeders to determine and use key traits enabling plants to adapt to their environment—for example, flowering time—to better survive environmental stressors. Also on the horizon are promising technologies that can target mutations and insertions to specific portions of the genome, enabling more precise breeding to support the needs of a growing and changing world.

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