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Crop Improvement by Conventional Breeding or Genetic Engineering: How Different Are They?

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One hears a lot of discussion these days about the power of genetic engineering, and many questions have arisen among farmers and consumers about the risks and benefits involved in its use. What exactly is genetic engineering, and how does it differ from conventional breeding that has been employed in various ways by people all over the globe for hundreds—even thousands—of years?

Methods compared

Let's look at methods first. When it comes to the "nuts and bolts" of crop improvement by conventional means versus genetic engineering, are we talking about different things?

The short answer is, "Yes, they are different." Most conventional breeding can be reduced to two fundamental steps. The first step is to generate a breeding population that is highly variable for traits that are agriculturally interesting. This is accomplished by identifying parents having traits that complement each other, the strengths of one parent having the capacity to augment the shortcomings of the other, and then cross-pollinating the parents to initiate sexual recombination. The genetic mechanisms that drive sexual recombination operate during gamete (egg and pollen) formation via meiosis, and include Gregor Mendel's famous discovery of independent assortment of genes and T.H. Morgan's discovery of crossing-over of homologous chromosomes. The key feature of sexual reproduction is that it allows and assures that all of the traits that differ between the parents are free to reassociate (segregate) in new and potentially better combinations in the offspring.

The second fundamental step involves selection among the segregating progeny for individuals that combine the most useful traits of the parents with the fewest of their failings. Thus, conventional breeding is essentially the normal mating process, but it is manipulated through human choice of the parents and selection of their offspring so that evolution is directed toward production of crops and animals with characteristics closely suited to human needs. Such selection over thousands of years has changed marginally useful wild plants into the specialized crops one sees in the produce departments of grocery stores today. Most of these are fully domesticated, having diverged from their wild ancestors to the extent that they can no longer survive outside of an agricultural environment.

Genetic engineering, on the other hand, employs a very different method to produce improved crops and animals. Instead of relying on sexual recombination to thoroughly stir the parental genes, genetic engineering preserves the integrity of the parental genotype, inserting only a small additional piece of information that controls a specific trait. This is done by splicing a well-characterized chunk of foreign DNA containing a known gene into a chromosome of the host species using "restriction" enzymes. Restriction enzymes cut the long DNA strand that makes up a chromosome at very specific places and in a very repeatable way, so that foreign DNA fragments, cut out with the same restriction enzyme, can be inserted and integrated into the host chromosome at the restriction site. There are many different restriction enzymes in use today, each recognizing specific, but different, sites in DNA molecules, providing great versatility in snipping out and inserting specific genes. Restriction enzymes are also employed in the sophisticated biochemical procedures that "engineer" the foreign gene, enabling the host organism to recognize the new information and use it at the proper time, in the proper cellular location, and to the proper extent.

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There are two common ways to transfer an engineered gene into a plant chromosome. *Agrobacterium tumefaciens* is a plant-pathogenic bacterium that has the ability to transfer a portion of its own genetic information into many plant species through a process called transformation, thereby causing the "crown gall" disease. This natural plant transformation agent has been modified by molecular geneticists in ways that enable it to move any engineered gene into host plants, without the associated disease symptoms. This method has the advantage of simplicity, but it is not well suited to transformation of the economically and nutritionally important cereal crops. Largely because of this limitation, a second method of plant transformation was invented that literally shoots the engineered genes into plant cells using tiny DNA-coated tungsten or gold particles as fine as dust. Although somewhat more expensive in terms of equipment requirements, the "gene gun" approach has the advantage of unlimited range of applicability.

Both procedures are typically applied to minimally differentiated cells cultured in test tubes, rather than to organized tissues, because plants that regenerate from individual transformation events will then consist entirely of genetically engineered cells. Neither transformation method is very efficient in terms of the percentage of cells that initially incorporate the engineered gene into a chromosome, so most of the plantlets regenerated via tissue culture lack the target gene entirely. In order to identify the rare successes, a selection system has been devised to eliminate all but the transformed plants. This is accomplished by including in the tissue culture medium an antibiotic that inhibits growth of typical plant tissues. Another genetically engineered gene linked to the inserted target gene detoxifies the antibiotic and allows transformed tissues to grow normally on the selective medium.

Risks for consumers?

So far, I have described some aspects of conventional breeding methods and genetic engineering, and how the two differ. What about risks to consumers inherent in these approaches? Do genetic engineering methods pose special hazards?

The sum of experimental evidence to date indicates that genetic engineering methodology poses no unique hazards to human health. Genetically engineered crops that have passed through a testing phase and into commercial distribution have provided no cause for concern. This positive conclusion must remain a tentative one, because much remains to be learned about the molecular mechanisms by which cells incorporate and express new genetic information. But this situation is not unique to genetic engineering, since there are also gaps in understanding of meiotic and sexual processes at the molecular level. What can be said is that all breeding methods, including genetic engineering, result in heritable change that follows predictable genetic principles; all methods are useful; and none seem inherently more or less hazardous than the others.

Need for oversight

If the genetic engineering process is not inherently more risky than other breeding methods, can there be any difference in the risk of consuming the products? Is there any reason to scrutinize genetically engineered products more carefully than conventionally derived products during the development phase?

Here I think the answer must be "Yes," since there is greater potential for accidental harm through inappropriate choice of the target gene, independent of the genetic engineering process by which it is introduced. The power to transfer traits across sexual barriers between species increases the potential for introduction of compounds that may have unsuspected secondary allergenic, toxic, or anti-nutritional properties. The potential for unintended side effects must be carefully evaluated in every new case. The Food and Drug Administration has responsibility to evaluate the human health and safety risks of genetically engineered foods before and after commercialization, although the process is technically voluntary on the part of developers at the present time. As a case in point, a brazil nut gene coding for a protein rich in an essential amino acid, methionine, was intended to improve nutritional quality in genetically engineered legumes, but the protein was found to be a strong allergen during tests prior to commercial release. Needless to say, it was not commercialized.

Concepts of what is natural

Some consumers avoid genetically engineered crops because they perceive them to be products of an "unnatural" process. In general, people tend to view as "natural" the foods they are accustomed to, while anything that might be done to change them is regarded as being unnatural. Consequently, people may think of the fruits and vegetables commonly available in grocery markets as natural, while attempts to modify these familiar products, whether by conventional means or by genetic engineering, may be regarded with suspicion. In reality, the opposite seems nearer to the truth. Examples exist in nature that are analogous to the human manipulation of plant and animal evolution, as well as to our exploitation of plant genomes by genetic transformation. In one of these examples, certain ants and termites have domesticated particular forms of fungi as food sources, and these fungi exist nowhere but in association with their host cultivators. Similar obligate associations have evolved between certain bees and unique scale insects that are "herded" within the nest for their waxy secretions. And we have previously mentioned *Agrobacterium* as a natural plant transformation agent that engineers tumors as food-producing factories for the benefit of the bacteria. So man's manipulation of plants and animals is neither new nor unique in the world of biology, and to call these processes unnatural is to confess our ignorance of the complexity of nature. On the other hand, the creatures that man has modified to suit his need by enlisting the natural processes of directed selection or gene insertion are now distinctly changed in genetics, appearance, and behavior from their ancestors, so much so that crops and animals well adapted to an agricultural setting can no longer compete successfully in the wild environments from which they originated. In this sense, our attractive, nutritious, and highly edible supermarket products (GMO or organic) are quite unnatural.

The bottom line is that essentially all agricultural organisms in all countries of the world are man-made, and in this context, the term "natural" has no biological meaning.

Methods in balance

The points presented so far suggest that there is no reason to fear genetically engineered food crops when they have been thoughtfully developed and carefully tested. But it is not unreasonable to ask why it is necessary for breeders to use the new technology when conventional methods have been so successful historically.

Conventional breeding is better suited for improving many traits simultaneously, or improving traits controlled by many genes, or traits for which the controlling gene has not been identified. It is also relatively inexpensive, technically simple, and free of government regulation. The major limitations of conventional methods derive from the limitations of the sexual process itself, and include constraints on the amount of genetic variation available within the crop (the genepool) and the fact that all traits differing between the parents are subject to segregation, and thus large populations and multiple generations of selection are required to identify rare individuals that combine the best qualities of both parents. In addition, sexual methods are useless for improving crops that are sexually sterile, such as banana.

The advantages of genetic engineering result mainly from the ability to circumvent the shortcomings of sexual reproduction. Hence, the genepool is unbounded. Improvement affects only the targeted trait (no segregation), so there is less need for large populations and multiple generations of selection. And, sterile and vegetatively propagated crops are as readily treatable by this approach as fertile crops. Likewise, the limitations of genetic engineering are complemented by the strengths of conventional methods, in that the new technology can usually target only simple, single-gene traits; it is expensive and technically demanding; and it is regulated by government agencies.

In summary, conventional breeding and genetic engineering are different but complementary ways of improving crops, and either can be appropriate or inappropriate in particular cases, depending on the breeding objectives. Although neither improvement strategy is totally without risk, the potential for a poor choice of target gene makes regulatory oversight important and obligatory during the development of transgenic crops through genetic engineering.