CENTER FOR THE PROTECTION OF INTELLECTUAL PROPERTY

The Gene Revolution

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EXECUTIVE SUMMARY

Mankind has been improving plants and animals for millennia. Simply by selecting and breeding those they liked best, our ancestors radically improved upon wild species. Today's biological inventors, with a deeper understanding of genetics, breeding, and heredity, and with the protection of intellectual property rights, are using the technology of genetic engineering to start a "Gene Revolution."

In the field of medicine, custom-built genetically engineered microorganisms are brewing up rivers of otherwise rare human hormones, life-saving medicines, and much-needed vaccines. In agriculture, scientists are combining their understanding of plant genetics with laboratory techniques of modern molecular biology to "unlock" the DNA of crop plants. By inserting genes from other plants or even common microorganisms, they are able to give plants desirable traits, solving problems that farmers have faced for millennia—faster and more precisely than ever before.

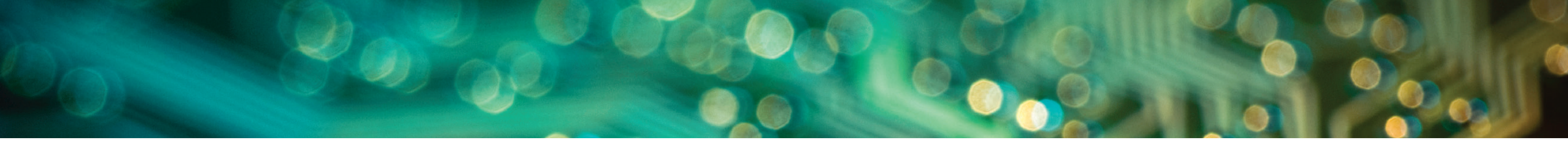
But despite its successes and a bright future, biotechnology is under attack by activists who spread misinformation and foster consumer mistrust. They have been directly responsible for onerous regulations and other hurdles to innovation that are threatening to stifle what could and should be the "third industrial revolution."

In an effort to combat this misinformation, this paper situates genetic engineering within mankind's long history of food improvement and then highlights how genetic engineering has dramatically improved human life. In it, you'll find 29 plants, animals, and microorganisms, from insulin-secreting *E. coli* to engineered cotton, from cheese-making fungus to chestnut trees, that represent the promise and possibilities that the Gene Revolution holds—*if* we hold precious and continue to protect the freedom to invent and the power of scientific innovation.

List of Genetically Engineered Innovations:

1. **Insulin**, *genuine human insulin*, brewed up by the vat
2. **Tumor- and arthritis-fighting drugs** like Humira and Avastin, which are just two of many created with biotechnology
3. **Ebola antibodies** genetically engineered and then grown in tobacco plants
4. **Flu vaccines** with a new customizability and quickness
5. **Artemisinin**, 35 tons of the malaria-fighting medicine
6. **Chymosin, the cheese-making enzyme** used in 80% of cheese eaten worldwide
7. **Vanilla flavoring** cheaper and closer to the original
8. **Sterile mosquitoes** released to fight dengue fever
9. **Avian-flu-resistant chickens** halt the spread of bird flu
10. **Herbicide-tolerant crops** are the world's most popular genetically engineered crops
11. **Insect-resistant trait** fortifies corn, cotton and eggplant against burrowing insects
12. **"Vaccinated" papaya** saved Hawaii's papaya farms from a nasty papaya disease
13. **Saving your OJ . . .**
14. **. . . and bananas**: two of your breakfast favorites could use a boost from genetic engineering

15. **The Arctic Apple**, the world's first truly non-browning apple
16. **Non-browning potatoes**, less susceptible to black-spot bruising
17. **Triple-stacked rice** grows come rain or come shine
18. **Pink pineapples . . .**
19. **. . . and purple tomatoes**: two novel fruits with added nutrition and color
20. **Fast-maturing salmon** grows in about half the time
21. **Bringing back the mighty chestnut**, a tree that was wiped out by a fungus
22. **Golden Rice** could save millions from blindness
23. **Golden bananas** are fortified with beta carotene
24. **Non-toxic cotton seeds** are packed with protein
25. **Cassava** engineered to fix some of the crop's fatal flaws
26. **Daisy the hypoallergenic cow**: the first cow that doesn't produce an allergy-causing protein in her milk
27. **A better brew**: wine and beer engineered for flavor and fun
28. **Roses are red, roses are blue**: genetic engineering aids in the quest for the first blue rose
29. **Glofish**, genetically engineered aquarium pets



The Gene Revolution

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Introduction

In the 1940s, Norman Borlaug, Father of the Green Revolution, began experimenting with wheat. With research fields in Mexico, he saw firsthand the difficulty the non-capitalist world had in growing enough to eat. He made it his life's mission to use science to make crops grow more plentifully and cheaply.

His Nobel Prize-winning invention, a variety of dwarf wheat with a short stalk to support its enormous head of grain, did just that. Harvests soared worldwide, wheat yields tripled, and countries like India went from famine to surplus as Borlaug's wheat was planted there.[1] It is estimated that "about half the world's population goes to bed every night after consuming grain descended from one of the high-yield varieties developed by Dr. Borlaug and his colleagues of the Green Revolution."[2] That's around three *billion* people.

And Borlaug's work was only the beginning. He opened the door to a whole new field of research into making food more nutritious, hardier, safer, and easier to grow. Today's biological inventors, using the technology of genetic engineering, are building on Borlaug's Green Revolution with a "Gene Revolution."

In the field of medicine, custom-built genetically engineered microorganisms are brewing up rivers of otherwise rare human hormones, life-saving medicines, and much-needed vaccines. In agriculture, scientists are combining their understanding of plant genetics with laboratory techniques of modern molecular biology to "unlock" the DNA of crop plants. By inserting genes from other plants or even from common microorganisms in just the right place, they are able to give plants desirable traits, solving problems that farmers have faced for millennia.

The development of biotech innovations depends in large part on having the proper legal mechanisms in place to underpin them. The Green Revolution was supported by the newly expanded applicability of patent rights to plants, which supplied agriculturists with the incentives and protections to invest their time and resources into developing new technologies.[3] Likewise, the Gene Revolution benefits from the property rights granted to inventors by the patent system.

Unfortunately, the policy debates surrounding new forms of biotechnology are too often distorted by misinformation, which threatens to smother both the innovators and the intellectual property rights that support them. A small but vocal group of activists claim that biotechnology is dangerous or, at best, not that useful. Although the truth is the exact opposite, the fear and hysteria drummed up by these anti-biotechnology groups has influenced policy-makers into subjecting genetically engineered plants to a harsh and unnecessary regulatory regime, created skeptical grocery store shoppers, fostered a general mistrust of scientists and agribusinesses, and succeeded in keeping life-saving foods off dinner plates around the world.

It is not the goal of this paper to address the specifics of the fear and hysteria surrounding genetically modified organisms (GMOs).[4] My purpose here is to combat the misinformation by providing a brief explanation of what genetic engineering is and by listing a variety of applications of the technology that demonstrate the kinds of problems it can solve and the wide range of benefits to which it has already given rise. First, however, let us begin by briefly surveying the history of man's attempts to improve plants and animals for human use—in order to situate genetic engineering in its historical context and to contrast it with older methods of biotechnology.

Genetic Modification Before the Green and Gene Revolutions

Man has sought for millennia to improve on nature by selective breeding. It was thousands of years ago that our ancestors first observed that individuals within a given species of plant or animal differ from each other in all kinds of ways—tree fruits vary in taste, shape, and color; one blade of grass is a little sweeter than the next; some wild turkeys are plumper and easier to catch than others. For centuries, we've been meticulously observing variations in organisms' traits in order to pick and choose the very best nature has to offer. For instance, Mesopotamians began

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cultivating date palms in the 5th century B.C.[5] A stone-carved relief, discovered in an ancient Assyrian palace, depicts a figure hand-pollinating date trees, presumably to ensure that royal gardens had the tastiest varieties.[6]

By selecting the best individuals for breeding, and by doing so over thousands of years, we've accomplished something unexpectedly radical: we've utterly transformed nature for our benefit. We've transformed the rough and mean wild-hoofed aurochs into docile milk-producing Holsteins and meat-rich Anguses. We've changed the ancient wolf into hundreds of completely different breeds of man's best friend. Even something as common as modern-day corn is utterly foreign to nature. Over 6,000 years ago, Mesoamerican people began to cultivate a wild, grass-like plant with tiny, hard kernels "sealed tightly in a stony casing."[7] Simply by choosing the seeds they liked and discarding the rest, they began a transformation that eventually resulted in today's varieties of bi-color, sweet and blue corn. Virtually everything in the grocery store, with the exception of wild fish, berries, and mushrooms, has been so profoundly altered from its original state that it would be unrecognizable to ancient man.

Our ancestors accomplished these radical changes without knowing *why* individuals vary in their traits or *how* they pass them on to their offspring. They simply exploited the natural variability they observed in order to enhance certain traits over many generations. It was this process of artificial selection, which Charles Darwin saw conspicuously in domestic canines and fancy pigeons, that was, at least in part, inspiration for his account of how nature produced the vast array of living species to begin with—*i.e.,* for his theory of natural selection.[8] He even tried his hand at the process by breeding his own fancy pigeons.

In the late 19th and early 20th centuries, experimental plant breeders in the New World took the spirit of innovation in the creation of useful plants to an extraordinary level. The most prolific of these was Luther Burbank, son of a Massachusetts farmer. If you've ever eaten a French fry, chances are it was made from a potato Burbank invented in 1871, the Russet Burbank Potato, today the most widely cultivated potato in the United States.[9] Burbank also experimented with grafting, the process of merging one plant with another by physically inserting a bud or branch from one plant into another. He created the first plumcot, a half apricot, half plum, this way.[10] Burbank created peaches, blackberries, nuts, plums, and daisies—all in all, more than 800 new plants, many of which he exhibited and sold in his seed catalog, "New Creations in Fruits and Flowers."[11]

Many more inventions would come from New World plant biologists. Darwin understood the weakness of inbreeds and the vigor of hybrids, the classic example being the sterile but robust combination of donkeys and horses: the mule.[12] This proved fertile ground for American inventors. A 1919 book on the subject depicts a sterile hybrid of a radish and a cabbage growing so large that it breached the greenhouse ceiling.[13] In 1908, George Harrison Shull at New York's Cold Spring Harbor Laboratory introduced the world to the new technology of *heterosic hybridization*—the process of combining two generations of highly inbred plants to create a vigorous plant that is much greater than the sum of its parents.[14] These plants are not strictly sterile, but don't "breed true," since their offspring aren't hardy like their parents. Today, hybrid varieties of corn, tomatoes, and other crops are the standard in the field.

Another experimenter, Lewis Stadler at the University of Missouri, noticed that although most barley seeds exposed to X-rays died, some grew with interesting properties—including pale yellow and striped leaves.[15] Stadler's 1920s experiments with barley held some promise of creating novel varieties, even though exactly what the radiation was accomplishing inside the seed remained a mystery.

With a nod to such innovators, in 1930, Congress passed the Plant Patent Act, which extended intellectual property protections that were forming the foundation of the age of industry to new varieties of non-sexually propagating plants, like grafts. Thomas Edison testified to Congress by telegram in support of the bill. Although Burbank died in 1926, before the law was passed, it was his catalog of creations that Edison had in mind when he wrote, "This [bill] will, I feel sure, give us many Burbanks."[16] Burbank was awarded 16 patents for peaches, plums, roses, and cherries posthumously.[17]

But neither Burbank nor Darwin nor other innovative breeders had any understanding of what gives rise to the variety of traits they worked with or how, exactly, artificial breeding worked to enhance those desirable traits. The first step toward such an understanding was taken by an Austrian monk in the mid-19th century.

The Discovery of Genes and DNA

It was Gregor Mendel who first discovered how the process of sexual reproduction worked. (Being a monk, he worked with plants.) Through careful experimentation in his pea garden, he established the rules of heredity. He discovered the link between the traits a plant could have and something inside the plant—what scientists would later term "genes." In experimenting with how different traits were expressed, he also gave the first hint of how human beings could better control the process. If Norman Borlaug opened the door to genetic engineering, Gregor Mendel surely found the door in the first place.

Borlaug, a plant pioneer like Burbank, concentrated his efforts on wheat, a plant that, because of its propensity to self-pollinate, was nearly impossible to apply the technology of hybridization to. He took Mendel's discoveries to new levels, seeking to improve the crop by a meticulous scientific approach. He "amassed germ plasm from Japan, the United States, Australia and Colombia" to begin and then crossed and re-crossed breeds, over 6,000 crossings in all, before he created his versatile wheat.[18] Borlaug's approach of gathering a wide variety of plants uniquely suited to the particulars of their environment laid the foundation for his success.

In 1970, the same year he won the Nobel Prize for his contribution to agriculture, Congress passed the Plant Variety Protection Act, which extended property rights to sexually propagating varieties, like Borlaug's wheat. And although Borlaug's technological breakthrough was, by his choice, in the public domain, he "could have received patent protection for seventeen years" under the Act.[19]

But it was a 1953 discovery that would bring an even deeper understanding of plant genetics, paving the way for the transition from plant breeding to plant engineering. On a Saturday morning in February, James Watson and Francis Crick discovered the double-helix structure of DNA in Cambridge's old Cavendish laboratory. Watson remembers Crick announcing: "We have discovered the secret of life" in a nearby pub later that day.[20] If you could zoom into the nucleus of a cell, you would see the stringy substance that Watson and Crick discovered to be the molecular basis for inheritance. The DNA that every school kid is familiar with, like recipes in an organism's recipe book, determines what traits an organism will have. In plants, like Mendel's peas, genes, which are made up of long segments of DNA, determine all sorts of characteristics, from the color of a pod to how sweet it will be to how tall or short the plant will grow.

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The variety that our ancient ancestors saw in the natural world could be explained by differences in DNA. The difference between a red and a yellow rose is found in the different versions (alleles) of the genes that instruct the developing plant what flower color to produce. Sexual reproduction does a shuffle of the allele deck for the next generation, dealing out different traits to different offspring.

If the allele for yellow pigment is dealt to an offspring, that gene will be expressed by the molecular machinery within the rose's cells. That bit of DNA will be copied and then used to build the protein it encodes for. "Yellow genes" instruct the plant to produce carotenoids, pigments that give flowers yellow and orange hues. If the rose instead has the "red" allele, the rose petals are constructed with anthocyanins, proteins that come in reds.[21] Many alleles exist and many combinations are possible, giving roses the rich tapestry of color that breeders strive for.

Applying Watson and Crick's discovery to Darwin's theory, it became clear that evolution was the manifestation of naturally selected changes in an organism's DNA over generations—*i.e.,* changes that persisted because they made the resulting species better suited to their environment. The idea of classification became stronger, and diverse organisms were seen as connected on a tree. Today, DNA analysis has confirmed 90% of the connections on the plant family tree that were originally drawn by looking at morphological traits.[22]

What Darwin was doing with his fancy pigeons, and what our ancestors were doing in creating corn, cows, and dates more suitable to human needs, was selecting among different versions of genes by choosing the traits that they liked best, thereby making more common the alleles that code for those traits. Norman Borlaug, by breeding together wheats from disparate parts of the world, was shuffling genetic cards from a wider variety of decks, hoping to stack it with more aces. Wheat that was successful in Japan could combine its genes with a Columbian breed to give a better chance that the offspring would be that "Goldilocks" variety that Borlaug was searching for.

Nature even has a way of creating new cards for a species' deck. Mutations cause the changes to the gene pool found in nature and they occur by a number of methods: *e.g.,* sunlight, cosmic rays, and other forms of radiation can create a mutation, and sometimes DNA can stick together or copying errors can occur in the nitty-gritty of cell division. Mutations create changes in a segment of DNA code that can be passed along to offspring. Some mutations are advantageous, but many are not. Combining random mutations with natural selection, organisms can change, adapt, and survive. This is why Stadler's practice of "atomic gardening" provided interesting results—increasing the rate of random mutations by bombarding a plant with X-rays could produce new varieties more quickly.

This deep understanding of how organisms come to express the traits they do naturally led to the question: What if we could give organisms desirable traits by making changes directly to their DNA? If we could identify stretches of DNA that are responsible for certain traits, perhaps we could go about our quest of improving upon nature more precisely.

Perhaps we could even "recombine" DNA from different organisms to let one borrow useful traits from another. Just 20 years after Watson and Crick's discovery, Stanley Cohen and Herbert Boyer successfully recombined DNA from two different sources in a test tube, proving that it could be done.[23] It was a technological breakthrough, but the process works because organisms all share the basic building blocks of life contained in our DNA.

The Advent of Genetic Engineering

The first leap forward in this new field of bioengineering came not in plants, but in the manipulation of a relatively simple creature—the common *E. coli* bacteria. Scientists got it to do something spectacularly useful—produce human insulin.

Mankind has been harnessing the power of tiny microorganisms for centuries. Bacteria transform milk into yogurt, remove waste from water, and facilitate the mining of copper. If you feed sugar to yeast, in a mixture of water and hops, it will reward you by producing carbonated beer.[24] If there is one thing that these microbes are good at, it is taking in one substance as food and turning it into another as waste. And what is one organism's trash could be another's treasure.

The idea is simple: genes within bacteria and yeast act like the foreman of a factory, instructing the organism what to manufacture out of the "food" it takes in from the environment. By changing the instructions—*i.e.,* by inserting into the bacteria's genes the segment of human DNA that codes for insulin—scientists were able to get bacteria to secrete human insulin as a byproduct when fed.[25] Insulin was the first of many medicines, vaccines, rare human hormones, and other substances that these miniature bioengineered beasts of burden churn out for us.

Extending that idea to plants was next. A 1987 paper describes one of the first bioengineered plants, a member of the genus *Nicotiana*. This tobacco plant was engineered to solve a problem: burrowing hornworms. Scientists borrowed a gene from common soil bacteria, *Bacillus thuringiensis* (or Bt), that causes the bacteria to produce a toxin that is deadly to the hornworm. Instead of spraying the plant with this common insecticide, genetic engineers inserted the Bt-producing gene into the DNA of tobacco plant cells, instructing the plant how to protect itself.[26] Plants produce all sorts of insecticides naturally, but the choice for this particular toxin was done with people in mind. It is deadly to hornworms, but harmless to humans.[27]

By decoding and mining stretches of DNA in the genomes of different organisms, from snapdragons to soybeans to soil bacteria, scientists have been able to determine which genes, or recipes, determine which traits. By extracting and moving these genes from one organism to another, they are able to make directed changes. In other words, they have been able to give a plant a new recipe for a desirable trait, creating a plethora of useful plants like beta-carotene-producing rice, herbicide-tolerant corn, non-browning apples, and virus-resistant papayas.

It's an extension of what human beings have been doing for ages—improving on plants and thereby improving our lot in life. But rather than a painstaking process involving generations of plants and people, this engineering can be fast. It took Borlaug and his colleagues a decade to breed the perfect wheat. A scientist in today's bioengineering labs can go from an idea to a newly invented organism in just years. And it's precise. Rather than mixing entire genomes in the process of sexual reproduction, in bioengineering, just a few genes are moved from one organism to another. If you imagine the genome of a plant as a book, the change amounts to editing a few sentences to make it read better.

And the technology has been incredibly successful. In the 20 years since the first biotech seeds were commercially planted, genetically engineered varieties of corn, soybeans, cotton, canola, and beets, engineered to resist insect attacks in the field, or engineered to make it easy for farmers to deal with weeds, have grown to represent about 90% or more of those crops planted in the United States.[28]

Last year, around the world, 18 million farmers pushed trillions of biotech seeds into millions of acres of dirt. Genetic engineering is one of the most rapidly adopted technologies in the history of mankind, planted today on 13% of all arable land.[29] Putting it in the negative, without biotechnological inventions, an additional amount of land equal in size to California, New Mexico, Arizona, and Nevada combined would need to be planted to meet the food needs of the 7 billion people on the planet.[30]

As Americans zoom by farm land in their cars, many are unaware of the story of how biological science is improving food. Despite the fact that many Americans don't know what a GMO (genetically modified organism, as they are called in popular culture) is, chances are they ate one for breakfast. It is estimated that 70–80% of food on store shelves contains ingredients grown from biotech seeds.[31] Both people and animals have consumed trillions of meals containing biotech ingredients in the 20 years since the first varieties of insect-resistant and herbicide-tolerant crops were planted.[32]

Developing today's high-yielding varieties of crops, from corn to cotton, requires a great deal of innovation. To paraphrase J. M. Mulet, a professor of biotechnology at Polytechnic University of Valencia in Spain: these plants have as much technology in them as an iPhone.[33]

In order to review the science of genetic engineering and to highlight the technology's contribution to mankind, I've picked 29 plants, animals, and microorganisms, from insulin-secreting *E. coli* to engineered cotton, from cheese-making fungus to chestnut trees, to represent the promise and possibilities that the Gene Revolution holds, that is, if we hold precious the freedom to invent and the power of scientific innovation.

From Rare, Inefficient, and Scarce to Common, Plentiful, and Cheap

Stories of the contribution of genetic engineering to the field of medicines and rare substances always seem to take on the same miraculous form. Before genetic engineering, it took 8,000 pounds of animal pancreases to harvest a single pound of life-saving insulin, 50 pounds of cured vanilla beans for a pound of vanilla-flavoring compounds, 100,000 farmers to grow the world's supply of anti-malarial medication, and 1.5 million calf stomachs to extract the milk-curdling enzymes needed to make enough cheese for Americans in the year 1916.[34]

These scarce substances were difficult and labor-intensive to produce in the needed quantities, which caused supply shortages and wild price fluctuations driven by a constant demand. But these are often just the kind of economic conditions that create opportunities for innovation.

In the 1970s, scientists discovered how to get microorganisms like bacteria and yeast to produce desirable chemical compounds by changing them on the genetic level. The change has been so transformative that some have called it the "third industrial revolution."[35] Here are just some of the common everyday substances that would be expensive, often prohibitively so, without genetic engineering.

1. *Insulin*

A press release dated September 6, 1978, announced the "successful laboratory production of human insulin using recombinant DNA technology."[36] Scientists had used their understanding of DNA to engineer common bacteria to do something spectacularly useful. Inside bacteria, tiny rings of genes called "plasmids" determine what substances the bacteria will produce. By splicing together the genetic code needed to produce human insulin and then inserting

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this plasmid ring into *E. coli* bacteria, scientists created a tiny insulin factory—one that multiplied when fed, creating many more of these factories until a veritable river of insulin could be produced.

The transformation of this particular medicine was nothing short of miraculous. Before synthetic biology, 1.5 million people around the world relied on insulin from pigs and cows to lift the death sentence of diabetes. It took 8,000 pounds of animal pancreases to produce just a single pound of insulin. It was labor intensive and expensive, and by the 1970s, the threat of shortages loomed.[37]

The first batches of human insulin were brewed with bacteria, but today genetically engineered yeast also does the job. Similar to beer, insulin is now "brewed" in large vats called "bioreactors." Compared to harvested porcine and bovine insulin, it is much cheaper to produce, there is no threat of shortages, and people with bad reactions to the animal variety can now get exact copies of genuine human insulin.

2. *Tumor- and arthritis-fighting medicine*

Today a whole slew of vaccines, rare human hormones, and much needed medicines are produced using the technology of genetic engineering. Fifty out of 100 of the United States' top-selling drugs in 2014, from tumor-fighting drugs like Avastin to the popular anti-inflammation arthritis drug Humira, were created using the technology of genetic engineering. Seven of the top 10 drugs in 2014 were biotech in origin "compared to five in 2008 and just one in 2000," according to a *Reuters Health* report.[38]

3. *Ebola antibodies*

In the 2014 Ebola outbreak, doses of a new antibody-based treatment called ZMapp were used to treat seven people.[39] Although its effectiveness is still being studied, genetic engineering emerged as a clear hero. The drug is produced by delivering strands of modified genetic material into a tobacco plant.[40]

The ZMapp antibodies, which act to prevent virus antigens from attacking cells, were created by first infecting mice with a protein from the Ebola virus and then genetically modifying the resulting antibodies "to more closely resemble human ones." Then the genetic code that will produce these antibodies was delivered into the leaves of a tobacco plant. The genetic code hijacks the plant's cells and replicates itself like a virus, causing the plant to produce large quantities of the desired antibody.[41]

The engineering affects only those plants grown; the genes are not incorporated into the plant genome, which eliminates the possibility of spreading the trait through pollination.[42] The technique is broadly called "biopharming," and if ZMapp is proved effective, genetic engineering could be on the forefront of helping combat future Ebola outbreaks.

The drug was created as a collaboration between Mapp Biopharmaceutical, Inc., LeafBio and others and grown by Kentucky BioProcessing.[43]

4. *Flu vaccines*

Biotechnology could mean more effective flu vaccines. Current technology, where the vaccines are grown inside of virus-infected chicken eggs, typically takes six to nine months, meaning that the vaccine is a prediction of what viruses will be common during the upcoming flu season. Frequent mutations often make the guess wrong, rendering the flu vaccine woefully ineffective.[44]

For the 2014 flu season, Novartis shipped the first batch of Flucelvax, "the first breakthrough in flu vaccine production technology in over 40 years." The vaccine is generated in genetically engineered mammalian cells. The "Flublok" vaccine was also in service for the first time this flu season, created using a viral protein generated in modified insect cells.[45]

A vaccine harvested from genetically engineered tobacco plants is also promising. "[O]ne little plant can do 50 doses," according to Andy Sheldon, CEO of Medicago, a Canadian biopharmaceutical company developing tobacco-grown vaccines. "Whereas when you're looking at one egg, which is what people use when they're making influenza vaccines, they can get about two doses," he added. In 2012, Medicago's tobacco plants produced 10 million H1N1 flu vaccines in just 4 weeks, promising flu vaccines with a new customizability and quickness.[46]

5. *Artemisinin—the anti-malarial drug*

Each year, millions suffer from malaria, and hundreds of thousands die. Hardest hit is Africa, where "a child dies every minute from malaria."[47] Artemisinin, a medicine derived from the leaves of a wormwood plant native to China, has shown itself to be highly effective in treating malaria (even more effective, it seems, than quinine, a popular anti-malarial drug). The Chinese Sweet Wormwood, from which the medicine is traditionally grown, is expensive to harvest in the needed quantities, which has caused availability to be unstable and seasonal. A hundred thousand farmers are needed to grow the world's fluctuating supply.[48]

Amyris, a California-based biotech company, has attacked this problem by using genetically engineered yeast to synthesize artemisinin. In a set-up reminiscent of a Star Trek-style replicator, technicians use a computer to insert the necessary sequence of genes to make yeast produce the medicine as a byproduct—"on demand." In 2013, Amyris produced 35 tons of the stuff, enough for 70 million treatments.[49]

6. *Chymosin, the cheese-making enzyme*

Genetic engineering is now used to make chymosin, an enzyme essential to cheese making. Chymosin is found naturally in the lining of a calf's stomach and helps the calf to break down and curdle its mother's milk for digestion. The best cheeses are made using genuine calf chymosin, but it is problematic to harvest in quantity.

Back in 1916, 1.5 million calf stomachs were needed by American cheese makers to do the job.[50] At a conference in Wisconsin in 1917, a representative from Parke-Davis warned that being "dependent on the fourth stomach of the calf to produce the one hundred million pounds of cheese for feeding humanity" could mean American cheese makers may not be able to keep up with demand.[51]

In 2013, the United States *alone* produced 11 billion pounds of cheese using an endless supply of bioengineered chymosin.[52] The process was worked out in the late 1980s, first using bacteria, until yeast and filamentous fungus were found to be more productive.[53] Knowing the genetic code that produces the enzyme within the lining of the calf's stomach, genetic engineers inserted that gene into a microorganism, which produces chymosin as the "waste product" when fed the nutrients it needs. By 1999, 60% of hard cheese produced in the United States was made with microorganism-generated chymosin.[54] Today, it is estimated that 80% of the global cheese market relies on it.[55]

A Danish company, Chr. Hansen, holds a patent for one of the world's most popular varieties, CHY-MAX, biosynthesized by a genetically engineered *aspergillus niger* fungus.[56]

7. *Vanilla flavoring*

Swiss company Evolva holds the patent for a biosynthesized vanilla, produced by yeast that have been genetically engineered to generate the flavoring as a by-product when fed sugar.[57] Real vanilla beans are expensive, harvested from the seeds of a finicky orchid that grows in rainforest climates in countries like Indonesia and Madagascar. Plants must be carefully pollinated by hand in the elusive 12-hour window in which the flowers open. Fifty pounds of cured vanilla beans contain just a single pound of vanillin, the main flavor compound that makes the spice so popular.[58]

Synthetic vanilla flavorings on the market today have failed to capture the complexity of genuine vanilla beans. But Evolva claims its biosynthesized vanilla comes much closer to the original and will be much cheaper to harvest.[59] Vanilla is second on the world's list of most expensive spices—the first is saffron, which comes from a crocus that grows in Iran. Evolva has also developed a yeast-brewed saffron, expected to be ready for commercial launch in 2016.[60]

Combating Disease in Clever Ways

Thinking outside the box, researchers are searching for ways to use genetic engineering to combat human disease by modifying the disease-carriers themselves.

8. *Sterile mosquitoes*

It is estimated that 37 million people will get dengue fever this year in India.[61] Also known as "breakbone fever," dengue causes severe flu-like symptoms including "bone-breaking" joint pain, and can be fatal. Dengue, along with yellow fever and chikungunya, is picked up and spread from person to person by infected *Aedes aegypti* mosquitoes.

Two and a half billion people live in areas where dengue is present, and the disease has now made its way to the Florida

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Keys as infected tourists are bitten by local mosquitoes. As in Florida, officials in India are considering releasing hordes of genetically engineered mosquitoes in an effort to curtail the disease-carrying insects.[62]

This method of pest control, broadly called "sterile insect technique," uses facts of the insects' nature to aid in their destruction. Females, the biting half of the species, mate and lay eggs only a few times before dying, which means there is only so much love to go around. Releasing males carrying a gene that will ensure still-born offspring results in fewer mosquitoes in the next generation. And fewer mosquitoes means fewer cases of dengue.

The technique was pioneered in the 1950s and was successful in eradicating the gruesome cattle screwworm from North America.[63] Until recently, "sterile" male insects were created by bombarding a population with high energy gamma-rays and separating the males from females using insect pheromone. It was expensive and unreliable.

Oxitec, a British biotech firm, has engineered all-male mosquito populations, modified so that the offspring they sire will die. The insects also have a marker—a gene from marine jellyfish causes the bugs to fluoresce when exposed to a certain light source. This makes them easy for researchers to identify and track in the field.[64]

Releases of Oxitec's genetically modified mosquitoes achieved an 80% reduction in local mosquito population in the Cayman Islands and a 96% reduction in Brazil, combating head-on the problem of dengue fever.[65]

9. *Avian-flu-resistant chickens*

A genetically engineered chicken tackles the spread of disease from a different angle. These chickens, created at the universities of Cambridge and Edinburgh, don't spread bird flu from chicken to chicken, keeping the disease in check. The modification, a small piece of genetic material that stops the virus from reproducing, has the potential to stop bird flu outbreaks from spreading within poultry flocks and to wild bird populations. This not only protects birds, but has the potential to halt the spread of mutated bird flu virus to human populations.[66]

The Technology of Genetic Engineering in Agriculture

Growing plentiful food is a necessary human quest, but one without any guarantee of success.

In 1791, George Washington conducted the first census of agriculture.[67] Back then, it's estimated that 90 out of 100 Americans were directly involved in the growing and securing of food.[68] Today it's just 1 out of 100.[69] Comparing a modern farm to a farm in George Washington's time, it's not hard to see why.

Back then, manual labor was the name of the game—people planted seeds using hooves and hands, and when insects or disease attacked your crops, there was little you could do but stand and watch nature destroy your work. A particularly hot or wet year could ruin your harvest. Good years were punctuated by shortages.

Since then, people have taken agricultural technology forward by leaps and bounds. Today's monitoring satellites in space snap pictures of fields and send signals to automatic watering systems. Modern farmers zoom across fields in fossil fuel-powered mega machines, receiving signals from GPS satellites that tell them where to plant seeds.

And those aren't your grandfather's seeds they're planting.

Genetically engineered crops designed to grow plentifully, come rain or shine, carpet American fields. Scientists have created plants (and even animals) with a myriad of favorable properties, adding nutritional content, increasing yields, enhancing flavor or simply creating new varieties.

10. *Herbicide-tolerant crops*

Weeds compete with crops for light, nutrients, and water. They can also be a harbor for destructive and disease-carrying insects. When harvested along with the crop, they degrade it and ensure that next year's seed also will be contaminated with weeds.

By transferring a gene from a common soil bacterium into a soybean, the Monsanto Company created the first genetically engineered herbicide-tolerant plant.[70] The soybeans were created to be "Roundup Ready"—the soybeans would survive when sprayed with glyphosate, a common herbicide and the active ingredient in Roundup weed killer. Since then, the herbicide-tolerant trait has become "the world's most widely adopted biotech trait," planted on billions of acres since 1996.[71]

The plants have many advantages. Herbicide can be used throughout the growing cycle and just a coffee-cup full of a relatively inexpensive, easy-to-manufacture herbicide is all it takes to control weeds on an area of land the size of a football field.[72] Glyphosate was chosen because it is relatively benign—it's about as toxic as baking soda, yet is extremely effective in killing weeds.[73] The trait does away with labor-intensive hand weeding, the standard in much of the world.

The Roundup Ready soybean is set to go off patent in 2015, but Monsanto has already engineered a second-generation variety that will be on patent for many years to come.[74] In 2014, Dow AgroSciences' Enlist corn and soybeans were approved for planting in the United States.[75] Paired with another common and relatively benign herbicide (2,4-D, commonly purchased as Scotts Turf Builder), the corn and soybeans will give farmers the option of rotation between herbicide-tolerant traits to slow weed resistance.

"In 2013 alone, herbicide-tolerant crops occupied 99.4 million hectares or 57% of the 175.2 million hectares of biotech crops planted globally." Of the major food crops in the United States, over 80% of soybeans, cotton, beets, alfalfa, canola, and corn planted were genetically engineered to be herbicide tolerant.[76]

(In an interesting side note, Chipotle restaurants recently announced that they would be rejecting any food grown from genetically engineered seeds on their menu.[77] They changed cooking oils from soy oil grown from herbicide-tolerant soybeans to sunflower oil grown from herbicide-tolerant sunflowers.[78] It was a bizarre move, indicative of the hysteria surrounding genetic engineering: Roundup Ready soybeans created using the technology of genetic engineering were viewed as unacceptable, but Clearfield Sunflowers, for example, created by crossbreeding a sunflower with a weed, were seen as "better" even though they are both "modified" organisms, created to exhibit the same useful trait.[79])

11. *Insect-resistant trait*

The stalk borer is a worldwide pest—it appears across large swaths of Europe, the United States, and Canada. In America, farmers have been dealing with the inconspicuous-looking moth for almost a hundred years. In years where it is particularly active, it can take down up to 30% of a corn harvest.[80]

The larvae of the moth burrow inside the corn stalk where they feast, dropping ears to the ground prematurely or simply killing the plant entirely.[81] There are pesticides that can kill the bug, but spraying on the outside of the plant can't reach inside of the stalk, where the insect is busy mining away.

Scientists first fortified plants against burrowing insects in 1987, with the invention of hornworm-resistant tobacco.[82] By 2010, multiple varieties of corn that were toxic to burrowing insects, like the stalk borer, were marketed with a similar trait, including Monsanto's YieldGard, Syngenta's Agrisure, and Dow's Herculex.[83]

Like hornworm-resistant tobacco, these corn seeds borrowed a gene from the *Bacillus thuringiensis* bacteria, instructing the plant to produce its own Bt insecticide. The toxin works by attaching itself to a receptor inside the insect's stomach, causing the insect's death, and was chosen because it is "considered safe to people and nontarget species."[84] Varieties differ by the specifics of the version of the Bt toxin they produce or the position the added gene occupies in the chromosome of the corn.[85]

In the United States, tens of millions of acres of insect repellant corn have been planted, increasing yields and saving precious corn plants from burrowing insects. In India, cotton with the same trait single-handedly raised farmers' bottom lines by 3.2 billion dollars in 2011. The crop is so successful against the cotton bollworm that 10 million additional acres of cotton were planted in the 12 years since its introduction, creating a thriving export market.[86] In Bangladesh, Bt eggplant was allowed for the first time in 2013. The eggplant is poised to be so successful that anti-biotechnology activists are out to stop the technology before it is widely adopted. Masked activists showed up at one eggplant field, threatening the farmer to falsely declare his crops a failure to a local newspaper in order to scare others out of planting it.[87]

12. *"Vaccinated" papaya*

The papaya ringspot virus gets its name from the symptoms it causes the papaya tree. The fruit of an infected tree develop bumps and prominent ring-shaped spots, the leaves appear distorted and curled, and the trees can no longer produce papayas.[88]

The virus spreads by hitching a ride on aphids as they fly from tree to tree. The aphids pick up and spread the disease within seconds, making insecticides nearly useless—the bugs simply cannot be killed quickly enough to prevent the disease from spreading.

In Hawaii, where the papaya industry thrives, the disease has a long history. The virus was discovered on the Hawaiian island of Oahu in the 1940s. By the 1950s, it had caused severe damage to the papaya industry there. In the 1970s, the virus made the hop to the Big Island. Dennis Gonsalves, a plant pathogen researcher who hails from Hawaii, became concerned that the virus could wipe out the Hawaiian papaya for good.[89]

Gonsalves began investigating a genetic solution to the disease after news spread of the invention of a virus-resistant transgenic tobacco plant. He wondered if it was possible to "vaccinate" papaya trees against the virus using genetic engineering.[90] The breakthrough came when Gonsalves and his colleagues found a way to include a small amount of the papaya ringspot pathogen in the chromosomes of the tree, thereby fortifying it against infection. They started their work none too soon.

In 1992, the virus engulfed the Big Island. But by 1998, the federal government approved the planting of two varieties of papaya ringspot-resistant papayas that Gonsalves and his team invented. Known by their trademark names, seeds of Rainbow and SunUp varieties were pushed into virus-laden soil by Hawaiian farmers.[91]

These papayas grew, saving Hawaii's papaya business, and are exported to grocery stores throughout the world to this day.

13. & 14. *Saving your OJ and bananas*

"Your glass of orange juice may be an endangered species," according to Florida plant scientist Kevin Folta.[92] Citrus greening, a disease "causing yellow mottling on the leaves and asymmetrical, bitter fruit that never ripens" is now present in over 90% of Florida's commercial orange groves.[93] The disease is caused by bacteria and carried from orange tree to orange tree by tiny infected insects. Trees that catch the disease are doomed to die within about five years, serving their remaining time as a harbor for the disease. There is no known cure and no known immune citrus varieties, meaning that cross-breeding for resistance is not an option.[94] Instead, researchers are looking for a gene to confer resistance, hoping to inoculate the trees against the bacteria the same way it was done with Hawaiian papayas.

Southern Gardens, a subsidiary of U.S. Sugar, is financing the development of a genetically engineered tree, "which could take a decade and cost as much as $20 million." Their trees borrow two genes from spinach to make them disease-resistant.[95]

Meanwhile, bananas in Africa have been devastated by a bacterial disease. Known as the "Xanthomonas wilt," this bacterium causes fruit to rot and ooze while still on the stalk and the plant to wither and die.[96]

Seeking to alleviate the effects of the disease and give bananas a defense against the wilt, genetic engineers transferred two genes from peppers that confer resistance. The trees are 100% immune to the disease. The fortressed banana holds so much promise to alleviate crop losses in Uganda that the country temporarily lifted its ban on genetically modified crops. The banana wilt caused $500 million in damage annually to banana growers there.[97]

15. *The Arctic Apple*

Early this year, Okanagan Specialty Fruits announced that their patented technology, the Arctic Apple, had been approved for sale in the United States and Canada.[98] Although they may look like any other Granny Smith or Red Delicious apple, these apples are different. Scientists at Okanagan invented the apples to solve a problem: browning.

When the cells of a typical apple are broken, two chemicals within the apple mix and react with oxygen to cause the flesh to brown.[99] Sliced apples are used in fast food meals and on top of prepared salads, but those apples must be sprayed with an expensive coating that changes the flavor in order to suppress browning. By inserting genes, which control the production of one of these browning chemicals, into a common apple, scientists at Okanagan were able to suppress that chemical's production. Arctic Apples, named for the ever-white color of their flesh, don't turn brown when sliced, bitten, or bruised. It's a simple, yet spectacular, invention that could save the food service industry millions.

The apples will also be one of the first direct-to-consumer biotech-enhanced products, rather than a product geared toward farmers.

16. *Non-browning potatoes*

J.R. Simplot, a company that produces over 3 billion pounds of potatoes each year, recently added a genetically engineered variety to their roster. Simplot's new "White Russet" potato is similar to conventional spuds, but borrows DNA from five varieties of potatoes, giving it some desirable traits.[100]

Among its selling points, Simplot scientists say they have fortified White Russet potatoes to be less susceptible to black spot—a type of bruising that occurs when potatoes are knocked about during harvest. As these spotted potatoes must then be picked out of the harvest, the bruising can account for wasting up to 5% of a potato crop.[101]

Similar to the Arctic Apple, White Russet potatoes are engineered to produce less of a chemical that would otherwise cause them to brown when sliced. For a company like McDonald's that sells 9 million pounds of French fries a day, these potatoes could mean an easy way to ensure all of their fries are that classic golden color and save them money in the process.[102]

17. *Triple-stacked rice*

Sometimes patient coaxing and careful tending are simply not enough to see a plentiful harvest spring forth from your field—the unpredictability of the weather and poor soil conditions can make that impossible. Getting plants to more efficiently use resources, such as water, sunlight, and nitrogen in the soil, can ensure that food is plentiful, come rain or come shine.

Researchers at Arcadia Biosciences in Davis, California, recently unveiled a strain of rice that they hope will be less vulnerable to some common growing problems. If successful, rice farmers will be able to plant this same strain of rice, year after year, "regardless of the conditions." Researchers have triple-fortified the rice to combat three problems that make rice hard to grow: drought, salty soil, and lack of fertilizer. The rice borrows genes from barley, cress, and *Agrobacterium* to give it the triple-stacked properties.[103]

Thinking outside the box, researchers are searching for ways to use genetic engineering to combat human disease by modifying the disease-carriers themselves.

18. & 19. *Pink pineapples and purple tomatoes*

Scientists from the John Innes Centre in the U.K. have invented a tomato that boasts a royal purple color produced by the natural pigment anthocyanin—the same chemical that gives blueberries their color. A gene from a snapdragon was used to achieve its production.[104]

Some have argued that anthocyanin has many potential health benefits, but the real improvement is that these tomatoes also last longer after being picked from the vine—a whopping 48 days—more than doubling the 21-day average of non-modified varieties. This means the tomatoes can stay on the vine longer. And longer vine times give flavors time to develop, bringing that fresh-picked flavor to your table.

Del Monte holds the patent for a new pineapple with pink flesh, which gets its color by producing an abundance of lycopene—the same chemical that gives tomatoes their red color. The Rosé pineapple was created by adding genes from a tangerine to a Del Monte Gold pineapple. Field trials were completed in Costa Rica and the pink pineapple is approved for import by the USDA.[105]

20. *Fast-maturing farm salmon*

Regular farm salmon take about three years to reach maturity. Despite abundant resources in a farm setting, salmon are programmed to grow only in the summer time. The AquAdvantage Salmon grows year round thanks to the help of genetic engineers. The fast-growing fish was engineered by inserting a gene from the Chinook salmon and another from the pout. They have the same nutritional content, the same fatty acids, and taste the same—but take just 18 months to reach full maturity.[106]

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AquaBounty, the company who pioneered these fish, applied for permission to sell them in the United States back in 1995.[107] Passed from administration to administration, these salmon have been in regulatory limbo for 19 years at the time of this writing.

21. *Bringing back the mighty chestnut*

Thanks to genetic engineering, soon squirrels from Florida to Maine could be hiding a nut they haven't seen in over 60 years: the American chestnut.

When settlers first came to America, American chestnuts trees would have been a prominent part of the forest. There were over 4 billion trees which produced billions of pounds of chestnuts every year for both squirrels and people to collect.[108] The nuts fell from groves in a seemingly limitless supply of shiny brown gems that could be scooped up and crushed to make bread or be roasted or eaten raw. People also desired the trees for their hardwood—they grow faster than oaks and produce a strong wood that is easy to split. Back in 1900, chestnut made up about 25% of all mature timber in the United States.[109]

Their tremendous size earned them the nickname "the redwood of the East." But the giant trees were virtually wiped out by an enemy thousands of times their junior. In 1904, people began to notice that the trees were dying off, and it was discovered that a fungus was to blame. The blight fungus hitched a ride to the new world on immune imported Asian chestnut saplings. Soon the fungus leapt from chestnut tree to chestnut tree and by 1950, the American chestnut was virtually wiped out.

William Powell at the State University of New York and Scott Merkle at the University of Georgia began searching for a genetic engineering solution in 1990.[110] Genomes from both the American and Chinese chestnut tree were mapped, and the genes that seemed to give these trees immunity from the blight were flagged. But the big discovery came from another plant entirely. The team noticed that wheat generates an enzyme that easily detoxifies this particular blight. Powell and his collaborators have now created a number of American chestnut trees that include a few genes from Chinese chestnut trees, other chestnut blight immune trees, and, of course, the special wheat gene. A group of 800 of these precisely engineered trees were planted in 2013 to see how they fare against the blight.

Making Food Safer and More Nutritious

Although anti-GMO activists relentlessly paint GMOs as dangerous, the truth is that patented technology is making food safer and more nutritious for people around the world.

22. *Golden Rice*

Rice is a staple crop for billions. Although an excellent source of calories and carbohydrates, plain rice lacks the nutrition needed for a balanced diet. Even among populations that have access to enough calories from rice to sustain them, they may still be susceptible to malnutrition. One particularly pervasive form of malnutrition is vitamin A deficiency.

The World Health Organization estimates that between 250,000 and 500,000 children go blind each year for want of vitamin A. About half of those children will be dead within twelve months. Last year, vitamin A deficiency affected "1.7 million children under the age of five and 500,000 pregnant and nursing women," according to the International Rice Research Institute. Vitamin A deficiency is the world's leading cause of preventable blindness and increases the risk of death from disease and infection.[111]

That was exactly the problem that scientists Ingo Potrykus and Peter Beyer hoped to tackle with genetic engineering.[112]

These scientists began the search for a way to fortify rice to help with vitamin A deficiency in 1982. In 1999, Potrykus and Beyer had come up with a prototype called "Golden Rice."[113] Golden Rice contains beta carotene, which is sometimes called "pro-vitamin A" because it can be converted into vitamin A by the body. Beta carotene is found in a number of vegetables, like spinach and carrots, but not rice.

The two researchers discovered that rice had all the pathways necessary to produce beta carotene, but it was lacking genes to turn that capability on. The new rice was created first by moving two genes from a daffodil into the rice and later by incorporating a maize gene and another gene found in a common soil microorganism.[114]

The idea is simple: offer the rice for free to any third-world farmers who wish to plant it. By growing Golden Rice in place of beta carotene-poor rice and propagating seed to neighbors, the rice could spread like a golden light preventing blindness.

Sadly, field trials of this rice are regularly destroyed by activist groups, such as Greenpeace. When a mob stormed a field trial in the Philippines in 2014, inventor Potrykus stated that he was "outraged" by the destruction and that it would set the project back months.[115] The Golden Rice that was growing in that field was going to be eaten by volunteers as part of a scientific test to see how much the rice could help in fighting vitamin A deficiency in the malnourished.

23. *Golden bananas*

Bananas are a major food and cash crop in Africa. In Uganda, it is estimated that "a typical adult will eat about three times his body weight [in bananas] in a year."[116] And in that region of Africa, 30% to 60% of daily calories come from bananas.[117] But bananas, like rice, lack beta carotene.

Researchers at the National Agricultural Research Laboratories in Uganda are testing out a genetically modified banana that has the potential to combat malnutrition. Similar to Golden Rice, researchers have planted test crops of a "golden banana." As this banana produces its own beta carotene, researchers hope the banana will help Ugandans combat blindness and vitamin A deficiency.[118]

24. *Non-toxic cotton seeds*

Chances are you have eaten a sunflower seed or a pine nut, but have you ever wondered why you've never tasted a cotton seed? Cotton seeds, like other nuts and seeds, are packed with a savory 22% protein, but are also packed with a deadly toxin called gossypol. Gossypol, when eaten, drops blood potassium to dangerously low levels and can severely damage the liver and heart. In other words, eating cotton seeds can kill you.

Researchers at Texas A&M have found a way to remove that toxin from the seeds without making the plant an easy target for insects. The cotton was produced with a technique called "RNA interference," where genetic engineers insert an extra copy of the DNA sequence coding for gossypol right next to the first, but in reverse. The two genes then "interfere" with each other thereby inhibiting gossypol's production entirely.[119]

The cotton already grown worldwide has enough protein in its seeds to feed 500 million people.[120] "Cotton is grown mainly in developing countries and by small farmers—these people could benefit hugely from this new variety because they will be able to use the cotton fibres for textiles and also the cottonseed for food," the seed's inventor said.[121]

25. *Cassava*

Most Americans have never heard of the tuber called "cassava," but the root is the main source of nutrition for 290 million people in sub-Saharan Africa.[122] It is known as a food-of-last-resort since it can be left growing underground, while other crops are plentiful, for up to three years before it must be dug up. But cassava is prone to disease, has the lowest protein-to-energy ratio of any staple crop, and lacks adequate levels of beta carotene, Vitamin E, iron, and zinc.

Cassava also contains elevated levels of cyanide, which have no effect when cassava is properly processed and is eaten in small quantities, but during food shortages, when corners are cut and large quantities are typically ingested, it can be toxic.

Using genetic engineering, Ohio State scientists have reduced cyanide levels by 99% in the plant's tuber, and two teams of genetic engineers at Missouri's Danforth Plant Science Center have set out to fix other flaws in the crop. One team is working on a virus-resistant variety and the other on a version that contains adequate zinc, protein, and beta carotene.[123]

Martin Fregene, a cassava geneticist at Danforth explains that genetic engineering is the only solution for the cassava: "You don't have a natural genetic variability for iron or protein in cassava. You don't have it there. You're stuck."[124]

26. *Daisy the hypoallergenic cow*

In their first year of life, about 2 or 3 in every 100 infants are allergic to a whey protein naturally found in cow's milk called beta-lactoglobulin (BLG). Researchers in New Zealand were able to target and prevent the gene in dairy

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cows responsible for BLG from expressing itself. They first modified a cow skin cell nucleus then transferred the nucleus into a cow egg using the same methods that resulted in Dolly the sheep. After implanting the fertilized egg in a surrogate mother cow and waiting, "Daisy" was born in 2012—the first cow that produces milk without BLG.[125]

The Lighter Side

Some genetically engineered innovations are experimental and just for fun, occupying a lighter side of life.

27. *A better brew*

In the brewing of alcohol, whether that be beer or wine, not all yeast is created equal. Yeast changes the flavor, alcohol content, and temperament of alcoholic beverages. University of Illinois scientists are working on a genetically engineered wine yeast that will reduce hangovers, while scientists in Spain have identified the genes that control the amount and quality of beer froth, opening the possibility of engineering these microbes to create the perfect brew.[126]

A team of beer researchers at the University of Leuven in Belgium have mapped the genome of the 220 most common brewer's yeasts, with the goal of creating yeast to give beer more flavor and to be able to change the alcohol content of various brews[127] In one experiment, researchers engineered a yeast to produce 100 times more of a specific flavor compound and then, on Belgium television, they tasted beer brewed with it. They have several genetically engineered yeasts stored in a lab freezer. The research team is considering ways to add flavor genes from fruit directly to the yeast to create a raspberry brew, for example. As a "perk," the team samples a brew every day, just before lunch.

28. *Roses are red, roses are blue*

Innovation in the cut flower business can be as simple, and yet as elusive, as a new color. For roses, a blue rose has been "the Holy Grail of rose breeders since 1840, when the horticultural societies of Britain and Belgium offered a prize of 500,000 francs to the first person to produce a blue rose."[128]

But over a hundred years of rose breeding couldn't produce one; roses simply don't have the genetic pathways that enable the flowers to produce a blue color. Australian flower company Florigene along with Japanese company Suntory announced in 2009 a new, genetically engineered variety.[129] Touted as the first truly blue rose, scientists gathered a gene from a pansy, an iris, and a synthetic gene developed to open the pathway within the rose needed to create blue pigment. These were then transferred into the genome of a rose to create the Applause. Applause roses have pale purple petals, putting us that much closer to the coveted blue rose.

Florigene has used a similar technology to create varieties of carnations in various hues of indigo and purple, from lilac to plum. These Mooncarnations are available at florists worldwide. Francis Bacon said that gardening was "the purest of human pleasures."[130] And what could be done more for pure human pleasure than changing the color of a rose?

29. *GloFish*

GloFish is patented technology that has graced American kids' aquariums since 2003.[131] The tiny fish look much like any other aquarium tetra, barb, or zebrafish, but when placed under a black light, GloFish, well, glow. The fish were originally created and patented for scientific research at the University of Singapore. But a Texas company, Yorktown Technologies, obtained rights to market the fish, seeing their potential as pets. Available in neon colors like Starfire Red, Electric Green, and Sunburst Orange, they were created by transferring genes from sea corals and jellyfish to give the fish fluorescent properties.[132]

In California the fish are outlawed, because as Fish and Game Commissioner Sam Schuchat explained, the fish are "a frivolous use of this technology."[133] It's unclear if Thomas Edison would have been told the same thing about a string of red and green Christmas lights.

Conclusion

Genetic engineering is responsible for a massive increase in human well-being, from a cornucopia of safer, more plentiful, and easier-to-grow foods to virtually limitless supplies of valuable vaccines and rare medicines.

Since the first genetically engineered organisms were created thirty years ago, the field has experienced an explosion of new and potentially game-changing products. It seems that the sky is the limit when it comes to the technology of genetic engineering.

But unfortunately, activists and regulators are striving to put the gene genie back in the bottle.

Those salmon? They've been in a regulatory holding pattern for 19 years in the United States. The Arctic Apple? It took years of delays before the technology was finally released, which caused the president of the biotech company that invented the fruit to say that he didn't hold out much hope for other small, innovative biotech start-ups.[134] Regulatory paperwork has made innovation too expensive for all but the largest biotech and pharmaceutical companies. The FDA pushed through the approval of insulin in just five months back in 1982. If bacteria-brewed human insulin were invented today, the process would take an estimated ten to fifteen years.[135]

An army of anti-GMO activists drum up fear and spread misinformation about the safety and efficacy of genetically engineered products. Horribly, even human insulin has been maligned.[136] It is my hope that this paper will help fortify policy makers and the general public with facts so they won't be misled by the unconscionable scaremongering about "GMOs."

Activists would like to see us halt genetic engineering, abandon the successes and contributions the technology has made to the betterment of our lives, and go down a path that much of the world is taking, where attitudes toward biotechnology remain draconian.

Sixty countries have significant restrictions on the planting and importing of food created by genetic engineering and many of these have outright bans.[137] About 80 acts of vandalism against GMO field trials have been recorded in Europe. Such attacks are not uncommon in the United States.[138]

Golden Rice was invented way back in 1999, but it has helped precisely no one. Because of fear drummed up by environmentalist groups like Greenpeace and the resulting attitudes of people and governments in nations like China and the Philippines, it is unclear not just when, but *if*, it ever will.

Genetic engineering is responsible for a massive increase in human well-being, from a cornucopia of safer, more plentiful, and easier-to-grow foods to virtually limitless supplies of valuable vaccines and rare medicines.

Oxitec's genetically engineered mosquitoes could help control or even eradicate disease, but are met with protests in every place they are proposed to be released.[139]

Even the pink pineapples aren't licensed for consumption in Costa Rica where they were developed—the government frowns upon biotech innovated foods there.[140]

American lawmakers are already headed in that direction.

Even though Hawaii's papaya industry was saved by biotechnology, the state has banned varieties of genetically engineered coffee and taro, slamming the door shut on any innovations made in those two crops. The County Council on the Big Island passed a measure banning the planting of genetically engineered seeds. And even though transgenic papayas were grandfathered in, the message is clear: biotechnology is seen as a dangerous threat.[141]

Josephine and Jackson Counties in Oregon have made the very act of planting a genetically engineered seed a crime. Scientists at world-renowned genetic research labs at Oregon State University waited in alarm to find out if research into ALS medicines using transgenic bacteria and virus-resistant grape vines would be snuffed out by a similar measure in Benton County.[142] Thankfully, the measure didn't pass.

The state of Vermont passed a "GMO labeling" law, requiring that all foods grown from genetically engineered seeds carry a warning label. Anti-GMO activists hope the measure will further steer the public away from biotechnology.[143]

Even the courts are used to thwart biotechnological inventions. The Natural Resources Defense Council (and other environmentalist groups) sued the EPA to block the rollout of Dow's Enlist corn, tying up the technology indefinitely in court.[144]

The very legal system that contributed to both the Green Revolution and the Gene Revolution, through the grant of property rights to inventors, is now being used to thwart the progress of scientific development. Onerous regulations, which erode intellectual property rights, are a direct result of the pseudoscience and fear-mongering of anti-GMO activists.

It is not the case that every new biotech product will necessarily be a winner, but regulatory burdens, anti-GMO activists, and consumer fear have ensured that good products are unfairly shunned, will never see the grocery store shelf, or, worse yet, will never even be created.

Dr. Peggy Lemaux, a genetic engineer at UC Berkeley, boasts a hypoallergenic wheat and a fast-sprouting barley among her list of inventions. But those seeds, along with others, are locked in the basement of the building where she works.[145] Because of the fear and hysteria surrounding any new biotech invention and the exorbitant regulatory cost of bringing new innovations to market, they remain buried treasure. And Lemaux is just one such scientist of hundreds in the United States.

Every life-changing invention throughout history has been met with irrational opposition that must be fought with the bright light of science and reason. In our age, anti-biotechnology activists are successfully strangling what could and should have been the "third industrial revolution."

The question is: Are we going to let them?

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