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In many countries, the debate surrounding the use of biotechnology in agriculture is often solely associated with genetically modified (GM) crops. As a result, many believe that biotechnology is only about developing these products. However, what many do not realize is that there are many other important applications of biotechnology beyond GM crops.

The present applications of biotechnology that are important for agriculture and the environment include:

- Conventional plant breeding
- Tissue culture and micropropagation
- Molecular breeding or marker assisted selection
- Genetic engineering and GM crops
- The 'Omics' - Genomics, Proteomics, Metabolomics
- Plant disease diagnostics
- Crop improvement

Biotechnology is defined as a set of tools that uses living organisms or parts of organisms to make or modify a product, improve plants, trees or animals, or develop microorganisms for specific purposes. These tools include classical techniques, bioinformatics, microbiology, molecular biology, and molecular breeding.

The Global Knowledge Center on Crop Biotechnology is a science-based information resource network designed to address the needs of developing countries on all aspects of crop biotechnology. Its activities include maintenance of an internet website, expert networking, continuous scanning of the agri-biotech environment, and multi-media communication.
The art of recognizing desirable traits and incorporating them into future generations is very important in plant breeding. Breeders scrutinize their genetic background to identify and select for specific desirable traits. The result is a plant that is more resistant to diseases, pests, and environmental stressors. This allows for increased yields and improved quality of crops, leading to a more sustainable and productive agricultural system.

**Conclusion**

Since the beginning of agriculture eight to ten thousand years ago, farmers have been altering the genetic makeup of the crops they grow. Early farmers selected the best looking plants and seeds and saved them for the next year. Once the science of genetics became better understood, plant breeders used what they knew about the genes of a plant to select for specific desirable traits to develop improved varieties. The selection for features such as faster growth, higher yields, pest and disease resistance, larger seeds, or sweeter fruits has dramatically changed domesticated plant species compared to their wild relatives.

Conventional plant breeding has been going on for hundreds of years and is still commonly used today. Early farmers discovered that some crop plants could be artificially mated or cross-pollinated to increase yields. They also found that desirable characteristics from different parent plants could be combined in the offspring to develop new and improved varieties.

Biotechnology in agriculture is not only about genetic modification but rather encompasses a number of tools and elements of conventional breeding techniques, bioinformatics, microbiology, molecular genetics, biochemistry, plant physiology, and molecular biology.

With the severe agricultural problems and challenges that developing countries face, scientists need all the tools available to ensure there is enough to eat for succeeding generations. Biotechnology is not a panacea for hunger and malnutrition but simply another set of tools to assist in developing better plants. The art of plant breeding is not a panacea for hunger and malnutrition but part of the solution to feed the world.
People start planting crops rather than relying on hunting and gathering for food. By 10,000-9,000 BC, agriculture had become the main source of food. Resilience to pests and diseases, and ease of maintenance, are key reasons why hybrid seeds are often preferred over open-pollinated seeds in terms of seed-breeding plans. Hybrid seeds are an improvement over open-pollinated seeds in terms of increased yields, resistance to pests and diseases, and ease of maintenance. Hybrid seed technology is the end result of plant breeding. The hybrid seed technology involves crossing of the parents to produce the hybrid seed. The hybrid seed is then used to produce the next generation of hybrid seeds. The hybrid seed technology is used to produce varieties of crops that are resistant to pests and diseases, and have higher yields. The hybrid seed technology is also used to produce varieties of crops that are better suited to specific environments, such as areas with high temperatures or low rainfall. The hybrid seed technology is a valuable tool for improving the productivity and sustainability of agriculture. Hybrid seed technology is used to produce varieties of crops that are better suited to specific environments, such as areas with high temperatures or low rainfall. The hybrid seed technology is a valuable tool for improving the productivity and sustainability of agriculture.
Hybrid seeds are developed by the hybridization or crossing of parent lines that are 'pure lines' produced through inbreeding. Pure lines are plants that "breed true" or produce sexual offspring that closely resemble their parents. By crossing pure lines, a uniform population of F1 hybrid seed can be produced with predictable characteristics.

The simplest way to explain how to develop an F1 hybrid is to take an example. Let us say a plant breeder observes a particularly good habit in a plant, but with poor flower color, and in another plant of the same type he sees good color but poor habit. The best plant of each type is then taken and self-pollinated (in isolation) each year and, each year, the seed is re-sown. Eventually, every line of the same pure line of the same type will be represented in the resulting F1 hybrid population. This is the simplest form of hybridization, but there are complications, of course. A completely pure line can sometimes take several years to achieve. Sometimes, a pure line is made up of several previous crossings to build in desirable features. The resulting plant is then grown on until it is genetically pure before use in hybridization.

In addition to qualities like good vigor, trueness to type, heavy yields and high uniformity which hybrid plants enjoy, other characteristics such as earliness, disease and insect resistance, and good water holding capacity have been incorporated into most F1 hybrids.

Examples of bioinsecticides and their mode of action.

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<th>Agent</th>
<th>Examples</th>
<th>Mode of Action</th>
<th>Mode of Action</th>
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<tr>
<td>Bacillus thuringiensis</td>
<td>Lepidopteran</td>
<td>Controls insects by entering natural body openings or by penetrating the insect cuticle directly.</td>
<td>Controls insects by entering natural body openings or by penetrating the insect cuticle directly.</td>
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<tr>
<td>Bacillus popilliae</td>
<td>Heterotrophic Nematodes</td>
<td>Controls insects by growing on them and secreting enzymes that weaken the insect's outer coat, and then getting inside the insect and continuing to grow, eventually killing the infected pest.</td>
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<tr>
<td>Agrobacterium radiobacter</td>
<td>Entomopathogenic Fungi</td>
<td>Controls insects by producing toxins that are detrimental to certain insect pests when ingested.</td>
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<td>Baculoviruses: Nuclear polyhedrosis virus (NPV)</td>
<td>Invertebrates: Arthropods</td>
<td>Controls insects by killing the insect when ingested. Insect's feeding behavior is disrupted thus it starves and dies.</td>
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<tr>
<td>Baculoviruses: Granulosis virus (GV)</td>
<td>Protozoa</td>
<td>Controls insects by killing the insect when ingested. Insect's feeding behavior is disrupted thus it starves and dies.</td>
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<td>Baculoviruses: Group C Entomopox</td>
<td>Nematoda</td>
<td>Controls insects by entering natural body openings or by penetrating the insect cuticle directly.</td>
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<tr>
<td>Entomophaga maimana</td>
<td>Arthropoda</td>
<td>Controls insects by killing the insect when ingested. Insect's feeding behavior is disrupted thus it starves and dies.</td>
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<tr>
<td>Zoophthora radicans</td>
<td>Nematoda</td>
<td>Controls insects by entering natural body openings or by penetrating the insect cuticle directly.</td>
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<tr>
<td>Neozygites floridana</td>
<td>Nematoda</td>
<td>Controls insects by entering natural body openings or by penetrating the insect cuticle directly.</td>
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<td>Nosema</td>
<td>Nematoda</td>
<td>Controls insects by entering natural body openings or by penetrating the insect cuticle directly.</td>
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<tr>
<td>Vairimorpha</td>
<td>Nematoda</td>
<td>Controls insects by entering natural body openings or by penetrating the insect cuticle directly.</td>
<td>Controls insects by entering natural body openings or by penetrating the insect cuticle directly.</td>
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<tr>
<td>Malamode</td>
<td>Nematoda</td>
<td>Controls insects by entering natural body openings or by penetrating the insect cuticle directly.</td>
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Controlled crossing is the method of choice for the production of F1 hybrid seed. In controlled crossing, the male parent produces pollen that is free of any female parent's genetic material. The female parent produces ovules that are free of any male parent's genetic material. This method ensures that the hybrid seed produced is the result of a controlled cross rather than chance. In addition, controlled crossing allows for the production of seeds with predictable and consistent genetic traits.
5,000 BC
Farming communities in existence.

4,000 BC
Egyptians use yeast to make bread rise.

Unfortunately, these advantages come with a price. Because creating F1 hybrids involves many years of preparation to create pure lines and these pure lines have to be constantly maintained so that the F seed can be harvested each year, seed is more expensive. The problem is compounded because to ensure that no self-pollination takes place, all the hybridization of the two pure lines sometimes has to be done by hand.

Another disadvantage is if the seeds of the F1 hybrids are used for growing the next crops, the resulting plants do not perform as well as the F1 material resulting in inferior yields and vigor. As a consequence, the farmer has to purchase new F1 seeds from the plant breeder each year. The farmer is, however, compensated by higher yields and lower price of the crop. Farmers who purchase new F1 seeds from the plant breeder each year.

Though more expensive, hybrid seeds have had a tremendous impact on agricultural productivity. Today, nearly all corn and 50% of all rice are hybrids.

In the USA, the widespread use of corn hybrids, coupled with improved cultural practices by farmers, has more than tripled corn grain yields over the past 50 years from an average of 35 bushels per acre in the 1930s to 115 bushels per acre in the 1990s. No other major crop has gained yields at such an impressive rate.

Hybrid rice technology helped China to increase its rice production from 140 million tons in 1978 to 188 million tons in 1990. Research at the International Rice Research Institute (IRRI) and in other countries throughout the world has contributed to the rapid adoption of hybrid rice technology in many countries.

Bioinsecticides have become available in North America and Europe.

Virus-Based Bioinsecticides

A group of virus-based bioinsecticides that have been registered for use are Bacillus thuringiensis. The Bacillus thuringiensis bacteria are able to produce a protein that is toxic to insects. The protein is toxic to insects because it is able to break through the outer surface of the insect's body and enter the insect's body.

Bioinsecticides based on Bacillus thuringiensis have many advantages. The bacteria do not begin to grow and cannot directly cause death.

2000
The first entire plant genome is sequenced, Arabidopsis thaliana.

5,000 BC
The first entire plant genome is sequenced, Arabidopsis thaliana. This allows researchers to gain greater insight into the genes that control plant function.

Bioinsecticides provide researchers with greater insight into the genes that control plant function.

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Many cultivars of popular vegetable or ornamental plants are F1 hybrids. In terms of improved plant characteristics, tropical vegetable breeders can point to some rather clear achievements over the last two decades:

**Yield improvement.** Hybrids often outyield traditional OP selections by 50-100% thanks to improved vigor, improved genetic disease resistance, improved fruit setting under stress, and higher female/male flower ratios.

**Extended growing season.** Hybrids often mature up to 15 days earlier than local OP varieties. For many crops, the hybrid’s relative advantage over the OP is most pronounced under stress conditions.

**Quality improvement.** Hybrids have helped stabilize product quality at a higher, more uniform level. This almost always means improved consumption quality (e.g., firmer flesh of wax gourd, or crisper taste of watermelon).

Conventional plant breeding resulting in open-pollinated varieties or hybrid varieties has had a tremendous impact on agricultural productivity over the last decades. While an extremely important tool, conventional plant breeding also has its limitations. First, breeding can only be done between two plants that can sexually mate with each other. This limits the new traits that can be added to those that already exist in that species. Second, when plants are crossed, many traits are transferred along with the trait of interest. This often results in a hybrid that is less desirable than either of the parent lines. The first hybrid can only be done between two compatible OP lines; the hybrid is not a new variety.

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3,000 - 2,000 BC

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7

Biopesticides, on the other hand, do not persist long in the environment and have shorter shelf lives; they are effective in small quantities, safer to biological organisms, and poses no risk to the environment compared to conventional herbicides.

While synthetic pesticides are invaluable tool for agricultural production, some of them also have harmful effects. They are expensive, and the use of them not only affects the targeted organisms but also affects non-target organisms.

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All non-target organisms.

With the advances of genetic engineering, new generation biopesticides are being developed that are more effective against weeds. Microorganisms are designed to effectively overcome the weed’s defenses. Weeds have a waxy outer tissue coating the leaves that microorganisms have to penetrate in order to fully infect the weeds. Through biotechnology, these microorganisms will be able to produce the appropriate type and amount of enzymes to cut through the outer defenses. Streamlining of the microbe’s plant host specificity will ensure that the weeds are taken out and not the crops. On the other hand, biopesticides can also be made to be

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Just as every person is different and unique, so is each plant. Some have traits like better color, yield, or pest resistance. For years, scientists have looked for methods to allow them to make exact copies of these superior individuals.

Plants usually reproduce by forming seeds through sexual reproduction. That is, egg cells in the flowers are fertilized by pollen from the stamens of the plants. Each of these sexual cells contains genetic material in the form of DNA. During sexual reproduction, DNA from both parents is combined in new and unpredictable ways, creating unique organisms.

This unpredictability is a problem for plant breeders as it can take several years of careful greenhouse work to breed a plant with desirable characteristics. Many of us think that all plants grow from seeds, but now, researchers have developed several methods of growing exact copies of plants without seeds.

Tissue culture is the cultivation of plant cells, tissues, or organs on specially formulated nutrient media. Under the right conditions, a single cell can regenerate an entire plant. Tissue culture is seen as an important technology for developing countries for the production of disease-free, high-quality planting material and the rapid production of many uniform plants.

Micropropagation, which is a form of tissue culture, increases the amount of planting material to facilitate distribution and large-scale planting. In this way, thousands of copies of a plant can be produced in a short time. Micropropagated plants are observed to establish more quickly, grow more vigorously, and have a shorter and more uniform production cycle than conventional propagules that are produced in a shorter time. Micropropagated plants also have higher yields than conventional propagules.

The use of bioherbicides is another way of controlling weeds without environmental hazards posed by synthetic pesticides. Bioherbicides are made up of microorganisms (e.g., bacteria, viruses, fungi) and certain insects (e.g., parasitic wasps, ladybugs) that can target specific weeds. For example, a variety of bacteria and fungi have been developed that can attack specific types of weeds. These microorganisms possess invasive genes that can detect the unique genes of the weeds they target, spreading their genes to other weeds in the area. This selective response makes bioherbicides very useful because they kill only the weeds that are targeted, leaving the rest of the environment unharmed.

The better understanding of the genes of both microorganisms and plants has allowed scientists to isolate microbes (pathogens) whose genes match specific weeds and are effective in causing a fatal disease in those weeds. Bioherbicides deliver more of these pathogens to the fields where they are needed, unlike synthetic herbicides, which are applied to the whole field, whether it needs them or not.

Bioherbicides are a safer alternative to synthetic herbicides because they target specific weeds and do not harm beneficial organisms like pollinators. They also reduce the risk of developing resistance in the weeds, which can occur with synthetic herbicides. Bioherbicides are a more sustainable option because they break the cycle of dependency on synthetic chemicals.

The benefits of using bioherbicides in agriculture are numerous. They reduce the environmental impact of farming, improve crop yields, and increase the profitability of agricultural operations. Bioherbicides can be used in conjunction with other sustainable practices, such as crop rotation and reduced tillage, to create a more healthy and resilient ecosystem.
Transgenic FlavrSavr® tomato is approved for sale in U.S. groceries. It was developed to have more flavor and to have a longer shelf-life than

Europe’s first hybrid plan: Thomas Fairchild, the forgotten father of the flower garden, creates 1700–1720, the first hybrid plant.

Plant tissue culture is a straightforward technique and many developing countries have already mastered it. Its application only requires a sterile workplace, nursery, and greenhouse, and trained manpower.

Unfortunately, tissue culture is labor intensive, time-consuming, and can be costly. Plants important to developing countries that have been grown in tissue culture are oil palm, plantain, pine, banana, date, eggplant, jojoba, pineapple, rubber tree, cassava, yam, sweet potato, and tomato. This application is the most commonly applied form of biotechnology in Africa.

**Examples of the use of tissue culture in crop improvement in Africa:**

1. **A new rice plant type for West Africa (NERICA – New Rice for Africa)** resulting from embryo rescue of wide crosses made between Asian rice (Oryza sativa) and African rice (Oryza glaberrima) followed by anther culture of the hybrids.

   **Benefits of TC technology for rice farmers in West Africa (Source: WARDA)**

   For years, scientists dreamed of combining the ruggedness of the African rice species (Oryza glaberrima) with the productivity of the Asian species (Oryza sativa). But the two are so different it was impossible to cross them. In the 1990s, rice breeders from the West Africa Rice Development Association (WARDA) turned to biotechnology in an attempt to overcome the infertility problems. Key to the effort was genebanks that hold seeds of 1500 African rices — which had faced extinction as farmers abandoned them for higher-yielding Asian varieties.

   Advancements in agricultural research helped scientists cross the two species — a breakthrough that is changing the lives of many rice farmers in West Africa.

   After cross-fertilization of the two species, embryos were removed and grown on artificial media in a process known as embryo rescue.

   Because the resultant plants are genetically almost identical, they are re-crossed on artificial media in a process known as embryo rescue.

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**Biopesticides**

Weeds are a constant problem for farmers. They not only compete with crops for water, nutrients, sunlight, and space but also harbor insect and disease pests; clog irrigation and drainage systems; undermine crop quality; and deposit weed seeds into crop harvests. If left uncontrolled, weeds can reduce crop yields and deplete soil organic matter. In addition, weeds can harbor disease-causing microorganisms and insect pests.

Farmers fight weeds with tillage, hand weeding, synthetic herbicides, or typically a combination of all techniques. Unfortunately, however, farmers are often dependent on crop rotation, which is effective but expensive and time-consuming.

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The fertility of the progeny was improved (often after several cycles of back-crossing), anther culture was used to double the gene complement of male sex cells (anthers) and thus produce true-breeding plants. The first of the new rices dubbed ‘New Rice for Africa’ (or NERICA) was available for testing in 1994 and since then, the techniques have been refined and streamlined, so that many new lines are generated each year. The dream had come true. The new plants had the best of both worlds – some of them combined yield traits of the *sativa* parent with local adaptation traits from *glaberrima*.

The NERICAs inherited wide, droopy leaves from their African parent, which smother weeds in early growth. That reduces labor, and allows farmers to work the same land longer, rather than constantly clearing new land.

The structure of the panicles, or grain heads, has also been changed. Panicles of the African species produce only 75-100 grains. The new rices inherited, from their Asian parent, longer panicles with ‘forked’ branches, and hold up to 400 grains. The new rices mature 30 to 50 days earlier than current varieties, allowing farmers to grow extra crops of vegetables or legumes. They are also taller than most rice, which makes harvesting easier—especially for women with babies strapped to their backs. They also resist pests and disease better than most rice, which makes harvesting easier—especially for small farmers. The new rices have also been designed to be resistant to common pests and diseases.

Biofertilizers help plants use all of the food available in the soil and thus

...
tolerate drought better than the Asian rices—vitaly important for rainfed-rice farmers. The new rices grow better on infertile, acid soils—which comprise 70% of West Africa’s upland rice area. They also have about 2% more body-building protein than their African or Asian parents.

Because of their success, NERICAs were quickly adopted by farmers. In 2000, it was estimated that the new rices covered some 8,000 ha in which 5,000 ha grown by 20,000 farmers was under the supervision of the national extension agency. In 2002, WARDA projected that 330,000 ha would be planted to NERICAs, sufficient to meet the country’s own seed needs, with surplus for export. Benefits of TC technology for small-scale banana producers in Kenya

2. Bananas propagated from apical meristem in Kenya have been shown to have increased vigour and suffer lower yield loss from weevils, nematodes, and fungal diseases.

30

For the countys whose farms produce 30% of the worlds’ rice, the more they can produce, the more food they can export to neighboring countries. This would be a significant achievement in providing the world with some 70% of the worlds’ rice.

Phosphate and Nitrogen are Important for Plant Growth

Many of the microorganisms that live in the soil actually help plants absorb nutrients. Plants and these friendly microbes are involved in "nutrient recycling." The microbes help the plant to "take up" essential energy sources, while the plants donate their waste products for the microbes to use for food. Because the microbes have helped plants digest more nutrients, plants develop stronger and bigger root systems.

In summary,借助微生物学发展生物肥料和生物杀虫剂

Scientists use these friendly microorganisms to develop biofertilizers and biopesticides.

Microbial Fermentation

For many years, man has been taking advantage of the activities of millions of microorganisms found in the soil to produce biofertilizers and biopesticides to assist plant growth and control weeds, pests, and diseases. These compounds exist naturally in the environment and are a humble part of the complex and interactive development world.

1866

Austrian monk Gregor Johann Mendel publishes important work on heredity that describes how plant characteristics are passed from parent to offspring.
With proper management and field hygiene, yield losses caused by pests and diseases at farm level have been reduced substantially. Tissue culture technology has made it possible for farmers to have access to the following:

- large quantities of superior clean planting material that are early maturing (12-16 months compared to the conventional banana of 2-3 years)
- bigger bunch weights (30-45 kg compared to the 10-15 kg from conventional material)
- higher annual yield per unit of land (40-60 tons per hectare against 15-20 tons previously realized with conventional material)

Moreover, uniform orchard establishment and simultaneous plantation development and marketing make it easier to coordinate with the possibility of transforming banana growing from mere subsistence to a commercial enterprise. An encouraging finding from a cost-benefit analysis of the project is that tissue banana production is more remunerative as an enterprise than traditional banana production. The project has also benefited mainly women who tend the crop, thus helping to narrow the gender gap.

**Sources**

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PCR

Polymerase Chain Reaction (PCR) also uses nucleic acid probes to detect the presence of a pathogen. This is a lot more sensitive compared to other techniques as PCR can detect very small amounts of a pathogen’s genetic material per sample and amplify certain sequences to a detectable level. PCR can also be used to detect if mutations are occurring in a given population of pathogens. These genetic mutations lead to the development of resistant strains.

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The process of developing new crop varieties requires many steps and can take almost 25 years. Now, however, applications of biotechnology have considerably shortened the time it takes to bring them to market. It currently takes 7-10 years for new crop varieties to be developed. One of the tools that makes this easier is molecular marker-assisted selection (MAS).

**Molecular Marker-Assisted Selection (MAS)**

MAS uses a short, specific plant marker that can detect the presence of a particular gene. The marker is linked to the gene of interest and can be used to select plants that carry the desirable trait. This allows breeders to quickly identify plants that are likely to carry the desired trait, reducing the time and effort required for traditional breeding methods.

The marker is detected using molecular techniques, such as polymerase chain reaction (PCR) or DNA sequencing. Once identified, the plants carrying the desired trait can be selected for further breeding.

Some traits, like flower color, may be controlled by only one gene. Other more complex characteristics, however, like crop yield or disease resistance, may be influenced by many genes. In these cases, MAS can be used to select plants that carry multiple desirable traits.

**Molecular Shortcuts**

Molecular markers are used in plant disease diagnostics to help identify specific genes. Scientists use what are called molecular markers to help identify specific genes in plant breeding. These markers are used in place of traditional methods, such as observing the plant's characteristics or using seedling tests. The markers are specific to a particular gene and can be used to select plants that carry the desirable trait.

**Molecular Markers**

Molecular markers are used to help identify specific genes in plant breeding. These markers are specific to a particular gene and can be used to select plants that carry the desirable trait. Molecular markers are used in place of traditional methods, such as observing the plant's characteristics or using seedling tests.

**Marker-Assisted Selection (MAS)**

Marker-assisted selection (MAS) is a powerful tool used in plant breeding. It allows breeders to quickly identify plants that carry the desired trait, reducing the time and effort required for traditional breeding methods.

**MAS in Practice**

MAS has been successfully used in the development of many crop varieties, including corn, rice, and soybeans. For example, MAS has been used to develop varieties of corn that are resistant to the herbicide glyphosate. This has allowed farmers to use this herbicide more effectively, reducing the need for multiple applications.

**MAS in Crop Breeding**

MAS is a valuable tool in crop breeding. It allows breeders to quickly identify plants that carry the desired trait, reducing the time and effort required for traditional breeding methods. This has led to the development of many new crop varieties, including those that are resistant to pests, diseases, and environmental stressors.

**MAS in Field Trials**

Field trials are conducted to test the performance of new crop varieties. These trials are designed to evaluate the yield, quality, and other traits of the new variety compared to existing cultivars. Field trials are an important part of the crop breeding process and help ensure that new varieties are ready for commercial release.

**MAS in Farming**

MAS is now being used in many farming practices. For example, MAS is used to select plants that are resistant to specific pests or diseases. This has helped farmers to reduce the use of pesticides and other chemicals, leading to a more sustainable and eco-friendly farming practice.

**MAS in Future**

As technology advances, MAS is likely to become even more powerful. New molecular markers are being developed that can detect even more specific traits. This will allow breeders to develop even more targeted and effective crop varieties.

**Conclusion**

MAS is a powerful tool in plant breeding. It allows breeders to quickly identify plants that carry the desired trait, reducing the time and effort required for traditional breeding methods. This has led to the development of many new crop varieties, including those that are resistant to pests, diseases, and environmental stressors. As technology advances, MAS is likely to become even more powerful, allowing breeders to develop even more targeted and effective crop varieties.
Biotechnology has also allowed the development of diagnostics which has assisted farmers worldwide in managing different diseases affecting their crops.

To successfully manage a plant disease, it is critical to correctly identify the cause of the disease in its early stages. Delaying this can result in extensive crop damage and financial loss to farmers. Some diseases can be diagnosed quickly by visual examination although sometimes, visual detection at the plant level is only possible after major damage to the crop has been done, by which time, it is too late.

Other diseases require laboratory testing for diagnosis which may take days or even weeks to complete and are, in some cases, relatively insensitive. Delays are frustrating when a quick diagnosis is needed so that appropriate measures may be taken to prevent plant injury and loss.

Fortunately, new diagnostic techniques are now available that require minimal processing time and are more accurate in identifying pathogens. These diagnostics are based on rapid detection of proteins or DNA that are specific to each pathogen, disease or condition. Some procedures require laboratory equipment and training, while other procedures can be performed on site by a person with no special training.

Examples of existing diagnostic techniques:

- **ELISA diagnostic kits**
  - ELISA (enzyme-linked immunosorbent assay) kits are based on the ability of an antibody to recognize a certain protein substance or antigen. The kits are very easy to use, some even allow the ability to test for a specific characteristic. Once the test is performed, a control and test region on a strip of a plastic or paper can be examined and an interpretation of the result given.

**Genetic markers** are a string or sequence of nucleic acid which makes up a segment of DNA. The markers are located near the DNA sequence of the desired gene. Since the markers and the gene are close together on the same chromosome, they tend to stay together as each generation of plants is produced. This is called genetic linkage. Genetic linkage helps scientists to predict whether a plant contains the desired gene. If a plant contains the desired gene, it is easier to identify the plant in the future.

- **Rapid plant disease diagnostics**

1870 - 1890

Plant breeders worked long ago to develop new varieties of cotton and other crops with desired traits. These varieties are now being used to improve yields and reduce the need for chemicals.
Researcher Luther Burbank developed the Russian Purple potato, and sweet potatoes, bananas, and peaches. He went on to develop several new hybrid fruits, including plums.

**Photos of chromosome and DNA strand on page 13 courtesy of the US Department of Energy Human Genome Program (http://www.ornl.gov).**

It should be noted, however, that molecular breeding through marker-assisted selection is somewhat limited in scope compared to genetic modification because: 1) it only works for traits already present in a crop; 2) it cannot be used effectively to breed crops which have lost an essential gene (e.g. maize); and 3) it cannot be used effectively in crops managed as clonally propagated species, including many staples such as yams, bananas, cassava.

1871 - Early 1900s

Researcher Luther Burbank developed the Russet Burbank Potato, and later went on to develop several new hybrid fruits, including plums, berries, prunes, and peaches.

1982

The first transgenic plant is produced - a tobacco plant resistant to a plant disease. 

**Images and graphics used in this section (‘Omics’ Sciences: Genomics, Proteomics and Metabolomics) are courtesy of the US Department of Energy Human Genome Program and US Department of Energy Genomics to Life Program. (http://www.ornl.gov; http://www.doegenomestolife.org)**
Over the last 30 years, the field of genetic engineering has developed rapidly due to the greater understanding of deoxyribonucleic acid (DNA) as the chemical double-helix code from which genes are made. The term genetic engineering, often interchanged with terms such as gene technology, genetic modification, or gene manipulation, is used to describe the process by which the genetic makeup of an organism can be altered using "recombinant DNA technology." This involves using laboratory tools to insert, alter, or cut out pieces of DNA that contain one or more genes of interest. The ability to manipulate individual genes and to transfer genes between species that would not freely interbreed is what distinguishes genetic engineering from traditional plant breeding.

Conversely, with conventional plant breeding, there is little or no guarantee of obtaining any particular gene combination from the millions of crosses generated. Undesirable genes can be transferred along with desirable genes or while one desirable gene is gained, another is lost because the genes of both parents are mixed together and re-assorted more or less randomly in the offspring. These problems limit the improvements that plant breeders can achieve. In contrast, genetic engineering allows the direct transfer of one or just a few genes, between either closely or distantly related organisms. Not all genetic engineering techniques involve inserting DNA from other organisms. Plants can also be modified by removing or switching off particular genes. The process is referred to as "natural genetic engineering." For example, Agrobacterium tumefaciens, a soil bacterium known as "nature’s own genetic engineer," has the natural ability to genetically engineer plants. It causes crown gall disease of a wide range of plants, including apple, pear, peach, cherry, almond, and more. The disease is caused by a plasmid transferred from the bacterium to the plant, which results in the overexpression of a single gene that causes the disease.

Metabolomics can be used to determine differences in the levels of thousands of molecules between healthy and diseased plants. The technology can also be used to determine differences in the levels of thousands of molecules between different plant species. These differences can provide clues to the mechanisms underlying disease resistance or other traits.

For example, metabolomics research at Iowa State University includes:
- An examination of changes in the corn proteome during low temperatures, which is a major problem for young corn seedlings
- Analysis of differences in the genome expression in developing soybean exposed to high temperatures
- Identifying the proteins expressed in response to diseases like soybean cyst nematode

Metabolomics aims at determining a sample's profile of these compounds at a specified time under specific environmental conditions. This provides a deeper insight into the factors that influence the expression of genes and the metabolism of plants.

Metabolomics and proteomics have provided extensive information regarding the genotype and phenotype of plants. However, genomics and proteomics have provided limited information about the phenotype. Low molecular weight compounds are the closest link to phenotype. The technology can be used to determine differences in the levels of thousands of molecules between a healthy and diseased plant. The technology can also be used to determine the nutritional differences between traditional and genetically modified crops.
Raspberry and roses. The disease gains its name from the large tumor-like swellings (galls) that typically occur at the crown of the plant, just above soil level. Basically, the bacterium transfers part of its DNA to the plant, and this DNA integrates into the plant's genome, causing the production of tumors and associated changes in plant metabolism.

Application of genetic engineering in crop production

Genetics and associated changes in plant metabolism. Where do these changes occur? In the plant's genome. The production of new traits requires the integration of DNA from the bacterium into the plant's DNA in the plant's genome. The plant responds and grows. The disease gains its name from the large tumor-like swellings (galls) that typically occur at the crown of the plant, just above soil level.

Modern plant breeding is a multi-disciplinary and coordinated process where a large number of tools and elements of conventional breeding techniques, bioinformatics, molecular genetics, molecular biology, and genetic engineering are utilized and integrated. The goal of modern plant breeding is to understand how different environmental stimuli can be used to develop a crop trait. The production of a crop trait is known as a trait expression profile, which can be influenced by various factors, including environmental conditions, soil composition, and plant genetics.

Genes are blueprints for the production of proteins. The production of proteins is a complex process that involves the transcription of DNA into RNA, followed by translation into protein. The complete set of proteins in a cell is known as its proteome. The study of protein structure and function and what every protein in the cell is up to is known as proteomics. The proteome is highly dynamic and it changes from time to time in response to different environmental stimuli. The goal of proteomics is to understand how the structure and function of proteins allow them to do what they do, and how they contribute to the processes that occur within the cell. For example, the complete set of proteins in a cell can be used to identify the presence or absence of a particular trait.

Figure 1. Identification and expression of genes involved in the production of a trait.

Once a trait is identified, it can be used to develop new crops. The goal of crop improvement is to introduce new traits into existing crops. This can be done through conventional breeding methods, such as hybridization, or through genetic engineering techniques. Genetic engineering techniques are only used when all other techniques have been exhausted, i.e., when the trait to be introduced is not present in the germplasm of the crop; the trait is very difficult to improve by conventional breeding methods; and when it will take a very long time to introduce the trait by conventional breeding methods (see Figure 1).

Conventional breeding techniques include:
- Selection of cultivars
- Development of new varieties
- Insertion of genes from other organisms
- DNA marker assisted breeding
- Mutation breeding

Genetic engineering techniques include:
- Gene transfer
- RNA interference
- CRISPR-Cas9

The application of genetic engineering is known as a trait expression profile, which can be used to develop new crops. The goal of trait expression is to understand how the production of proteins allows them to do what they do, and how they contribute to the processes that occur within the cell. For example, the complete set of proteins in a cell can be used to identify the presence or absence of a particular trait.

Proteomics is an entry point for looking at the other 'omics' sciences. The information in the genes of an organism, its genotype, is largely responsible for the final physical makeup of the organism, referred to as the phenotype. However, the environment also has some influence on the phenotype. DNA is the genome of the organism, and the complete set of proteins in a cell is known as its proteome. The study of protein structure and function and what every protein in the cell is up to is known as proteomics. The proteome is highly dynamic and it changes from time to time in response to different environmental stimuli. The goal of proteomics is to understand how the structure and function of proteins allow them to do what they do, and how they contribute to the processes that occur within the cell. For example, the complete set of proteins in a cell can be used to identify the presence or absence of a particular trait.

Figure 1. Identification and expression of genes involved in the production of a trait.
Genomics is the new science that deals with the discovery and noting of all the sequences in the entire genome of a particular organism. The genome can be defined as the complete set of genes inside a cell. Genomics, therefore, is the study of the genetic makeup of a species and the entire genome. In 2002, the draft genetic sequences of two agriculturally important species, indica and japonica, were published. Once completed, the genome sequence allows for a more efficient production of crops. Genomics is exquisitely important for the production of crops and a deeper understanding of the entire genome of plants. Genomics is exquisitely important for the production of crops and a deeper understanding of the entire genome. Genomics also helps in identifying and targeting important genes in order to produce more nutritious and safe food while preserving the environment.

The International Rice Genome Sequencing Project is a collaborative effort of several laboratories worldwide. This project aims to completely sequence the entire rice genome (12 rice chromosomes) and subsequently apply the knowledge to improve the rice genome. Once completed, the rice genome sequence will serve as a model system for other cereal grains. Significant progress has been made in sequencing the genomes of other important crops.

In crop agriculture, the main purpose of the application of genomics is to gain a better understanding of the entire genome of plants. Genomics is exquisitely important for the production of crops and a deeper understanding of the entire genome of plants. Genomics is exquisitely important for the production of crops and a deeper understanding of the entire genome. Genomics also helps in identifying and targeting important genes in order to produce more nutritious and safe food while preserving the environment.

Development of transgenic crops

Although there are many different and complex techniques involved in transgenic crop development, the basic principles are reasonably simple. In order to create a transgenic crop, the desired gene or genes are isolated from the organism of choice. These genes are then mass-produced in a host cell to make thousands of copies of the desired gene. Once the DNA is isolated from the rest of the DNA extracted, these genes can be inserted into the plant's DNA. Once inserted, the desired gene/s can be expressed in the plant, allowing for the production of these crops.

1. Isolation and selection of the desired sequence.
2. Extraction and purification of DNA.
3. Transformation of the selected sequence into a vector.
4. Introduction of the vector into the desired host plant.
5. Expression of the desired gene.

The process of transgenic crop development is a complex and time-consuming process. Although there are many different and complex techniques involved in transgenic crop development, the basic principles are reasonably simple. In order to create a transgenic crop, the desired gene or genes are isolated from the organism of choice. These genes are then mass-produced in a host cell to make thousands of copies of the desired gene. Once the DNA is isolated from the rest of the DNA extracted, these genes can be inserted into the plant's DNA. Once inserted, the desired gene/s can be expressed in the plant, allowing for the production of these crops.

Step 1: Nucleic acid (DNA/RNA) Extraction

Step 2: Gene Cloning

Step 3: Screening for transgenic plants
Gene Design and Packaging

Once the gene of interest has been cloned, it has to be linked to pieces of DNA that will control how the gene of interest will work once it is inside the plant genome. These pieces of DNA will switch on and off the expression of the gene inserted. Gene designing/packaging is done by replacing an existing promoter with a new one and incorporating a selectable marker gene.

Promoters allow differential expression of genes. For instance, some promoters cause the genes inserted to be expressed all the time, whereas others allow expression only at certain stages of plant growth, in certain plant tissues, or in response to external environmental signals. The amount of the gene product to be expressed is also under control, linked to the gene of interest to selectable marker genes are also usually linked to the gene of interest to facilitate its detection once inside the plant tissues. This enables to select the cells that have been successfully incorporated with the gene of interest, thus saving considerable expense and effort. Currently, genetic engineers use antibiotic resistance marker genes to screen plant tissues with the insert. Those cells that survive the addition of antibiotics to the growth medium indicate the presence of the inserted gene. Because of some concern that the use of antibiotic resistance markers will increase antibiotic resistance in humans and animals, genes coding for resistance to non-medically important antibiotics are preferred. In addition, alternative types of marker genes are being developed.

Once the gene of interest is packaged together with the promoter and the marker gene, it is then inserted into a bacterium to allow for the creation of many copies of the gene package.

Sources:


http://croptechnology.unl.edu/download.cgi

Step 4. Transformation

Once the gene package is ready, it can then be introduced into the cells of plant being modified through the process called transformation or gene insertion. The most common methods used to introduce the gene package into the plant cells include biolistic transformation using the gene gun or Agrobacterium-mediated transformation. The main goal in any transformation procedure is to introduce the gene of interest into the nucleus of the cell without affecting the cell’s ability to survive. If the introduced gene is functional, and the gene product is synthesized, then the plant is said to be transformed. Once the gene inserted is stable, inherited and expressed in subsequent generations, then the plant is considered a transgenic.

Step 5. Backcross Breeding

Backcross breeding is the final step in producing genetically engineered crops. This is done by crossing the transgenic plant with elite lines using conventional plant breeding methods. This enables the combination of the desired traits of the elite parents and the transgenic into a single line. The offspring are repeatedly crossed back to the elite line to obtain a high yielding transgenic line.

The length of time in developing transgenic plant depends upon the gene, crop species, available resources and regulatory approval. It varies from 6 to 15 years before a new transgenic hybrid is ready for commercial release.

New and future initiatives in crop genetic engineering

With genetic engineering, more than one trait can be incorporated into a plant. Transgenic crops with combined traits are also available. Examples of these products include: crops with higher insect resistance, crops with improved nutritional and food quality, crops with resistance to herbicides and pesticides, and crops with improved yield and nutritional content.

Commercially available crops improved through genetic engineering

There has been a consistent increase in the global area planted to transgenic or GM crops from 1996 to 2003. Close to 68 million hectares was planted in 2003 with high market value transgenic crops such as herbicide tolerant soybean, maize, canola, cotton; insect resistant maize and cotton; and virus resistant tomato.

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New and future initiatives in crop genetic engineering

To date, commercial GM crops have delivered benefits in crop production, but there are also a number of products in the pipeline which will make more direct contributions to food quality, environmental benefit, pharmaceutical production, and non-food crops. Examples of these products include: rice with higher levels of iron and b-carotene (an important precursor of vitamin A in the diet); improved oil for use in frying; and more nutritious potatoes.

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Genetic engineering

Watson and Crick describe the DNA molecule in 1953, providing more insight into how DNA carries genetic information. The double helix structure of DNA was discovered by Watson and Crick in 1953. The discovery of DNA as the genetic molecule in other words, it is the blueprint for life. DNA is a polymer of nucleotides, each of which contains a sugar (deoxyribose), a phosphate group, and one of four nitrogenous bases (adenine, thymine, cytosine, or guanine). These bases pair with each other according to specific rules, forming the two strands of the double helix. The process of DNA replication involves the separation of the two strands, the synthesis of new complementary strands, and the reassembly of the double helix. This allows genetic information to be passed from one generation to the next.