HORT 102: Biotechnology

Cultivated Plants: Lecture 14

[Kim Kidwell]

Slide #: 1 **Slide Title:** WSU Online Title Slide Title: Lecture 14: Biotechnology Speaker: Kim Kidwell Created by: Theresa Koenig & Kim Kidwell **Audio:** Music
Slide #: 2 **Slide Title:** Lecture 14: Biotechnology Molecular Crop Improvement *[Image of colonized pollen from http://upload.wikimedia.org/wikipedia/commons/2/2a/Misc_pollen_colorized.jpg]* **Audio:** Lecture 14 is about biotechnology and specifically, I am going to focus on how we apply biotechnology to crop improvement. So, this kind of links with the genetics, reproduction and the plant breeding lectures that you just experienced.
Slide #: 3 **Slide Title:** What is Biotechnology? Bio=biology Technology=application The application of biology (for the use of humans) **Audio:** What is biotechnology? That question is hotly debated these days in many, many arenas and if you really want to look at the controversy of this all you have to do is google the word 'biotechnology' and you will find an onslot of popular press debates about this topic and what is good about it, what is bad about it. What I really want you to focus on in this lecture is getting a clear understanding of what biotechnology is so that as you read and look at some of these materials you can make a good decision about what you think is true and what you think is not true related to this topic, but in its simple form biotechnology means bio as in biology and technology as in application. So, it is the application of biology, in our case, to crop improvement.
Slide #: 4 **Slide Title:** Biotechnology Biotechnology in one form or another has been present since prehistoric times.

- Fermenting juice into wine
- Turning milk into cheese or yogurt
- Using yeast to make bread rise
- Selectively breeding livestock

Audio:
In one form or another, biotechnology has been around for hundreds of years and so very simple processes that involve the application of biology to food production are really great examples. So, fermenting juice into wine – that is a biotechnology process. Turning milk into cheese or yogurt, using yeast to make bread rise and selectively breeding livestock are just some examples of this and it just really involves the implementation of a biological process to change the shape or form of the food into something different. Like yeast being activated to create gluten structure in bread so that it holds gas bubbles and it raises into bread. That is a biological processes that people explored and discovered to help make rich bread products.

Slide #: 5
Slide Title: Biotechnology

- Biotechnology: a field of applied biology that involves the use of non-living organisms and bioprocesses in engineering, technology, medicine and other fiends requiring bioproducts.
    - Encompasses a wide range of procedures for modifying living organisms for human purposes
- Plant biotechnology: developing ways to improve the production of plants in order to supply the world's need for food, fiber and fuel. http://en.wikipedia.org/wiki/Biotechnology

Audio:
Biotechnology is a field of applied biology that involves the use of non-living organisms and bioprocesses in engineering, technology, medicine and other fiends requiring bioproducts. In encompasses a wide range of procedures for modifying living organisms for human purposes. In our case, plant biotechnology focuses on developing ways to improve the production of plants in order to supply the world's need for food, fiber and fuel.

Slide #: 6
Slide Title: GMO's

- Many people associate the word biotechnology with Genetically Modified Organisms (GMOs).
- Although GMOs are an aspect of biotechnology, there're are also many non-GMO biotechnology techniques
- Biotechnology is often used during the breeding process, resulting in products that are not GMOs

Audio:
Now, many people associate the word biotechnology with this term genetically modified organisms and it is extremely important to me that you understand that these are not the same thing. These are not synonyms and in fact that fuels much of the debate in the popular press and

amongst scientists about the issues associated with the value of biotechnology considering there are some serious concerns from some folks about using/consuming genetically modified products.

So, although GMOs are an aspect of biotechnology, there are also many non-GMO biotechnology techniques. Later, I am going to go into pretty thoroughal definition of what a genetically modified organism is, but for the moment, let's focus on defining biotechnology as a non-GM approach.

Now, for many of you that think they are one and the same this might be new information for you, but as far as the content of this course is, at some point we are going to want you to be able to explain the difference between these two in some detail so that we know that you clearly understand that genetically modified organisms are not equivalent to products of biotechnology.

Slide #: 7
Slide Title: Non-GMO Biotechnology Tools

A. Genome Sequencing and Genetic Mapping
B. Marker-Assisted Selected
C. Tissue Culture
D. Noodle Color Test for Polyphenol Oxidase Activity

Audio:
So, I am going to give you some examples of some non-GMO biotechnology tools. Now, the premise here is that most of these techniques simply involve using some application, a biological application to improve plants and so these four examples that we are going to go through are just really great non-GMO approaches that we use for plant improvement very routinely. They are used in laboratories all over the world as a matter of fact.

Slide #: 8
Slide Title: Not GMO's

Products of these techniques are NOT considered to be GMOs because they are developed via sexual reproduction.

Audio:
Again, products of these techniques are not considered to be GMOs because they are developed via sexual reproduction. So, one thing to note, if you go through that very normal sexual reproduction process that we talked about when we went through the meiosis piece, that process, when you are actually identifying things, recombining genes through sexual reproduction, that tends to be an indicator that that is non-GMO approach. Genetically modified organisms are developed through an asexual process that I will describe to you a little bit later. There are a few ways to do it, but the sexual reproduction piece is really important distinction between just a regular biotech tool and the development of a genetically modified organism.

Slide #: 9
Slide Title: Genome Sequencing

A. Genome Sequencing and Genetic Mapping

- Genome sequencing is the process of determining the exact order of all the chemical building blocks (A,T,C,G) that make up the DNA of a plant's chromosomes
- Once the genetic makeup is determined, it can be used to make a genetic map
- A genetic map is a graphic representation of the arrangements of DNA sequences on a chromosome

Audio:
So, I am going to describe a few things, not in a tremendous amount of detail, but I want to give you a bit of a frame for how this might work. So, this slide is title genome sequencing and genetic mapping. And again, this is a huge area of discovery and research in humans and animals and in plants. In genome sequencing, what we are trying to do is figure out the order of the nucleic acids in the DNA strands. So, it is the process of figuring exactly what that order is like so we know what the coding region is for all the genes that make up a chromosome.

Now, you may wonder why that is important. Well, it is a lot like reading a book. If you can get all the words linked together, you have a better ability to understand what is happening there and so it kind of is the decoder key for makes up the composition of very specific genes. If you can figure out where the gene is, then you can figure out where the sequence is, you actually can manipulate that in a very constructive way.

Once the genetic makeup is determined, we can use some pretty cool techniques to figure out what the orders of those genes are and I don't want to go into it here because it is a complicated process in some ways that I want you to have to remember and explain at this point in time, but you can look it up if you are interested in that. It is kind of like the process of taking a shuffled deco cards and sorting it into suits and then putting those suits in the right order. That is exactly what we try to do when we create gene maps. We want to figure out what is the linear order of genes on a chromosome. So, if we figure out where their location is and we identify some markers that help us know that gene is there, we become more efficient in the selection process. A genetic map is a graphic representation of the arrangement of DNA sequences on a chromosome.

Slide #: 10
Slide Title: Genome Sequencing Images

[Image of wheat DNA in a tube]
[Image of fingerprints of wheat plants]

Audio:
So, this is an example from my lab of just some very routine processes that we have been doing for almost 30 years now. In the picture on the left you see a tube that appears to have some liquid in it and kind of a cottony snotty substance in the tube. Well, that is actually wheat DNA and it is in alcohol. DNA is not soluble in alcohol, so you can precipitate it out of solution very easily by extracting it from leaf tissue, root tissue – you can use almost any kind of plant tissue to get DNA out these days and you go through a pretty simple procedure and that is essentially all the chromosomal DNA wound up together in what is a very big blob.

Now, we have undergrads do this in our research labs every day. In fact, the process has become so automated that at this point in time you can take a leaf punch out of a leaf and in a very small Petri dish with very, very small wells in it you can grind these things up electronically and just in a matter of minutes actually come up with a DNA sample.

Then the question is what do you do with that? Well, on the right side of the side this is what we call a DNA fingerprint of a wheat plant. This isn't very different from the technology you might be familiar with on some TV shows like CSI where they are talking about DNA and they are showing you all these different pictures of how they figure out whose blood is where by matching up the banding profiles of the blood sample at the crime scene with the person they actually think committed the crime.

We can actually fingerprint wheat in this same way and what you see in each of these lanes – the long linear lanes on this gel, those are a bunch of genes that are present in each individual wheat plant. So, we took DNA from, in this case, there are probably about 30 plants here in this panel. We extracted the DNA from each of those plants individually and then we ran a DNA profile. In essence to figure out how genetically similar these plants are to each other.

So, if you look at this, you will see that some of the dark bands, each of those bands represents a gene as a matter of fact, you will see that some of the plants, all of them have the same band. And in some cases, one plant will have it, the next one won't. You can kind of look through here and get a feel for how genetically similar or different these plants are by looking at their DNA profiles.

That creates a big possibility for us to figure out if a plant actually has a very unique gene and that unique gene, based on the DNA profile, is affiliated with a particular trait that is also unique to that plant. We then call the dark bands here the piece of DNA that is affiliated with that trait the DNA marker. So, the cool part here is I can look at the DNA and see if the genes I want are there as opposed to waiting till those plants grow up and see if they really express that phenotypic trait, when we talked a little bit about traits when we talked about the genetics of plants in an earlier lecture.

Slide #: 11
Slide Title: Genetic Maps

These genetic maps allow scientists to more rapidly identify which genes provide desirable fruit characteristics or disease and drought tolerance

Please pause this presentation and view the video "WSU-Apple Genome" found in the Lessons Overview Page of this section

Audio:
So, if we go through our process of trying to correlate the DNA bands that we saw on the last slide with traits in plants. We can create a genetic map and identify a DNA tag for particular gene. Now, what is nice about these genetic maps is that it allows scientists for more rapidly identify which genes provide desirable traits that we are looking for. It could be fruiting characteristic, disease resistance, drought resistance.

They also do a similar kind of work in humans and so in a very similar fashion, people identifying genes related to breast cancer or cystic fibrosis and so it is a very, very powerful tool that you can use as an indicator to whether or not the gene is present in an individual. So, at this point I am going to ask you to pause this presentation and take a look at a video about a project at WSU on creating a sequence project and a genetic map for apple. This video is called WSU Apple Genome and it is found in the lessons overview page of this section. So, please pause the PowerPoint and take a look at the video.

Slide #: 12
Slide Title: Genetic Mapping of Alfalfa

Loci have been identified for potential use in marker – assisted selection
Genes that effect yield and regrowth have also been identified
[Image of genetic map for alfalfa from http://upload.wikimedia.org/wikipedia/commons/a/ae/PE_Lib1.jpg]

Audio:
So, genetic mapping has been done in many different types of plant species at this point and time and just to give you an indication of how powerful it is we talked about polyploidy earlier as well and that means the plant has multiple chromosome sets. In the case of alfalfa, there is actually four chromosome sets in that species. Well, you can do genetic mapping in complex systems as well and so there have been great maps made in alfalfa.

In fact, when I was a grad student it was one of my projects for my Ph.D. work was developing one of the first genetic maps that was ever created in this species and what is really important about using markers in things like apple and things like alfalfa – it takes either a very slow growing species, tree breeding is very difficult because of how long it takes to regenerate an apple plant. Alfalfa is difficult to breed because of the complexity within the population, but if you can use DNA markers for selection so that you identify traits earlier, it just expedites the process in a really powerful way and so time is an issue and complexity makes it much harder to get what you want.

If you can produce some DNA profiling and figure out whether or not the genes you want are present, it just really is a great advantage for the breeding process. So, in alfalfa, a couple traits that have been really important that they have improved through the use of DNA technology are yield, forage yield and actually persistence or how well these plants re-growth and live over time. So, that is kind of the value of the tool is it is a much, much more efficient and effective way to facilitate plant improvement if you do it well and if you have the resources to do it right.

Slide #: 13
Slide Title: B. Marker-Assisted Selection (MAS)

- Use of DNA markers that are tightly linked to target loci as a substitute for or to assist in phenotypic screening
- Can mark and identify important genes

Audio:
So, when I talked about the affiliation of a DNA marker, one of those black spots that we saw on

DNA fingerprint in profile with the particular trait, we call the use of those markers marker-assisted selection, what simply means that we are looking at the DNA, we are trying to find a DNA marker or DNA tag that is tightly linked to a trait of interest. And the deal is, instead of waiting to see if the plant actually has that trait by letting it go through its whole lifecycle, you can grab a leaf when it is little, you can do a DNA profile on it and you can see if the marker for the gene is actually present.

Now, the way I use this technique the most in my breeding program was to eliminate plants from the breeding process that didn't have target genes of interest that were essential like for fungal disease called stripe rust that just decimates wheat plants. If plants don't have resistance to that disease, we actually can't release them for commercial production because the farmer is then at risk of growing a crop that becomes highly infected. It costs a lot of money to put spray on those plants to prevent that disease from taking over the crop and we would much rather do it genetically because it is free essentially and it is always present so the plants have genetic insurance so to speak against that disease.

So, marker-assisted selection or MAS as it is referred to commonly involves the use of those DNA markers to identify those traits of interest in the breeding process and a lot of research that is done worldwide in plant improvement involves identifying DNA tags for very important genes of interest to facilitate that breeding process and I am going to show you how that works in the next couple of slides.

Slide #: 14
Slide Title: Advantages of MAS

- Rather than going through numerous field trials to determine disease or drought resistance, breeders can simply use MAS to determine if that gene is present (saves time)
- Can determine if parents to be crossed have desirable traits
- Can check for desirable traits during seedling stage rather than waiting until maturity http://www.idosi.org/aaja/1(2)08/2.pdf

Audio:
There are some advantages of marker-assisted selection that really make you a much more powerful and effective researcher. Rather than going through numerous field trials to determine disease or drought resistance, breeders can simply use MAS to determine if that gene is present. So, it saves a lot of time. Now, the caveat to this though is just because the gene is in there, that doesn't necessarily mean it is going to express.

So, we know that there are environmental factors that influence gene expression and it doesn't always turn on or doesn't always express to the level that we need it to. So, you eventually have to grow these out in the field, put them out in the environment and see really if what you predict to be genetically actually happens, but you can definitely get a long way just through identifying the presence or absence of the gene.

Now, the deal is it is not going to express if it isn't there. So, ensuring that it is actually present though DNA technology is a great asset in the breeding process. You can also take a look at the parents that you are using in a cross to make sure that the desired traits are there. Again, you are not going to recover a very particular trait if the parents don't carry it and so it is a great way to make sure that you are targeting things that are essential. You can also target multiple genes at the same time. So, this isn't done for just one trait.

You can have a whole cascade of DNA markers that you are screening for in the breeding process just to make sure that the plants have all those traits that you are interested in and the thing that I really like about it is you can check for those traits during the seedling stage rather than waiting for maturity and you know, it is a huge advantage in annuals because you save a lot of space by just not transplanting or transferring things to the field that don't have the genes that you want, but when you think about perennial crops like trees or even alfalfa or anything that, you know, all the grasses, if it takes a long time to go from seed to adult maturity, it really is a valuable thing to be able to call or to identify individuals you are most interested in through DNA market technology and also trees aren't small when they are growing and so it takes a lot of space to create a tree nursery and if you can manage that more constructively by hedging your bet and making sure that the plants have the genes that you want through DNA profiling it just really helps the success rate of your breeding program.

Slide #: 15
Slide Title: Advantage of MAS

- Can separate actual genetic makeup from environmental effects
- More accurate and efficient selection of specific genotypes
- Faster variety development
- More efficient use of resources

http://www.idosi.org/aeja/1(2)08/2.pdf

Audio:
The other thing that is interesting about this – I talked a bit about environmental effects. You can also identify the genetic makeup of a plant very succinctly without being impacted by environmental factors. So, sometimes in the field, even if the gene is there, the environmental conditions aren't exactly right for it to express. That doesn't mean that the gene isn't there and in fact if you put it in a different environment, it would show up. So, this is really good for things like disease resistance because if you don't get the disease, you don't know if the gene is there.

If a plant isn't challenged, it doesn't have the opportunity to demonstrate that it would ward off the disease or protect itself from being infected, but if you know the gene is there because the DNA tag is present and there isn't any disease in the area, you would still select those and so it is kind of a great backup plan just in case you don't have the right environment for that trait to express.

It allows us to more accurately and efficiently select specific genotypes. It facilitates the right development process. It does go faster, but you still have to do field testing and so that part is important and it is really essential that we do that over multiple years to make sure that the plants perform stably.

So, it is more efficient and it is more effective, but it doesn't eliminate any of the need to field test. You still have to do that to make sure the plants are actually doing what you think they are going to do based on their genetic makeup.

Slide #: 16
Slide Title: Marker-Assisted Selection for Stripe Rust Resistance Genes

[Image of DNA tags stripe rust resistance genes]

Audio:
So, this is a much less complicated example than the DNA fingerprinting profile that I showed you earlier. This is an example of the application of marker-assisted selection for stripe rust resistance genes in wheat and so the black spots here that you see on this profile slide represent DNA that has been extracted from plants and we have three different types of plants here. We duplicated them so if you look at the top of the figure you will see reading from left to right it is a zak, zak – those are DNA samples that were extracted from two different zak plants that are side by side, run out by individual lanes in a DNA gel.

The next two say Yr5 and Yr5 – those are duplicates of plants that contains a gene called Yr5 that fights off stripe rust. So, it is a resistance gene that when present in the plants, they don't get infected and challenged by the disease. Now, the caveat with this is zak is highly susceptible to stripe rust and so our goal was to move the Yr5 gene into zak.

There is also another gene called Yr15 that is a little bit further to the right on that panel and you see that it has a different DNA profile too and when we run those genes out, what you see here is they are unique based on size and so they migrate through this gel matrix and they stop or they migrate at a different rate depending on how big they are.

And that has a lot to do with the DNA sequence, with the order that it is in. We go in and clip these up with what we call restriction enzymes to get some of these banding patterns figured out, but we have done the genetic work to figure out that whenever we have that 120 bp that stands for base pair band in Yr5, that means that gene is there. That is the marker that is affiliated with that Yr5 gene.

For yr15, there is a 114 base pair fragment that is affiliated with the resistance gene in Yr15. You will notice that Zak has a little bit of a bigger piece – it is a 124 base pairs long. That is the susceptible DNA profile. So, we don't want that one in Zak. Our goal is to get that Yr5 and that Yr15 band into Zak together so that it has two resistance genes to help ward off that disease.

Now, this is a disease that when farmers spray for it, they can prevent Zak from getting this stripe rust problem, but if they don't spray, it will decimate the crop to the point of crop failure in a really heavily diseased year. So, this is kind of what breeders do is manipulate genes and in a way that we improve that variety so it is better for growers and it is less risky to grow.

If you want to know what is going on the far right side of the slide, that actually just a DNA ladder that helps us figure out how big those fragments are.

So, this is how we do marker-assisted selection for one particular trait and it is really powerful because at the end of the day, if it goes well, you see something like this.

Slide #: 17
Slide Title: 'Alpowa' with Seedling Resistance to Stripe Rust

[Image comparing Alpowa leaf to Alpowa with Yr5 and Alpowa with Yr15]

Audio:
Although this is a different variety, Alpowa also has some troubles with stripe rust and in this examples you can see three different leaves. Alpowa is the cultivar that is in commercial production here and you will notice that there are some really big kind of necrotic streaks on these leaves. So, the deal there is we are looking some photosynthetic area because of the resistance reaction that happens n Alpowa. When spores of the stripe rust fungal pathogen land on that leaf, it kills the tissue underneath.

That is how it prevents the whole leaf from getting infected. But you can see that under heavy pressure, you can lose quite a bit of the photosynthetic area of that leaf and that just reduces yield potential. So, our goal was to keep Alpowa from losing that much leaf tissue and so what we did using marker-assisted selection was we put Yr5 into a plant very similar to Alpowa. We did it using a technique back-cross breeding and marker-assisted selection and you can see in that top leaf that is labels Alpowa with Yr5, there is no leaf tissue lost there.

The whole leaf is green. It is healthy. There is no necrosis on that leaf at all. Those spots actually are aphids, there is a little bit of aphid activity of these plants. We didn't this trial so there are some insects running around in there, but aside from that, the leaf looks really, really good. So, when you increase your photosynthetic area and keep your plant tissue healthy, you tend to get higher yield and higher quality product, which is the goal there. Same with the leaf on the very bottom.

That line actually has Yr15 in it, which is the other resistance gene I talked about in the last slide. And again, you can see that the leaf tissue is really healthy and we don't have those big yellow or white streaks that are covering most of the middle leaf there and that is the point of that. So, at the end of the day in improved variety that is very similar that is very similar to Alpowa would be one that had Yr5 or Yr15 in it.

Slide #: 18
Slide Title: C. Tissue Culture

A method of asexual propagation used to produce clones of a plant under controlled, sterile conditions.

- Many plant cells are totiplant, or able to regenerate a whole plant from one cell.
- Plant tissue culture relies on this ability.

[Image of a plant flowering inside a test tube from http://upload.wikimedia.org/wikipedia/commons/1/12/Vitex_negundo_flowering_inside_the_test_tube.jpg]

Audio:
The next non-GMO biotechnology technique I want to talk about is tissue culture. Now, tissue culture is a form of asexual propagation. It is used to produce clones of a plant under controlled,

sterile conditions. You can see in the figure on this slide that this is a little bit of a – it is a tube, a test tube that has some re-growth media on the bottom of it and you can see that there is a plant growing in there.

Some roots on the media and then the upper part of the plant is growing into the tube there. Most plant cells are totipotent and what that means and this is a review. Totipotency means that you can regenerate a whole plant from a single cell. Plant tissue culture relies on this ability to produce whole plants by culturing a few cells.

Slide #: 19
Slide Title: C. Tissue Culture

Sterilized plant materials are placed on the surface of a culture media:

- Media is usually composed of salts, nutrients, vitamins, and plant hormones.
- Precise composition is important for development of roots and/or shoots.

[Image of carrot materials in culture from http://upload.wikimedia.org/wikipedia/commons/6/65/Carrot_in_glass.JPG]

Audio:
This is a different example where this is a Petri dish that has a little bit more surface area in it. Again, there is a media in the bottom of it and there are some embryos that have been placed in that media and you can see they are different sizes because the cells are dividing and they are regenerating.

So, what you do is put sterilized plant materials in a media culture and it is usually a solid culture in this case. So, you put the plant piece on the culture. You can use ovaries. You can use embryos. There are many different parts of plants that will regenerate, but they have to be totipotent. So, the media has salts and nutrients, vitamins and different plant hormones that trigger or stimulate growth or specialization.

So, the plant hormones dictate whether roots will form or shoots will form. So, the composition of the media is very important and there is a tremendous body of literature out there that you can take a look at if you want to know what is in these media and how they figure out what does what. The precise composition is very important for the development of roots and/or shoots and that is what it is going to take to be able to recover an intact.

So, the composition of the media matters and it has been customized for many different kinds of plants. Sometimes it needs to tweaked to get the media to allow regeneration for particular species.

Slide #: 20
Slide Title: Applications of Tissue Culture

- Conservation of rare and endangered species
- Produce virus free plants
- Produce large numbers of identical individuals
- Plant genetic engineering

[Image of Petri dishes with tissue cultures]

Audio:
Now, what do we use tissue culture for? Well, many, many, many things. It is used often to conserve rare or endangered species. So, especially things that don't reproduce easily by seed or don't reproduce at all by seed. You can use tissue culture to maintain that germplasm base which is a very important use of tissue culture.

It is also a great way to reproduce plants in a virus-free manner. You can also reproduce a very large number of identical individuals through tissue culture and again, this works really well for species that have a hard time reproducing sexually or for species that are very long lived. Some of the woody species in a tissue culture medium is really just a great way to get a lot of copies of a very good individual.

The other thing that you can use it for is genetic engineering, which we are going to talk about very soon and that would be a genetic modification technique. So, good uses for tissue culture techniques.

Slide #: 21
Slide Title: D. Noodle Color Test for Polyphenol Oxidase Activity

Noodles are made from wheat flour and much of U.S. wheat is exported to Asia

- High levels of polyphenol oxidase cause discoloration in Asian noodles
- Can screen for high polyphenol oxidase levels in varieties and eliminate those with undesirable levels

[Image of noodle color test for polyphenol oxidase activity]

Audio:
The last example I am going to give you of a biotechnology approach for plant improvement doesn't involve DNA directly at all. It is an enzymatic assay that is used to identify wheat varieties or wheat plants that are good for noodle making and so this is a 96 well tire dish on the slide and you can see there that each well contains a little bit of liquid in it. Some of the liquid is yellow; some of it is clear; some of it is really, really dark black. That is segregation happening in a population for what we call polyphenol oxidase activity.

So, this is the enzyme that activates when you bite into an apple and you might leave it on your desk for a little bit and you will notice that it starts to turn brown. When exposed to air, you get this browning phenomena that is related to polyphenol oxidase and so we actually try to select against that because people in general don't like their food to brown at that rate and in noodles in particular, especially in Asian countries, noodle color is a very important attribute as far as getting people to consume the product and so people don't like off color dark noodles.

So, we select against that for wheat varieties that are going to be used for noodle production. So, when we have high levels of polyphenol oxidase the noodles turn black and that is not desirable. So that is not a good product to put into the noodle making market. We screen for this very simply by soaking seeds in a little bit of substrate and going through an enzymatic reaction and I simply don't select the lines that are affiliated with the black dark circles and the ones that are light, yellow or white, we advance in the program and that is how we select for noodle color in the spring wheat breeding program at Washington State University. It is a very easy. It is a very inexpective and it is biotechnology and it is non-GMO.

Slide #: 22
Slide Title: Polyphenol Oxidase Activity

Greenhouse *[Image of a greenhouse from outside] [Image of a greenhouse inside]*
Crossing
Seed Increases
Mutation Breeding
Gene Discovery
Disease Screening
→
Laboratory *[Image of a laboratory] [Image of a DNA profile]*
Gene Mapping
Genetic Therapy
Marker-Assisted Selection
Selection for End-Use Quality
→
Field *[Image of a filed with test plots] [Image of a scientist] [Image of a combine]*
Agronomic Evaluations
Direct Seeding Trials
Disease Screening
Fertility Trials

Audio:
So, when you look at the overall flow of how we use some of these techniques in a plant improvement program, I kind of always look at it three ways. There is kind of three legs to the stool in the breeding process if you want to kind of consider that to be how this works and it is a very balanced approach.

We make a lot of crosses in our greenhouse. We have a state of the art facility on campus. Greenhouses are one of the most important tools for anybody that is doing plant research because it is summer all year long and you can turn on the lights to any day length that you need.

So, it is really easy to produce seed and advance plants there. In the greenhouse, we do all our crossing. We do seed increases sometimes. We can actually do mutant screenings to try to mess up the DNA a little bit in the plants to create new genes that we are interested in. We do our gene discovery work there. We do a lot of disease screening work there. And then, that kind of flows into what we are doing in a laboratory as well.

And you can see in the lower panel here there is somebody actually working at the bench in the laboratory. There is a DNA panel there. We do all our gene mapping there – our genetic therapy. That means we are actually selecting for genes to improve a really good variety like putting that Yr5 gene into Zak or into Alpowa, an example I just showed you.

The marker-assisted selection work happens in the laboratory; some of the end-use quality work that I talked about for noodle coloring. That happens in the laboratory, too. That information can feed our greenhouse program. It also can be used to select for plants that are out in the field and that is really the most important aspect in some ways is to make sure that we are doing really good field trials to ensure that the plants are doing what the DNA says they are supposed to do.

So, out in the field, we run lots and lots of test plots and if you take a look at this picture, you will see that there is a small combine running/harvesting a bunch of field plots. They are in little squares that are about 6 feet by 20 feet long and each one of those little squares contains a different variety or a different line of wheat. We actually do a lot of testing as we get more seed and decide the plants are, you know, these are pretty good ones, we increase the seed volume, increase the size of the field testing plot until we feel like we have a pretty good product that a farmer might want to grow, but that field piece takes a long time because you only can get one crop a year for an annual that way.

So, we have to do that for at last three years before we feel any confidence that the performance of the line is repeatable. So, that phase is expensive and really takes a long time so what happens in the greenhouse in the laboratory to make sure that we are only testing lines that have really, really good potential is where we gain all of our efficiency.

So, the synergy between the greenhouse program, the lab program and the field program facilitates our ability to develop and improve varieties in a much more timely manner and like I said, I am addicted to wheat because that is what I build my career on here and I have the most experience with, but for essentially every crop that we are improving, people are using similar strategies.

You know, depending on the breeding habit of the crop, you might have to tweak this a little bit and do different types of techniques or use different kinds of procedures to get plants to grow in the greenhouse, but this has really modern plant breeding where people have infused these different approaches to improve plants in a more efficient and effective manner.

Slide #: 23
Slide Title: From Laboratory to Reality

[Image of wheat plant in the crossing process] Crossing → *[Image of DNA profile for wheat]* Trait selection → *[Image of wheat field]* Tara 2002 *[Image of combine harvesting wheat]* Washington Farmers → *[Image of grain production from http://www.ksre.ksu.edu/aawf/original%20images/Photo%20162.jpg]* Shepherds Grain → *[Image of cookies]* WSU Food Services

Audio:
So, I am going to walk you through an example of how this impacts commercial production. How we go from the variety development piece to creating a better product that has added value for farmers. In this case, you see in the top part of the panel we made a cross. We did some marker-assisted selection and we actually ended up releasing a variety called Tara 2002 that has very unique attributes for bread making.

A couple of farmer friends of mine that were in a cooperative called Columbia Grain Growers wanted to test here because their goal was to start growing and selling wheat flour more locally. About 90 percent of the wheat that is grown in the Pacific Northwest is exported to Asia and Pacific rim countries. We don't sell a lot of our wheat here. In fact, most of the wheat products that you eat here are from wheat that is grown in Montana or Kansas.

It seems kind of silly. So, these guys wanted to take advantage of being able to grow a crop here that they could sell locally. It actually really is a great idea because they save lots of money in fuel costs because they don't have to transport it very far, but people weren't very used to using wheat from Washington so this was kind of unique opportunity.

So, they did some testing and figured out that Tara is really exceptional for making good bread and it also has a very good flavor. We did some of the selection for the bread quality in our laboratory and they created a flour blend called Shepherds Grain. The unique attribute here is they grow this wheat in a sustainable production system, which means they use reduced chemicals and they direct seed it to prevent soil erosion, things like that and they created a very interesting niche market.

So, this started off, I don't know, it is probably about 10 years ago now or so and they have done very well in selling bags of Shepherds Grain flour to people all over the region from California all the way up the coast and even into Montana and Idaho a bit. So, they created a specialty flour that is grown and produced here in Washington state. The wheat is grown here and the flour is actually extracted from that grain around Cheney and they distribute it all over the place and I think the thing we are most proud of is WSU Food Service – we use Shepherds grain on campus and so it is really a great story of local farmers producing a local products that was developed at WSU and it is actually used in our food service to feed cougars.

So, we have a lot of press on this story and I really love it because it comes full service from research that we do on-campus to an application that creates an industry that generates income for our farmers and produces a product that is really good for our consumers and in this case it is a big bonus because the consumers are students.

Slide #: 24
Slide Title: Not GMO's

Products of these techniques are NOT considered to be GMOs because they are developed via sexual reproduction.

Audio:
I am going to remind you again that these are not considered to be GMOs. They are developed through sexual reproduction and the only thing that we had done is used slick biotechniques to facilitate the selection process.

Slide #: 25
Slide Title: Genetic Transformation

Genetic transformation, gene splicing, and genetic modification involve the identification, isolation, duplication and insertion of genes or pieces of DNA from one genome intro another. Genetic composition is altered without sexual reproduction.

Audio:
So, now we are going to talk about what it takes to create a genetically modified organism. Genetic transformation, gene splicing, and genetic modification involve the identification, isolation, duplication and insertion of genes or pieces of DNA from one genome intro another. This is actually done without sexual reproduction. It is done in a different way and whenever you are taking DNA that is not naturally there and inserting it into a plant, even if it is from the same species, though some asexual means, you have developed a genetically modified organism.

Slide #: 26
Slide Title: Genetic Engineering or Modification Involves Asexual Gene Manipulation

Genetic composition is altered without sexual reproduction

- No hybridization
- No meiosis

[Image of a diagram depicting meiosis in a red crossed over circle from http://upload.wikimedia.org/wikipedia/commons/6/6f/MajorEventsInMeiosis_variant_int.svg]

Audio:
Now, to clarify this, genetic engineering or genetic modification involves asexual gene manipulation. That is an indicator key, that asexual piece, that the DNA has been genetically modified. The genetic composition of the plant or the species or whatever you are working with, it could be an animal species, plant species, you can do this in many, many different things, but the genetic composition is altered initially without sexual reproduction. So that means we are not doing cross hybridization and meiosis is not occurring.

Slide #: 27
Slide Title: Developing GMOs involves:

Gene cloning: the identification, isolation, duplication and insertion of genes from one species to another.
Asexual transfer of cloned genes within or among species

Audio:
So, how do you do this? How do you develop a GMO? Well, it involves gene cloning. You actually have to identify, isolate, duplicate and insert the gene from one species to another or even to the same species. So, we have to figure out what that DNA sequence is. We have to isolate it. We have to put it into a vector, usually some type of bacterial vector to transfer it from one organism to the other.

You can't really do this effectively at all if you don't know the DNA sequence and you haven't identified what specific gene sequence, what specific DNA sequence is affiliated with the gene of interest. And then, you asexually transfer the cloned gene within or among species.

So, it doesn't necessarily mean that you are taking DNA like from an elephant and putting it into a wheat plant. If I isolate a gene from a wheat plant and insert it into another wheat plant through asexual means, it is a genetically modified organism. And I am going to show you a couple techniques of how you do the gene insertion.

Slide #: 28
Slide Title: Slide 28

DNA of interest *[Image of a DNA helix structure from http://upload.wikimedia.org/wikipedia/commons/e/eb/DNA_helix_structure.png]*

Agrobacterium method →
Introduction of DNA into Agrobacterium →
[Diagram showing bacteria DNA and tumor plasmid containing DNA of interest]
Bacterial transfer of DNA
[Diagram showing bacteria DNA, tumor plasmid and chromosome pairs from http://commons.wikimedia.org/wiki/File:Chromosome_pair_drawing.svg]

DNA particle gun method →
DNA coating of microscopic metal particles →
[Diagram of metal particles and DNA]
Acceleration of particles into plant cells
[Diagram showing acceleration of metal particles into plant cells]

Audio:
Although I didn't explain to you how the genes are actually cloned, it is kind of a complicated process, but it is done routinely in many labs. Once you have identified that DNA sequence, there is a couple of different ways that you can actually get it into a different individual. So, be it among species or between different species, these are two approaches that can be used.

So, on the right side of this slide, you will see something called the DNA particle gun method and on the left hand part of this slide it is the agrobacterium method. So, they are different and at the end of the day, the goal is to get that cloned DNA sequence integrated into the DNA of the target plant and to get it to replicate normally in mitosis in that plant. So, we will do the gene gun method first because it is actually the easiest to explain in some way because it is a little bit more random.

You take your DNA sequence that you want to insert into the species and you code it on microscopic metal particles. They are usually tungsten and these particles that are impregnated with the DNA are actually blasted into the cells of the target species. Now, this really works very much like a gun approach where there is a like a bullet gun powder and a high trajectory acceleration of those particles into the plant cells. They cause tremendous amounts of damage on insertion and if you use enough plant cells and have a high enough population size there occasionally the DNA will integrate into the cell and it won't be damaged to the point of death.

It actually will be able to integrate that DNA piece and replicate and it will infuse into the DNA of the plant, the target plant that you did the acceleration process with. So, it is the gene run method and you are essentially using biolistics to shoot the DNA into the target cell of interest. You do hundreds of thousands of these, plate them on a media. The probability of it working is fairly low, but if you do enough attempts in enough cells, you do recover some and they will contain the DNA of interest that will be integrated into the chromosomes of the target cell and it will replicate. So that is one way to do it.

The other way to do is actually the original way that a lot of people worked on because it is a natural process. So agrobacterium tumefaciens is a disease of trees and if you have ever been out hiking you may have noticed there some big tumors on some trees – there is like a big growth that looks like a tumor on a tree. Well, that is actually caused by agrobacterium and so the way that this works is the bacteria infects the tree and integrates its DNA into the tree species.

So, that is kind of a rudimentary explanation of how that works, but people noticed this phenomena and started to do some work on that and decided that they could do some research to figure out how agrobacterium could serve as a vehicle to transfer DNA of interest into plant species. So, lots of work and year later, what you essentially do is intergrade the DNA of interest into agrobacterium. You create a construct. You put your DNA into this construct. It is uptaken by the bacteria and the bacteria serves as the transporter of your target DNA into your target species.

So, you introduce the DNA into that bacteria. It has a plasmid in it that contains the DNA of interest. Again, that is called the construct. You infect your target plants with that bacteria and the bacteria transfers you target DNA to the DNA of the species. Again, these are kind of complicated processes that I don't expect you to explain. If you want to learn more about it, just do a little bit of research so you can get the story straight, but just know that there is a couple ways to get these genes inserted – particle gun, agrobacterium. In both cases, it is asexual integration of the target DNA into the target species, but the key to success is that DNA has to integrate into the chromosome of the target species and replicate.

Slide #: 29
Slide Title: Slide 29

DNA Insertion *[Diagram of chromosome pair from http://commons.wikimedia.org/wiki/File:Chromosome_pair_drawing.svg]*
→
Cell Division *[Diagram of cell division]*
→
Plantlets Regenerate *[Image of cells cultured in a media]*
→
Plants with Target Trait *[Image of plants grown in a pot from http://upload.wikimedia.org/wikipedia/commons/1/1e/Wheat_hybrid_B938_plant_comparison.JPG]*

Audio:
Once the DNA has inserted, once you have your target DNA inserted into your cell of interest, then you have to get those cells to divide and again, you know, there is a probability factor here and it takes some time to finestimate that work, but the goal is grow an entire organism from a cell that has the integrated DNA. So, a lot of this is done in a tissue culture medium. So, you are trying to regenerate plants that have been subjected either to biolistics or to agrobacterium, you are going to screen for you target gene of interest.

This example is about herbicide resistance and so the goal was to engineer a herbicide resistance gene into these plants so that if you grew them up in the field, you could put herbicide over the top of the plant, kill the weed, but the crop plant would live and we are going to talk about that a little bit more later as well.

So, in the selection media here, actually there is herbicide in there and so any cells that don't contain the herbicide resistance die. And the ones that do contain the herbicide resistance genes, especially because there is also some plant growth hormones in here as well, they will start to divide and flourish and eventually you can change the media in the plant hormone's signals in there so the plants will regenerate, these cells will into a whole plant and eventually you can grow up individuals like you see on the right here that actually contain the target trait and in this case, these plants are resistant to herbicide.

So, again a very simple schematic to explain a very complicated process, but the goal is to insert the target DNA into your species of interest, recover viable cells that will divide, select for your target trait of interest and eventually generate a plant that expresses your target trait of interest.

Slide #: 30
Slide Title: Genetic Engineering Results in GMOs:

- Incorporates genes from different species such as bacteria, weeds, and animals into plants. Traditional breeding relies on genetic combinations possible within existing populations of closely related plants.
- Removes sexual incompatibility barriers.
- No hybridization or meiosis is involved.

Audio:
Genetic engineering results in a genetically modified organism. So, you can use this approach to incorporate genes from different species such as bacteria, weeds or animals and plants. Traditional breeding relies on genetic recombinations possible within existing populations of closely related plants for improvement. This approach allows you to break down sexual compatibility barriers and move DNA sequences among species.

Hybridization doesn't occur and meiosis doesn't occur in the initial stages of developing this improved plant out of the process and that really is the key. You know, when I really think it is important that people understand the distinction between using biotechnology tools to enhance different selection processes as opposed to gene manipulation where you are integrating DNA sequences from one species to another using genetic engineering approach.

They aren't the same at all. Now, they both can involve improving varieties at the end of the day, but how you do it is very distinct and so biotechnology does not necessarily mean that you are doing genetic modification.

Genetic modification or genetic engineering is a biotechnology tool and it has just created so much confusion because people use them interchangeable and they are really not the same, they are really not the same. So, just know that the hybridization and meiosis piece involving crop improvement is a very distinctive feature of biotechnology that does not occur when you are genetically modifying a plant, at least in the initial stages of product development.

Slide #: 31
Slide Title: Breaks Down Sexual Incompatibility Barriers Among Species

Plant genes → Other species
Bacterial genes → Plants
Animal genes → Plants
Human genes → Plants

Audio:
So, the approach of genetic modification allows us to break down sexual incompatibility barriers and those barriers have allowed different species to breed true. You know, it is impossible to exchange DNA in a traditional way between an animal and a plant species, but in this case, we can take genes from anything and move them into something else and that actually has created a lot of controversy around genetic modification. If I can put an animal gene into a plant, is that a good thing or a bad thing? Can we actually put human genes into plants? Or can you take plant genes and put them into people? One of the very first examples of genetic modification occurred when an antifreeze gene was identified from a fish that survived at very, very low temperatures and it was genetically transformed into a strawberry plant and the goal there was to keep strawberries from getting frost damage in the crop year by making them more tolerant to freezing. Theoretically, it sounded like a really great idea and I think the unexpected consequence was people were absolutely not all on board with the idea of eating a strawberry that had a fish gene in it. Some people didn't care at all. DNA is DNA and it didn't matter, but it created a response in the science community and then society that said, "Hey, is this a good thing to do or is this not okay?" and that has really fueled a lot of the controversy around genetic modification. It also explains why I want you to be clear about the difference between biotechnology and genetic modification. If I am improving a plant using biotechniques and it has no association at all with genetic modification, people really shouldn't have that much concern about it, but when those are used incorrectly, any variety that I develop through biotech, if somebody perceived it to be GMO and they are anti-GMO, they have actually gotten upset about something that is not true for that particular line and that just creates a lot of ankhs and a lot of confusion in the conversion around biotechnology and genetic modification. So, that is my frame around why it is really important to me that you understand the difference.

Slide #: 32
Slide Title: Potential Target Traits

- Herbicide resistance
- Insect resistance
- Disease resistance
- Pharmaceuticals
- Increased nutrient content

Audio:
People have focused on very specific target traits for genetic modification. It is actually not an easy process to do and it is fairly expensive. So, people have been specific about what kinds of research they are conducting to identify target traits to move into plants through genetic modification. Herbicide resistance has been a big target as has been insect resistance, disease

resistance, pharmaceutical production or increased nutrient content. Herbicide insect and disease resistance have high value to growers in particular because they create genetic insurance for their crop. All of these are designed to reduce the risk of production. So, wheat competition is the number one yield limiting factor in crop production.

Herbicide resistant plants make disease control much easier because as I said earlier, the crop plant won't be impacted by herbicide application, but the weeds will die when herbicide is applied to that field. Insect resistance is very important. You never know when you are going to get an infestation. Some crops have very cyclical patterns of insect problems and if you combat that with a resistance gene, you are in a good shape. True for disease resistance as well.

Pharmaceuticals is kind of interesting. You know, you can engineer plants to be a little pharmaceutical producers and so kind of an efficient way to produce those in mass and I think an interesting aspect is the approach to increase nutrient content or food value or health and wellbeing value from a plant based on manipulating how good it is for you or what vitamins are present there or what the iron content is in different respects for different food products.

We are seeing a lot of cosseting now of multiple aspects, multiple DNA sequences cosseted together to create a plant that not only has herbicide resistance, but also has increased nutrient content. So, trying to get more than one value out of a trait through genetic modification process is the goal of lots of major companies and research programs that are involved in this type of work.

Slide #: 33
Slide Title: Major GM Crop Plants

Herbicide resistance

- Round-Up ™ Ready Corn
- Round-Up ™ Ready Soybeans
- Round-Up ™ Ready Alfalfa
  (January 2011)

Insect resistance

- Bt Corn
- Bt Cotton
- Bt Alfalfa

[Image of Bt cotton from http://upload.wikimedia.org/wikipedia/commons/6/68/CottonPlant.JPG]
[Image of Boll weevil on Bt cotton from http://upload.wikimedia.org/wikipedia/commons/2/26/Boll_weevil.jpg]

Audio:
So, I want to give you a couple examples of major GM crop plants that are in commercial production. In the herbicide resistance arena, there are a lot of round-up ready products out there that were genetically modified - corn, soybeans and alfalfa. There are other herbicides that have been genetically engineered into plants, but some of the most popular are these.

Round-up, which is also known as glyphosate has been released under lots of different label configurations since that patent went off the product. It is a really cheap chemical that is fairly benign and so people like it because it is easy to use and it works fairly well, but it has increased the amount of round-ups that is used because more people are growing round-up ready crops.

The insect resistance is really kind of a cool story because the resistance gene that is used the most is bacillus thuringiensis, which is often used as an organic pesticide. So, it was genetically engineered into corn, cotton and alfalfa and here is the important aspect of this. We didn't have resistance to the cotton boll weevil before they developed Bt cotton and you can see that there is just a tremendous difference in the ability of the plant to survive. This is a devastating pest of cotton. They used to have to spray for it many, many, many, many times just to control it and it absolutely decimates the cotton crop. But when you use Bt cotton, it prevents the insect from feeding on the cotton balls and you actually get a nice quality product and in many ways people think this has been kind of a saving grace of the cotton industry in the south.

Slide #: 34
Slide Title: Percentage of GM Crops Planted in the U.S.

Crop	2003	2010
Corn	35	86
Soybeans	65	93
Cotton	50	93
Wheat	0	0

http://www.gmo-compass.org/eng/news/

Audio:
It is surprising how many of the crop plants that are grown in the U.S. are actually genetically modified and these are data from 2010, so these numbers have increased a little bit since then although I couldn't find the latest 2012 numbers.

So, if you look at this table, for corn, soybeans, cotton and wheat, there is a wide range in production and in 2003, 35 percent of the acreage of corn that was planted in the United States was genetically modified. In 2010, that number had increased to almost 90 percent. In soybeans, in 2003, about 65 percent of the acreage was roundup ready, now over 90 percent is – 93 percent and in fact, the latest reports on those numbers are that it has exceeded this and over 95 percent of the soybeans in U.S. are genetically modified. Most of them are Round-up ready. In cotton, it has gone from 50 percent to 93 percent.

Interestingly enough, there is absolutely no genetically modified wheat in commercial production in the United States nor any place else in the world and this is kind of an interesting scenario. So, when genetically modified crops first started to hit the marketplace, they were in crops that we don't usually directly notice as being consumable. You know, we have a tremendous amount of high fructose corn syrup in our food chain, but people don't really identify it with corn because you don't see big chunks of corn in your soda pop, for example.

There is a lot of high fructose corn syrup in it, but you can't really detect it because the corn kernels have been processed. It has been extracted out of the corn and you can't really see it in anything and it is true for soybeans as well. Although we eat a lot of soybeans, it is also used, soybeans are used a lot for feed as is corn, but you don't tend to see unprocessed soybeans or really have an association between the soybean and the product that we consume. Wheat is a completely different story. Most people are very familiar with wheat products, mainly bread, which is a staple for most people and when there was a surge to develop genetically modified wheat in around 2000, 1998, around 2000, something like that and there was just an outcry from the public about genetically modifying a food product.

Now, we have been eating this stuff anyway for many, many years. The craze in GM development happened in the mid '90s, but when it hit wheat and people were so familiar with the food value of wheat, there was a huge protest and even now, and this has been after almost 20 years of research, genetically modified wheat still isn't produced and in fact, the whole affiliation of wheat in food created a very different response because there is such a direct relationship between that. People know we eat wheat. People are not as attuned to what is done with processed corn and processed soybeans in our food chain.

Slide #: 35
Slide Title: Products Potentially Containing GMOs

Cereals
Corn chips
Soda
Soy burgers
Taco shells
Juices
Baby formula
Baby food
Corn muffins
Tofu
[Image of Pepsi from http://upload.wikimedia.org/wikipedia/commons/8/8a/Row_of_Pepsi_Cans.jpg]
[Image of Gerber baby from http://upload.wikimedia.org/wikipedia/en/8/85/Gerberbaby.jpg]
[Image of tofu from http://upload.wikimedia.org/wikipedia/en/a/a4/Driedtofu.JPG]
[Image of Kellogg's corn flakes from http://upload.wikimedia.org/wikipedia/en/a/af/Frosted-Flakes-Box-Small.jpg]

Audio:
So, if you go to the grocery store, many of the products that you see of the shelves potentially contain GMOs. So, anything that contains any processed soybean or any processed corn that comes out of a product line from the United States is very, very likely to have a genetically modified product in it. So, that would be the cereals, our corn chips, soda, soy burgers, taco shells, juices, baby formulas, baby foods, corn muffins, tofu. It is everything and we either aren't aware of it or don't know it. We are going to talk a little bit about some of the issues surrounding labeling of genetically modified products, but in the U.S. at this point in time, it is not a requirement that you have to label food products that contain genetically modified organisms and I will explain a little bit more about the history of that in a couple slides.

Slide #: 36
Slide Title: Potential Benefits of GMO's

- Facilitates gene transfer
- Decreased pesticide inputs into the environment
- Less input expenses for farmers
- Enhanced nutritional attributes

Audio:
What are the potential benefits of genetically modified organisms? Why are people interested in those? Well, one, it facilitates gene transfer. You can simply move genes around more quickly in plants in some ways using genetic modification. It is not instantaneous, but it is faster and that is really valuable for crops that can be difficult to propagate like tree fruits.

There is a little controversy about the second bullet, but it is an aspect that depending on the trait is very true. You can decrease pesticide inputs into the environment with genetically modified products. Now, for herbicide resistance, that is not necessary true because developing a herbicide resistant plants facilitates the use of chemical in the production system. But when you are looking at insect and disease resistances, if you actually genetically engineer those plants to resist pests in that way, you don't have to spray the. So, that is a big upside as far as reducing inputs cost in your production system if the cost of the genetically modified variety is worth it.

That would then reduce the input expenses for farmers and again, it has to be cost effective for them to want to do it. I think what it does more so than anything is reduce some of the production risk for farmers and that is a big deal. You know, you don't necessarily know what disease patterns are going to happen in a particular year or what water use efficiency is going to be. Anytime you can reduce the risk for a grower, it tends to be a good thing. So, that actually helps with stabilizing production.

The other thing is you can genetically modify plants to improve nutritional value. The best example and most well-known example is with vitamin K in rice and I will talk a little bit more about that specific example soon as well.

Slide #: 37
Slide Title: Enhanced Nutritional Attributes

- Vaccine producing bananas
- Vitamin A enhanced canola
- Rice with enhanced iron content
- Golden Rice – high vitamin K

[Image of bananas from http://upload.wikimedia.org/wikipedia/commons/4/4c/Bananas.jpg]
[Image of canola from http://upload.wikimedia.org/wikipedia/commons/f/fa/Canola_field_temora_nsw.jpg]

Audio:
Here are four examples of enhanced nutritional attributes that have been created through genetic modification of plants. So, vaccines have been genetically engineered into bananas so that the banana serves as the delivery mechanism for the vaccine. The beauty of that particular system is you don't have to ship the vaccine to a developing country where refrigeration is an issue. The goal was to grow bananas. People could eat it and then they would actually have the natural

vaccine access without having to do a food processing or refrigeration piece. It created a different concern though over exposure to the vaccine. So, a plus and a minus there.

Canola has been genetically engineered with increased vitamin A levels. Rice has been genetically engineered to enhance iron content and an example I really want to focus on is Golden Rice, which is a rice that has been engineered to have higher levels of vitamin K.

Slide #: 38
Slide Title: Issues with Acceptance

- Golden Rice is yellow not white
- Animal feed is not acceptable for human consumption, even if starvation is a concern

Human consumption of GMOs is not accepted in many developing countries
[Image comparing rice to Golden Rice from http://upload.wikimedia.org/wikipedia/commons/2/29/Golden_Rice.jpg]

Audio:
So, the golden rice story is bitter sweet in many ways because this was developed with the hopes of increasing vitamin K access for people in developing countries where vitamin K deficiency specifically was resulting in blindness in children. So, we all require vitamin K in our systems and when you don't get enough vitamin K, it can really cause some very serious ailments and blindness is common in areas where vitamin K deficiency prevails. But the problem was, it actually worked well and they were able to increase the vitamin K content of Golden Rice, but the problem is, as its name might imply, it is yellow. It is Golden Rice.

It is actually yellow in color, it is not white and even in countries where poverty is an issue, there are social stigmas around food. So, if it is not the normal white product that they are used to, it is actually used as animal feed and socially, people were absolutely not willing to eat an off-colored rice. So, even though it was supposed to be better for them, even though the children theoretically, if they were eating Golden Rice would have enough vitamin K to prevent blindness, in the society that it was introduced into, they absolutely refused to eat it and it was a shocker to the scientific community and also a really great wakeup call in lots of ways, too.

Many countries don't accept GMOs as a food source, much around some of the controversies that have been created and this one is a really good example of what we really did wrong in lots of ways and I think this has been common in many scientific venues. So, scientists felt like this was a great thing to do. Then what we didn't do is work with people on the ground in countries where they wanted to introduce this and talk about the fact that the rice was going to be off-colored. Get them involved in the process, get them used to be, get them willing to actually try it and work with them to do some tests to see what the impacts would be.

It was developed, it was introduced and it was rejected and that really kind of created an uproar about GMOs for reasons I am going to talk about a little bit more soon, but it was a great wakeup call to include the people that where being served by the technology in the development process. So, I was in graduate school when a lot of this hit and it was just a shocker to go to meetings and talk to the people that developed this because they did have a noble purpose and they weren't able to achieve that goal and were just heartbroken about the unexpected consequence and in some ways it was pretty naïve to think that people would be willing to trust science and to trust the process without having any exposure to the product when it was being developed.

So, Golden Rice is actually kind of a sad story and the interesting fix to this was the next generation of Golden Rice products were white on the outside and yellow in the inside. So, they still had higher vitamin K, but the rice looked white.

Slide #: 39
Slide Title: Concerns about GMOs

- Escape of cloned genes into the environment
- Second hand transgene escape
- Allergenic responses to GM food

Example: Brazil nut gene transformed into soybean caused nut allergies
[Image of a poster for round-up ready resistant super weeds from http://www.infiniteunknown.net/tag/roundup-ready]

Audio:
So, let's talk a bit about some of the concerns about GMOs and there are many, many, many out there by some foods. These are just a couple. Again, if you do a little bit of research, you will find lots of literature on this particular topic, but some of the concerns where these non-natural genes that aren't usually found in these plants are going to be released into the environment and the risk of out crossing or gene escape into natural environments was very concerned with people.

It was like they aren't here naturally, we are introducing them and we don't know what they are going to do to the ecology and it is true that every ecological change has a consequence and so many people were absolutely not supportive of releasing non- natural genes into the environment.

The biggest fear that we had was super weeds. If crop plants out crossed with weedy relatives, we would developed woody species that we can't control, especially for herbicide resistance and you know, there is some logic to that. When you think that is it possible? Yes. How would you control the super weed? Well, you would spray it with a different herbicide then the one it is genetically engineered to tolerate and so there was some pretty good stewardship around how you would manage this and we have seen gene escape for sure with genetically modified crop plants.

The other piece that became important was the second hand transgene escape and that is just this type of genetically modified product getting into food train chains that were unintended. So, if I am growing canola that is not genetically modified and I have pollen drift from a field that is close to mine of a genetically modified product, it actually escapes into my field and I didn't even want it.

So, creating barriers for that transmission has been very concerning. And this has actually resulted in some tremendous legal battles between people that have bordering property lines. One is developing – they are growing a genetically modified product; the other person is not, we get that pollen flow into the tangenal crop. There is some selection pressure there. They go in and do a screening and they find that transgene in a farmer's field where he didn't pay for the seed, the technology fee for the seed. This has been a scandal beyond belief and has created tremendous ankhs especially with canola production up in Canada. So, again, it is worth taking a look into, but people were very concerned about that because you can't control the biology of the plants and you can't restrict the pollen flow.

I think the third example and there are many more, but the third example is very concerning as well because it relates to food allergies. Many people have food allergies. Many children are actually allergic to peanuts which is concerning and so they took a genome Brazil nut and they transformed it into a soybean plant or genetically engineered it into a soybean plant and then they tested people that had nut allergies with a genetically modified soybean and sure enough, they had an allergic response to that.

The danger of that piece is the soybean doesn't look like a peanut and people wouldn't expect to have that allergic reaction to eating a soybean. So, the Food and Drug Administration did some pretty heavy regulation around what can be genetically engineered into food to avoid that, but it is very unsafe for somebody that has a severe allergy to see a product that they think is safe for them that has a nut gene in it and then to eat it. So, that is a legitimate concern that people definitely have had some worries about in the production of genetically modified organisms.

Slide #: 40
Slide Title: Ethical Concerns

Do you have a right to know what you are eating?

- Current FDA policies state that labeling GM products is not required in the US.
- As a positive advertising mechanism, many companies now label products as "GMO free".

[Image of logo for nongmoproject.org] [Image of a Non-Gm ingredients label]
[Image of a GMO free label]
[Image of a label saying 'Made with non-GMO soybeans]

Audio:
There have been tremendous debates about whether or not it is right to genetically modify anything and most of these are ethical. Do you have the right to know what you are eating? Is it the onus of the federal government or the national government, depending on what country you are in, to tell you what is in your food?

The way that this was executed in U.S. is the Food and Drug Administration initially when they went through the GMO regulation process decided, based on all their research and all the evidence that they have had in hand, that all the steps that we got through currently in the U.S. to prove that food is safe were good for genetically modified or genetically non-modified food. So, in the U.S. it is not a law where you have to actually label food products that have GM products in it.

Now, interestingly enough, that is the law today and this is being highly debated in Washington, DC at the moment because many people aren't happy about that. They are like, "I want to know what is in my food. I am not comfortable with some of the implications of moving genes around in plants. I don't want to eat that kind of stuff and I want this food to be labeled." There are some marketing issues around this, too. I mean it is a big commodity issue to have to label your products or not label your products and so they is just lots of lobbyists around this from different organizations that are very concerned about unnatural processes and companies that make a lot of money sign products that have GM in them.

So, that is being debated and there are a lot of people that really hope that the policy is changed and food products with GM in it will have to be labeled, but what the market and industry has done to combat that, instead of labeling that products contain GM pieces in it, people label things as GMO free. So, if you go to the store and look around, you will see that a lot – no GMO. In fact, there is not a food aisle that you can go down where you won't see that on some product and that is a marketing tool guaranteeing that if I don't want to eat GMO products, I don't have to. I can pick things that are GMO free.

So, that has become a very positive advertising mechanism and many companies go for organic products that are GMO free. Now, initially when organics became popular, people really thought in the science industry that people that were into organic food would love GM products because you know, if I could genetically engineer a plant to resist a particular pest and I had a higher food quality that would be great.

But the whole deal is people aren't comfortable with eating foreign DNA. You know, it hasn't been in the food stream long enough for people to realize that there are health risks and there is a lot of fear around that. So, the organic community absolutely went into an uprising and said, "No way. GM products are not suitable for organic production and the regulations around organic production in the U.S. restrict the use of genetically modified products in them so organic products are GMO free."

Again, another big surprise to the science community that "Wow, our target audience is not interested in using this product." It probably could have been resolved or done much more constructively if conversations from day one involved both parties. So, again, a kind of communication issue. It has a definite impact on the uptake and utility of the technology.

Slide #: 41
Slide Title: GMOs are Banned in Europe

- Food safety is a major concern due to deaths associated with Mad Cow disease.
- Excellent way to control international crop markets.

http://www.gmo-free-regions.org/conference2010.html
[Image of a poster saying "GMO-free EUROPE 2010]

Audio:
The Europeans have had a tremendous impact on the status of genetically modified food in the world. GMOs are banned in Europe. They aren't grown at all though a lot of testing has been done. Still today there aren't commercial production of genetically modified food products in Europe and a lot of that story stands around food safety. When mad cow disease occurred in Europe and people lost their lives, it created a lot of concern about the safety of the food supply

in European countries and people became very aware of risk.

When you take a technology and to introduce it to people that are afraid of whether or not their food is safe, it is just not palatable. And so, there was just an outcry of "Don't mess with our food. We had mad cow. We want to be careful. We are not going to do this." But the other side of that coin is it has become a very good way for Europeans to control their import and export markets. So, there is a premium on food in some of these countries because there is an import ban so we can't get products into any of these countries because of the high prevalence of soybean and corn in the U.S. that is genetically modified.

So, it is a good marketing control method and many people have accused marketers and business people of creating hysteria among consumers so that they make more money. Be it true or be it not true, it just speaks to the vulnerability of people. Consumers do control the market flow and so this has definitely been a story that also has received a tremendous amount of press that you can take a look at if you do a bit of a literature search.

Slide #: 42
Slide Title: Do scientists have the right to "play God" by making "unnatural" exchanges of genes within and among species?

- Violates certain religious beliefs
- Potential to violate civil rights:
  - Genetic prescreening to obtain health insurance
  - Selective abortion based on genetic potential

Audio:
Some of the controversy has surrounded whether or not people have the right to "play God" by making "unnatural" exchanges of genes within and among species. And again, that is an ethical concern - whether or not that is the right thing to do, whether or not we should be allowed to do that, whether or not it is necessary.

I will say that we have been improving plants for thousands of years without the use of genetic modification. Is it essential? No, we have been doing it anyway. Does it create unique opportunities that could be helpful? Perhaps. And it definitely upsets people to talk about this and in classes that I teach this is one of the controversial discussions that I have with students. And it gets so heated because it becomes personal.

For some people it violates their religious beliefs. For some people they feel like it is a violation of their civil rights. There is a lot of talk about whether or not we are going to start genetically screening people to see if they are predisposed to diseases. That influences whether or not they can get health insurance. There are also concerns about conducting selective abortions based on the gene profiling of a fetus in vitro. I will tell you what, both of those things actually though are biotechnology tools.

Those are not genetic modification tools, but it is the application of science in a way that makes people uncomfortable and when that discomfort occurs, it creates controversy and what is difficult is to have a well grounded conversation based on facts and I think that is where you empower yourself to make a really good decision.

I mean I am not going to say they are right or wrong, but my goal is to support you in being able to look at the information and say, “Is that scientifically valid? Do I believe that based on the facts, not on the emotion?” because that is really important. And people say the only way we are going to stop world hunger is through. There are scientists that absolutely believe that is not true. The question is can we solve world hunger anyway if we tried to do it? There are, people argue that we have enough food to do that now. We just can’t get it to the right places. So, it is a really interesting conversation that gets emotional and is definitely worth looking into and thinking about.

Slide #: 43
Slide Title: Consumer Acceptance, or Lack Thereof, Will Determine the Fate of GMOs.
?
Roundup Ready ↔ USDA ORGANIC *[Image of USDA Organic seal from http://commons.wikimedia.org/wiki/File:USDA_organic_seal.svg]*

Audio:
At the end of the day, at the end of the day, consumer acceptance or lack thereof is going to determine the fate of GMOs and that is absolutely true. Consumers have tremendous power in this equation. Now, for those of us that have been consuming genetically modified corn syrup and soybean products without knowing it for a long time, many people don’t care though like I am pretty comfortable with food safety requirements in the U.S. and I feel okay about it.

Other people feel like they were duped and again I think the communication piece has been absolutely mismanaged in lots of ways to create concern about the conversation and my challenge to you is to do some research and figure out what you think is true because the USDA organic label is kind of being challenged in some way where is actually the use of roundup ready crops a good thing to do for organic food production considering how erosive and expensive weed management in organic systems has become.

So, it is a bit of a debate out there and I try to give you a snippet to kind of navigate some of that controversy with and I challenge you to be curious about it, to really kind of look into this and be curious about it and make a good decision for yourself. I think this is a debate that is going to range on for many, many years to come.

It will be interesting to see what happens in Congress surrounding food labeling here and it will be very interesting to see what happens in the future and I image your voice will matter a lot in that discussion. So, I hope at least you have a clear understanding of the difference between biotechnology, genetic modification and have some curiosity about trying to do a little bit of exploration on your own to get a clear picture of what your perspective is.