GMO’s and Herbicide Resistance in Trees

Opportunities and Drawbacks

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Goals for today

• What are GMOs?
• What are the major GMO crops
• State of GMO trees
• Herbicide tolerance in trees - Roundup resistant cottonwood
• Drawbacks and prospects
Most crops are highly genetically modified
Many crops derived from wild cabbage

- Kale, 500 BC
- Kohlrabi, Germany, 100 AD
- Cauliflower, 1400's
- Broccoli, Italy, 1500's
- Cabbage, 100 AD
- Ornamental kale, Late 1900's
- Brussel sprouts, Belgium, 1700's
Many plant varieties derived from induced mutations

Calrose 76 semi-dwarf rice

Over 2,000 crop varieties derived from mutagenesis have been commercialized

High oleic sunflower

Rio Red grapefruit
GMO method (genetic engineering) defined

- Traditional plant breeding
- Variety A
- Variety B
- Genetic engineering
- Asexual modification or insertion from any gene source
Regeneration of GE plants
Then propagated normally (seeds, cuttings) and tested for health and new qualities, incorporated into breeding programs.
GMO crops widespread, rapidly adopted
Grown on >10% arable land on planet, extensive uptake in developing world

Four crops dominate, 8 crops grown in USA

Major reports on GMO crops show very large positive impacts on economics, sustainability, in USA
“147 original studies were included.”

“On average, GM technology adoption has reduced chemical pesticide use by 37%, increased crop yields by 22%, and increased farmer profits by 68%.”
Herbicide tolerant plants promote conservation tillage – With many environmental benefits thereof

Conservation Technology Information Center

• Lowers greenhouse gas emissions
• Improves soil organic matter
• Reduces erosion and fertilizer runoff into water
• Often provides better wildlife habitat

Global: In 2012 reduced CO2 emissions by ~27 billion kg, equivalent to ~13 million cars off the road

http://www.isaaa.org/resources/publications/briefs/46/topfacts/default.asp
There are legitimate concerns that GMOs with weed management traits have not been managed well.
Poor weed management has led to rapid development of herbicide-resistant weeds.
Herbicide-resistant weeds are an old problem in agriculture, but exacerbated by GE herbicide tolerant crops.
Trees!
GE of diverse value for trees
All demonstrated in the field

- Improved fruit quality/durability
- Resistance to insects and diseases
- Tolerance to salinity and temperature stress
- Phytoremediation of environmental toxins
- Modified properties to improve processing of wood for biofuels and pulp
- Tolerance to herbicides
GE of diverse value for trees
All demonstrated in the field

• Accelerated flowering for faster breeding and research
• Fertility control for control of spread and improved growth
• Improved growth rate and yield
• Synthesis of new, renewable bioproducts such as fragrances and chemical feedstocks
RNAi: Virus-resistant papaya

“Immunization” via by implanting a viral gene in the papaya genome – RNAi (RNA interference)

Courtesy of Denis Gonsalves, formerly of Cornell University

GMO, virus-resistant trees
HoneySweet plum with RNAi resistance to plum pox virus – USDA approved

Ralph Scorza  USDA-ARS
Non-browning “Arctic Apple”
RNAi suppression of native polyphenol oxidase gene expression – USDA approved

Courtesy of Jennifer Armen, Okanagan Specialty Fruits, Canada
Resistance transgenes promising solution/s to devastating ‘citrus greening’
Defensin-like proteins from spinach promising
Overexpression of endogenous flowering genes induce early-flowering in many trees.

Apple

Orange

Plum

Poplar
Early flowering effective in eucalypts

Valuable to speed breeding and genomic selection
Caterpillar (lepidopteran)-resistant poplars commercially approved in China - *Bt cry1* 

- Trait stable
- Helps to protect non-Bt trees
- Reduced insecticide use
- Improved growth rate
TBGRC Coop at OSU: Beetle resistant Bt-cottonwoods in eastern Oregon field trial (cry3a)
TBGRC: 10-20% growth benefits despite low insect pressure during field trial

Bt-Cry3Aa transgene expression reduces insect damage and improves growth in field-grown hybrid poplar

Amy L. Klocko, Richard Meilan, Rosalind R. James, Venkatesh Viswanath, Cathleen Ma, Peggy Payne, Lawrence Miller, Jeffrey S. Skinner, Brenda Oppert, Guy A. Cardineau, and Steven H. Strauss

Abstract: The stability and value of transgenic pest resistance for promoting tree growth are poorly understood. These data are essential for determining if such trees could be beneficial to commercial growers in the face of substantial regulatory and marketing costs. We investigated growth and insect resistance in hybrid poplar expressing the cry3Aa transgene in two field trials. An initial screening of 502 trees comprising 51 transgenic gene insertion events in four clonal backgrounds (Populus trichocarpa × Populus deltoides, clones 24-3405, 50-957, and 195-634; and P. deltoides × Populus nigra, clone OP-4067) resulted in transgenic trees with greatly reduced insect damage. A large-scale study of 402 trees from nine insertion events in clone OP-4067, conducted over two growing seasons, demonstrated reduced tree damage and significantly increased volume growth (mean 14%). Quantification of Cry3Aa protein indicated high levels of expression, which continued after 14 years of annual or biennial coppice in a clone bank. With integrated management, the cry3Aa gene appears to be a highly effective tool for protecting against leaf beetle damage and improving yields from poplar plantations.

Résumé: La stabilité et la valeur de la résistance transgénique aux ravageurs pour favoriser la croissance des arbres ne sont pas bien connues. Ces données sont essentielles si l’on veut déterminer dans quelle mesure de tels arbres transgéniques pourraient être profitables pour des producteurs commerciaux considérant les coûts substantiels liés à la réglementation et la mise en marché de tels arbres.
Lignin-modified trees in Belgium, France gave large improvements in ethanol or pulp yield.
Production of 2-phenylethanol

Lignin reduction

Fragrances and jet fuel feedstock
Large scale field trials of a variety of genes and insertions underway

Norman Lewis, Washington State University
Many exotic diseases have damaged or ravaged North American forests

Examples
1892 - White pine blister rust
1904 - Chestnut blight
1923 - Port-Orford-cedar root disease
1920s - Beech scale complex
1930 - Dutch elm disease
1967 - Butternut canker
1976 - Dogwood anthracnose
2000s - Sudden oak death

American elm
American Chestnut most advanced case with GE approach

The American Chestnut's Genetic Rebirth
A foreign fungus nearly wiped out North America's once vast chestnut forests. Genetic engineering can revive them
By William Powell

In 1876 Samuel B. Parsons received a shipment of chestnut seeds from Japan and decided to grow and sell the trees to orchards. Unbeknownst to him, his shipment likely harbored a stowaway that caused one of the greatest ecological disasters ever to befall eastern North America. The trees probably concealed spores of a pathogenic fungus, Cryphonectria parasitica, to which Asian chestnut trees—but not their American cousins—

March 2014 issue
Scientific American

Courtesy of Bill Powell, SUNY Syracuse, USA
Freeze-tolerant, male-sterile Eucalyptus
Proposed for commercial deregulation in USA

Results from first winter in South Carolina
Control
Lead Line

Results from second winter in Alabama
Lead Lines + Control

Provided by Arborgen
Many eucalypt field trials underway

12 Months

Two years

Three years

Four years

Seven years

Courtesy of Les Pearson, Arborgen
Growth improved GE Eucalyptus (Futuragene) Proposed for commercial use in Brazil

Brazil considers transgenic trees

Genetically modified eucalyptus could be a global test case.

By Heidi Ledford

Viewed from above, Brazil’s orderly eucalyptus plantations offer a stark contrast to the haphazardly surrounding native forests. The trees, lined up like regiments of soldiers on 3.5 million hectares around the country, have been laid out decades to grow quickly.

On 4 September, a public hearing will consider bringing even more vigorous eucalyptus to the market. Genetically engineered eucalyptus that produces around 20% more wood than conventional trees and is ready for harvest in five and a half years instead of seven. Brazilian regulators are evaluating the trees for commercial release; a decision could come as early as the end of this year.

Researchers, businesses and activists are watching closely. Eucalyptus (Eucalyptus spp.) — native to Australia — is grown on about 20 million hectares throughout the tropics and subtropics, and approval of the genetically engineered trees in Brazil could encourage their adoption elsewhere. “It would have triple effects on a large scale. The ubiquity of eucalyptus makes Brazil’s decision on the modified trees a special concern to environmental activists who oppose the use of genetically modified crops,” says Walter Krell, a forestry officer with the Food and Agriculture Organization of the United Nations in Rome.

A consortium of activists opposed to the plan intends to present a letter at the 4 September meeting, urging Brazil’s National Technical Biosafety Commission to reject the trees. In all, 290 organizations — 106 of them from Latin America — have signed the letter, which expresses concern that the trees pose risks to the environment and could encourage the expansion of plantations.

The trees were developed by FuturaGene, a biotechnology firm in Rehovot, Israel, that was spun out of the Hebrew University in Jerusalem in 1993. The company found that certain proteins accelerate plant growth by facilitating cell-wall expansion. FuturaGene inserted into

FuturaGene’s chief executive Stanley Hirsch is quick to point out the environmental benefits of his company’s creations. The trees’ speedy growth boosts absorption of carbon dioxide from the air by about 12%, he says, aiding in the fight to reduce greenhouse-gas emissions. The genetically modified trees may also require less land to produce the same amount of wood, reducing the conversion of natural forest into plantations.

Hirsch says that the company has tried to avoid public-relations mistakes made by agricultural biotechnology companies in the past: rather than drum activists, he has invited them to tour the company’s field trial sites. “Some of them were so surprised,” he says. “They said, ‘Wow, these look just like normal trees.’” His pitch has not convinced everyone. Anne Petersmann, executive director of the non-profit organization Global Justice Ecology Project in Buffalo, New York, says that FuturaGene is trying to stave off opposition by ‘greenwashing’ its product. Faster-growing trees require more water and extract more nutrients from the soil, she adds, and they will only add to the economic incentive to clear more plantations.

Genetically engineered trees do pose some biosafety issues that do not apply to agricultural crops such as maize (corn) or soy, notes forest geneticist Steven Strauss of Oregon State University in Corvallis. They remain in the environment for years, increasing their potential impact on the plants, animals and soil around them. And trees tend to disperse pollen farther than crops near the ground do, raising concerns about gene flow to native relatives. But eucalyptus has no native relatives in Brazil and is not particularly invasive in most areas of the country, says Strauss.

FuturaGene says that it identified no major environmental problems in eight years of field trials that collected data on everything from gene flow to leaf litter decomposition to the composition of honey made by bees that visit the trees. Myburg, who does not work with FuturaGene but is familiar with the company’s safety data, says that he found the firm’s studies to be well designed and thorough.

While FuturaGene tests the waters in Brazil, a US company awaits a regulatory decision regarding its genetically engineered, freezing-tolerant eucalyptus. In 2008, ArborGen of Ridgeville, South Carolina, petitioned the US Department of Agriculture to allow commercialization of the trees in the southeastern United States. Delays of this length are not uncommon in the US regulatory system, says ArborGen’s director of regulatory affairs Leslie Pearson.

For now, just the prospect that the trees might be approved has been enough to rally
Vandalism at Futuragene/Suzano research site in Brazil in March 2015
Vandalism at Futuragene/Suzano research site in Brazil in March 2015
Disruption of national biosafety committee meeting (CTNBio) in Brazil capital in March 2015
Sign petition in protest?
bit.ly/scinotviolence

Science Not Violence!

73% Support
731 Supporters
1,000 Goal

Sign the Petition
I condemn the vandalism of scientific research facilities and the associated disruption of biosafety deliberations in Brazil. We urge scientists to continue their important research and not to give in to violence and intimidation.

Eu condeno o vandalismo dos laboratórios de pesquisa e a interrupção associada à pesquisa de biossegurança no Brasil. Nós encorajamos os cientistas a continuarem seu importante trabalho e não cederem à violência e intimidação.

First Name
Last Name
Email Address
City
TBGRC Coop at OSU / Monsanto: Glyphosate herbicide resistance in cottonwood

Screen of primary transformants  2 yr-old field trial

Wild type controls
Compared conventional vs. Roundup-resistance-tailored weed control
Weed cover drastically reduced in Roundup-resistance tailored vs. conventional weed control
Growth benefit in Roundup-resistance tailored system: ~20% volume at 2 years
Reduced greenhouse gas emissions per unit wood produced

![Bar chart showing greenhouse gas emissions (kg) over time for conventional and Glyphosate methods.](chart.png)

- **2 years (end of experiment)**
  - Conventional: [Value]
  - Glyphosate: [Value]

- **6 years (3 coppice cycles)**
  - Conventional: [Value]
  - Glyphosate: [Value]
Genetic containment – Important for some traits, social acceptance?
Best prototype to date RNAi: *LFY* catkins remained tiny and did not produce seeds or cotton.
Precise gene editing technology recently developed = stable containment

PLANT BIOTECHNOLOGY

Zinc fingers on target

Matthew H. Porteus

The existing methods of creating genetically modified plants are inefficient and imprecise. Zinc-finger technology offers the prospect of opening up a swifter and more exact route for crop improvement.
Red tape, transaction costs and obstacles of biotech -- major hindrances

Arrested Development
Intellectual property and regulations hinder research

By Jim Myers | Posted on October 10th, 2014

Genetic engineering has become a valuable scientific tool. It has enabled us to gain tremendous insight into the mechanisms of plant reproduction, disease resistance and other useful traits. However, commercial use of this technology has not lived up to expectations and has created serious hurdles for plant breeders. That in turn hampers genetic progress and innovation.

In fact, conventional plant breeding can achieve results efficiently and for much lower cost.

Take the case of the Indigo Rose tomato, which has a purple skin and contains high levels of antioxidant compounds known as anthocyanins. Produced with standard plant-breeding techniques, the variety developed by my program became commercially available in 2011. It has been successful beyond my wildest imagination. Already sold for three seasons in the United States, seeds will soon be available in Japan, Canada and Europe. It has been featured in numerous articles and blogs and was recently highlighted in the premier epicure’s magazine, Bon Appétit.

Last year, there were a half-dozen new Indigo varieties, some developed by breeders who had easy access to our seeds. Next year there will be more than 20 new varieties of Indigo tomatoes, three of them from my program and the

http://oregonstate.edu/terra/2014/10/arrested-development/
“Green” certification of forests create severe barriers to research and development
Forest certification systems universally ban all GM trees – no exemptions

<table>
<thead>
<tr>
<th>System</th>
<th>Region</th>
<th>GM Tree Approach / Reason</th>
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<tbody>
<tr>
<td>PEFC : Programme for Endorsement of Forest Certification</td>
<td>International</td>
<td><strong>Banned</strong> / Precautionary approach based on lack of data</td>
</tr>
<tr>
<td>FSC : Forest Stewardship Council</td>
<td>International</td>
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<td>CerFlor : Certificação Florestal</td>
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<td><strong>Banned</strong> via PEFC registration / No additional rationale</td>
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<td>CertFor : Certificación Forestal</td>
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<tr>
<td>SFI : Sustainable Forestry Initiative</td>
<td>North America</td>
<td><strong>Banned</strong> via PEFC registration / Awaiting risk-benefit data</td>
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<tr>
<td>ATFS : American Tree Farm System</td>
<td>USA</td>
<td><strong>Banned</strong> via PEFC registration / No additional rationale</td>
</tr>
<tr>
<td>CSA : Canadian Standards Association</td>
<td>Canada</td>
<td><strong>Banned</strong> via PEFC registration / Allows public to determine approach</td>
</tr>
<tr>
<td>CFCC : China Forest Certification Council</td>
<td>China</td>
<td><strong>Banned</strong> via PEFC registration / No additional rationale</td>
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Adam Costanza, Institute for Forest Biotechnology
Global admixture of GM and non-GM crops/food create immense coexistence, trade problems under current regulations

Many costly cases of trade disruption and lawsuits with corn, soy, and rice

Oregon with major struggles over way forward
Oregon GMO “wheat-gate” shows the risk in even doing research

An agreed safe, well studied, extremely rare GMO left over from earlier research nearly crippled Pacific Northwest trade in wheat, led to lawsuits.
So despite amazing science progress...
The way forward a bit difficult
In summary

- Remarkable progress and benefits from GMO crops
  - Significant mismanagement of herbicide tolerant crops hurts value, credibility
- Many successes with transgenic trees on a wide variety of fronts, but little commercial uptake
- Extraordinary GMO regulatory and social barriers
  - USA National Academy of Sciences 1987
    “There is no evidence that unique hazards exist either in the use of rDNA techniques or in the movement of genes between unrelated organisms”
- Way forward unclear, difficult
  - Need for national and global regulatory, market, certification changes to enable progress and coexistence