50 shades of GM – facts and issues

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Research priorities – Murdoch University
10,000 years of crop evolution

- Agriculture is one of mankind’s major technical innovations
- Change from hunter-gatherer lead to the development of civilisation: about 10,000 years ago
- Development of farming and pastoral societies
- Most plants destined to be domesticated and become crops come from distinct ‘centres of origin’
- Mendelian Genetics – the Green Revolution
- DNA – the Gene Revolution
- GM crops

Source: U.S. Census Bureau, International Data Base, July 2015 Update.
What your food would look like if it weren’t genetically modified

- Lettuce and wild lettuce
- Carrots – orange colour only selected to please the Dutch ‘House of Orange’!

- Wild cabbage
- Kale, 500 BC
- Kohlrabi, Germany, 100 AD
- Cauliflower, 1400’s
- Broccoli, Italy, 1500’s
- Brussels sprouts, Belgium, 1700’s

- Watermelon
- Corn
- Banana
- Aubergine/eggplant
- Carrot
- Cabbage, kale, broccoli, etc.
Plant breeding and natural genetic engineering

- Conventional plant breeding involves genetic manipulation
- Bread wheat contains large chunks of rye genes, transferred by cytogenetic methods (eg resistance gene Sr31 for stem rust transferred from rye to wheat)
- Genetic engineering is natural
- Horizontal gene transfer between organisms is very common
- Eg. The plant pathogen, Agrobacterium tumefaciens, transfers 6 genes into host plant cells – it is a natural genetic engineer!

### Conventional plant breeding

DNA is a strand of genes, similar to a strand of pearls. Traditional plant breeding combines many genes at once.

- **Traditional donor**
- **Commercial variety**
- **New variety**

\[
\begin{align*}
\text{Traditional donor} & \quad \text{Desired Gene} \quad \text{X} \quad \text{Commercial variety} \quad = \quad \text{New variety} \\
& \quad \text{(crosses)} \quad & \quad \text{(many genes are transferred)}
\end{align*}
\]

### Plant biotechnology (GM)

Using plant biotechnology, a single gene may be added to the strand.

- **Desired gene**
- **Commercial variety**
- **New variety**

\[
\begin{align*}
\text{Desired gene} & \quad \xrightarrow{\text{transfer}} \quad \text{Commercial variety} \\
& \quad = \quad \text{New variety} \quad \text{(only desired gene is transferred)}
\end{align*}
\]
Breeding pedigree of the most widely grown rice – note insertions, deletions, recombinations

Mutations
Recombinations
Translocations
Deletions

Ultimate Landraces
IR64

Breeding pedigree comparisons

Conventional breeding
Current cultivar × Wild relative
Backcross × F1 Generation × F2 Generation
Many backcrosses
New cultivar

Beneficial genes
Unwanted genes

Transgenesis
Current cultivar × Unlabelled organism
Beneficial genes
Unwanted genes
Transfer into
Agrilectrum
Genes required for transfer
New cultivar

Cisgenesis
Current cultivar × Unlabelled organism
Beneficial genes
Unwanted genes
Transfer into
plasmid in
Agrilectrum
Genes required for transfer
New cultivar
Green fluorescent protein from *Victoria aequoria* (jellyfish) expressed in plants and animals

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**GLOBAL AREA OF BIOTECH CROPS**

*Million Hectares (1996-2014)*

- Total Hectares
- Industrial
- Developing

28 Biotech Crop Countries

A record 18 million farmers, in 28 countries, planted 181.5 million hectares (448 million acres) in 2014, a sustained increase of 3 to 4% or 6.3 million hectares (~16 million acres) over 2013.

Source: Clive James, 2014.
Global Area of Biotech Crops, 1996 to 2014: By Crop (Million Hectares, Million Acres)

Source: Clive James, 2014

Global Adoption Rates (%) for Principal Biotech Crops (Million Hectares, Million Acres), 2014

Source: Clive James, 2014
Hectarage based on FAO Preliminary Data for 2012.
Insect pests of cotton – an Australian case study

- Helicoverpa spp. – main pests (cotton bollworm – Lepidoptera)
- 19 years ago...
  - pesticide reliance
  - ~40% variable costs
  - $200 million/year
Natural enemies + unsprayed Bt cotton perform as well as non GM plus insecticide sprays

Unsprayed  Sprayed 7 times

What happens without Bt or insecticide sprays (left)
Environmental benefits after 16 years of Bt cotton

- spectacular reduction in pesticide use
- fewer cultivation passes, almost no spray drift
- elimination of endosulfan (insecticide) residues in cattle from cotton areas – no cases since 2000
- elimination of endosulfan residues in the Namoi and Gwydir rivers
- No evidence of Bt resistance due to rigorous management strategies
- Significant enhancement of on-farm biodiversity and beneficial insects

Increasing amylose content (Resistant Starch)

Mechanism 3.
Increase amylose synthesis

Mechanism 2.
Decrease Amylopectin Synthesis

Mechanism 1.
Decrease Branching Activity

ADPglucose → Amylose → Amylopectin

GBSSI → SSI → SSIIa → SSIII → Isa1 → BEI → BEIIa → BEIIb
Purple as a tomato – increased anthocyanins by altering two genes

Golden rice. In 2012 the WHO reported that about 250 million preschool children are affected by Vitamin A Deficiency, and that providing those children with vitamin A could prevent about a third of all under-five deaths - up to 2.7 million children - could be saved from dying unnecessarily. VAD is most severe in Southeast Asia and Africa. For 400 million rice-consuming poor, the medical consequences are fatal: impaired vision, irreversible blindness; impaired epithelial integrity, infections; reduced immune response; impaired haemopoiesis (reduced capacity to transport oxygen in the blood) and skeletal growth; among other debilitating afflictions.
Benefits and traits in the pipeline

**Benefits (1996-2013)**
- Increasing crop production valued at US$133 billion
- Reduced chemical pesticide use by 37% (saving 500 million kg a.i. of pesticides)
- Increased crop yields 22%
- Increased farmer profits 68%
- In 2013 alone, reduced CO2 emissions by 28 billion kg, (equivalent to taking 12.4 million cars off the road for one year)
- Helping alleviate poverty for more than 16.5 million small farmers (65 million people) – some of the poorest in the world.

(Source: Brookes and Barfoot, PG Economics)

**Current and in the pipeline**
- 10 food and fibre crops
- Maize, soybean, cotton, canola, apples, potato, vegetables such as papaya, eggplant and squash, and blue grass
- Smarstax corn: 2 HT+ 6 BT
- New: low acrylamide and non-browning potatoes (US), insect resistant egg plant (Bangladesh), sugarcane (Indonesia)
- Improved oil content for human health
- ‘Fish oil’ (EPA and DPA) production in plants
- India has developed 50 new GM crops/traits
- Insect resistant rice in China

Questions about GM foods

- Is it safe to eat?
- Are the regulations adequate?
- Will there be any long term effects from eating GM food?
- Could they contain new allergens?
- When does an introduced gene become a plant gene?
- What happens to the transgene when we eat it?
- Will the public be able to choose GM or non-GM food?
Animals or humans eating GM food do not become GM!!!

- We eat hundreds of thousands of genes a day – we are designed to digest DNA from any source
- When you eat a banana you do not turn into a banana!
- We did not evolve with our current food crops
- We constantly eat new genes, e.g. sea urchins gonads

Risk assessment – Stanford model

All food on supermarket shelves should be safe to eat, but not all are safety tested: order of food safety is: GM safer than conventional safer than organic
Natural does not necessarily equal good!

- Plants cannot run away from danger, so they evolved chemicals to protect themselves
- Domestication of wild plants usually involves selecting for lines with fewer toxic compounds
- Fifty-two toxic compounds in brassicas (cyanide compounds, cyanogenic glycosides, goitrin, glucosinolates etc)
- Developing lupins as a crop in WA involved selection for low alkaloids (‘sweet lupins’)
The blurring of GM and non-GM technologies

- Using genomics to select and combine new gene combinations
- Targeted gene silencing
- Ectopic delivery of RNAi
- GM rootstocks, non-GM scions
- Cisgenic plants
- Synthetic biology
- Nano(bio)technology
- Cloning
- Marker-assisted breeding
- New plant breeding technologies
- Genome wide selection
- Genomic editing

GM technology

- Conventional breeding technologies
- Pollination management
- Hybridisation technology
- Mutation breeding
- Non-molecular chromosome manipulation
- Protoplast fusion
- Micropropagation

Conventional plant breeding

- Involves combining complete sets of genomes
- Translocation of chromosome arms
- Forcing cross pollination
- Involves genetic changes

Molecular technology WITH regulatory oversight

- Using genomics to select and combine new gene combinations
- Targeted gene silencing
- Ectopic delivery of RNAi
- GM rootstocks, non-GM scions
- Cisgenic plants
- Synthetic biology
- Nano(bio)technology
- Cloning
- Marker-assisted breeding

Molecular technology with NO regulatory oversight

- Traditional technology with NO regulatory oversight
- Using genomics to select and combine new gene combinations
- Targeted gene silencing
- Ectopic delivery of RNAi
- GM rootstocks, non-GM scions
- Cisgenic plants
- Synthetic biology
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- Cloning
- Marker-assisted breeding

Relative risks, conventional vs GM Nematode resistant tomatoes

Conventional breeding

- Root knot nematode resistance (Mi gene)
- Cross transferred a chromosome fragment from Lycopersicon peruvianum to tomato
  Mi gene + >500 unknown genes.
- Poisonous plant with toxic alkaloids
- No regulatory approval needed
- Grown worldwide on conventional and organic farms

All wheat grown in Australia contains rye genes introduced artificially!
Triticale – an artificial hybrid between wheat and rye

No regulation

Cytogenetic manipulations (not GM!)

(b) Reciprocal Translocation

Before Translocation	After Translocation

No gain or loss of genetic information
Fusing the complete genomes of two incompatible species is not GM

Potato cells fused with *Solanum brevidens* (wild species with virus resistance)

Mutation breeding

*Gamma field for radiation breeding: 100m radius 89 TBq. Co-60 source at the centre - shielding dyke 8m high*

Irradiate plants to cause DNA breaks – multiple mutations at unknown locations

Not GM!
Mutation breeding, or ‘Atomic Gardening’ - The Ultimate Frankenfoods!

• In the last 60 years, mutation breeding has been used to produced a range of crops.
• Varieties of wheat, including almost all of the most popular varieties used to make top-grade Italian pasta, vegetables, fruit, rice, herbs and cotton have been altered or enhanced with gamma rays, or soaked in mutagens, in the hope of producing new, desirable traits.
• these varieties are marketed as conventional and organic foods

No opposition, no labelling, no protesters, no fear. OK for organic cultivation and the EU.

Ruby Red Grapefruits - just as nature intended?
Or not?

Products of Gamma irradiation and mutagenesis!

Ruby Red grapefruits, with 3,000 other crop varieties consumed by millions every day, were developed by mutation breeding.

Plants were exposed to gamma irradiation, many genes modified

BEFORE & AFTER
Genome editing

- A new mechanism to silence or change the sequence of a target gene
- Makes double stranded cut in DNA, errors in re-joining ends generate mutants which silence that gene
- No external DNA incorporated, FDA has agreed that this is non-GM – ie the same as a mutation

CRISPR/Cas9 targeted double-strand break. Cleavage occurs on both strands, 3 base pairs upstream of the NGG protospacer adjacent motif (PAM) sequence on the 3' end of the target sequence.

GM apples in which PPO is supressed

Welcome to Okanagan Specialty Fruits, home of nonbrowning Arctic® apples

No frankenfood here, folks – just apples, now with suppressed PPO to stop enzymatic browning.

The perfect fruit just got better

Yummy, good for us, varieties galore. We all love apples! Until they turn brown, that is. Arctic® apples are everything you love about apples, without the “vick” factor that you don’t. (Now if we could just get rid of the seeds!)

Arctic® apples approved in Canada!
Transgenic/rootstock applications

- Apple – fireblight resistance, scab resistance
- Other fruit trees – peach, cherry, pear, plums – for resistance to plum pox virus (RNAi of PPV coat protein)
- Avocado pears – rootstocks GM for resistance to fungal pathogen (Horticulture Australia funded)
- Vines engineered to resist soil root pathogens (field trial in France was destroyed by activists)

Apples growing on transgenic rootstocks

Non GM apple scions growing on transgenic rootstocks at North Western Agricultural and Forestry University, China.

Rootstock modified for better salt tolerance.

Are the apples GM or not?
No food is ever 100% pure – allowed adventitious presence is never labelled!

- 50 g cornmeal (FDA/ORA Filth Standard CPG 7104.02, Sec 578.200)
  - < 1 whole insect, or
  - < 50 insect fragments, or
  - < 2 rodent hairs, or
  - < 1 rodent excreta fragment

- 100 g tomato paste (CPG 7114.29, Sec 585.890)
  - 29 fly eggs, or
  - 14 fly eggs + 1 maggot, or
  - < 2 maggots

- White rice - Codex Alimentaris (3.2.2.1)
  - Impurities of animal origin (including dead insects) of 0.1% m/m max

Beware of dis-information on the web

- Publication by Seralini - used rats developed for cancer research fed BT corn and herbicide
- Nasty photos on the web designed to frighten
- Supported by anti-GM groups
- ‘Food and Chemical Toxicology’ RETRACTED this article: Long term toxicity of a Roundup herbicide and a Roundup-tolerant genetically modified maize
- Still used by anti-GM activists........
- Most anti-GM rhetoric is not based on science, but on politics, perceptions, beliefs, ideology, prejudices, dislike of multi-nationals etc
Food safety

• GM food is marginally safer than conventionally bred food

• Organic food is the least safe

• Don’t believe all the misinformation on the web and in the press! Check the underlying science

• ‘The science is quite clear: crop improvement by modern molecular techniques is safe’ (AAAS)

A scientific paradox!

• If an imprecise technology is used (like plant breeding, cytogenetics, mutation breeding or cell fusion) there is no oversight

• When single genes are transferred, based on in depth scientific knowledge of the basis of a trait, then it is highly regulated

• This does not make scientific sense!
Conclusions

• All food crops are genetically manipulated
• GM technology is just another tool for plant breeders
• What is and is not classified as GM is simply a matter of definition (which is in severe need of review)
• The vast majority of farmers want to use the best technologies: coexistence of all forms of farming can readily be achieved
• GM food is safe
• The world will need 70% more food by 2050 to meet demand, with less land, fewer resources and a changing climate
• GM technology is a vital part of increasing food production and quality in a sustainable manner: this will also help preserve biodiversity for future generations

References

• http://www.abca.com.au/materials/booklets/ Agricultural Biotechnology Council of Australia – can download their booklet on Gene technology in Australia – simple explanations, covers the science, research in the pipeline, benefits, regulation, issues, co-existence of GM and organic crops
• http://www.isaaa.org/ International Service for the Acquisition of Agri-Biotech Applications
• http://www.goldenrice.org/
• http://www.okspecialtyfruits.com/ Okanagan Speciality Fruits – GM apples
• http://ac.els-cdn.com/S0278691512005637/1-s2.0-S0278691512005637-main.pdf?_tid=2ed73a8a-4405-11e5-9546-00000aabf278&acdnat=1439722655_610cf5f1fffc5c823960a0ec0e5751ae3 (Seralini retracted article)
• http://www.sciencedirect.com/science/article/pii/S0278691512005637 (Letters to the editor re Seralini’s retracted paper)
WA farmers want the choice to grow GM or not

Total canola area in WA: 1.1-1.2 M ha, 260,000 ha GM canola

Sources: DAFWA, ABCA