DESIGNER FORESTS - The Development of GM Trees

GeneWatch UK

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Genetic modification has not only been applied to food crops - trees are also being genetically engineered. The intention is to improve productivity by making trees grow faster, have straighter trunks and less branches, be tolerant to herbicides and resistant to insect attack as well as being easier to turn into paper. For forest trees used in timber and paper production, issues about environmental safety have been raised. For fruit trees, the issues also include food safety. This briefing considers the genetic modification of trees, the risks and benefits and how these can be evaluated.

Background

Trees are long-lived, large and have lengthy reproductive cycles. These characteristics have contributed to their relative lack of domestication (adapting them to particular human needs) through conventional breeding techniques. In contrast to, for instance, maize or rice - where one, two or more generations can be obtained in a single year (with judicious use of both hemispheres) - even the most rapidly growing trees take at least 4 or 5 years, and often much longer, to produce the next generation. However, genetic engineering brings the prospect of speeding up the domestication of trees to meet 21st Century demands for more efficient pulp and paper production. Speed and uniformity of growth and ease of processing and management are the driving forces behind tree breeding for this sector[1,2]. In fruit and nut production, earlier maturity and increased yields are the main goals.

GM trees are being developed across the globe and there is considerable interest in promoting their use. Whilst the USA has conducted most tests, other countries which have conducted outdoor trials with GM trees include the UK, Finland, Germany, France, Spain, Portugal, China, Australia, New Zealand, Canada and South America. However, controversy has already surrounded such experiments with GM trees and trials have been destroyed in both the USA and Europe.

Investment in long-term research in forestry is small compared to crop production[3] and trees have proved more technologically demanding to manipulate than other plants[1]. The only GM trees in commercial use is a papaya, genetically modified to be resistant to a viral disease and licensed for growing in the USA.

Forest Trees

Table 1 shows the types of outdoor or field trials with GM trees that have taken place worldwide, most of which are intended to be grown in "*intensive, short-rotation (e.g. 3-25 years) plantations*"[4]. The main species involved are the poplar (including aspen and cottonwood), eucalyptus, spruce and pine. GM spruce and pine are much less advanced than poplar and eucalyptus as they are technically more difficult to genetically engineer.

In parallel with developments in crop genetic modification, the two most common ways in which trees are being modified are to be tolerant to herbicides and resistant to insect attack. These utilise the same genes that have been used in crops and mirror their pattern of use. Tolerance to glyphosate (Monsanto's *Roundup*) is the most common type of genetic modification although trees tolerant to glufosinate, 2,4-D and sulphonyl urea have also been developed. Herbicide tolerance is considered useful in forestry because weeds can interfere with establishment of new tree plantations[5]. The use of insecticidal toxin genes from *Bacillus thuringensis* (Bt) dominates the approach to insect resistance and is intended to target pests such as spruce budworms and gypsy moths[1,5].

Table 1: Genetically modified trees which have been grown in field trials and are most advanced[6]. Other tree species have been genetically modified and grown in laboratories and greenhouses (see text for examples) but comprehensive information is not available.

Common Name	Species	GM Trait
Silver birch	*Betula pendula*	Marker genes
American chestnut	*Castanea dentata*	Blight resistance
European sweet chestnut	*Castanea sativas*	Herbicide tolerance (glyphosate)
Eucalyptus/ Red River Gum	*Eucalyptus camuldensis*	Marker genes Herbicide tolerance (glyphosate)
Rose gum/ Flooded gum	*Eucalyptus grandis*	Marker genes Herbicide tolerance (glyphosate)
Tasmanian blue gum	*Eucalyptus globulus*	Marker genes
Sweetgum	*Liquidambar spp*	Herbicide tolerance (2,4-D)
Spruce/ Norway spruce/ Scots pine	*Picea spp* including: *Picea abies* *Picea sylvestris*	Insect resistance (Bt toxin) Markers
Poplars/ Aspen/ Cottonwood	*Populus spp i*ncluding: *Populus nigra* *Populus tremuloides* *Populus deltoides* *Populus tremulata*	Herbicide tolerance (glufosinate, sulphonyl urea, glyphosate) Insect resistance (Bt toxin) Disease resistance Altered lignin content Male sterility Female sterility Increased growth rate Bioremediation Marker genes
Apple	*Malus domestica*	Marker genes Improved rooting Disease resistance (scab and blight) Altered flowering time Insect resistance Altered fruit ripening Altered sugar content
Crab apple	*Malus sylvestris*	Insect resistance Fungal disease resistance
Plum/ Cherry	*Prunus spp* *Prunus domestica*	Disease resistance Altered morphology Altered ripening Marker gene
Orange	*Citrus spp*	Marker gene
Kiwi	*Actinidia deliciosa*	Fungal disease resistance
Olive	*Olea europea*	Fungal disease resistance
Papaya	*Carica papaya*	Virus resistance Delayed ripening
Walnut	*Juglans spp*	Insect resistance (Bt toxin) Improved cutting rootability Disease resistance Altered flowering time

The two most common ways in which trees are being genetically modified are to be tolerant to herbicides and resistant to insect attack

Another similarity with GM crop development is the production of male and female sterility to contain gene flow and so prevent cross-fertlisation, a particular environmental problem with GM trees (see below). Disease resistance to a range of pathogens has also been tested.

Applications which are more specific to forest trees include reducing the lignin composition of wood. In the production of pulp and paper, much of the cost involves the energy demands of removing lignin and even small reductions could save many millions of pounds because of the scale of the process[3]. Much of the early work in this field involved genetic modifications which altered the activity of enzymes that are important in the synthesis of lignin by the tree. This led to alterations in lignin structure but no overall reduction in content[7]. However, by targeting different enzymes, scientists in the USA have succeeded in reducing the levels of lignin in aspen trees which also had the unexpected and unexplained effect of increasing growth rate[8]. An accompanying increase in cellulose was thought to account for the lack of cell wall collapse, a side-effect of many earlier efforts to reduce lignin content.

Laboratory and greenhouse work with GM forest trees includes attempting to alter tree form and performance

Whilst not yet at the stage of being field trialled, laboratory and greenhouse work with GM forest trees includes attempting to alter tree form (e.g. to have less branches) and performance by, for instance, modifying the production of the plant growth hormones auxin and giberellin to increase growth rate. Enhancing growth rate by increasing giberellin synthesis also increased fibre length (which improves the strength of paper produced) but reduced early root formation[9]. In addition, genomics research to determine the function of genes is being used to identify targets for improving salt and drought tolerance[10] and disease resistance[11].

Very recently, scientists at Dundee University reported that they have genetically modified elm trees which they hope will be resistant to Dutch elm disease, a fungal disease brought into the UK which has destroyed most of the species[12]. However, they have not yet demonstrated that the resistance will work. Scientists are also attempting to genetically modify the American chestnut – an important source of timber and nuts - to counteract another imported fungal disease, chestnut blight, which has devastated the species in the USA[13].

The use of trees for bioremediation - where living organisms are used to clean up toxic chemical waste - is also being investigated. Using a gene from a bacteria which is resistant to high levels of toxic organic mercury by converting it to less toxic elemental mercury, yellow poplar have been genetically modified so they can grow in high concentrations of mercury and convert it to the less toxic form[14]. However, the mercury is then released from the tree in vapour form and will eventually be recycled into the more toxic organic form.

Because forestry is an industry which is increasingly global in nature, corporations are heavily involved in research on GM trees

Because forestry is an industry which is increasingly global in nature, corporations are heavily involved in research on GM trees both directly and by sponsoring research in the public sector. For example, corporate members of Oregon State University's Tree Genetic Engineering Research Cooperative (TGERC) include many multi-national timber companies such as International Paper, Westvaco and Weyerhauser[15]. MacMillan Blodel, Monsanto and Union Camp are also reported to be funding research at TGERC along with public input from the US Department of Energy and Environmental Protection Agency[16]. A similar consortium at Washington State University - the Plant Molecular Genetics Cooperative – receives financial support from Westvaco, Weyerhauser and Champion International.

Another joint venture, ArborGen, has been formed by Fletcher Challenge Forests (a New Zealand company), International Paper (the world's largest producer of paper and packaging), Westvaco (a US company owning 1.5 million acres of forest in the USA and Brazil) and Genesis (a New Zealand tree genomics company)[17]. ArborGen has been established to facilitate research on GM trees and to try and overcome some of the obstacles restricting access to intellectual property - many genes and techniques have been patented by others making it more efficient to join forces and license the technology from them.

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As with GM crops, therefore, GM tree research, its control and direction (both through funding and patenting) is dominated by the interests of the multi-national forestry companies.

Fruit Trees

There has been much less attention paid to the genetic modification of fruit trees and the majority of this research is located in the public sector at universities and institutes. This is probably because fruit trees have not been industrialised in the same way as forest trees. Papaya, genetically modified to be resistant to papaya ringspot virus and produced by the Universities of Cornell and Hawaii, is the first and currently the only GM tree species to be given a licence to be grown commercially (in the USA). However, many other GM fruit trees have been field trialled (see Table 1) and it can be seen that the focus is on disease (viral and fungal) and insect resistance rather than herbicide tolerance as ways of increasing productivity. Controlling flowering is being investigated to determine timing of fruit production, and delayed ripening - to facilitate transport and storage - is also being developed.

Recently, in laboratory studies, Spanish scientists have reported reducing the time to flowering and fruiting in orange trees from 6-10 years to just one year[18]. By transferring genes which control flowering from another plant, *Arabidopsis*, the juvenille period of the trees was reduced dramatically which, if successful in the field, would enable much faster returns on investment. Disease resistance in banana trees is another important goal of research.

The Risks of GM Trees

There is considerable concern about the environmental, social, economic and political implications of GM trees

Despite the claimed advantages of developing GM trees, there is considerable concern about their environmental, social, economic and political implications. Most attention has been paid to the risks directly associated with the genetic modification, the change it causes in the tree (insect resistance or herbicide tolerance, for example) and how stable they will be over time. The likelihood of harmful effects will alter according to the species involved. For instance, an apple or spruce tree will be grown for many years whilst papaya trees produce fruit in the first year and then are only grown for another eighteen months. However, as with GM crops, there are also wider questions about the intensive production systems GM trees will facilitate.

Gene flow - Trees have developed excellent mechanisms to transfer genetic material over wide areas. Pollen and seed may travel many miles and some trees can also reproduce asexually via suckers. Because even those trees grown in plantations - such as eucalyptus and aspen - are relatively undomesticated, related native trees with which they can cross fertilise are often nearby. Again, like GM crops, the foreign genes transferred in the GM process will not be containable. Transfer to native species is therefore inevitable unless all GM trees are made infertile (although this could have its own environmental consequences – see below). Much of the debate about gene flow has centred on whether such gene flow would matter – would native trees become more invasive if they acquired beneficial genes from GM trees and were better able to survive insect or disease attack for example or would the GM trees themselves become invasive[19]? Whilst there is limited knowledge about crossing (hybridisation) between plantation trees and native species, the introduction of non-native species shows that the potential is real. The Japanese larch (*Larix kaempferi)* was introduced into Scotland, hybridised with the native European larch (*L. decidua)* and produced a fast growing hybrid now used in forestry. Similarly, in France, a hybridisation between introduced Eastern cottonwood (*Populus deltoides)* and native black poplar *(P. nigra)* has also become widely used in plantations[20]. Some trees have become invasive in new environments. For example, the sycamore (*Acer pseudoplatanus*) was introduced into Britain in the 18th Century and has been considered a major pest[21].

Sterility – In an attempt to avoid the dangers of gene flow, several GM trees have been modified to be sterile and since trees can often be propagated vegetatively, continued reproduction would still be possible. However, whilst rarely used for human food, the flowers and seeds produced by forest trees are important in maintaining the biodiversity of forests by providing food for insects, birds and mammals. Even in poplars, where insect use of flowers is thought to be limited[23], little data exists upon which to base predictions. Also, because trees are so long-lived, it is uncertain whether they would remain sterile throughout their lifetime. In orchard situations, flowering and fruiting are crucial parts of the system and sterility is therefore not an option. Despite the emphasis on controlling gene flow, economic factors are also behind the research into sterility since preventing reproduction *"could increase yield by redirecting resource allocation into wood production"* [3] and would also avoid the irregularities in wood caused by flowering and seed production.

The early stages of plantation development are important for woodland biodiversity, which would be threatened by the increased use of herbicides

Herbicide tolerance – GM trees have been made tolerant to a range of different herbicides (see Table 1) with the claimed advantage that herbicide application would be easier during the establishment phase when minimising competition from weeds is important. However, not only may such trees eventually spread the herbicide tolerant gene and possibly cause problems in tree control elsewhere, but the early stages of plantation development are important for woodland biodiversity, which would be threatened by the increased use of herbicides[22].

Insect tolerance – Currently, insecticide use in forestry is much more restricted than for crops because of the problems of scale and application. The use of GM insect resistant trees would lead to the insecticide (usually the Bt toxin from the bacterium *Bacillius thuringiensis)* being present in the forest ecosystem for many years. Not only would there be effects on target species, but the beneficial insects feeding upon them could be harmed as could organisms involved in the decomposition of leaves and dead trees[22]. Resistance among target insects is also likely to develop, threatening the effectiveness of Bt sprays which are used on forests[5]. The use of refuges - areas of non GM trees intended to reduce the likelihood of Bt resistance emerging - has been proposed[23]. However, such strategies have not been followed by farmers growing GM Bt maize commercially in the USA where about one third did not include refuges in 2000[24] so such safeguards may not be successful.

Altered lignin content – Lignin is an important structural component of trees as well as playing a role in defence against disease and pests. It is too early to say what the effects of alterations to lignin content would be if these were transferred to native species or the impacts on biodiversity arising directly from their use. It could alter palatability to species feeding on them, disease resistance and, by potentially increasing susceptibility to wind damage, where trees can grow[22]. Because lignin affects the rate at which decomposition takes place, impacts on soil are also possible. Syngenta's four year trials with low lignin GM trees in England and France detected no change in growth rate or disease resistance while pulping qualities were improved[25] but ecological impacts were not investigated.

Food safety – Fruit and nuts from GM trees will raise similar questions to those associated with GM crops. The genetic modification could bring about unintended changes resulting in the production of toxins. Following the genetic modification of an aspen tree in Germany, it began to flower in its third, rather than its seventh year as expected[26], highlighting how unexpected changes may arise through the genetic modification process. The introduced protein could also prove to be allergenic.

Fruit and nuts from GM trees will raise similar questions to those associated with GM crops

Plantations – Plantations raise questions about environmental sustainability, equity and aesthetics[27]. Exotic species are often used (such as eucalyptus in South Africa) and monocultures are common. As such, they can have negative effects on biodiversity and are highly susceptible to disease and insect attack. Plantations also have social consequences. Heavily mechanised and centralised, they offer little in terms of local employment and profit but frequently rely on local subsidies[27]. They also contribute to local environmental degradation through removal of water and nutrients. Increasingly, plantations are being established in more tropical regions to improve growth rates as a result of better climates and to improve economic gains through cheap labour and land. Southern countries will, therefore, bear a disproportionate risk, socially, economically and environmentally.

Do We Need GM Trees?

The reasons that GM trees are claimed to be needed in forestry have been given in the position statement of the International Union of Forestry Research Organisations (IUFRO) Working Party on Molecular Biology of Forest Trees[28]:

> *"Tree plantations are expected to continue to expand as a result of increasing demand for their many renewable products, their importance to mitigation of greenhouse gases, and the environmental protection afforded to large areas of native forest. It is therefore important that rates of plantation productivity be made as high as possible within the context of good environmental stewardship. Transgenic technology, wisely used, promises significant economic and environmental benefits."*

How real are these benefits and do they justify the development of GM trees despite the ecological and social harm that may arise?

Little attention has been paid to the option of reducing demand through decreasing usage and recycling

- *Increased demand?* – Like the justification for GM crops, increasing populations and the demand for more wood products for paper and construction are given as the main reasons for developing GM trees because of their predicted productivity increases. However, little attention has been paid to the option of reducing demand through decreasing usage and recycling. Enormous amounts of unnecessary packaging are now used and much of the predicted increase in demand is predicated on consumption patterns following those in the USA.

- *Mitigation of greenhouse gases?* – In addition to GM low lignin trees reducing the amount of energy required for the intensive, polluting processes used in paper production, it is also claimed that growing more trees more quickly will help to absorb the carbon dioxide (CO_2) produced by burning fossil fuels. Trees, like other plants, absorb CO_2 and use it to grow. With trees, the CO_2 is 'fixed' in their wood and oxygen is released. However, the science is extremely uncertain and no-none knows exactly how much CO_2 will be fixed by a tree under different conditions and, as climate changes even more, a net increase in the production of CO_2 from trees is considered possible as their metabolism may alter. If such a strategy were pursued, there could also be enormous social consequences for developing countries if they were 'persuaded' to set land aside to grow trees to compensate for the polluting activities of the developed world[29]. As importantly, it diverts attention from strategies to reduce the production of CO_2 in the first place, which is a much more straightforward way of tackling climate change but not in the economic interests of the developed world and its industries.

There could be enormous social consequences for developing countries if they were 'persuaded' to set land aside to grow trees to compensate for the polluting activities of the developed world

- *Protecting native forests?* – If trees can be grown more productively in plantations, the argument is that there will be less demand placed on native forests. However, this avoids looking at alternative options for how native forests can be best preserved and how the reduction in use and recycling of tree products could be improved. Instead, commercial interests are keen to promote an increased use of paper and packaging.

Conclusions

Establishing agreement about the environmental safety of releasing GM trees to the environment will pose more challenges than for GM crops. The data considered necessary to determine genetic stability, the extent and rate of gene flow and the persistence and invasiveness of a GM food crop typically involves experiments lasting over several generations of the plant conducted under different environmental conditions. The characteristics which make trees so attractive to genetic engineers - namely their long generation times and slow growth – means that collecting similar data about their environmental performance will require much longer periods if it is to match that considered acceptable for GM crops. However, having to conduct ecological research over many years would compromise the economic viability of GM trees and conflict with the claimed benefits of speeding up tree domestication and improvement.

Establishing agreement about the environmental safety of GM trees will pose more challenges than for GM crops

Reconciling these issues in a manner which commands public confidence will be a particular challenge for the regulation of GM trees. Judgements will have to be made much more explicitly given the lack of data, revealing the inevitably subjective nature of risk assessment. Even more demandingly, the approach which is taken will either have to satisfy, or be sensitive to, different social, economic and regulatory regimes in different countries to avoid acrimonious trade disputes. A rigorous assessment of the claimed justifications for GM trees and a detailed evaluation of the alternatives are essential.

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