Breeding radiata pine - future technical challenges

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Summary

Radiata pine is, genetically, still in a very early stage of domestication. Genetic improvement, which is a key plank of domestication, is set for continued advances in several directions that have already been clearly identified. These include improving wood properties, better definition of breeding goals, various improvements in propagation technology, and much better integration of molecular biology with classical breeding. Yet radically intensified domestication may depend largely on both control of flowering and effectively redesigning trees as wood factories rather than as competitors in an evolutionary rat race. Control of flowering can mean more efficient wood production and provide a platform for realising the full potential of genetic engineering. Redesigning might both improve efficiency of wood production and reduce the troublesome within-log variations in wood properties. As with any investment aimed at high returns, genetic improvement entails its risks. To manage the risks entails institutional challenges as well as the technical ones.

Introduction

The role of genetic improvement in the domestication of radiata pine has been major, and will almost certainly become even bigger. Future challenges include refining of breeding goals, achieving major improvements in wood properties, enhancing vegetative propagation technologies, and integration of molecular biology with classical breeding. Yet more radical domestication of forest trees, in some directions taken with traditional crop plants, has barely started, and will be reviewed. Risk-management issues are likely to loom larger as genetic improvement progresses, posing major institutional as well as technical challenges.

Branching 'ideotypes', which are addressed in a separate article (Burdon 2008), will remain an issue for future genetic improvement, certainly as long as there are markets for solid-wood products.

Wood properties

Genetic improvement of wood properties will undoubtedly remain a major thrust. This reflects a combination of the various shortcomings of corewood and the pressures to reduce effective growing costs by increasing growth rates and generally shortening rotations, although carbon credits may reduce downward pressures on harvest age. In improving wood properties, conventional breeding will be informed by functional genomics and probably eventually complemented by genetic engineering. Genetic engineering has an ambitious agenda for improving wood properties. A perceived Holy Grail is to convert conifers to producing hardwood lignin (syringyl) (Chiang *et al.* 2001), which makes pulping cheaper, rather than conifer lignin (guaiacil). The full metabolic compatibility of such a switch for conifers will need to be established. And the lack of side-effects on mechanical stability of trees would need to be confirmed for this attribute and for other major genetic modifications of wood properties. Also, it remains to be confirmed that radical improvements in pulping properties would not significantly compromise solid-wood properties.

Breeding goals

Benefits of genetic improvement are greatly dependent on targeting appropriate breeding goals, which in turn depends on ascertaining comparative economic weights among different traits, especially where there are adverse genetic correlations between traits. Other complications include: the complex production systems that often exist for radiata pine in New Zealand, with multiple product lines; the fact that much selection must be done early in the rotation whereas value resides in harvest-age products; and some non-linearities of economic-worth functions which could be important under clonal systems.

Vegetative propagation systems

For breeding work itself and especially clonal deployment, there is still a strong call for enhanced vegetative propagation systems. The somatic embryogenesis technology has yet to reach the point of being commercially viable for all the genetic material that the breeder might want to select for deployment. And we have yet to achieve anything like complete control of maturation state. Seeking to be able to rejuvenate any material at will is technically a high-risk quest. But, if achieved, it would give much greater flexibility, as well as constituting a big advance in fundamental science.

Integrating breeding and molecular biology

Molecular biology (MB), of which one application is genetic engineering (GE), stands to enhance conventional breeding rather than to supplant it. MB stands to inform breeding, in targeting traits for improvement, and would serve as a tool for making individual selections. For managing populations it can have various applications, including doing away with laborious control-crossing

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procedures through having the means of verifying or reconstructing pedigrees. Through GE, MB can make available attributes that could not be conferred by conventional breeding. For breeding for resistance to diseases, use of genomics has a special potential to guarantee durability of resistance against pathogen mutation.

Integrating breeding and MB poses challenges. While the use of MB is often sold as a means of avoiding some of the drudgery of conventional breeding, its development is still making some increased rather than decreased demands on the conventional-breeding infrastructure. That greatly complicates the task of resource allocation between different areas of activity.

More radical domestication

Despite the very rapid progress of genetic improvement, the species is, genetically, still in a very early stage of domestication. In almost any plant and animal breeding, management systems and genetic improvement are interactive, and ideally, strongly synergistic. That is vividly illustrated in the domestication of cereals. Early on, selection occurred, wittingly or unwittingly, for resistance to spike shattering, which made possible the gamut of systems for grain harvesting. Much more recently, there has been the "Green Revolution" (Evans 1993) based on dwarf varieties, which invested much less biomass in straw and responded extremely well to fertilizer, but required good weed control. Another example is with canning tomatoes, with tough skins and fruit ripening all at once, which allowed highly efficient machine harvesting.

So far, while there has been some interaction between genetic improvement and management systems in radiata pine, it has been on a very minor scale compared with the examples just mentioned. Two directions in which domestication of a forest tree can be much intensified are:

- Engineering flowering "on command and command only",
- Redesigning tree architecture, to produce a 'crop ideotype'.

Flowering control

The species is dependent on seed production not only in nature but also in a breeding programme. Yet producing seed, which entails producing abundant pollen as well as cones, represents a considerable diversion of primary biomass. Especially in the case of pollen, that represents 'high-grade' biomass with a high nutrient content. Such diversion is doubtless at some cost in wood production, although this is remarkably difficult to demonstrate and quantify rigorously. Suppressing reproduction has another attraction, as a means of containment in genetically engineered material, genetic containment being a major issue in regulatory acceptance of GE. As such, a means of genetic containment could be a key plank for realising the various genetic advances that are dependent on GE rather than conventional breeding.

Achieving full, yet reversible reproductive sterility, however, will pose great challenges. While complete reliability is highly desirable, its inherent feasibility is controversial. And even if it is feasible, there is the question of possible side-effects on field fitness, especially with complete suppression of all reproductive structures. Also, suppressing pollen production would remove a mechanism, of unknown significance, for spreading nutrients over the landscape. Problematic, too, would be its effects on animal life, apart from depriving possums of a favourite diet item. With a complete lack of pollen catkins, crown habit is likely to become denser and more compact, such that some compensatory 'redesign' of crown ideotype may be indicated for optimal performance of material in which reproduction is to be suppressed.

Controlled reversal of sterilisation, while nice to have as an option, may not be crucial, because operational use of GE could remain confined to commercially deployed clones.

Crop ideotype

Selection for growth performance in forest trees has tended to select for competitive ability. Since domestication for plantation forestry has mainly involved 'pioneer' or early successional species, such selection has largely matched natural selection. Yet in crop-plant breeding many of the features that have made the crops commercially productive have also made them poor competitors, saved by cultivation and other modes of weed control. For a classic illustration, I return to the breeding of the dwarf wheats of the Green Revolution. In them the usable proportion of biomass, i.e., the harvest index, is boosted, while response to fertiliser is not vitiated by crop lodging. Indeed, genetic gains in crop yields have tended to come in harvest index rather than in total biomass (Evans 1993).

The potential implications for forest trees are twofold: in wood yield and in wood quality. Since stemwood is typically a very high proportion of biomass production, the scope for improving harvest index is much less than in seed crops. Even so, some of the long-term genetic gains in wood production may well come in exploiting divergences between competitive ability and whole-crop productivity. For efficient capture of such gains clonal forestry, using monoclonal blocks, would seem the ideal vehicle. Selecting efficient 'crop ideotypes', rather than just strong competitors, would require good definition of appropriate ideotypes, since large-scale empirical screening for crop performance would surely be prohibitive.

As a competitor, a tree will grow to be able to secure light and other resources with the minimum commitment to wood production, consistent with maintaining mechanical stability. This is achieved in part by within-stem variations in wood properties that generate a raft of problems with utilisation. Such patterns of variation differ widely among species, representing alternative strategies whereby much the same end is served. But whatever they do for the intact log, they can be extremely undesirable in processed products, e.g. in pieces of sawn timber.

Paradoxically, we would want trees that are mechanically inefficient, being 'over-designed' with respect to the need to support their crowns. They could be relatively short (*cf* Tuskan 2007), saving energy in supplying the crown with water, gratuitously stout with minimal lower-bole taper, and with wood of uniformly high quality. Challenges will arise in combining these attributes with the capabilities for rapid site occupation and self-righting.

Risk-management issues

Genetic-improvement programmes, through pursuing high returns, will naturally incur risks. There will always be risks relating to feasibility of new technologies - not only must a technology succeed in itself but it must also belong in a winning chain of technologies. For the genetically improved crops themselves, major risks are seen in the marketplace and in their biological security.

Market risks, involving unforeseen shifts in market preferences, are inevitable, with the time lags between producing the planting stock and harvest, even with a fast-growing species like radiata pine. In principle, they can be addressed through risk spread by having a portfolio of breeds or clones, in the hopes that some component of the harvest may hit the jackpot with a niche market that appears.

Biological risks involve climatic damage, or disease or pest epidemics. Climatic damage, which may be accentuated by climatic change, can be addressed to some extent by evaluating candidate selections on sites or in simulated conditions that pose likely climatic hazards. Forearming against future epidemics poses complex challenges. For radiata pine in New Zealand, fungal diseases are likely to be a bigger long-term risk than insect epidemics; the species is widely grown in relatively moist climates which tend to favour fungal pathogens, while insect pests are often amenable to biological control. Border control is a strong and logical line of defence against new pests and pathogens, but it is not impregnable. Also, experience indicates that the greatest such dangers are likely to materialise from 'left field', in agents with no previous record of being dangerous (*cf* Carter 1989). Forearming with genetic defences against the arrival of new diseases is therefore indicated. That entails numbers, especially in the breeding population; having the full natural range of the species represented; and if possible being able to recruit resistance through hybridisation with other species. For all that, new technology will help, but institutional commitment is likely to be crucial. Preparing such defences will incur both direct costs and the opportunity costs of keeping and managing back-up material.

A major difference exists here between short-term risk management and the long-term aspect. The short-term provisions involve material being currently deployed, in which risk spread is the main tool. For the longer term breeding for resistance is an option, which can work with much lower incidence of worthwhile resistance in the population.

Institutional issues

Addressing the technical challenges cannot be considered in isolation from institutional issues. Those issues that affect tree improvement pervade most aspects of commercial forestry. There is at once the cyclical nature of the sector and yet the technical needs for sustained commitment, plus the behaviours that tend to be associated with rapid changes which have been occurring in forest ownership and management personnel.

The sheer success of the breeding programme has increased the opportunity costs of maintaining genetic material that may be needed for long-term risk management, and thence a reluctance to engage on that front. Yet the focus on growing intensively improved stock with a relatively narrow genetic base has accentuated the potential need for back-up genetic material. Moreover, with globalisation, which has certainly affected our sector, risk-management considerations for individual players in the sector may not align well with New Zealand's national interest. Overall, we must be braced for continuing institutional challenges.

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