Australian tree breeding research revolutionising the industry

Over the past 20 years, significant research strides have been made around tree breeding in Australia.

Tree breeding is a unique science. Decisions need to be made well ahead of time, to account for the long crop cycles of our softwood and hardwood plantations.

These timeframes (up to 35 years for pine trees, and up to 18 years for eucalypts) mean the future is often uncertain, and the risk is heightened. The ability to make accurate predictions around potential growth and quality is even more critical in forestry than other primary industries, where breeding is generally a much quicker process.

"A big difference between trees and annual crops such as wheat is that we can't respond immediately," said Dr Tony McRae, General Manager at Tree Breeding Australia.

"If you want to test a crop variety you can conduct a trial and have the results within a year. This is not the case with trees, so we've had to be super creative and innovative in our approach to testing and making predictions."

Tree breeding history, in brief

In Australia, the growth of plantation species has been supported by advanced generation tree improvement programs, with pine programs starting in the 1950s, and eucalypt programs beginning in the 1970s. Since then, plantation tree breeders have focused on breeding and selecting material that is superior to previous generations.

Over the years, privatisation, consolidation of ownership, advances in technology, and a willingness to collaborate amongst industry have resulted in continued improvements in yield and quality, which means better returns for growers, sawmillers, supply chain participants and investors.

Challenges for the industry to overcome

Despite the genetic improvement already achieved, support for the adoption of 'next generation' breeding technologies is needed as the industry faces challenges now and into the future.

Current research activities are addressing the breeding of genetic material to be more resilient to predicted climates and biosecurity threats forecast to be exacerbated by climate change.

Support for succession planning has also been identified as a priority for investment to engage and retain research talent within the sector.

Tree Breeding Australia (TBA)

TBA is a consortium of forest owners and managers, seed and plant propagators, and research organisations. It manages Australia's national cooperative tree improvement programs. In addition to conducting its own breeding programs, TBA's work supports the breeding programs of companies by providing access to online systems for data management and genetic evaluation.

TBA is a not-for-profit organisation funded by membership fees, royalties, grants, and fees for services. Founded in South Australia in 1983 (and originally named the Southern Tree Breeding Association), TBA was initially focused on breeding and producing radiata pine seed, before it divested of seed production in 2001 to focus solely on breeding pines and eucalypts.

"The start of the modern era of tree breeding innovation in Australia was largely driven by the formation of TBA, which saw the consolidation of many individual programs in this space around Australia," said Dr Josquin Tibbits, Research Leader, Plant Functional Genomics at Agriculture Victoria.

"TBA was created to consolidate and share resources, in order to reduce the risk carried by organisations conducting programs in siloes, as well as to reduce research costs and boost gains."

Tree breeding programs conducted under TBA have largely been guided by economic and environmental objectives, and programs are well supported by collaborating scientists from various research agencies. This encourages innovation and ensures research outputs are rapidly adopted by industry.

"FWPA has played a key role in enabling collaborative research programs, both domestically and internationally, that are driving genetic gain," said McRae.

"By coming together, we can all learn from each other, and generate a lot more meaningful data for the entire industry to enjoy. A cooperative research model is particularly vital in an industry like forestry, where lag times involved are so long."

The adoption of Best Linear Unbiased Prediction (BLUP) technology

One of the first big innovations under TBA came in the 1990s, with the adoption of BLUP technology for modelling data. This provided industry with access to much more accurate estimates of breeding value.

"Previously, research had tended to be conducted on a trial-by-trial basis. A project would be conducted to answer a specific question or meet a specific need, with the necessary actions taken based on the results," said Tibbits.

"Although this meant the industry had a wealth of valuable data and insights at its disposal, this was all disconnected and difficult to access. The adoption of BLUP technology would allow industry to access all available data, at any time, to estimate genetic worth.

"To facilitate the adoption of BLUP, TBA launched a national online DATAPLAN database in 2001 to house data and pedigree information for hundreds of field trials established over decades of breeding. The database system was fully integrated with other critical software for analysing the data (TREEPLAN) and tools for managing the breeding and deployment populations (SEEDPLAN).

"This platform essentially put the industry at the cutting-edge of machine learning, long before the term was even coined!"

"The national database was effectively designed to easily produce accurate breeding values for industry as new data was generated," added McRae.

"The focus of the industry wide databases is to identify the best parent trees in the population, and BLUP technology has enabled solid predictions of parental breeding values, taking into consideration variables across different regions and seasons."

The rolling front

Another major innovation spearheaded by TBA came in the mid-90s, with the shift to 'rolling front' breeding, where overlapping operations of breeding and testing could occur at any time.

"Prior to rolling front, breeders would conduct distinct generational breeding," explained Tibbits.

"Due to the long timeframes involved, this would mean crossing and establishing trials, waiting for the material planted in trials to grow, then measuring and making selections, before repeating the process again based on the results."

This made for a very slow process and meant huge ebbs and flows of activity over time. Consequently, it was difficult for many organisations to justify investment in expensive scientists during the quieter in-between periods.

"With 'rolling front', the process is completely different. It essentially means that every year scientists make crosses, establish trials, take measurements and identify selections, with various materials at different stages in the growth cycle," continued Tibbits.

To capture the benefits of a rolling front, implementing BLUP technology in TREEPLAN was critical. It enabled TBA to combine data and information across space (programs, site types and regions) and time (years, age classes and generations).

"This has had an enormous impact on the efficiency of breeding programs and the rate of genetic gain. It has meant there is always new data for growers to take advantage of and apply it to their decision-making and has provided a more continuous delivery of quality germplasm (genetic material) to the industry. As a knock-on effect, the workforce has become more stable and consistent."

"Rolling front has been critical because it enables us to bring forward decision making," added McRae.

"It allows us to roll out more substantial programs using limited resources. It means our scientists can be busy all year round, so there's also a significant impact on efficiencies that can't be overstated."

Developing and sharing tools and systems

In recent years there has also been a big investment by industry and FWPA in the development of systems and tools made specifically for tree breeding.

"These systems and tools enable the industry to exploit data and confidently make the genetic selections they know will get maximum value from their plantations," said Tibbits.

"Basically, every year growers can use the available tools and data to estimate the value the germplasm is having in their estate and make adjustments accordingly. They can also better quantify genetic risk by ensuring their plantations have enough diversity to cope with variability relating to weather, pests and diseases."

The ability of growers to select the best germplasm for their plantations supports decisions toward enhanced economic outcomes, thanks to economic models that predict demand in different markets. Access to these predictions has huge implications on profitability, competitiveness, and investment, by allowing foresters to grow wood with particular properties to meet expected future demand.

"In any breeding program, you need a breeding objective, whether that's faster growing trees or better wood quality," explained McRae.

"Since the late 90s, TBA has been able to use economic models to help growers determine the monetary importance of various traits in the timber they are growing. For instance, we can help them determine how much value a unit increase in timber stiffness or log straightness would yield for them, in economic terms."

Tree and timber quality

One significant example of the systems and tools developed in Australian tree breeding is TREEPLAN – a leading analytical system for genetic evaluation, which was launched in 2001 as the result of sustained and strong collaboration among Australian tree breeders.

Decades worth of data underpins the evaluations made using this tool, which was developed to help Australian growers select suitable plantation radiata pine and eucalypt trees based on attributes associated with their pedigree. This ultimately increases the profitability of the whole industry, while also promoting ongoing improvements to the Australian softwood and hardwood resource.

The tools have continued to evolve over time, and the data itself recently underwent a thorough reliability check, to help ensure grower decisions are made based on the most accurate information possible.

Until recently, TREEPLAN only combined tree pedigree and phenotypic (observable) data collected in-field to generate breeding values used by growers during tree selection.

Now, by combining this information with genomic data, the tool generates 'single-step' genetic evaluations, offering a single set of objectively comparable breeding values. These values can strengthen the accuracy of predictions and improve the selection process.

"We can also measure timber attributes more effectively now, thanks to the advent of tools such as IML-RESI, and acoustic wave velocity," said McRae.

"This technology uses small-diameter drills to quickly, accurately and cost effectively capture details of a tree's diameter, wood variability and quality. Having access to this type of data on standing trees is important to inform decision making that will help increase genetic gain for timber stiffness and strength."

A changing climate

Climate change is likely to have a significant impact on the Australian forestry industry in the future. Changing conditions bring both new threats and new opportunities.

The projected long-term impact of climate change and demand on the forestry industry, together with urban expansion, has the potential to force the future establishment of plantations in environments where the current plantation species will need to be adapted to cope with variable site conditions.

A current focus of TBA is the pre-emptive testing of material across a range of environments likely to reflect future climates and industry expansion.

"We need to make sure we are prepared for a changing climate by identifying genetic material that we know is adapted to potential future conditions," said McRae.

"For that reason, we are testing our genetic materials at atypical sites, so we know what will survive and grow as the climate changes. With changing conditions, there will also be new pests and diseases to contend with in the future, so testing offshore is an important aspect of building knowledge that will be beneficial in the future."

Genomics

Meanwhile, the ability to bring DNA information into breeding is also becoming increasingly commonplace.

"Use of genomics has the capability to rapidly increase the rate of genetic gain. Encouragingly, the application of genomics in Australian forestry is well ahead of other countries, largely thanks to the adoption of rolling front, which allows us to seamlessly implement innovations that would otherwise disrupt the much lengthier timelines associated with traditional breeding programs," said Tibbits.

"Investments in this area will afford Australia a global advantage by giving the national forest estate a head-start against international competitors. In the next ten years, genomics could help place the Australian estate two to three generations ahead of where we might otherwise have been."

"Genomics adds another valuable tool to our breeding toolkit and will help add value to the ongoing evolution of tree breeding in Australia, making it an area of significant investment moving forward," added McRae.

"To make these new technologies operational, industry must continue to collaborate across species and at a national level."

Dr McRae said it is important to proof the breeding values and the predicted gains based on these technologies. "It's very encouraging to see that realised genetic gain is consistently being demonstrated in many large plot trials for the main plantation species.

"This means tree breeding is working effectively and delivering gains largely consistent with expectations. Industry and growers can depend on future productivity improvements through the adoption of improved genetics, which compounds the benefits of new investments in genetics as they build on previous gains.

"We are looking to more than double the current annual rate of genetic gain to more than one per cent improvement in productivity (from 2.5 to 5 m^3 per hectare per annum over a full rotation for pines). This means that potential productivity per hectare can improve more than 10 per cent over the next decade without compromising wood quality – equivalent to more than 17 million m^3 of softwood forest resource or 8 million m^3 of eucalypt fibre available for future harvests.

"We have seen significant lifts in productivity over previous rotations through tree breeding and improved silviculture impacting on harvest volumes. FWPA and industry are investing in new initiatives that will deliver these productivity improvements in future rotations."