



*How did Hawaii hijack
the macadamia?*

*Graeme O'Neill outlines
research aimed at
helping Australia to
wrest it back.*

Winning back the macadamia

Australia's macadamia industry is booming. By the year 2000, two million young trees – in orchards from Lismore in northern New South Wales to Walkamin in northern Queensland – should begin yielding top quality native nut crops worth more than \$100 million annually.

This burgeoning output, which has already seen Australia eclipse Hawaii as the world's leading macadamia producer, is merely scratching the surface of potential demand. In 1995, macadamias accounted for less than 0.5% of the global trade in tree nuts.

With such a rich future in store for the macadamia, the local industry is leaving nothing to chance. The Australian Macadamia Society, recognising the need to outperform its overseas competitors, is investing heavily in research. This year alone (1996) a 3.3 cents a kilogram levy will generate \$1.26 million for studies aimed at a range of problems including improving cultivation and pest control and the breeding of cultivars better suited to commercial production. With access to the macadamia's native gene pool, Australian scientists have an advantage in this research.

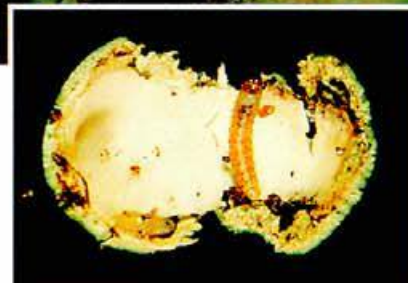
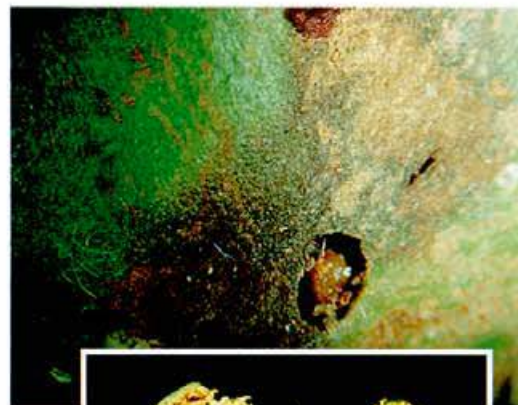
Initial steps toward the development of new cultivars have been taken by Dr Cameron McConchie of CSIRO's Division of Horticulture in Brisbane. Along with botanists from the University of Queensland, McConchie and his team have been exploring the genetic diversity available in wild macadamias, with a view to borrowing their traits to enhance the performance of existing domestic species. 'Our group is the first to define which of the *Macadamia* species interbreed and thus the extent of the germplasm available to improve the commercial macadamia by conventional breeding techniques,' McConchie says.

Given that the *Macadamia* genus is native to Australia, and that macadamias are now one of the country's most valuable horticultural crops, it's surprising to learn that McConchie and his colleagues are the first to fully explore the available germplasm to capitalise on this valuable asset. Significant work on breeding and germplasm preservation has been done by private enthusiasts, and varieties they have developed are performing well in the Australian industry. Formal research of this nature, however, has been a long time coming. Why is this the case?

The answer to this question dates back to 1881, when an American, William Purvis, collected a pocketful of nuts from a macadamia tree planted in a Brisbane backyard. This hastily collected pocketful – the beginnings of Hawaii's macadamia industry – is thought to have tapped the genetic diversity of two species. The Brisbane tree probably was a natural hybrid between the two edible *Macadamia* species, *Macadamia integrifolia* and *M. tetraphylla*.

Even though the world's first macadamia farm was established at Rous Mill in northern NSW in 1882, it was in Hawaii that the industry flourished. Their macadamias have been marketed so successfully that most international tourists now leave Honolulu convinced the 'Hawaiian nut' is native to the islands.

While the Australian industry slumbered, Hawaiian growers and breeders were selecting high-yielding cultivars whose nuts were tasty and productive. When a new wave of commercial plantings swept Australia in the 1970s, grafted Hawaiian cultivars were the best commercial stock available. Most modern Australian orchards therefore contain trees descended from Purvis's 'pocketful'.



Nutborer is the major pest of macadamias and if not controlled can cause serious losses. Larvae tunnel within the husk and kernel before shell hardening and cause premature nut fall. Nutborer eggs can be seen on the lower left of the damaged husk. The larvae appear to survive better in some varieties than others, offering hope that resistant trees can be developed.

Creating the perfect snack

Macadamias are members of a great dynasty of flowering plants that emerged from the humid rainforests of the southern supercontinent of Gondwana early in the Cretaceous period some 130 million years ago. From ancient DNA preserved in living Australian trees, McConchie's team plans to breed thoroughly modern macadamias that will ensure Australia dominates the industry in the 21st century.

'The major focus of the new breeding program is to increase disease resistance, thereby reducing or eliminating the need for the presently low levels of chemical control,' McConchie says. 'One of the best methods of biological control is to begin with disease-resistant trees.' A range of cultivars is being screened for resistance to a common fungal pathogen called husk spot, and to the macadamia nut borer (some trees are thought to have a less penetrable husk).

Queensland's Department of Primary Industries (QDPI) and New South Wales

The Australian Macadamia Society is funding a new breeding program that will borrow traits from wild macadamia species to improve both the efficiency of Australian orchards and the quality and variety of nuts they produce.





Most existing cultivars begin flowering between three and six years of age. A priority of the breeding program is to select trees that have a shorter juvenile phase.

through the manipulation of growing conditions. 'We also hope that by understanding more fully the composition of the nuts' oils and sugars we will throw light on their processing characteristics (such as their response to roasting) and shelf life,' McConchie says.

'We are keen to learn from established industries such as wheat and beef which have diversified their products to suit particular end uses and developed objective techniques for quality measurement. This will help us to get the greatest value from our germplasm as quickly as possible.'

An example of this might be the breeding of cultivars that produce smaller nuts, offering a diversity of product to suit the needs of growers, confectioners and the all-important nut eaters. 'If you're using macadamias in confectionery, you don't want gobstoppers,' McConchie says.

'Macadamias are more expensive than chocolate, so it's cheaper for a manufacturer to put fewer, smaller nuts into a chocolate bar. And people buying roasted macadamias may feel they are getting better value if they get 30 small nuts instead of 10 big ones.'

The ideal commercial macadamia tree will grow to about seven metres, little more than half the height of today's varieties (right). The smaller trees will be more manageable in orchards, and will invest a greater share of energy in nut production. *Macadamia jansonii* (below), the 'runt' of the genus, could provide genes for more compact cultivars.



Populations lost

The two edible macadamia species are indigenous to the coastal ranges between Lismore and Gladstone. But a combination of logging, dairying and sugarcane farms have decimated the sub-tropical rainforest that once existed there.

There is no way of knowing what genetic riches may have been lost due to clearing and development, but McConchie's team is pleasantly surprised at what remains. Dr Julia Playford of The University of Queensland's botany department has sampled the DNA of about 10 remnant populations of wild macadamias and found a wealth of genetic variation. As this is an ongoing project, more surprises may be in store.

'The more botanists look at the surviving wild populations of macadamias, the more genetic diversity is being discovered,' McConchie says. 'It's amazing that these trees with edible, commercial-quality nuts are just sitting there, in such a highly developed, heavily populated area.' But even these surviving trees are under threat, in part due to age and isolation.

Last year University of New England botanist Dr Caroline Gross conducted a

Agriculture are an integral part of this project. Dr Peter Mayers of QDPI will screen cultivars for resistance to husk spot, and those resistant to nut borer will be selected by Gus Campbell of NSW Agriculture. The involvement of these researchers, both of whom have extensive experience in their field, will ensure the optimum use of Australian expertise during the new macadamia breeding program.

An early priority of the program will be to select trees that have a short juvenile phase. These will flower sooner, giving early returns to the growers. At present, most cultivars take three to six years to flower, returning commercial yields in their seventh or eighth year. 'We aim to prune this schedule by at least two years,' McConchie says. 'Although all future components of the program will benefit from a shortened breeding cycle, it is expected that 10 to 15 years will be needed to develop new cultivars improved by the introduction of wild genes.'

Other traits to be examined during the breeding program include tree size and nut yields and characteristics. Existing cultivars yield well (between 20 and 30 kg of nuts at maturity), but their large size (up to 10 metres) hampers their capacity to produce stable yields. The large trees intergrow, making it difficult for machinery to penetrate the orchard rows, and yields appear to decline due to self shading. 'The ideal macadamia tree will probably grow to about seven metres, little more than half the height of today's varieties,' McConchie says. 'We will be selecting trees that put more energy into producing greater quantities of high quality kernel, instead of structural wood and leaves.'

Another part of the project aims to understand how nut quality can be influenced by the macadamia's genes and environment. More desirable characteristics can then be amplified, by breeding, and





In most commercial orchards, European honeybees (above) pollinate macadamia flowers. When native *Trigona* bees (left) perform the same service, yields can be up to 20% higher.

botanical revision of the genus *Macadamia* for Volume 16 of *Flora of Australia* (see boxed story on page 21). Her revision of the genus recognises nine *Macadamia* species: four from south-eastern Queensland and northern NSW, four from the rainforests of north-east Queensland and Cape York peninsula, and a lone species from the Indonesian island of Sulawesi. (Macadamias are curiously absent from the rainforests of New Guinea.)

During field surveys near Lennox Head, just north of Ballina, Gross found two old, isolated trees of *M. tetraphylla* in a patch of rainforest. More than 400 metres away, across pastureland, she found several other trees in a larger patch of rainforest. While the species is well conserved in reserves north of Ballina, Gross says the viability of these small, scattered, orphan populations is in doubt because little is known about the population size needed to sustain macadamias.

In most commercial orchards, European honeybees pollinate macadamia flowers. But McConchie says that when native *Trigona* (stingless) bees perform the same service, yields can be up to 20% higher. The decimation of rainforests in heavily-cleared areas of northern NSW has made *Trigona* bees scarce, and isolated, aging trees may no longer be producing enough seeds to perpetuate the bees' precious genes. In other areas where surviving forest remnants harbour good

Trigona populations, a critical issue may be the capacity of the bees to carry pollen between patches of trees.

A more encouraging sign is the discovery by Gross that the size and shape of macadamia flowers varies considerably within and between populations in different areas. Some *M. tetraphylla* trees have pink rather than cream flowers. Such visible traits are an indication of the hidden genetic wealth that awaits breeders.

Populations found

Another discovery that demonstrates the potential value of wild plants to a commercial breeding program was made by amateur naturalist Ray Jansen. In 1982, Jansen found a small, isolated population of low-growing trees with small nuts in a patch of rainforest near Gladstone. The 'runt' of the genus, *M. janseni*, grows to seven metres and McConchie believes it could provide genes for more compact cultivars. It may also help to overcome a major limitation to the expansion of Australia's macadamia industry: a shortage of suitable land.

McConchie says existing macadamia cultivars are temperature sensitive and do not grow well in conditions above 30°C. *M. janseni* is the most

northerly growing of the four southern-growing species (*M. integrifolia*, *M. tetraphylla*, *M. ternifolia* and *M. janseni*), and therefore may be more heat tolerant. If cultivars could be bred with this trait, orchards could be established in more marginal areas further north.

M. janseni could easily have slipped into extinction before it came to the notice of botanists. It almost certainly grew more widely in the recent past. McConchie says botanists have recently found trees with features intermediate between *M. janseni* and another macadamia species, *M. ternifolia*, which ranges between Brisbane and Gympie.

These trees may be natural hybrids or even a new species, McConchie says. Along with *M. ternifolia*, which has small, relatively thin-shelled nuts, they could allow breeders to develop a peanut-sized macadamia for the snack food and confectionery industries.

At the other end of the scale, the macadamias from tropical north-east Queensland are giants, towering 30 or 40 metres into the rainforest canopy. Their nuts are much bigger than those of the southern species, none more so than those of *M. claudiensis*, a recently described species from the Iron Range north of Cooktown. *M. claudiensis* produces nuts up to six centimetres in diameter, without a hard shell.

A macadamia minus its hard shell would reduce the cost of processing, and consumers might like the idea of munching on a mandarin-sized nut. But McConchie says the giant nuts are extremely bitter and toxic. A first, exploratory taste is usually enough to deter the hungriest predators (including humans) from ingesting a lethal dose. All species except *M. tetraphylla* and *M. integrifolia* are presumed to have toxic



M. tetraphylla L.A.S. Johnson

M. integrifolia Maiden and Betche

M. ternifolia F. Muell

M. janseni Gross and Weston

M. whelanii F.M. Bail

Wild macadamia nuts vary in size and toxicity. A knowledge of how to manipulate cyanide production will help scientists to develop non-toxic cultivars in a range of nut sizes.



Interspecific macadamia crosses. The Australian research team was the first to define which species interbreed.

nuts, although Gross says that Aborigines are reputed to have eaten the very large, bitter nuts of *M. whelanii*, probably after a prolonged period of leaching in water to remove cyanogenic compounds.

Macadamia plants employ a variety of tactics to defend their protein and oil-rich seeds against would-be predators. While many species are protected by the presence of cyanide in their kernels, the two edible macadamia species (*M. integrifolia* and *M. tetraphylla*) have cyanide-free kernels which they protect with a formidable physical barrier: a tough, thick shell.

Two species from southern Queensland (*M. ternifolia* and *M. jansonii*) seem to have taken the middle road, producing small, relatively thin-shelled seeds containing moderate levels of cyanide. The small size of their nuts may also be a subtle deterrent to predators, which would have to collect and crack more nuts to make a meal.

McConchie says desirable genes from these species are readily accessible, because they hybridise with the two edible species. But none of the four Macadamia species from north-east Queensland hybridises with the southern species, reflecting their long evolutionary isolation. More advanced breeding techniques therefore may be required.

Cracking the cyanide defence

University of Queensland post-graduate student Adam Vivian-Smith, working in McConchie's CSIRO laboratory, measured levels of cyanide compounds in the seeds of the four southern macadamias, (*M. integrifolia*, *M. tetraphylla*, *M. ternifolia* and *M. jansonii*) and of *M. claudiensis* and *M. whelanii* from north Queensland. He describes the huge, shell-free nuts of *M. claudiensis* as 'hypertoxic', while the two bitter-tasting southern species, *M. ternifolia* and *M. jansonii*, have lower cyanide levels.

Ripe nuts from commercial hybrids and their edible parent species are free of cyanide. In 1992, however, another post-graduate student from the University of Queensland, Janelle Dahler, was surprised to find that when the nuts are germinating, they contain even more cyanide than the bitter kernels of *M. ternifolia*. Fallen nuts that absorb moisture then become bitter and inedible, and young seedlings have high cyanide levels in their leaves.

Dahler suspects these species time their cyanide production so that the genes switch on only when the nuts are vulnerable to predation: before the shell develops, and when it is cast off during germination. Her research could help reduce production losses due to nuts turning bitter after falling to the ground. Subsequently, Vivian-Smith found that cyanide also accumulates in the shell and husk of the edible nuts, but not in the kernel, during the pre-ripening stage, while they are still green and soft.

Vivian-Smith says that plants other than macadamias – including stone fruits such as apricots and the tropical grain sorghum – use a similar form of defence for their seeds and leaves. Genes involved in the cyanogenic pathway have been well-studied in sorghum, which also synthesises a cyanide precursor molecule called dhurrin in its shoots. The first key step for the production of dhurrin and other cyanogenic compounds is catalysed by an enzyme called a cytochrome p450. After synthesis, dhurrin can be in turn cleaved by an enzyme called beta-glucosidase to release the cyanide. However, most plant species store cyanogenic compounds in different tissues to beta-glucosidases to prevent large

If the cytochrome p450 enzyme could be 'switched off', species such as *Macadamia ternifolia*, with its small but toxic nuts, would become edible.

scale release of cyanide. Therefore it is only upon tissue disruption that cyanide is released in large quantities (such as by chewing the nut). Macadamias and their relatives also synthesise dhurrin and proteacin (a closely related compound), as well as possessing beta-glucosidases that release their cyanide.

Vivian-Smith says that both the cytochrome p450 and beta-glucosidase genes have been cloned from other species, such as sorghum and cassava, and could serve as genetic probes to isolate the equivalent genes from macadamias. If the cytochrome p450 gene could be switched off, it would block the cyanogenesis pathway, so that a species such as *M. ternifolia*, with its small but toxic nuts, would become edible. The challenge would be to manipulate the gene so that it was selectively silenced in the kernel, but not in the seed coat or outer husk, where cyanide may be a valuable deterrent to insect attack.

Another possibility is to increase or alter the activity of the beta-glucosidase gene, so that all the cyanide is released from the plant's tissues and dispersed before the nut ripens. A more conventional approach would be to hybridise the edible species with the cyanogenic species, to yield non-cyanogenic hybrids with some of the desirable characteristics of the smaller, inedible species. Whatever techniques are adopted, the outcome is bound to represent a significant return on investment for Australia's macadamia industry.

More about macadamias

Dahler JM McConchie CA and Turnbull CGN (1995) Quantification of cyanogenic glycosides in the seedlings of three Macadamia (Proteaceae) species. *Australian Journal of Botany* Volume 43(6), pp 619-28.

Gross CL (1996) Macadamia. In *Flora of Australia* Volume 16, pp 419-425.

