A MAKEOVER FOR THE WORLD'S MOST HATED CROP

Oil palm has a reputation as an environmental menace. Can the latest genetic research change that?

BY WUDAN YAN

Nathan Lakey practically has to shout to be heard over the whirring machinery in the laboratory at Orion Biosains near Kuala Lumpur. One source of the din, and a major point of pride for Lakey, is a microwave-oven-sized robotic assembler that is snapping plastic widgets together and laser-etching them with serial numbers. The devices are leaf punches, destined for Indonesia, Malaysia and Myanmar. And Lakey — an American biochemist and chief executive at Orion — hopes that they will help revolutionize a much-maligned industry.

Palm oil is a commodity that generally evokes images of mass deforestation, human-rights violations and dying orangutans. In Indonesia and Malaysia, where some 85% of the world's palm oil is produced, more than 16 million hectares of land — rainforest, peat bogs and old rubber plantations — have been taken over by oil palm, and there is no sign of the industry slowing down.

Despite its bad reputation, oil palm is the most productive oil crop in the world. Oilseed rape (canola) currently produces only about one-sixth of the oil per hectare — soya bean only one-tenth. But oil-palm plantations still aren't getting as much as they could out of their plants.

The main problem is that genetic and epigenetic variables can cause some palms to underproduce. And because oil palms mature slowly, growers typically don't know for three to four years whether the trees they plant will turn out to be star performers or worthless wood.

That's where Orion comes in. When the leaf punches sent out around southeast Asia return, Orion technicians process the disc of greenery within and can send growers a report on the quality of their young plants. Lakey predicts

Oil-palm fruit ready for processing in Myanmar.

TAYLOR WEIDMAN

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Oil-palm plantations have replaced millions of hectares of rainforest across Southeast Asia.

that, if adopted on a large scale, the test could raise industry revenue by about US$4 billion per year. And, importantly, it could do so without expanding plantations. "We can get more oil for an equivalent area of land — this could help take the pressure off deforestation," Lakey says.

Scientists applaud Orion for trying to apply decades of research on oil-palm genetics across the industry. But the company's grand plans aren't guaranteed to bear fruit. Its efforts are being threatened by poor regulation, political corruption and significant inertia, particularly among the smallholding farmers, who produce about 40% of the palm oil consumed worldwide. "Unless you also have a better national system to provide the finances, training and technical assistance, the science won't have the impact that it should," says Andrew Bovarnick, global head of the Green Commodities Programme at the United Nations Development Programme in Panama City. Some experts even worry that boosting the productivity of the trees could do more harm than good.

GOOD SHELLS, BAD KARMA

Oil-palm plantations carpet the landscape north, east and south of Kuala Lumpur. From above, they look tidy and lush, but at ground level they are muddy, hilly and a world away from the high-tech sterility of Orion's lab. Workers trudge among the rows, hoisting long poles with scythes at the end into the canopy to bring down spiky bunches of fruit. The bunches are then brought to the main roads so that trucks can load and transport them to the mills.

Slicing open one of the golf-ball-sized fruits reveals an orange outer mesocarp, which generates the oil used for cooking and processed foods, then a brown shell that separates the mesocarp from the white palm kernel. Kernel oil is typically used in cosmetics, soaps and detergents.

Although the plants largely look the same, growers know that there are three types of seed and that they yield dramatically different amounts of oil: dura, pisifera and tenera. Dura seeds produce a thick-shelled fruit with little oil. Pisifera seeds tend to abort during development, but when they do produce fruits, they are often shell-less. Tenera seeds, a hybrid of pisifera and dura, produce a nice thin shell and copious oil. The gene that controls shell thickness, creatively named *SHELL*, was identified in 2013 by researchers at Orion, Cold Spring Harbor Laboratory in New York and the Malaysian Palm Oil Board (MPOB), a government research institute based near Kuala Lumpur[1].

Conventionally, plant breeders generated tenera seeds by taking pollen from male pisifera trees and crossing it to flowers belonging to the female dura. The seeds mature and can germinate nine months later. Saplings need to spend a year in a nursery before they can be planted in the field, and trees don't start bearing fruit for another 3–4 years; they can then be productive for the next 20–30.

Breeding is time-consuming and doesn't always produce the best seeds. So, in the 1970s, scientists turned to cloning. Researchers realized that they could cut open the top of the trunks of their highest-yielding trees, extract stem cells and grow up clones by the thousands in lab dishes. At first, clones helped to increase oil production on plantations, but in 1977, something strange started to happen.

At the time, Tan Yap Pau was a plant breeder and researcher at United Plantations, a Danish palm-oil company based in Malaysia. Field assistants started noticing atypical fruits forming on a plot of land that was populated by clones, and brought them to Tan. The fruits were jagged, disfigured and tulip shaped. Tan knew from his research that young plants could develop abnormally in culture, but he took these misshapen fruits as a bad omen. Many of the 'mantled' fruits produced no oil at all, despite being genetically identical to high-yielding plants.

It took nearly 40 years to unpick the mystery. In 2015, Meilina Ong-Abdullah, a plant biotechnologist at the MPOB — and, coincidentally, Tan's niece — identified the culprit[2]. She and her colleagues found *Karma*, a mobile piece of DNA known as a transposon, inserted in the middle of an important gene for normal oil-palm fruit development called *DEFICIENS*. Cells can silence transposons by attaching methyl groups to them. The fruit develop normally when *Karma* is highly methylated (scientists call this *Good Karma*). But low methylation — *Bad Karma* — results in mantled fruit.

In addition to selecting for tenera seeds with *Good Karma*, there are other traits in the plant that could be mined for optimization. Rajanaidu Nookiah, a plant breeder at the MPOB, spent more than 30 years travelling the world to understand natural variation in oil palm. He has amassed more than 110,000 oil-palm seedlings — the largest collection in the world.

His specimens host a number of traits that plant breeders would want to see in oil-palm trees. According to Sime Darby, one of the largest palm-oil corporations in Malaysia, the ideal tree would not only yield a lot of oil, it would also be on the shorter side, making it easier to reach fruit stalks. The fruit stalks themselves would be longer and therefore easier to cut. The trees would be more resistant to disease. And the fruit would contain more carotene and iodine, so the oil would potentially be healthier for consumers.

PUNCHING UP

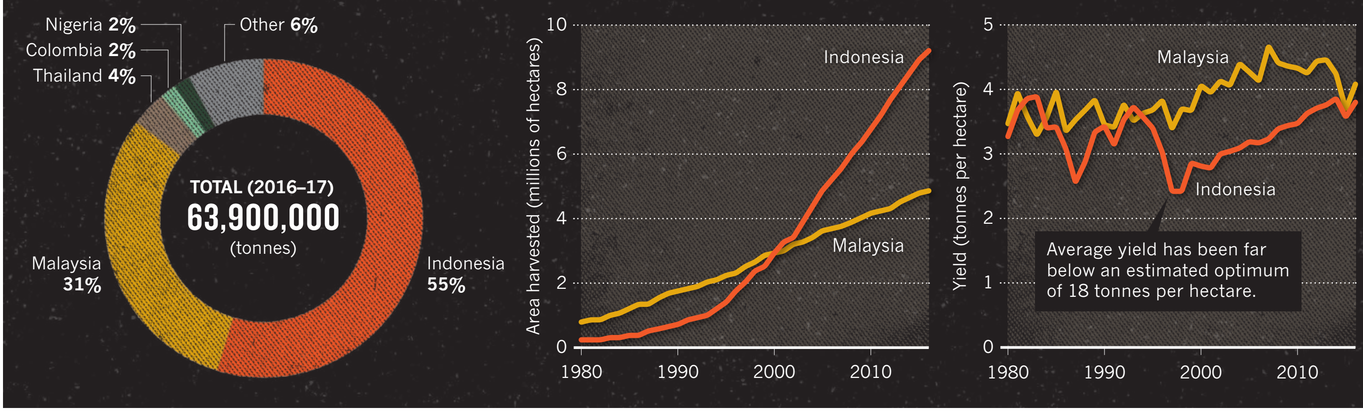
Being able to look at *SHELL* and *Karma* alone could have a huge impact on the industry, according to Lakey. In theory, growers can squeeze as much as 18 tonnes of oil in a year from one hectare of oil palm, but currently they are attaining only about 4 tonnes per year on average (see 'Mass production'). Smallholders typically perform the worst. Without in-house research facilities to help breed and identify the best plants, they generate about half the amount of oil per hectare that large plantations can.

Lakey is hoping that the leaf-punch tool that Orion sells can benefit smallholders. For about $4 per tree, Orion can screen for hybrid tenera palms with *Good Karma* and help farms and nurseries cull unproductive plants before investing too much time and resources in them. The company is looking to incorporate other genes, too, such as a gene variant that makes fruits change colour more dramatically as they ripen. This could reduce the likelihood of harvesting immature fruit.

But reaching smallholders could be difficult. They are generally either independent or part of cooperatives, in which case they get planting

MASS PRODUCTION

Indonesia and Malaysia produce some 85% of the world's palm oil. Although the land area devoted to oil palm has been increasing more rapidly in Indonesia than in Malaysia, Indonesia's yield — the amount of oil produced per hectare — has generally been lower. It remains to be seen whether boosting yields will help to stem the deforestation associated with the industry.



SOURCE: US DEPARTMENT OF AGRICULTURE

materials and assistance from a nearby corporation. In Malaysia, independent smallholders get planting material that has been validated by the MPOB from trusted oil-palm breeders, but that layer of quality control doesn't exist in Indonesia. According to Tri Widjayanti — national project manager for the United Nations Development Programme's Sustainable Palm Oil Initiative Project in Jakarta — many of Indonesia's independent smallholders lack the resources to obtain the best plants.

If farmers can't access a nursery or don't have the finances to buy high-quality seeds, they may just grow whatever falls from their trees. The offspring of high-oil-producing tenera hybrids will generate high-yielding progeny only about half the time. Researchers have found that non-tenera palms constitute about 11% of the planting material on smallholders in Malaysia[3].

But it's not just about seeds. Many of those farmers can't afford good fertilizer let alone keep abreast of the best farming practices. "These smallholders don't necessarily need seeds with a better genome," says Bovarnick, who has worked in Indonesia since 2010. Moreover, smallholders have little incentive to plant the most productive trees because they are often paid for their fruit by the kilogram. Some farmers have learnt that mantled fruits soak up moisture and gain weight in the night time. They have used this fact to their financial advantage.

"Smallholders know about contamination, but they don't care," Lakey says. Some mills, he adds, are starting to assess fruit quality over weight. That could shift incentives. But others are sceptical that any technology can actually amend palm oil's destructive reputation. "The current system on the ground cannot deliver deforestation-free palm oil," says Cynthia Ong, executive director of Forever Sabah, a non-governmental organization focused on environmental issues in Malaysian Borneo. "When we go into the field or hold workshops, villagers say, 'I want to take all my remaining land that's rainforest and just grow oil palm'." For these villagers, palm oil seems to be the easiest way to make money from the land.

In areas of Indonesia and Malaysia, the economic and political agendas of international investors, corporations and local officials might also thwart Orion's efforts. Agus Sari — chief executive of the Belantara Foundation, a non-profit organization focused on environmental conservation and rehabilitation in Jakarta — says that weak law enforcement is a major challenge. Large plantations bribe local officials to give them additional land titles, making it hard for others to obtain them legally. The same is true in Malaysia, according to Ong.

"ADVANCES TO INCREASE YIELD MUST BE ACCOMPANIED BY STRICTER REGULATION."

And although scientists might think that yield-improving technology will decrease the pressure to clear more land, others predict the opposite. Technological boosts to efficiency could increase the profitability of palm oil, making it even more attractive to developers. "Advances to increase yield must be accompanied by stricter regulation and legal limits to the amount of land that can or should be devoted to palm oil," says Jeff Conant, who directs the international forests programme for Friends of the Earth, an environmental-justice organization in San Francisco, California.

Reforming the industry will require broad buy-in, and there is some promise that this is starting. In 2004, industry members formed the Roundtable for Sustainable Palm Oil (RSPO), which established standards of practice and a label for producers that comply. But the group has a backlog of complaints about non-compliance of its members. One Malaysian company, IOI Group, had its status suspended last April and then reinstated in August, leading some to question the credibility of the RSPO label. Darrel Webber, chief executive of the RSPO, acknowledges that there is room for improvement. "The only way for us to provide solutions is if others provide feedback to us."

Despite the challenges, Lakey is undeterred. Back in the noisy lab space, technicians are analysing samples — more than 1,000 per day. And Lakey wants to start sending punches to Africa, South America and Thailand soon, and to analyse up to 10 million punches per year. Part of what drives him and the other scientists he works with is the knowledge that demand for palm oil is rising, even as the land to grow it on dwindles. Compared with global demand for palm oil in 2000, demand is expected to double by 2030 and triple by 2050.

"I don't see any other crop that can satisfy the world's needs," says Raviga Sambanthamurthi, a biochemist and former director of the MPOB's Advanced Biotechnology and Breeding Centre. "We don't have much more land to open up, so we have no choice but to make oil palm more productive." ■

Wudan Yan *is a journalist in Seattle, Washington.* *Travel funding was provided by the Pulitzer Center on Crisis Reporting.*

1. Singh, R. *et al. Nature* **500,** 340–344 (2013).
2. Ong-Abdullah, M. *et al. Nature* **525,** 533–537 (2015).
3. Ooi, L. C. *et al. Front. Plant Sci.* **7,** 771 (2016).