Coffee to go: Is this the end of our favourite drink?

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With global warming threatening the future of the world's coffee beans, the hunt is on for ways to keep the caffeine flowing.

COFFEE-LOVERS be warned. Whether you are a three-double-espressos-a-day addict or just indulge in the occasional cappuccino, enjoy it while you can: a coffee drought may be on its way. Changing climate threatens to reduce the flow of coffee that fills 1.6 billion cups a day to a trickle. It may not be long before that after-dinner espresso costs more than the wine and some caffeine addicts will be forced to go cold turkey.

If that prospect fills you with dread, you are not alone. There are some 26 million farmers who depend on coffee to feed their families. Coffee is the most valuable tropical export crop, and as the world's favourite drink it is big business. Our seemingly insatiable appetite for macchiatos and lattes has made coffee the second most traded commodity after oil, with exports worth a whopping $15 billion a year. All that is under threat because the coffee industry is built on a plant that is peculiarly vulnerable to our changing climate.

We may already be seeing signs of what's in store. Rising temperatures and erratic rainfall have sent yields plummeting in key coffee-growing countries. And with every bad harvest, the price of coffee soars. With so much at stake, the hunt is on for ways to future-proof the industry. But time is short and the options limited. So what are the chances of keeping the coffee flowing?

Coffee cultivation began around the 6th century when a few trees from the highlands of Ethiopia found their way to Yemen. But the coffee-drinking habit really took off in the 17th and 18th centuries, when Europeans established plantations in their tropical colonies. Today coffee is grown in 70 countries. Around two-thirds of beans come from just one species: Coffea arabica, the original tree plucked from Ethiopia all those centuries ago. Arabica beans have a mild, delicate flavour that attracts the high prices that make it possible for millions of subsistence farmers to make a living growing coffee. But it is this reliance on a single species that threatens your daily fix.

As a plant that evolved in the understorey of cool, cloud-capped forests at altitudes between 1000 and 2000 metres, C. arabica is very picky about the conditions in which it will grow. It flourishes best at a fairly constant 18 to 21º C. As the temperature rises, trees become stressed and yields fall. Exposed to long periods above 30º C, their leaves fall and tumours appear on the stems. But well before then, at temperatures above 23º C, the development and ripening of berries accelerates, resulting in poorer quality beans. "Just a couple of degrees extra and beans lose their fruitiness and acidity and the coffee is bland," says Tim Schilling of World Coffee Research, a global network of research institutions funded by the coffee industry. With emissions of greenhouse gases currently tracking the worst-case scenario of the Intergovernmental Panel on Climate Change (IPCC), we're on course for a global temperature rise of 4º C by the 2060s, and between 5 and 6º C by 2100 (*New Scientist*, 17 November, p 34).

Coffee trees are fussy about water, too. "Coffee is very demanding," says Peter Baker, a coffee specialist at CABI, a not-for-profit organisation that advises farmers in developing countries. "It needs dry weather to build up buds and then rain to trigger flowering. But if it then rains too much, the fruit doesn't set." Once the berries are growing they need showers while they swell and mature. "What they need is increasingly what they are not getting," he says.

Climate models predict that rising temperatures in the tropics will be accompanied by changing patterns of rainfall, more extreme weather and more frequent El Niño and La Niña events. Some regions will see prolonged drought, while others will be inundated. Expected shifts in seasonal rains and cloud cover will hit coffee growers hard. To add to their woes, the changing conditions will also see pests and diseases spread into new areas, just as their crops become increasingly vulnerable.

The most damaging pest of all, the coffee berry borer, is predicted to spread rapidly into higher altitudes as they warm (see "Evil weevil").

There is mounting evidence that coffee-growers are already feeling the effects of global warming. "The main areas of worry are East Africa, where the climate is increasingly variable with more drought, and Central America, where we are starting to see lots of effects from changing climate," says Baker. Colombia, the second-largest producer of Arabica beans after Brazil, provides a stark warning of what could be in store. From 2009 to 2012, growers experienced three years of almost non-stop rain. Without the dry period the trees need and with an epidemic of fungal disease, yields plunged to a 35-year low. "Generally, in all coffee regions, the sorts of changes we are seeing and that farmers are telling us about are consistent with the climate models," says Baker. "In fact, often what we see now is worse than we had expected."

With so much to lose, growers need help fast. In the short term, it should be possible to counter some effects of warming, perhaps by growing shade trees to help keep the coffee cool or using mulching and irrigation to combat water shortages. But if it is too wet, there is little that can be done, says Baker. His organisation is developing strategies to help growers adapt. "There's no magic bullet," he says. "You need to go to each area, figure out what's happening and design a package of measures for the short and medium term."

Trouble brewing

Faced with a threat of such magnitude, the logical strategy for the longer term would be to breed more resilient Arabica trees. But breeders face a major obstacle: almost all the trees in cultivation are descended from the handful transported to Dutch and French colonies in the 17th and 18th centuries. The result is a tiny gene pool, containing as little as 1 per cent of the genetic variation in the species as a whole. "All breeding programmes are essentially using and re-using the same genetic material," says Schilling.

He and his colleagues at World Coffee Research are looking beyond the plantations for more variety. A number of coffee-growing countries have "field genebanks" - collections of Arabica trees that include mutants with unusual characteristics and trees grown from seed acquired in Ethiopia in the 1960s. These contain at least 10 times as much genetic diversity as cultivated trees, says Schilling, and could be used to create a population of superdiverse trees for breeding. "This is our best shot at developing climate-change resilient varieties and hybrids that can be ready for distribution to farmers by the early 2020s," he says.

If these few hundred trees hold untapped potential for breeders, then how much more might there be in the wild? "Trees growing in different parts of the species' natural range will have different characteristics, and unlike the trees in plantations and collections, these continue to evolve and adapt," says Aaron Davis, head of coffee research at the UK's Royal Botanic Gardens in Kew. Economists estimate that the genetic resources contained in Ethiopia's wild coffee trees are worth between $0.5 and $1.5 billion a year to the industry. However, access to this great repository will have to wait until the thorny issue of biological property rights is settled, and that could take years. Ethiopia is very protective of its natural resources, all the more so since its attempt to trademark its most famous beans in 2006 led to a protracted wrangle with US coffee giant Starbucks.

Ethiopia's wild trees may hold the key to coffee's future, but alarmingly they are also at risk. Late last year, Davis dropped a bombshell: with climate change on its current trajectory, Arabica coffee could be extinct in the wild within decades (PloS One, vol 7, e 47981). Davis and colleagues from Kew and Ethiopia mapped the places people have recorded wild Arabica growing and found that the largest and most diverse populations are in the highlands of south-west Ethiopia, with satellite populations in the Bale Mountains and on the Boma Plateau just across the border in south-east South Sudan (see map). The team then modelled the likely present-day distribution of the species, based on where habitat and climate meet its requirements. Alarm bells began to ring when they went on to model how those conditions might change over the rest of the century.

The results suggest that under the IPCC's most optimistic scenario for future carbon dioxide emissions, 65 per cent of the places where wild coffee now grows will have become unsuitable by 2080. Under the IPCC's worst-case scenario, that figure rises to 99.7 per cent. "Our analyses are conservative," says Davis. "We haven't taken into account deforestation and changing land use between now and 2080. And there will be other ecological changes, such as the disappearance of birds that disperse coffee seeds." Nor does the model include the worsening impact of pests and diseases. "What the model shows is that climate change alone could lead to the extinction of wild Arabica," he says.

On an expedition to the Boma Plateau last April, Davis and Schilling got a glimpse of the future. They went looking for what was described in 1941 as a forest of tall, healthy Arabica trees. What they found were weedy specimens struggling to produce flowers, with few seedlings to replace them. "The model predicts that this place will be unsuitable for Arabica coffee by 2020," says Davis. "It certainly looks as if it could be gone within 10 years. It was a shock to see the state of those trees. But it does suggest the model has validity." That's important because it also pinpoints Arabica populations that might be able to tough it out until 2080. "What we need to do now is thoroughly assess those 'core' localities so that they can be appropriately managed for the long term," he says.

Robusta alternative

One day, genes from wild Arabica could be used to create trees for cultivation that can cope with climate change. But Arabica isn't the only species of coffee and, with its future so uncertain, others are starting to attract attention. Coffea canephora, which currently provides a third of our coffee, is the most obvious. Known in the trade as Robusta, it is native to the hot, steamy forests of lowland Africa. It is hardier than Arabica and thrives at between 22 and 26º C, although it cannot tolerate much higher temperatures or drought. And then there's the taste. Its beans give a strong, bitter brew and most are blended with Arabica to make instant coffee. Although widely grown in lowland regions of Brazil, Vietnam and India, the lower prices they fetch mean that, for most Arabica growers, switching to Robusta is not an option. But that might change if something could be done to improve Robusta's flavour.

Like Arabica, Robusta coffee could benefit from some gene hunting in its original home. "Somewhere in central Africa there might be the raw material to produce more flavoursome beans," says Davis. Speciality coffee companies have started to broach the subject, says Schilling. "The species has a lot to offer. If you work on it genetically, in all likelihood you could produce a decent cup."

Davis points out that there are plenty of other species of coffee. In the 15 years he has been studying the coffee family, he has discovered 22 new species, bringing the total so far to 125. "Many are used locally and there are reports that some wild species produce a good cup of coffee," he says. Even if their beans will never replace Arabica, some may have genes that could help Arabica adapt. "There are several species that thrive in temperatures well above 30º C. They could be useful for breeding."

As coffee supplies start shrinking, an industry that relied almost entirely on one type of bean will itself be forced to adapt. "Who knows, by mid-century we may be drinking an alternative species of coffee," says Davis. The current crisis is a challenge we simply have to meet. "We can't just write off coffee. Too many people depend on it."

Evil weevil

The coffee berry borer, Hypothenemus hampei, is a small weevil that attacks the most valuable part of the coffee plant - the beans. Females bore their way into coffee berries and excavate galleries inside the beans, where they lay their eggs. The emerging larvae consume still more of the beans. Unusually, they can break down caffeine, which kills most other insects.

Responsible for losses worth some $500 million each year, this tiny beetle is already one of the coffee industry's worst enemies. The borer is native to lowland equatorial Africa, but in the past century it has been introduced to every coffee-growing country except China and Nepal. "With so much exchange and trading between coffee-growing regions it's only a matter of time before it turns up there as well," says Juliana Jaramillo of the International Centre of Insect Physiology and Ecology in Nairobi, Kenya.

Climate change is also on the borer's side. In 2009, Jaramillo predicted that a rise in temperature of just 1 ⌊C would lead to more serious damage to Arabica crops as the borer proliferated faster - doubling the number of generations a year - and pushed into higher altitudes. "It seems that this is already happening," she says. Reports indicate that the weevil has migrated almost 200 metres in altitude in Indonesia and Uganda. "In Tanzania, it has travelled 300 metres up Mount Kilimanjaro in the past decade."

More recently, Jaramillo modelled the likely spread of the coffee berry borer in East Africa, based on climate change predictions for the region (PLoS One, vol 6, p e24528). The results suggest that by 2050, outbreaks of borer will have worsened in some of the best Arabica growing regions of Ethiopia, Uganda, Kenya, Rwanda and Burundi. The higher temperatures would also see the number of generations of borer per year soar to 10 or more.