Crop strength through diversity

Martin S. Wolfe

In conventional farming, single varieties of crop plants are grown alone. But mixing varieties may be a better option: several rice strains, planted together on a large scale, are more resistant to a major fungal disease.

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Figure 1 **The main disease of rice (rice blast, pictured inset) spreads more slowly in mixtures of rice varieties than in monocultures, as Zhu *et al.*[1] discover in their large-scale experiments in China.**

Attempted solutions to the problems caused by modern agriculture, such as the overuse of fertilizers and pesticides, are usually expensive and often lead to new problems. But this need not be so, as Zhu and colleagues show on page 718 of this issue[1]. By growing a simple mixture of rice (*Oryzae sativa*) varieties across thousands of farms in China, they restricted the development of rice blast — the most significant disease of rice, caused by a fungus — to levels that are both acceptable and require no treatment with fungicide. This approach is a calculated reversal of the extreme monoculture that is spreading throughout agriculture, pushed by new developments in plant genetics.

Until about 100 years ago, monoculture was practised only at the level of species, with, for example, wheat, maize or rice becoming dominant in different climatic regions. Monoculture has since expanded to different levels, reducing the numbers of species, of varieties within species, and particularly of genetic differences within varieties. Monoculture is convenient: it is easier to plant, harvest, market and identify one variety of crop than several.

But there is a problem. If, for example, all the rice plants in a field are identical, a pathogenic fungus able to attack one plant has a potentially unlimited opportunity to spread throughout the field. At the moment, the solution is either to breed resistant varieties or to develop new fungicides. But the limitless potential for pathogen spread in monocultures leads to rapid selection of pathogens that can overcome resistant crop varieties and survive in the presence of fungicides. Continual replacement of crops and fungicides is possible, but only at considerable cost to farmer, consumer and environment.

A different approach is to reverse the tide of monoculture by growing several pathogen-resistant varieties as a mixture within a field. Darwin[2] knew that mixtures of wheat are more productive than single varieties, but explanations for this phenomenon were lacking. It later emerged that mixtures restrict the spread of pathogens and, as a consequence, of disease. The explanation for this phenomenon is complex. The presence of several varieties in a mixture provides a physical barrier to the spread of fungal spores among the plants of one variety. But this is not the only explanation. For example, there is an immunization process among mixed plants. If a form of pathogen that is unable to infect a plant attempts to do so, the plant's disease-resistance mechanisms are activated in the part of the plant affected. Any genetically different spores that would normally be able to infect the plant fail to do so if they try to invade at the same place.

As Zhu *et al.*[1] point out, the net result is a damping of the development of epidemics within the field, with an increase in the complexity of the pathogen population, which may also slow the adaptation of the pathogen to the mixture[3]. This is because there may be competition among individual pathogen genotypes that are well adapted to specific varieties in the mixture, and those that thrive on different combinations of varieties but are less specialized. Using different mixtures of varieties in different fields in different years could slow down adaptation of the pathogen even more.

Zhu *et al.*[1] sought to answer one main question: if we can slow down the development of epidemics in one field, what happens if we greatly increase the area of mixed varieties? Will the damping effect multiply across fields? The answer was a clear 'yes'. But first the authors had to persuade all the rice farmers in a large area — within the Yunnan Province, China — that they should grow a particular mixture of rice varieties. The effectiveness of the response from the rice, and from the farmers, thousands of whom participated, was such that it was relatively simple to increase the size of the experiment further in subsequent years. The level of rice blast (Fig. 1; caused by the fungus *Magnaporthe grisea*) was hugely decreased in the target areas, and the farmers stopped using fungicides. This deceptively simple experiment deserves wide attention, partly because of the principle that it illustrates, and partly because it may never be repeated on such a scale.

Some important questions could not be

tackled in this study. The experiment was designed to look at a single major pathogen, the fungus that causes rice blast. But, because the same principles apply to many plant pathogens[4], it is possible to show that several diseases can be restricted in one crop mixture. For example, during studies for the Elm Farm Research Centre, Hamstead Marshall, Berkshire, UK (see ref. 5), I have recorded the simultaneous restriction of at least three observable diseases in mixtures of wheat varieties relative to single components of the mixtures. There is also evidence that mixtures can buffer against unpredictable abiotic variables, such as cold winter temperatures[6]. Indeed, it is likely that the stability of yields from variety mixtures over different environments[5], compared with yields from their components grown as monocultures, results partly from combined restriction of biotic and abiotic stresses.

So why is the mixture approach not used widely? Is it just too simple, not making enough use of high technology? One reason has been concern among farmers and end-users about the quality of the product of the mixtures relative to that of pure varieties: mixtures are said to be unpredictable in terms of quality and ease of harvesting. In practice, such concerns appear to either evaporate or be easily dealt with, as Zhu *et al.* show. In their case, for example, harvesting by hand — a practice common among rice farmers in Yunnan Province — ensured that rice varieties with different qualities could easily be separated and retained for their individual markets. There is also evidence[7] that mixtures can be designed not only to provide significant disease restriction, but also to improve product quality by combining complementary characters and providing stability.

Variety mixtures may not provide all the answers to the problems of controlling diseases and producing stable yields in modern agriculture. But their performance so far in experimental situations merits their wider uptake. More research is needed to find the best packages for different purposes and to breed varieties specifically for use in mixtures. And so far researchers have looked only at mixtures of varieties. Mixtures of species provide another layer of crop diversity, with half-forgotten advantages waiting to be exploited in contemporary approaches[8,9]. It is widely recognized, for example, that high-yielding mixtures of grains and legumes (grass plus clover, maize plus beans, and many other combinations) can restrict the spread of diseases, pests and weeds[10]. At the same time, such mixtures can provide near-complete nutrition for animals and humans alike, without recourse to expensive and uncertain forays into genetic engineering. ■

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Artificial noses

Picture the smell

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There is a growing interest in 'soft' measurement techniques that measure a particular quality of a sample rather than the quantities of individual properties making up this quality. This type of information gathering mimics the human senses, and has led to the development of 'electronic noses' for environmental monitoring, medical testing, and food and drink production. In the most sophisticated systems a unique chemical fingerprint can be generated by an array of sensors and then identified by pattern-recognition techniques as the smell of a rose, for example. On page 710 of this issue[1], Rakow and Suslick suggest that human vision may soon become an important part of what is now known as artificial olfaction.

Attempts to measure odours with electronic instruments[2] were made as early as the 1950s, but the modern field of artificial olfaction began in 1982 with the work of Persaud and Dodd[3], who used a small array of gas-sensitive metal-oxide devices to classify odours. There has since been a steady increase in the number of systems using chemical sensor arrays. The success of artificial olfaction depends not only on the development of new sensor technologies, but also on the availability of powerful pattern-recognition software. This is particularly important for sensor arrays that produce a composite response.

Human vision is probably the most efficient pattern-recognition system available in terms of versatility and speed. Its ability to quickly observe and draw conclusions from changes in the observed images has not been superseded by man-made pattern-recognition systems. It has long been recognized that the most natural way to represent large amounts of data is as an image.

Data from chemical sensor arrays are often presented as images of various types. The most common approach is to cluster data into a two-dimensional image using statistical methods for data reduction and interpretation, such as principal-component analysis. Several ways of creating a visual signature from complex gas mixtures have been suggested — for example, a plot of the different sensor responses in a polar diagram (Fig. 1a).

Ten years ago, our group developed a device in which the properties of a surface coated with catalytic metals change when the surface interacts with different gases[4,5]. A light pulse scanned across this surface converts the chemical responses into electrical currents, which are then used to generate pixelated images that are quite different for different smells.

A few years ago, another breakthrough in the imaging of smells came with the development of optical-fibre bundles as chemical sensor arrays[6,7]. In this system, each fibre is coated with a combination of a dye and one of several polymers to give different fluores-

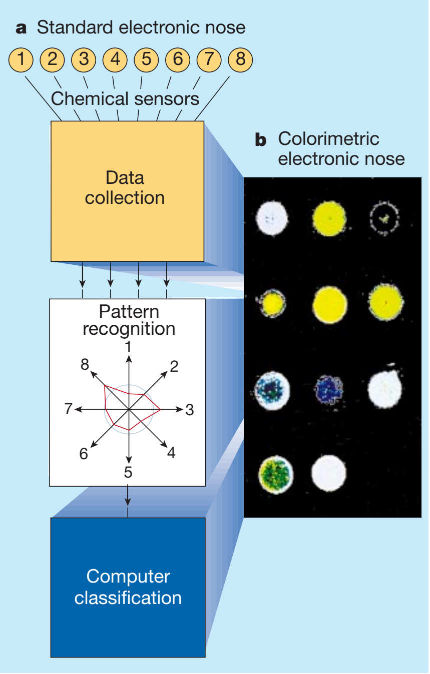

Figure 1 **Smelling by colour.** a, **A typical 'electronic nose' consists of an array of chemical sensors with overlapping selectivity profiles for the smells (gas mixtures) to be measured. This is followed by data collection, a pattern-recognition routine (such as the polar diagram shown), and eventually a computer-based decision.** b, **According to Rakow and Suslick[1] the colorimetric changes of an array of metalloporphyrins upon exposure to organic vapours can replace, with the help of the eye and brain, the various systems used for odour classification. The image here shows an example response from their device to a mixture of 2-methylpyridine and trimethylphosphite vapours.**