Potrykus is still hopeful that golden rice will be accepted by farmers in developing countries, but knows that it will be an uphill battle that is essentially out of his hands. "It depends upon the political success of a radical anti-GMO lobby supported by an EU attitude," he said. Encouragingly, he has found that people in Europe are supportive of his development as people are truly concerned about the fate of blind children. "The public is not against the technology if they see a reason for it. In the EU, they don't see why they should accept a risk—if there is a risk—if there is no benefit." Equally, using the fate of poor farmers as 'emotional blackmail' for these crops to gain acceptance in the EU should be avoided. Torgesen warns that this message requires more sophistication. "Emotional appeals to save starving children are a bit hard to swallow and counter-productive as many people are turned off by such statements." Consequently, there needs to be 'a golden rice for Europe'. Bevan said, "We as scientists need to make it seem beneficial to the consumer. At the moment, it only benefits the producer. We need to make products that the public can see are valuable and can't be done any other way." Interestingly, recent research from the Broom's Barn Research Station

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in Suffolk, UK, which was published online in January 2003 in *Proceedings of The Royal Society of London*, series B (www.pubs.royalsoc.ac.uk), indicates that GM herbicide-tolerant crops can be of benefit to the environment by increasing numbers of endangered wildlife. This, of course, must be balanced against the many reports that have suggested they have a negative impact on the environment (for a debate, see Trewavas & Leaver, *EMBO reports* 2, 455–459 (2001); and Flothman & van Aken, *EMBO reports* 2, 644–647 (2001)). Nonetheless, if genetic engineering can be shown to counteract certain trends about which society is concerned, the acceptance of GM crops is much more likely to be forthcoming.

With golden rice, the proof of principle has been established, and this technology could help to feed the poor and increase the nutritional quality of their food intake. To expect GM food to cure such a complex issue as world hunger is totally naive and unrealistic, but it is a potentially useful tool that should not be dismissed out of hand by more privileged countries. Unfortunately, the current focus of agricultural research funding is on high-technology approaches, which are designed to benefit large-scale industrial agriculture rather than the needs

or interests of developing countries. Ingo Potrykus still hopes that one day it will be possible to assemble, in one variety of crop, a series of transgenic quality-traits such as provitamins, high-quality protein and high iron levels, combined with a series of agronomic traits such as pest and disease resistance. "But it must be done only by someone who can afford to be considered crazy," he said.

Susan R. Owens

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DNA and consumer confidence

DNA fingerprinting and DNA-based labelling systems are gaining importance in the security market to verify the authenticity of products

In the 1970s, the once-famous Italian redwine Chianti acquired a bad reputation for being cheap and often of low quality. Many wine makers had concentrated on quantity rather than quality and frequently mixed their must, the starting extract from grapes, with that of cheaper grapes from other regions of Italy. To regain the former standing of Chianti wines, in 1984 the Italian government issued the DOCG (Vino di origine controllata e garantita—Wines of controlled and guaranteed origin) label, which puts strict requirements on wine producers as to which grapes they are allowed to use for each quality of wine. The Chianti wine makers complied and, today, the reputation of the wine is restored. The policy also paid dividends as prices increased with quality—a premium Chianti Riserva from the Gallo Nero region between Florence and Siena now easily fetches €40 or more.

But the higher price of Chianti created a new problem: as prices rose, so did the temptation for unscrupulous fraudsters to use cheaper grapes and sell their wine under the Chianti label—a practice that wine producers everywhere face, be it in Italy, France or California. This does not necessarily pose a challenge for the expert, who can tell if a Spanish Rioja is made from the right grapes, said Javier Ibáñez from the Instituto Madrileño de Investigación Agraria e Alimentaria in Madrid, Spain. But it is more of a problem for the consumers and wine sellers who put their trust in what is stated on the bottle. Ibáñez's group is thus developing DNA fingerprinting as a means to identify grape varieties in must and bottled wines that would allow laboratories to verify a wine's content. Although this is not a problem at the moment for Spanish wines, he thinks that it is a worthwhile tool to have to hand. "I don't think that it is a major problem, but we anticipate that it may be in the

future because the monovarietal wines [in which only one type of grape is used] are increasingly important," he said. "It could be important to have a tool just in case there is suspicion about a wine."

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Ibáñez is not alone. Scientists at the Bavarian State Institute for Viticulture and Horticulture in Würzburg, Germany, also use DNA fingerprinting to analyse wines. As genetically modified (GM) yeast and GM vines are now undergoing field trials, this method may become important to detect whether GM yeast has been added to boost the fermentation process or whether grapes from GM vines have been used. This will be of interest to consumers who are wary about GM organisms in their food. And it is not only wine that needs to be verified. After the various food scandals that have haunted Europe and the USA during the past decade, consumer confidence is of increasing concern to growers and distributors, particularly when dealing with GM food. As new European Union legislation, agreed last November, requires all food products that are derived from or that contain GM organisms to be labelled as such, the demand for appropriate verification methods will certainly increase.

And the problem of false labelling is not just one for European consumers concerned about GM food, it also casts a shadow in other areas. Wang Jun and his group at the Chinese University of Hong Kong used DNA fingerprinting to differentiate between *Panax ginseng* (ginseng) and *Panax quinquefolius* (American ginseng), which are two important herbs in Chinese medicine. "As the price of *P. quinquefolius* is usually 5–10 times greater than that of cultivated *Panax ginseng*, the latter is frequently misrepresented as the former in the market," Wang and his colleagues dryly summarized when they published their results last year in the *Journal of Agricultural and Food Chemistry* (2002, **50**, 1871–1875). "Therefore, it is essential to develop effective authentication methods to differentiate the two ginsengs to safe-

guard public health and to protect consumers' rights."

In fact, the verification of any consumer product in an economy that increasingly relies on consumer trust is of great concern for the industry. "There is not much that is not forged. And there are many industries that have problems with forgery," said Jörg Hassmann, Chief Technology Officer of November AG, a company in Erlangen, Germany, that specializes in authentication and verification technologies. DNA fingerprinting is therefore an increasingly important tool for verification and is used by analytical laboratories around the world. But it has its limits. In the case of wine, for instance, Ibáñez pointed out that the small amount of DNA that remains in bottled wine after filtration makes it very hard for laboratories to analyse fully the variety of grapes used and their origins.

Although DNA fingerprinting is a logical method to track biological material from the producer to the consumer, the use of DNA is certainly not restricted to this market and has already attracted the attention of experts in the security business. In particular, the power of this molecule to store information has made it the hottest candidate in authentication technologies for non-biological products, such as aeroplane replacement parts and medicines, where proper verification and authentication could literally save lives. Various companies are already developing DNA into a labelling system for all kinds of products, from jewellery and artwork to food products, medications and oil. Trace Tag International, Ltd,

Ginseng root

The discovery of sophisticated fake €100 and €200 notes earlier this year shows that forgers are already able to overcome safety labels once thought to be foolproof.

a company in Cardiff, UK, has been selling its DNA-based CypherMark technology to tag a large variety of goods, packaging, labels and logos. Their CypherMark labels contain 100-base-pair long single-stranded oligonucleotides that not only provide a unique label for each product, but also encode additional information about manufacturing, distribution networks and markets. They can also be used in inks to label sensitive documents, bills or packages during the printing process. The company also cites another interesting application—by labelling industrial fluids, such as oil cargo, it will be possible to establish proof of guilt or innocence in cases of environmental pollution.

Informium, a small start-up company in Cologne, Germany, has already taken the technology a step further to increase the level of security. They hide their custom-made coding labels in a huge sea of other oligonucleotides to make analysis and copying even more difficult. This 'needle in a haystack' principle, also known as steganographics to the computer science community, adds another layer of safety that allows Informium's products to fulfil the highest security levels demanded by forensics and military applications, according to Hilmar Rauhe, Informium's director and co-founder. In fact, the company was born out of a joint DNA computing project between the Universities of Cologne and Dortmund in Germany. Their work on DNA-based cryptography automatically led them to steganographics and eventually sparked the idea of founding a company, as Rauhe described. Consequently, at the heart of Informium's technology are algorithms to create unique DNA molecules and a vast amount of other meaningless molecules to hide the encoding oligonucleotide. This mixture of DNA can be added to many liquids, including inks, and thus printed on solid products as well. Analysis and identification can be performed by extraction of the DNA and either multiplex PCR amplification using primers specific for the coding molecule and/or sequencing after PCR amplification. According to Rauhe, the technology is safe against any attempts to

A failproof labelling system for medicine could protect consumers from fraudulent products.

break and copy the code and, thus, could be held up in court as evidence. Its drawback is that verification of the DNA markers needs laboratory equipment and cannot be done by the customer or consumer themselves. "This system is developed for high security and not necessarily for high-speed [verification]," Rauhe said. Nevertheless, he envisions further technological developments, such as hand-held PCR machines, which are now being developed. These will eventually provide consumers with a cheap and reliable method to detect DNA markers in products and thereby verify their originality.

November AG is already about to close this gap in detection. This company, together with Siemens AG Automation and Drives in Fürth, Germany, is developing a scanner-based system that allows the analysis of DNA markers within seconds. A small label on the product has a field that contains coding DNA, again hidden in a vast amount

of non-coding molecules, and a reference field. The key used to unlock the code will be a pen that contains labelled DNA complementary to the coding molecule in the label. The customer just needs to quickly trace the label with the pen and then, with the scanner developed by Siemens, to verify that the label contains the right coding oligonucleotide. This takes a matter of just a few seconds the company claims.

November AG guarantees that the DNA labels are stable for two years under normal storage conditions. And "this DNA-based method offers the highest possible safety against forgery," Hassmann pointed out. "An analysis is not possible with current technologies and it is therefore not possible to create false labels." Furthermore, the company designs individual DNA codes for every customer and stores them in a secure computer in a specifically designed 'safe trust centre', so even the end users do not know which sequences are present in the labels they buy. November AG's technology, particularly due to the ability to perform a quick test without laboratory equipment and trained personnel, has already drawn the interest of Bristol-Myers Squibb. This pharmaceutical company plans not only to use the DNA labels on its drug packages to verify their origin, but also to track distribution paths from production to the consumer.

DNA may have a bright future in the security business as other, widely used methods of verification and authentication become increasingly unsafe. The discovery of sophisticated fake €100 and €200 notes earlier this year shows that forgers are already able to overcome safe-

guards once thought to be foolproof. According to Hassmann, even holograms, such as those used on currency and credit cards, can now be faked. And DNA marker technologies, in addition to being impossible to copy, have another great advantage—they are cheap. "In principle, there is no other medium that allows such cheap units," Rauhe said. However, there are limitations, mainly due to the instability of the molecule in heat and light. "To try to do everything with DNA would be silly. If the demand is on high security, we use DNA, if the demand is high robustness, we use other systems," Rauhe pointed out.

Nevertheless, the interest in DNA for verification will undoubtedly increase in many other niches. Some of these, such as DNA fingerprinting to verify wines, or to show that crab paste contains genuine crabmeat, are becoming increasingly important and beneficial for consumers. And, as the technology becomes more sophisticated, reliable and cheap, Ibáñez thinks that supermarkets and food distributors will use independent analytical laboratories to verify the quality and origin of their products. The use of DNA as an invisible barcode extends the range of this technology much further into non-biological products, particularly as the power of information storage, detection and specific amplification makes it an ideal material for this context. As industry needs more and more safeguards to protect its products from fraud, DNA-based authentication holds great promise for consumers, patients, distributors and producers alike.

Holger Breithaupt

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