

unintended presence of the Cry9C protein in some of them. After newspaper and television news reports announced that the unapproved protein—which EPA regulated as a pesticide—was found in food products taken from grocery store shelves, 28 people reported that they had experienced allergic-like reactions after eating food products that contained corn. However, an intensive investigation of adverse effects reports by the US Centers for Disease Control was not able to confirm a single allergic reaction: “Although the study participants may have experienced allergic reactions, based upon the results of this study alone, we cannot confirm that a reported illness was a food-associated allergic reaction.”

Despite this conclusion and the absence of other evidence of harm of any kind to anyone, because there was no regulatory approval for StarLink in human food, a class-action lawsuit alleging that consumers ate food unfit for human consumption was successfully concluded with a settlement against Aventis (Lyon, France), producer of the StarLink corn variety.

The EPA has since decided that it will never again approve a recombinant DNA-modified crop for split use. Any crop intended for feed or industrial uses that could conceivably find its way into the food supply will have to meet the standards

for human food use to gain government approval.

The StarLink saga should provide a cautionary tale to BASF, the creator of the Amflora potato: recombinant DNA-modified crops not approved for human consumption present the risk of legal liability, even if no consumer has suffered any toxic, allergic or other health-related harm. It should also concern EU regulators but likely will not, given their discriminatory stance against recombinant DNA technology applied to agriculture.

The StarLink contretemps resulted from a fault not with the product itself or the legal system but from flawed regulatory policy and an unwise series of decisions by regulators. Such problems are the inevitable result of a regulatory approach that treats recombinant DNA-modified products as though they pose some inherent, unique risks, although all the evidence is to the contrary.

COMPETING FINANCIAL INTERESTS

The author declares no competing financial interests.

Henry I Miller

The Hoover Institution, Stanford University, Stanford, California, USA.

e-mail: henry.miller@stanford.edu

1. Ryffel, G.U. *Nat. Biotechnol.* **28**, 318 (2010).
2. Fox, J.L. *Nat. Biotechnol.* **19**, 298–298 (2001).

erratic weather and limited or no access to irrigation and other inputs—often lack the control required to perceive subtle differences in the value of competing varieties.

This background of confounding factors may challenge marginal farmers’ ability to learn how to assess the net gains of drought-tolerant varieties for two reasons. First, the relative yield benefit of drought-tolerant varieties is conditional on drought pressure. During seasons with good rainfall, both drought-resistant and conventional varieties appear identical; indeed, marginal farmers may even view drought-tolerant varieties as inferior if increased cost is not associated with benefit or if yield is comparatively inferior when water is plentiful. Second, the relative benefits of drought-tolerant varieties peak at moderate levels of drought; if drought severity increases, these benefits quickly fade. This not only makes it difficult for breeders to test drought-tolerant traits, but also makes it much more difficult for marginal farmers in completely uncontrolled environments to discern differences between drought-resistant and conventional varieties.

Contrast this with insect-resistant *Bt* varieties, which confer perceptible benefits to poor households even when pest pressure is low due to imperfect baseline pest control in most farming regions. What’s more, the heavier the target pest pressure, the more exaggerated the relative performance of *Bt* varieties—a signal that easily outcompetes any other factor affecting the farmers’ perception of relative merits.

In our recent publication¹, we built a model to predict the effect of drought presence and farmer perception of relative yield benefit on the uptake of drought-resistant varieties over 100 seasons. In the model, farmers chose to plant either a drought-resistant or conventional variety. The yield of these varieties was determined by the underlying drought stress, which is random. If a farmer growing the drought-tolerant variety interacts with a farmer growing conventional variety (or vice versa), the model assumes the farmer notes that season’s yield difference. According to our model, the subsequent decision to adopt the drought-tolerant or conventional variety is based on this difference. Adoption grows as the population of drought-tolerant adopters grows relative to nonadopters (increasing the probability of observing drought-resistant crop performance) and as the number of seasons increases (offering more opportunities to observe yield differences). We also formulated the model so that the drought-tolerant variety stochastically dominates the conventional variety in terms of farmer expectations, so the

Why drought tolerance is not the new *Bt*

To the Editor:

Given rapid uptake of *Bacillus thuringiensis* toxin (*Bt*) cotton by farmers in several developing countries, it is often assumed that poor farmers will clamor for drought-tolerant varieties in an era of tightening water resources and climate change. There are, however, important differences between *Bt*-mediated insect resistance and drought tolerance. We would like to bring to the attention of your readers some of these differences, which, based on the output of a stochastic model that we published last month¹, are predicted to hinder the uptake of drought-resistant cotton by smallholders.

Few agricultural research objectives have ever attracted the intensity of attention and investment from private, public, academic and philanthropic sectors as drought tolerance. In the past decade, total investment in drought-tolerance research has

almost certainly surpassed \$1 billion. With climate change, growing water scarcity and impending water disputes, the prospective welfare gains from effective drought-tolerant varieties are enormous. Among the poor, such varieties may limit catastrophic losses and help households recover from drought and famine. Many proponents also argue that the higher economic security afforded by drought-resistant crops will encourage the households of resource-poor adopters to become more entrepreneurial as a whole.

Decades of research in economics and other social sciences have emphasized learning as a central process that influences the uptake of technology. Learning from experience is nowhere more important than with the highly heterogeneous agricultural production of smallholder agriculture in developing countries. Yet, marginal farmers—who typically face poor soils,

question is never whether drought-tolerance is better (it is), but how long it takes a farmer to discover this.

Although our model is not specific to a particular crop, we parameterized the model to reflect India's experience with the diffusion of *Bt* cotton: after ~10 years, on-average diffusion of the crop was 90%. When we used the same parameters for drought-tolerant varieties, however, it took four times longer to reach the same level of diffusion. Similarly, when we looked at the effect of farmer aversion to risk, vulnerable (highly risk averse) farmers—the ostensible target clientele of many drought-tolerant research efforts in the public sector and in public-private partnerships—took four times longer to reach 90% diffusion than their less vulnerable (and less risk averse) peers. This trend was observed because risk-averse farmers are highly sensitive to extreme drought and to the background context that may occasionally make the drought-tolerant variety look worse than the conventional variety. For example, an extreme drought that stunts even drought-tolerant varieties would likely be catastrophic for a risk-averse farmer. And if, as expected, climate change increases the probability of severe drought, this possibility becomes even more likely and further hampers learning and adoption among vulnerable farmers in particular.

Our analysis should in no way detract from the real potential of drought-tolerance research to help poor rural households cope

with and recover from drought. But we hope that our model can inform the research and development process of looming downstream challenges for drought-tolerant varieties. For example, our modeling exercise emphasizes not only the importance of generalized gains in water use efficiency and early maturation traits that confer benefits across a broader range of rainfall outcomes, but also the importance of pricing; indeed, diffusion of drought-tolerant crops is likely to be especially sluggish among vulnerable farmers if their seeds cost more than conventional crops. If we seek to ensure the efficient uptake of drought-resistant varieties, demonstrating effectiveness in laboratories and test plots will be only part of a solution. The quandary of a marginal farmer in drought-prone Africa trying to figure out whether his neighbor's maize really did better than his own emphasizes how adoption of such varieties is unlikely to be as smooth and rapid as experienced previously with *Bt* cotton.

COMPETING FINANCIAL INTERESTS

The authors declare no competing financial interests.

Travis J Lybbert¹ & Adrian Bell²

¹Agricultural & Resource Economics, University of California, Davis, Davis, California, USA.

²Human Ecology, University of California, Davis, Davis, California, USA.

e-mail: tlybbert@ucdavis.edu

1. Lybbert, T.J. & Bell, A.V. *AgBioForum* **13**, 13–24 (2010).

adverse health outcomes, such as NTDs. In the following analysis, we present the first attempt to evaluate the health impact of folate-biofortified rice. Analogous to previous impact studies of other biofortified staple crops⁵, we apply the disability-adjusted life years (DALYs) approach⁶ to evaluate the potential health benefits of rice with a high folate content in China.

Several interventions are available to increase folate intake levels in malnourished populations, including folic acid pills supplementation, folic acid fortification and dietary diversification to increase the consumption of folate-rich foods. Implementation of these approaches can often be problematic, however. For example, in poor, rural regions, such as Shanxi Province in Northern China or Balrampur District in Northern India, where industrial fortification is not well established, folate pill distribution often does not reach the targeted individuals and dietary habits are difficult to alter. In this context, folate biofortification (that is, improving the folate content of staple crops) offers an additional approach for alleviating the burden of folate deficiency (Supplementary Discussion, section 5)².

China is an important study location to evaluate folate-biofortified rice for two major reasons. First, it is not only the world leader in the production and consumption of this staple crop, but also considered one of the pioneers of R&D and commercialization of genetically modified (GM) rice⁷. In 2009, for instance, China's Ministry of Agriculture issued a bio-safety certificate to pest-resistant *Bacillus thuringiensis* toxin (*Bt*) rice, which should lead to large-scale production of this transgenic crop in about 2 to 3 years⁸. This makes rice, the world's main staple crop, an appropriate food vehicle for folate biofortification. Second, China as a rice-consuming country is characterized by large folate deficiencies and high NTD prevalence rates⁹. Each year, about 18,000 pregnancies in China are affected with an NTD (Supplementary Discussion, Table 4). Because of significant differences in rice consumption, folate status and the prevalence of NTDs between the northern and southern regions, a regional comparison of the health impact of folate biofortification in China will further underpin its *ex-ante* evaluation. Shanxi Province for instance, has one of the highest reported NTD prevalence rates in the world¹⁰, in part because folate intake

Health impact in China of folate-biofortified rice

To the Editor:

Despite efforts to reduce the burden of malnutrition, large numbers of people still consume insufficient micronutrients, including folate¹. Folate deficiency, characterized by a suboptimal daily intake of folate (<400 µg) may lead to the onset of diseases and disorders, such as neural-tube defects (NTD), megaloblastic anemia and aggravation of iron-deficiency anemia². In line with the main micronutrient deficiencies (zinc, iron and vitamin A), folate deficiency is

more prevalent in less developed, non-Western countries. In China, for instance, ~20% of the population is considered to be folate deficient³ (for an overview on folate deficiency and NTDs, see Supplementary Discussion, sections 2 and 3, respectively). In 2007, a report in this journal by Storozhenko *et al.*⁴ reported folate biofortification of rice by metabolic engineering. These authors proposed folate biofortification as an alternative to tackle deficiency of the micronutrient and its

