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Statement of Arjun Makhijani at the Press Conference on *Ecology and Genetics*

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I wrote *Ecology and Genetics* to outline a framework for understanding the relationship of genetic structures of living beings to the ecosystems they inhabit and to examine the implications of that approach for understanding the potential ecosystem impacts of genetic engineering.

My basic hypothesis is that genetic structures of living beings are internal biological expressions of the ecosystems they need to survive. As a result there is a systematic correspondence between ecosystems and the genomes of the various species within them. The jaguar's skin, for instance, which provides it with camouflage, arises from the jaguar's genetic structure, which can therefore be regarded, in part, as one biological expression of the patterns of light and dark in the forest. As another example, the hemoglobin protein in blood is precisely structured so that oxygen can literally fit into it. It is also structured so as to absorb carbon dioxide and help transport it out of the body. Very similar hemoglobin-supported oxygen-carbon dioxide transport systems exist in a wide variety of animals. One way to view the internal genetic structure that produces hemoglobin is that it has evolved as an internal expression in animals of the oxygen-carbon dioxide system needed to sustain life.

It is now well recognized that living beings shape the environment. But the reproduction of the immense and complex relationships in nature could not occur if the everyday acts of living of the species within it were merely incidental to ecosystems. Consider again the oxygen-carbon dioxide cycles, essential to almost all life forms. These cycles are maintained by energy production, processing, and consumption, that is by the every day acts of plants and animals. That activity is carried on mainly chloroplasts in plant cells, which turn sunshine, carbon dioxide, and water into carbohydrates, and by mitochondria in plants and animals, which consume the carbohydrates and yield carbon dioxide and water (as well as adenosine triphosphate). Hemoglobin's role as the carrier of oxygen and carbon dioxide in a wide variety of animals and as part of the carbon-oxygen cycle is fulfilled within this overall chloroplast-mitochondrial context. Chloroplasts and mitochondria have their own circle-shaped DNA and are not part of the double-helix-shaped DNA in the nucleus. But they are essential to the energy production and utilization system without which we could not exist. Nuclear DNA could not reproduce itself without them. Nor could the oxygen-rich atmosphere of the Earth be sustained.

The competitive tensions and symbioses that have resulted in evolution by adaptation over the ages have created a complex set of interconnected genetic structures. The near-total focus on the dissection of nuclear DNA has resulted in important new understanding of life at the molecular level, but it also means that our understanding is incomplete and mainly mechanistic. There is a serious deficit in the understanding of how the entire genetic structure of a living being functions and of the relationships of genomic structures to ecosystems and to non-genetic aspects of adaptation.

One way to think about the interaction between ecosystems and genetic structures is that it is like a complex piece of music in which the notes work together to create the whole. We may say that genetic engineers have set out to do the equivalent of rewriting bits of Beethoven's violin concerto without understanding how the existing notes and themes relate to one other, recognizing, of course, such analogies can only give a very limited glimpse of the complex issues.

Creating new genomic structures by inter-species genetic engineering would be a risky proposition under any circumstances, but it is particularly rash in the face of the fundamental gaps in knowledge of how genomic structures express themselves in ecosystems. For instance, when the genetically engineered corn known as Bt corn was created there was no study of its effects on butterflies or many other flora and fauna that share the local ecosystem with corn. Yet, it turns out that Bt corn pollen is toxic to monarch butterfly caterpillars.

If Bt corn pollen looks and tastes like corn pollen but is laced with poison, does the monarch butterfly caterpillar have the genetic structure to enable it to detect the danger? It would appear that it does not. How widespread is the new biological ignorance of danger? How many different types of living beings may be affected and how? A labeling system for genetically engineered food would help alert human beings to the presence of engineered plant materials, but what about butterflies and other living beings? Whether Bt corn will actually have severe impacts on monarch butterfly populations is less important to the overall issue than the fact of the unanticipated toxicity of Bt corn pollen. It should serve as a huge warning signal of the possibility of ecosystem disruption due to the widespread introduction of engineered species.

The very basis of regulating genetically engineered plants as suitable for use in food may be conducive to increasing ecosystem uncertainties. The approval process involves showing "substantial equivalence" between the traditional and the engineered variety in terms of some of its short-term, observable effects as human food. But this approval process has no systematic place for long-term ecological impacts, which may be masked by the lack of any readily observable short-term effects. This increases the uncertainty in ecosystem interactions between genetically engineered species and the ecosystems in which they exist and reduces the chance that potential adverse impacts will be detected in time to prevent serious damage.

Traditional creation of hybrids breeding involves trial and error. But negative outcomes in these experiments are restrained by the fact that exchange of genetic material occurs between sub-species that can interbreed naturally. In other words, traditional hybridization can only occur between living beings that are very close in genetic structure. Genetic engineering extends trial and error system to the evolutionary heart of living beings by allowing genes to cross and arbitrarily violate natural reproductive boundaries. Even conventional hybridization has resulted in ecological damage in many cases. Trial and error at the genetic level may produce far more nasty surprises since it considerably expands the uncertainties.

Engineered species create two other dangers that we are only now beginning to glimpse. The first is the threat to food supply. The potential for such a problem is illustrated by StarLink. This variety of genetically engineered Bt corn was approved only for animal consumption, but some of it entered human food supplies. A massive recall ensued. Were the 430 million recalled bushels of corn that were recalled all destined for destined for human consumption (in this case most were not), there may have been a considerable disruption in food supply. In the alternative, the government may make a decision to allow consumption of contaminated food. Such a dilemma is being faced everyday by people and governments in currently populated areas that were significantly contaminated by fallout from the 1986 Chernobyl nuclear reactor accident. A similar problem of food supply contamination is within the realm of possibility for genetically engineered food on an even larger scale.

The second problem relates to possible biological warfare applications of genetic engineering. An Australian genetic engineering experiment with mousepox virus (which does not affect humans, but is closely related to the smallpox virus) shows that genetic engineering may result in the creation of new creatures that are deadly and that can defeat vaccinations. The results of the experiment were a surprise because they were the opposite of what was expected. The genetic modification was supposed to strengthen the immune system of the mouse. It weakened the mice to the point that many of them died and the rest were permanently disabled. The engineered virus even overcame mice that had been vaccinated.

The implications of the experiment for the creation of new agents of biological warfare are so serious that the results were kept under wraps for two years. But on reflection, the scientists decided that publication of the results to encourage public discussion and prevention strategies was a wiser course.

The spread of nuclear weapons has been limited by the great difficulty of obtaining plutonium or highly enriched uranium. So far, the industrial infrastructure needed to make these materials is huge, costly, and easily detectable. These technological restraints do not apply to genetic engineering. The technology of genetic engineering is now commonplace. It can be done on a small scale and its raw materials, such as bacteria and viruses, are ubiquitous.

We do not yet understand the potential ecosystem impacts of genetic engineering well enough to have an informed debate on the subject. It is urgent that the recommendation of biologist Richard Strohman be adopted. He has suggested that "biogenetic engineering of humans and of plant where unanticipated results could cause damage to individuals or to millions of acres of cropland will have to cease except possibly under tightly controlled laboratory conditions."

Even laboratory work must be carefully thought through because genetic engineering may increase the risks of accidental or deliberate release of new versions of biological warfare agents that are more virulent than natural ones. The pursuit of genetic engineering should take into account the risk that it may exacerbate the biological warfare threat by enabling the creation of agents that are resistant to drugs and vaccinations.

If the interactions of genomes and ecosystems were well understood, we could at least have a well-informed debate about genetic engineering. Today, we cannot. We are broadcasting the seeds of possible severe genetic and ecosystem damage without even making a good-faith attempt to know what we do.