



Ecological Research and Risk Assessment of Genetically Engineered Crops

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In a 1995 paper, “Assessing weediness of transgenic crops: industry plays plant ecologist,” Purrington and Bergelson¹ criticized the quantity and quality of data used to determine the weediness potential of genetically engineered (GE) crops then under regulatory review. The implication of the title was that risk assessments need some serious plant ecology that was not being provided by regulatory studies. Purrington and Bergelson’s critique is an example of a widely held view that data obtained by basic ecological research is essential for environmental risk assessment; however, while basic research and risk assessment are similar, there are important differences that, if not recognized, can be detrimental to effective risk assessment².

Similarities between basic research and risk assessment

The idea that science derives true statements (“laws”) inductively from accumulated observations is intuitive and widespread. Nevertheless, philosophers since David Hume in the eighteenth century have pointed out that induction is logically flawed—any number of events agreeing with a law cannot guarantee that subsequent events will be in agreement. The impossibility of proving empirical laws is the so-called problem of induction. In the 1930s, Karl Popper offered a solution to the problem for science by proposing that science does not verify laws but postulates theories that are tested by comparing predictions with observations. A theory that has withstood rigorous testing may appear to be a law, but further testing may show the theory to be false.

In later works, Popper proposed that his logic of scientific discovery applied to the development of all objective knowledge: a problem is identified; a trial solution to the problem is proposed; the solution is tested to eliminate errors; and corroboration or falsification of the trial solution provides new knowledge with associated new problems. The process can be represented schematically³:

→ initial problem [P₁] → trial solution [TS] → error elimination [EE] →
new knowledge and a new problem [P₂] → TS₂ →

In science, problems are inconsistencies or inaccuracies of existing theory about nature; trial solutions are testable hypotheses; error elimination is the testing of those hypotheses; and new problems are improved theories with different inconsistencies or inaccuracies.

Effective risk assessment fits Popper’s scheme for the development of objective knowledge: it cannot prove something is safe, but it can increase knowledge of risk by testing hypotheses⁴. A risk assessment begins with the identification of protection goals, the desired state of environmental variables, which are often specified by law; they are usually general objectives, such as protection of the environment, which are difficult to analyze scientifically. From general goals, specific targets for protection are identified; for example, if the protection goal is maintenance of biodiversity, a specific target may be the population size of certain species in a given area. The targets are called assessment endpoints, and their unambiguous specification is crucial to focus the risk assessment. Identification of protection goals and derivation of assessment endpoints defines the initial problem [P₁].

Next, one develops a conceptual model that describes how what is proposed, such as the cultivation of a GE crop, may adversely affect the assessment endpoints. From the conceptual model, specific risk hypotheses are derived. Risk hypotheses postulate the absence of phenomena necessary for harm (unacceptable adverse effects)⁴; for example, if adverse effects could arise because of toxicity of a transgenic protein, one could test the conservative hypothesis that the assessment endpoints will not be exposed to concentrations of the protein in excess of the lowest concentration that could have an adverse effect. The risk hypotheses are trial solutions [TS].

Risk hypotheses are tested with data acquired from the literature or from new studies: this is error elimination [EE]. New studies should be required only if existing data do not test the risk hypotheses with sufficient rigor to adequately characterize the risk (the probability and magnitude of potential adverse effects to the assessment endpoints); for example, regulatory risk assessments usually do not require new data on horizontal gene flow because sufficient data exist to satisfactorily corroborate the hypothesis that harm will not arise by this route.

Tests of a risk hypothesis characterize risk and lead to a new problem [P₂]. In general, this problem is whether to stop testing because risk is adequately characterized, or to require further studies: new data may be required to test an existing



risk hypothesis more rigorously, or to test a new risk hypothesis⁴. A decision to stop testing does not mean that the risk hypothesis is proven; new information, or a new definition of harm, may trigger further testing.

Basic research and risk assessment cannot inductively verify laws or prove safety. In both domains, experiments should test hypotheses, not seek unattainable proofs by accumulating data. While basic research and risk assessment have the same logic, it is important to recognize their differences to maximize the effectiveness of studies for risk assessment.

Differences between basic research and risk assessment

Basic research and risk assessment produce objective knowledge; however, the production of objective knowledge has subjective elements. In basic research, selection of problems depends upon subjective personal interests of scientists, and societal interests mediated through allocation of research grants; in risk assessment, problem selection depends on what society regards as harmful. A mistaken idea that problem selection is objective may not matter for basic research; however, attempts at objective problem selection are detrimental for risk assessment because it must focus on protecting things of value, which cannot be deduced objectively².

A second important difference between basic research and risk assessment is the nature of the hypotheses under test. All scientific hypotheses seek to be accurate and effective. In basic research, effective hypotheses are interesting, which is judged by their testability and precision³; for example, a hypothesis that predicts rain will fall in London tomorrow at 3pm is more testable (more at risk of being shown to be false) and interesting than a hypothesis that predicts rain will fall somewhere in Europe in the next month. In risk assessment, the effectiveness of a hypothesis comes from its value for decision-making. A hypothesis that accurately predicts no harm is more effective than a hypothesis that makes precise predictions of undefined consequence; for instance, a hypothesis that predicts no hybrids will form between a GE crop and a wild relative in a given area is more effective than a hypothesis that predicts 30,000 hybrids will form. The first is straightforward to test, and it is easy to see how corroboration or falsification would lead to different decisions; the second is more interesting scientifically, but is difficult to test, and unless 30,000 hybrids is a threshold for harm, it is difficult to see how testing this hypothesis could help decision-making.

A similar problem arises when basic research tests a null hypothesis of no difference. Many ecological studies compare the abundance and diversity of insects in fields of GE and non-GE crops. In these studies, no precise prediction is made; however, precision of prediction is replaced by precision of measurement. As many variables as practicable are measured to test the null hypothesis or no difference, whereas a risk assessment study should concentrate on variables that indicate potential harm².

A final contrast between basic research and risk assessment is the preferred method for testing hypotheses. In general, ecology has been wary of laboratory testing: laboratory studies may...“magnify incidental or trivial factors... indeed, laboratory experiments can likely show some effect of any factor by using sufficiently extreme conditions. Laboratory studies are effective in isolating the response to a factor, but the response may not be ecologically relevant”⁵. Over-estimation of the importance of an effect is problematic in basic ecology because one may waste time developing theories with no predictive power in the field. On the other hand, over-estimation of effects is valuable for testing risk hypotheses of no harm, because if the effect cannot be detected in the laboratory, one has high confidence of no effect under field conditions⁴. Tests of a risk hypothesis in the field are less rigorous, and conclusions may apply only to the particular conditions of the test. Thus, laboratory studies are usually more rigorous tests of risk hypotheses, whereas field experiments are more rigorous tests of basic research hypotheses.

Effective studies for environmental risk assessment of GE crops

Studies for environmental risk assessment of GE crops should follow three principles. First, studies should test risk hypotheses that postulate the absence of harm. Secondly, studies should test risk hypotheses rigorously, which usually means under strictly controlled laboratory conditions. Finally, studies must have the potential to improve risk characterization and thereby increase confidence in decisions: if existing tests have not falsified the risk hypothesis, but there is still unacceptable uncertainty about the amount of risk, additional studies are warranted should they provide a more rigorous test of the hypothesis. If laboratory tests have falsified a risk hypothesis, additional “higher tier” studies can test a new risk hypothesis that harm will not be realized under conditions of greater realism; however, confidence in, and the generality of, the conclusions will be less than from corroboration of the original hypothesis in the laboratory⁴.

Basic ecological research is driven by different principles (**Table 1**) and is characterized by attempts to describe nature in detail⁵, not to predict the likelihood of harm². Failure to address harm means that basic ecological research is



a source of what Craig *et al.*⁶ call, “the risk of competent authorities being submerged by excessively large amounts of data that may be of questionable pertinence to verifiable safety questions.”

Table 1. Differences between basic research and risk assessment principles

Stage	Basic Research	Risk Assessment
P ₁	Problem selection is apparently objective Arises from objective analysis of prior problems	Problem selection is subjective Arises from definitions of harm
TS ₁	Hypotheses aim to be interesting Hypotheses make precise predictions Null hypotheses of no change in anything	Hypotheses aim to be useful Hypotheses predict no harm Hypotheses of no harmful change
EE ₁	Testing aims to falsify the hypothesis Hypotheses are corroborated by the presence of phenomena in field studies	Testing aims to falsify the hypothesis Hypotheses are corroborated by the absence of phenomena in lab studies
P ₂	Is TS ₁ falsified? Test TS ₁ more rigorously or test new hypothesis TS ₂ ?	Is risk characterized adequately? Stop testing, test TS ₁ more rigorously, or test new hypothesis TS ₂ ?

The consequences of irrelevant data

The consequences of irrelevant data go beyond the time wasted producing and reviewing them. Collecting data and making vague assertions that they are relevant to risk assessment, without providing specific predictions about harm, is confusing and increases unease⁷. Unease triggers conservatism in data requirements, thereby increasing the cost of complying with regulations, which may mean that fewer GE crops are developed, particularly by small companies and public sector institutions; and regulatory reviews of GE crops may take longer. Consequently, the introduction of environmentally beneficial products may be delayed or prevented, and products with greater potential to be harmful may receive inadequate review. Thus, applying basic research methods to risk assessment may decrease confidence in decisions while increasing environmental risk^{2,4,7}.

References

1. Purrington CB and Bergelson J (1995) Assessing weediness of transgenic crops: industry plays plant ecologist. *Trends in Ecology and Evolution* **10**, 340-342
2. Raybould A (2007) Ecological versus ecotoxicological methods for assessing the environmental risks of transgenic crops. *Plant Science* **173**, 589-602
3. Popper KR (1972) *Objective Knowledge: an Evolutionary Approach*. Oxford University Press
4. Raybould A (2006) Problem formulation and hypothesis testing for environmental risk assessments of genetically modified crops. *Environmental Biosafety Research* **5**, 119-125.
5. Peters RH (1991) *A Critique for Ecology*. Cambridge University Press
6. Craig W, Tepfer M, Degrassi G, Ripandelli D (2008) An overview of general features of risk assessments of genetically modified crops. *Euphytica* DOI 10.1007/s10681-007-9643-8
7. Johnson KL, Raybould AF, Hudson MD, Poppy GM (2007) How does scientific risk assessment of GM crops fit within the wider risk analysis? *Trends in Plant Science* **12**, 1-5

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