Natural Selection, Genetically Modified Food,
and the Environment

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1. Introduction

A large percentage of the work on the ethics of genetically modified (GM) food has focused on its potentially harmful effects on human health and on the rights of consumers to have their food labeled. A smaller, but still significant percentage has focused instead on the potential environmental impacts of genetically modified food. For example, some authors argue that genetically modified food could lead to a loss of genetic diversity within a particular food crop, leaving that food crop vulnerable to extinction (see, e.g., Lappé and Baily 2002). Another type of argument focuses on potential side effects of genetically modified food. Perhaps there will be gene flow from genetically engineered herbicide resistant crops to a weedy relative, producing a "superweed" that could lead to a "bioinvasion" that takes over an entire ecosystem (see, e.g., Shiva 2002). And Monarch butterflies made headlines when it appeared that corn that was modified to kill corn borers also killed the butterflies, leading to concerns that other species could suffer harm at the hands of genetically modified food as well.

These arguments have not been without their challenges. Proponents of genetically modified food argue that it has environmental benefits, permitting reduced use of herbicides and pesticides that will preserve natural biodiversity of "farmland species," i.e., species that that depend on farm crops for survival (Johnson and Hope 2002). Natural weeds that are resistant to particular herbicides are not uncommon, and we eliminate those by simply using a different

herbicide (Trewavas 2002b); perhaps the same can be done with a GM "superweed," if necessary. Moreover, it is argued that reports of the Monarch butterfly's demise were overblown or simply "groundless," in light of numerous laboratory studies and recent migration numbers (Trewavas 2002a).

Nonetheless, even if the risks have been overstated, the potential harms suggest that we ought to proceed carefully – a stance that can be supported by a wide range of ethical viewpoints. The most obvious ethical grounding is perhaps an anthropocentric one. Genetically modified foods potentially threaten our food supply and other species on which we depend. However, to the extent that other living beings such as the Monarch butterfly could suffer from unintended side effects of genetically modified crops, a biocentric argument against genetically modified food could be made as well. And, of course, large-scale threats to species would be of concern from an ecocentric position as well, since biodiversity and the health of entire ecosystems could also be threatened.

But it is not my goal today to make an argument for or against genetically modified food from an environmental perspective. Rather, I want to explore an aspect of the arguments against genetically modified food that has been largely overlooked. A recent essay by Barbara Kingsolver indirectly illustrates what is missing from these arguments: the role that natural selection plays. Kingsolver, who is a biologist-turned-novelist-and-essayist, wrote "A Fist in the Eye of God" for a general audience, rather than for biologists or philosophers. Nonetheless, I think her article is worth careful philosophical attention. Environmental ethicists frequently look to ecological science, but it is much less common for them to draw on the theory of natural selection.

In what follows, I will first try to clarify the connections that Kingsolver sees between natural selection and the effects of genetically modified food on the environment by elaborating on her arguments in the context of natural selection theory. I will then explore some further connections between natural selection and the arguments against genetically modified food. These arguments suggest that an understanding of the theory of natural selection is required for a complete understanding and analysis of these issues. As a philosopher of biology interested in environmental issues, my hope is that the kind of analysis that is useful in my area of philosophy

will be fruitful in environmental ethics as well.

2. Genetic Diversity and Natural Selection

Kingsolver's first argument against genetically modified food concerns a potential loss of genetic diversity. In the United States and in other industrialized countries, there is very little genetic diversity within a given food crop. However, in places such as the Near East, northern China, Mesoamerica, and Ethiopia, farmers have been practicing traditional farming methods for centuries. These methods involve saving seeds that produce different benefits – for example, popcorn, tortilla corn, and roasting corn. More importantly, however, farmers save and replant seeds from many different types of seasons – wet seasons, dry seasons, hot seasons, cold seasons, etc. The result is that whereas crops in the U.S. and other industrialized countries are genetically uniform, crops in regions that still practice traditional farming methods are quite genetically diverse.

Why is the genetic diversity of food crops important? Kingsolver considers the example of wheat. If a crop of wheat plants is genetically diverse,

> ...some will grow into taller plants and some shorter, some tougher, some sweeter. In a good year all or most of them will thrive and give you wheat. But in a bad year a spate of high winds may take down the tallest stalks and leave standing at harvest time only, say, the 10 percent of the crop that had a "shortness" gene. And if that wheat comprises your winter's supply of bread, plus the only seed you'll have for next year's crop, then you'll be almighty glad to have that small, short harvest. Genetic diversity, in domestic populations as well as wild ones, is nature's sole insurance policy. Environments change: Wet years are followed by droughts, lakes dry up, volcanoes rumble, ice ages dawn. It's a big, bad world out there for a little strand of DNA. But a population will persist over time if, deep within the scattered genetics of its ranks, it is literally prepared for anything. When the windy years persist for a decade, the wheat population will be overtaken by a preponderance of shortness, but if the crop maintains its diversity, there will always be

recessive aspirations [i.e., recessive genes] for height hiding in there somewhere, waiting to have their day (97-98).

Kingsolver points out that these wheat crops are undergoing natural selection. Let's look at that claim in more detail. Four conditions must be true for natural selection to operate in a given population:[1]

1. In any given generation, more offspring are born (or, in this context, more seeds are produced) than can survive, leading to what Darwin termed a "struggle for existence."[2]

2. There is variation among the offspring or seeds.

3. Some of the variation is heritable, i.e., can be passed from one generation to the next.

4. Some of the heritable variations confer a greater ability to survive and reproduce in the given environment than other heritable variations.

All four of these conditions are satisfied by Kingsolver's wheat example. Many more wheat seeds are born than can survive. There is variation among the seeds, and because the variation is *genetic* variation, it can be passed from one generation to the next. And, given the particular environment of high winds, some of the wheat plants will have a greater ability to survive and reproduce than others. The result is natural selection; wheat plants that have a greater ability to survive the high winds will most likely have a greater representation in the next generation, i.e., we expect that there will be an increase the percentage of wind-resistant wheat plants from one

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[1] My presentation here differs slightly from that of Kingsolver's, although the differences are irrelevant to the arguments here.

[2] Lennox and Wilson (1994) point out that a number of authors leave this condition out, although Kingsolver, to her credit, does not. They argue that "struggle for existence" should be interpreted broadly to include checks on population size that occur as a result of "environmental forces including predation, climatic conditions, disease, dependency on other populations, and limited energetic resources" (Lennox and Wilson 1994, 69). They make a persuasive case that, when interpreted properly, the struggle for existence must be included as one of the necessary conditions for natural selection.

generation to the next.

Natural selection is, then, a means by which populations can adapt to changing conditions – not within a given generation, but over the course of generations. Wheat produced by traditional farming methods, since it preserves genetic diversity with regard to differential survival ability, satisfies the necessary conditions for natural selection and is thus able to withstand future environmental changes. However, wheat that is genetically uniform does not satisfy the necessary conditions for natural selection. Thus, it cannot withstand future environmental changes. There are only two options for genetically uniform wheat: perpetuate with the same genetic composition year after year,[3] or be extinguished.

In some sense, it is intuitive that a genetically diverse crop will be better able to survive future environmental changes than a genetically uniform crop. After all, as the old saying goes, "Don't put all of your eggs in one basket." Or, perhaps more appropriately, "Let many flowers bloom." What I think is important about Kingsolver's argument is that it moves beyond these intuitions to show us exactly *why* genetic diversity is preferable to genetic uniformity with respect to food crops. It gives us a more complete understanding of the phenomenon that is taking place.

The rest of Kingsolver's argument proceeds as other similar arguments have. Genetically modified wheat, like the crops sown in industrialized countries, is genetically uniform. This is because, as Lappé and Baily (2002) point out, genetically modified seeds must be a "uniform product" in order to be patented. However, we are now considering selling these uniform products to *traditional* farmers, i.e., farmers whose crops are currently genetically diverse. This makes the farmer's crops vulnerable to whatever new blight or environmental disaster might come along.

But if genetically uniform crops are so vulnerable, how is it that those of us living in industrialized nations have been able to get along just fine with them? Kingsolver's answer is that we have been able to do so precisely because we have always had the diverse crops of other nations as a backup – as an "insurance policy." According to Kingsolver, "when a crop strain succumbs all at once to a new disease, all across the country (as happened with our corn in

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[3] Unless, of course, there is a mutation among the wheat plants. The role of mutation will be discussed further below.

1970), researchers must return to the more diverse original strains for help" (100).

So, if traditional farmers switch *en masse* to genetically modified wheat, not only are their own livelihoods at risk, but worldwide food supplies are also put at risk. If sound, this is a whopper of an argument from any anthropocentric perspective that you choose. However, to the extent that other organisms such as insects and birds depend upon these food crops, biocentrists and ecocentrists have reason to be concerned as well.

Yet, Kingsolver notes, these points are lost on those who don't accept the theory of natural selection – e.g., creationists, who, as a result, may fail to recognize the potential dangers of genetically modified food. However, I think that those who *do* accept the theory of natural selection also easily overlook the role of natural selection in "genetic diversity" arguments. I suspect this is because the theory of natural selection, in its bare bones form, can seem as though it is stating the obvious. What could be more obvious than saying that those who are better able to survive and reproduce in a given environment are more likely to survive and reproduce in that environment? As Thomas Henry Huxley is said to have remarked, "How stupid of me not to have thought of that."

3. Unintended Effects and Natural Selection

I don't think I would call Huxley "stupid," lest we label all 19th century scientists except Charles Darwin and Alfred Russel Wallace[4] stupid, but there is certainly a problem with failing to take seriously the lessons that Darwin and Wallace taught us. Kingsolver worries about "less knowledgeable people" who "comfort themselves on the issue of genetic engineering by recalling that humans have been pushing genes around for centuries, through selective breeding of livestock and crops" (102). And yet even those who know the difference downplay the difference. Leighton Jones points out that whereas for centuries humans have been "shuffling genes in increasingly systematic ways and using extensive crossing and artificial selection," genetic modification, for the first time, allows for genes to be transferred *between* species (1999, 581). And yet, he says that genetic modification "is an extension" of these previous practices.

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[4] Wallace independently developed a theory that is virtually identical to Darwin's Theory of Natural Selection.

Is it really just an extension, or is there an important difference? To answer this question, we must again look to the theory of natural selection. Kingsolver states:

> The farmers who select their best sheep or grains to mother the next year's crop are working with the evolutionary force of selection, pushing it in the direction of their choosing. Anything produced in this way will still work within its natural evolutionary context of variability, predators, disease resistance, and so forth (102).

This quote needs a bit of unpacking, because there is a sense in which farmers *are not* working with the evolutionary process[5] of selection at all, and there is a sense in which farmers *are* working with the evolutionary process of selection. When a farmer selects the grains for next year's crop, he or she is selecting on the basis of criteria that matter to humans: color, edibility, or size, for example. This is *artificial selection*. The traits that the farmer selects may or may not be traits that would be adaptive in the given environment. In this sense, the farmer is not working with the evolutionary process of selection; or, more precisely, he or she is not working with the evolutionary process of *natural* selection, although *artificial* selection is taking place. A crop of tasty wheat may not be a crop of robust wheat.

However, a farmer using traditional farming methods *is* working with natural selection in the sense that, as was discussed previously, genetic diversity is being preserved. So, even though the farmer may be artificially selecting for tasty, but less robust wheat, there is still a great deal of genetic variability among the wheat seeds that are selected. That is, among the seeds that are planted, there will still be some wheat plants that are better at surviving drought, whereas others are better at surviving a given disease, etc. Moreover, the "context" is the same as it is for natural selection. There are no *new* genes being introduced to the population,[6] only an artificial selection of the ones that were there before. In particular, there are no genes from radically different species being introduced (so-called "transgenes"), although crosses between close relatives have been done.

To show why this difference matters, Kingsolver discusses the well-known case of Bt

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[5] I prefer the term "process" to "force," for reasons not relevant to this discussion.
[6] Except, of course, as due to mutation, which will be discussed below.

corn. Bt corn is corn that has part of a Bt (*Bacillus thuringensis*) bacterium's genes spliced into its genome – a naturally occurring bacterium that causes caterpillar's stomachs to explode but which is harmless to humans and many other species. The problem is that corn pollen is spread by the wind, so the corn pollen lands on trees and bushes that surround farmland, where it can be eaten not only by corn "pests," but also by Monarch butterflies – on which it should have the same exploding effect. Now, as I mentioned previously, the case of the Monarch butterfly is somewhat controversial – were the butterflies really affected by the Bt corn? Are their numbers back up again? But, as Kingsolver points out, "no reasonable person can argue that dusting them with a stomach explosive is going to help matters" (103). And the general point is transgenes may have unintended and unforeseen side effects on other species. Again, this is reason for ethical attention, whether one is anthropocentrically worried about humans not having the beautiful Monarch butterfly to enjoy, whether one thinks that the butterfly has intrinsic value, or whether one is concerned about the effect that the loss of the butterfly or other species might have on ecosystems.

There is another potential problem with introducing what is essentially a pesticide (or rather, a biopesticide) into a food crop. Kingsolver states,

> The massive exposure to Bt, now contained in every cell of this corn, is killing off all crop predators except those few that have mutated a resistance to this long-useful pesticide. As a result, those superresistant mutants are taking over, in exactly the same way that overexposure to antibiotics is facilitating the evolution of antibiotic-resistant diseases in humans (104).

Kingsolver doesn't elaborate, but this is natural selection once again. Consider a population of corn-feeding caterpillars, a few of which have developed mutations that protect them from the effects of the Bt bacterium. Now consider what would happen if there were no Bt bacteria. The Bt resistant mutations, since they are few in number, could be lost by chance through random genetic drift. That is, by chance, the Bt resistant caterpillars could fail to reproduce and thus not leave any offspring in the next generation. Or, it is possible that the caterpillars that are resistant

to Bt are less robust in other ways, and so would tend to be selected against. Finally, even if the Bt resistant caterpillars remained in the population, their numbers would probably stay low unless being Bt resistant conferred some other sort of benefit on the caterpillars.

However, once you add Bt corn into the equation, you have changed the environment, and so you change the way that natural selection operates in the population. The Bt resistant caterpillars, which were likely to be lost or remain in low numbers, now have the selective advantage. The Bt corn kills off all or most of the nonresistant caterpillars – presumably, much more effectively than the bacteria on their own ever could – leaving only Bt resistant caterpillars. Now the Bt resistant caterpillars can reproduce without any competition from nonresistant caterpillars and so their numbers will increase. The farmer, stung by natural selection, is now faced with a crop of corn and a population of "super caterpillars" that he or she must find a new way to control.

4. Further Insights from Natural Selection

We have seen how the theory of natural selection enhances our understanding of some of the environmentally related arguments against genetically modified food. It helps us to understand 1) why genetic diversity is important, 2) how GM food could have unintended side effects, and 3) how super-resistant species could evolve. But the question is, does the theory of natural selection do anything more than enhance our understanding? Does it, for example, point us in directions that can help us decide the strength of these arguments? The answer to this question, I will argue, is "yes." Let us take a deeper look at the theory of natural selection.

Ernst Mayr (1978) emphasized that evolution by natural selection is a two-step process. The first step is the *production* of variation. How are new variations introduced into a population? The most obvious answer is "mutation." Mutation, like genetically modified food, can introduce new genes into a population. And yet, if we were comparing an *already established* genetically modified population to a population that is the result of traditional farming methods, *both* would presumably undergo mutations at approximately the same rate. If there is a difference in the production of new variation in a given population of genetically

modified food and a given population of traditionally farmed food, the difference does not lie with mutation.

So, then, when the question arises as to how new variations are introduced, Kingsolver's answer is not "mutation," but rather, "sex." Or, in more precise (and boring) terms, *independent assortment* with *recombination*. *Independent assortment* refers to the independent alignment of the maternal and paternal pairs of homologous chromosomes; when the pairs segregate, each member of the pair has an equal chance of facing one pole or the other on the equatorial plate (Gardner, Simmons, and Snustad 1991: 66). So, in other words, for each pair of chromosomes, it is a chance process as to which member of a pair of chromosomes will be part of which gamete, with the result that different assortments of chromosomes are possible. *Recombination*, on the other hand, is a possible result of crossing-over (the exchange of chromosome segments) whereby a new combination of genes is formed (Gardner, Simmons, and Snustad 1991: 165). So, when gametes are formed from a pair of parental chromosomes, not only are different combinations of chromosomes possible (as a result of independent assortment), but also, within each chromosome, different assortments of genes are possible (as a result of recombination). Together, the processes of independent assortment and recombination determine the assortment of genes into gametes, and thus determine the genotypes that are to be represented among the gametes. The result is that each generation will contain new genetic combinations. Since the physical traits produced by a gene are influenced by the presence of other genes, new genetic combinations each generation mean that there will be new physical specimens of wheat each generation.

What this discussion shows is that the term "genetic diversity" doesn't mean that there are two or three different types in a population, or even that there are one hundred different types. It means that, under normal conditions of natural selection, each individual is *completely unique*. The amount of variability is astronomical. Thus, it makes it plausible to think that if a new disease arises, somewhere amongst all that variability there is a plant or two that will survive.

The question is, do traditional farming methods really produce as much diversity as there is in a natural population? Or, if not as much, is the amount close? And how much diversity is

required to give a species some "insurance" against future environmental changes? These are empirical questions that, if answered, may or may not give support to the argument concerning genetic diversity. If it turns out that the genetic diversity that results from traditional farming methods is rather low after all, then perhaps not much is lost by switching to genetically modified foods. However, if Kingsolver is correct about the amount of diversity that results from these methods, her arguments would be strengthened.

The second step of evolution by natural selection, according to Mayr, is the *perpetuation* of variation, meaning, the way in which variations in the population are transmitted from one generation to the next. Perpetuation of variation can occur by natural selection, as we have seen; the organisms whose genes confer a greater ability to survive and reproduce will tend to have a greater genetic representation in subsequent generations. However, it is worth noting that variations can be perpetuated by other means. For example, suppose that there is variation in the population, but that the variation does *not* confer any difference in survival and reproductive ability. Perhaps, for example, some of the wheat plants are lighter in color than the others, but that they have equal survival and reproductive potential. Nonetheless, the lighter colored plants might have greater representation in the subsequent generation. Why? Perhaps by chance, the lighter colored plants are on the far edge of the field and are therefore exposed to less wind. This is an alternative evolutionary process known as random genetic drift. Thus, there is another lesson to be learned from the natural selection perspective: not all variations that can be found in a population will necessarily contribute to the perpetuation of the species. Recalling that differences in reproductive and survival ability is one of the necessary conditions for natural selection calls our attention to those cases where this necessary condition is not met. Once again, this is an empirical question for us to explore.

But let us return to the issue at hand, which is the perpetuation of variation into subsequent generations by the process of natural selection. Actually, this raises a bit of a puzzle, as we will see. Let's suppose that, year after year, the wheat crop is buffeted by strong winds, and let us further assume, as Kingsolver does, that the shorter wheat is better able to survive the strong winds. What would you expect to happen? In each generation, the gene pool would contain more and more of the "shortness" gene. As Kingsolver notes, genes for greater height

would persist in a recessive state, but over time, there would be fewer and fewer recessive genes, too. Natural selection would eventually cause the shortness gene to be omnipresent in the population, a state biologists refer to as "fixation." Thus, the puzzle is that whereas mutation and recombination act to introduce new variation into a population, natural selection seems to act to reduce it. In other words, eventually only the advantageous variations are perpetuated. So, where is the diverse population, the "insurance policy" that Kingsolver spoke of?

In fact, this very puzzle occupied biologists for much of the second half of the 20th century, once they discovered that variation in natural populations was much higher than they originally expected (see, e.g., Beatty 1987 for discussion). Kingsolver's answer to this puzzle is that the environment does *not* remain constant. One year there may be strong winds, but the next year there might not be. One year there might be drought, the next a flood. In other words, the environment is fluctuating through time. Under these conditions, one would expect that variation would be preserved. One year, taller wheat might have the advantage; another year, shorter wheat. In a third year, wheat of intermediate height might be what is preserved. As long as the environment fluctuates from year to year, no one type will have a chance to become fixated in the population. And again, if the genetic variation is preserved, it can then provide an "insurance policy" to protect against the potentially devastating effects of those same environmental fluctuations.

Note, however, that the claim of a fluctuating environment is an empirical claim that may be more or less accurate for a particular situation. We once again have a claim that we can test and that will help us decide the strength of Kingsolver's arguments, namely, how much fluctuation do the environments undergo in places where traditional methods are still practiced? And the question can be made more precise than this. Roughgarden, in chapter 13 of the well-known textbook *Theory of Population Genetics and Evolutionary Ecology,* demonstrates some very specific conditions under which a fluctuating environment can maintain genetic diversity. The details are too complex to get into here, but suffice it to say that not just any fluctuating environment will maintain genetic diversity. Whether or not genetic diversity can be maintained depends on the frequency and severity of the environmental changes, among other factors.

Furthermore, a fluctuating environment is not the only mechanism through which genetic

diversity can be maintained. One other possible mechanism is heterozygote advantage. Consider the well-known case of sickle-cell anemia. People who have two copies of the recessive gene (the homozygous recessives) have sickle-cell anemia and usually die in childhood. On the other hand, people who have two copies of the dominant gene (the homozygous dominants) are susceptible to malaria. But people who have one copy of the recessive gene and one copy of the dominant gene (the heterozygotes) will be resistant to malaria, although they will suffer from a moderate form of sickle cell anemia. Thus, genetic variation is maintained in the population because there is an advantage (resistance to malaria) conferred to the heterozygote, even though one of the homozygotes has the disadvantage of sickle-cell anemia and the other has the disadvantage of susceptibility to malaria. Thus, both genes are maintained in the population.

Another mechanism that can maintain genetic diversity is through a "tradeoff." For example, in a recent study of the montane willow leaf beetle, it was determined that a particular gene enhances cold tolerance, but that it exacts a penalty in terms of energy expenditure (Neargarder, Dahlhoff, and Rank 2003). Under extreme conditions, beetles having the gene will be at an advantage, but under less extreme conditions, they may be at a disadvantage. Thus, genes that enhance cold tolerance *and* genes that do not can both be maintained in the beetle population.

Now clearly, these three mechanisms – fluctuating environment, heterozygote advantage, and "tradeoffs" – can interact in complex ways. Yet again, however, they point us in specific directions through which we can evaluate the strength of arguments concerning genetic diversity.

5. Conclusion

Theodosius Dobzhansky stated that, "nothing in biology makes sense except in the light of evolution" (1973, 125). While I haven't proved that claim here, I hope to have given evidence for the lesser claim that nothing in the arguments concerning genetically modified food and the environment make sense except in the light of the theory of natural selection. Genetics may be king when it comes to getting grants, but natural selection still has the last say. Furthermore, a

deeper exploration of natural selection illuminates some empirical claims that are implicit in the environmental arguments against genetically modified food. Thus, natural selection points us in a direction by which we may evaluate the soundness of these arguments.

My claim, then, is that an understanding of natural selection is necessary for making an environmental argument concerning genetically modified food. But is it sufficient? This is a larger question than I can adequately tackle here, but my position would be, "no," it is not sufficient. In the end, it is our values – our ethical reasoning – that must determine what we ought to do about genetically modified food, not the facts of the case. However, I do think, as I have suggested at several points, that a number of different ethical perspectives would support a position against genetically modified foods if the arguments discussed by Kingsolver turn out to be sound. That would not make an understanding of natural selection sufficient to argue against genetically modified food, but it would certainly make the case compelling.

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