CONVENTIONAL PLANT BREEDING FOR HIGHER YIELDS AND PEST RESISTANCE

Roberto García-Espinosa
Colegio de Postgraduados en Ciencias Agrícolas, Texcoco, México

Raoul A. Robinson
Retired crop scientist living in Ontario, Canada

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Contents

Summary

The purpose of conventional plant breeding is to improve (a) the yield, (b) the quality of crop product, (c) the agronomic suitability, and (d) the resistance to the important parasites of the crop in question. The last of these improvements has caused the most difficulty and is emphasized in this article.

Macro-evolution is the production of a new genetic code, while micro-evolution is merely the re-arrangement of the existing genetic code. Plant breeding is micro-evolution. All protection mechanisms against parasites are either unstable or stable; that is, they are either *within* or *beyond* the capacity for a micro-evolutionary change of the parasite. Unstable mechanisms fail on the appearance of new strains of the parasite, and they are temporary; stable mechanisms do not fail in this way, and they are durable. Resistance to crop parasites is similarly unstable (vertical resistance) and temporary, or stable (horizontal resistance) and durable.

Vertical resistance is due to the gene-for-gene relationship and in the wild it functions as a system of locking. This system has been ruined by uniformity in agriculture, and vertical resistance is consequently temporary resistance. Its use during the twentieth century led to the “boom and bust” cycle of plant breeding. Horizontal resistance is not due to a gene-for-gene relationship and it is quantitative in its inheritance and its effects. Vertical resistance is unstable, big space, high profile, small time, and few cultivars. Horizontal resistance is the opposite in these characteristics and is stable, small space, low profile, big time, and many cultivars.

Horizontal resistance is a second line of defense. It is also useful, universal, and durable, but it can be eroded. The methods of breeding for horizontal resistance are simple and are described. On site screening, cumulative progress, plant breeding clubs, and past successes with horizontal resistance are described. The possibility of an inverse correlation between yield and resistance is dismissed, and methods of conventional

plant breeding are described. Conventional plant breeding and genetic engineering are compared; conventional breeding for vertical resistance and genetic engineering are both confined to single—gene genetics, and the necessity for many-gene genetics will ensure the continuing importance of conventional breeding. The future of conventional plant breeding may involve a self-organizing system of plant breeding clubs working with horizontal resistance and producing near-perfect cultivars for each agro-ecosystem.

1. Introduction

There are four main objectives in conventional plant breeding (see Section 12.4 of this paper). These are the improvement of:

- t he yield,
- the quality of crop product,
- the agronomic suitability, and
- the resistance to pests and diseases of the crop in question.

For the past century, modern plant breeding has been extremely successful, but it has also been dominated by the recurring problem of resistance to pests and diseases (see Section 8.3). Accordingly, much of this discussion about plant breeding involves resistance to crop parasites, but the other three objectives are also considered.

2. Macro-Evolution and Micro-Evolution

When Darwin coined the phrase “evolution by natural selection” to explain the origin of species, he made no distinction between two categories of evolution that are now called macro-volution and micro-volution (see *Microevolution and Variations in Population Genetics*; and section 5 of this paper). Macro-evolution (Greek: macro = large) requires geological time, measured in millions of years, and it produces new species. For example, humans and chimpanzees are different species which had a common ancestor about seven million years ago. Micro-evolution (Greek: micro = small) occurs during periods of historical time, measured in years, and it produces new ecotypes. These ecotypes are variants within a species and they result from differing selection pressures within an ecosystem. Unlike macro-evolution, micro-evolution is reversible. One ecotype can usually be changed into another, and back again, by experimental procedures.

The basic difference between the two kinds of evolution is that macro-evolution involves the production of a new genetic code, while micro-evolution involves the rearrangement of the existing genetic code. Possibly the best example of micro-evolution, and the changing of ecotypes, is called industrial melanism. In England, during the industrial revolution, the bark of many trees turned black from the soot in the polluted atmosphere. Some seventy different species of moth, which had superb coloring on clean bark, then became very conspicuous to moth-eating birds when at rest on black bark. In all seventy species, the moths produced new ecotypes that were black. Micro-evolutionary breeding experiments showed that it was quite easy to change black moths into light-colored camouflaged moths, and back again.

Conventional plant breeding is micro-evolution. It differs from natural micro-evolution in that it is the result of artificial selection, rather than natural selection. Natural micro-evolution produces wild ecotypes. Plant breeding produces agro-ecotypes, otherwise known as crop varieties or cultivars (i.e. *culti*vated *var*ieties).

3. Domestication

Domestication is defined by Allard as "the bringing of a wild species under the management of man," and it is a form of micro-evolution by artificial selection. In some crops, the process of domestication has continued for so long that it has almost become macro-evolution. An agro-ecotype of a crop that is thousands of years old has often been so altered from the wild form that it is unable to survive in the wild, and its wild progenitors are often difficult to identify. This domestication is a remarkable achievement of the early civilizations. Simmonds argues that the total genetic change achieved by farmers over some nine millennia is probably far greater than that achieved by the scientific efforts of the last two hundred years. Buddenhagen comments that, although many crop varieties are the products of recent scientific breeding, many, surprisingly, are not. It is perhaps a shock to realize that millions of acres of many modern crops are varieties that were selected by ancient farmers, long before agricultural science had developed. Nevertheless, Robinson considers that the success of scientific plant breeding during the twentieth century has been spectacular, with important increases in the yield and quality of many major crops. But he also considers that the frequent failures of crop resistance have created such pessimism that the breeding for resistance has tended to be abandoned. As a consequence, many modern crops are high yielding and of high quality, but they are unduly susceptible to pests and diseases. This susceptibility is the main reason why we now use crop pesticides in very large quantities.

4. The Worldwide Redistribution of Plants

People in different parts of the world domesticated different species of plant according to the wild species available. The crops of the New World, for example, were entirely different from those of the Old World. When the European voyages of discovery began in the late fifteenth century, it became possible to redistribute crops around the world, and this was an essential element of crop improvement. Some of the effects were dramatic. Medieval Europe had suffered recurring famines, until New World maize and beans were taken to southern Europe, and potatoes and beans to northern Europe. Combined with improving medicine, these new crops allowed the population of Europe to soar. The resulting wave of cheap labor made the industrial revolution possible and, for the first time, armies began to be measured in millions of men.

Similarly, the introduction of wheat and cattle transformed North America, while Old World sugarcane and coffee provided the main source of wealth for Latin America. Red peppers, which originated in Mexico, have become so important in Indian cooking that most Indians believe them to be of Indian origin. Walk onto any farm, anywhere in the world, and many, possibly all, of the crops being grown will be of foreign origin.

However, in the course of moving species around the world, considerable ecological chaos has been caused. Obvious examples include rabbits and cacti in Australia, killer bees in South America, and both Colorado beetle of potatoes, and *Phylloxera* of grapes, in Europe. These disasters were totally unforeseen and, at the time, they were unforeseeable. They were also expensive and difficult, if not impossible, to correct. Genetic engineering engenders fears of similar unforeseen, expensive, and possibly irreversible ecological chaos. For this reason alone, genetic engineering should be pursued with caution (see Section 12.4).

5. Stable and Unstable Protection Mechanisms

Every protection mechanism against a parasite can be classified into one of two categories. An unstable mechanism is *within* the capacity for micro-evolutionary change of the parasite. Such a mechanism fails to function when the parasite produces a new ecotype that is unaffected by it (see Section 9). In common usage, the resistance is then said to have "broken down". Examples of unstable protection mechanisms include antibiotics which are famous for their breakdown to new strains of bacteria. There are many unstable insecticides, including DDT, which houseflies, malarial mosquitoes, and other insects became resistant to. A typical unstable fungicide is metalaxyl, which has led to the development of new strains of potato blight and other plant parasitic fungi. Warfarin has been proven unstable against rats and mice, and there are herbicide-resistant dandelions. Typically, an unstable protection is a temporary protection, and it endures only until the pest or parasite produces a resistant strain, a new agro-ecotype. In plant pathology, these parasite agro-ecotypes were traditionally called physiologic races, or pathologic races. In crop entomology, they were known as biotypes.

A stable mechanism is *beyond* the capacity for micro—evolutionary change of the parasite. Natural pyrethrins are a stable insecticide. Pyrethrum (*Chrysanthemum cinerariifolium*) is native to Dalmatia, and the people of this area have been putting dried pyrethrum flowers in their bedding for centuries to control fleas and bed bugs. No resistant strains of these parasites have ever appeared. Similarly, people in Southeast Asia have used extracts of Derris roots (*Derris ellyptica*) to control body lice, apparently for centuries, and no resistant lice has appeared, and a solution of soft soap (or synthetic detergent) provides a stable protection against aphids. Bordeaux mixture is a stable fungicide against downy mildew of grapes and potato blight, as more than a century of use has demonstrated. And sulfur is stable against powdery mildews. The important feature of these stable protection mechanisms is that they are durable. Every crop plant has resistance mechanisms against every one of its pests and diseases. Some of these mechanisms are stable, and others are unstable. It is these unstable mechanisms that have been the base of plant breeding for the past century.

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Biographical Sketches

Roberto Garcia-Espinosa is a Mexican citizen with a B.Sc. in Biology, from Mexico's National University, and an Ms. and Ph.D. in Plant Pathology from Colegio de Postgraduados, Mexico, and University of Florida, USA, respectively. He worked for ten years in the tropical rainforest regions of Mexico, where he developed the "sustainable agriculture modular units" which were intended as agricultural systems under an ecological approach, where diseases did not cause disasters. He has been teaching a course on the ecology of soil-borne diseases for the last 25 years and also a course on genetic host management for disease resistance for the last 10 years. He conducted a bean breeding program, financed by IDRC of Canada, for the development of horizontal resistance during the last 12 years, producing new varieties, with high levels of horizontal resistance to all locally important parasites, derived from local land races from the "Mixteca" region of Mexico: varieties that yield five times as much as the regional or commercial bean varieties.

Raoul Robinson is a Canadian citizen who has an Honours degree in Agricultural Botany from Reading University, Postgraduate Diplomas from Cambridge University and Imperial College of Tropical Agriculture, Trinidad; and an Honorary Doctorate from Colegio de Postgraduados, Mexico. He worked for twenty years in Africa (Kenya, Ethiopia, Nigeria), and for many years with Food and Agriculture Organization of the United Nations. He has been professionally involved with many different species of crop, in some fifty-five countries. He is the author of three published books on horizontal resistance (two of which have also been published in Spanish), and a fourth book that is ready for publication.