CALESTOUS JUMA

The Gene Hunters

Biotechnology and the Scramble for Seeds

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The Gene Hunters

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Contents

Tables

Figures

History celebrates the battle-fields whereon we meet our death, but scorns to speak of the ploughed fields whereby we thrive; it knows the names of the king's bastards, but cannot tell the origin of wheat.

—J. H. Fabre
The Wonders of Instinct

I am not here to argue that human species ought to take responsibility for evolution on the planet, and begin through public and private institutions to make collective decisions about such matters. If that were the question . . . I would advocate that we put it off for a few centuries or more — let things run themselves while we get accustomed to the idea of evolutionary governance, develop the appropriate ethics and myths and political structures, and perhaps mature a bit. However, that is not the question before us, since we are already governing evolution.

— Walter Truett Anderson
To Govern Evolution

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Calestous Juma

Abbreviations

Most acronyms used in this book appear in the Appendix (institutions, conserving genetic resources). I have listed those acronyms most frequently used.

ARIPO	African Intellectual Property Organization
CATIE	Centro Agronomico Tropical de Investigacion y Enseñanza
CGIAR	Consultative Group for International Agricultural Research
CIAT	Centro Internacional del Agricultura Tropical
CIMMYT	Centro Internacional del Mejoramiento del Maiz y Trigo
CIP	Centro Internacional de la Papa
CPGR	Commission on Plant Genetic Resources
CRRI	Central Rice Research Institute
DNA	deoxyribonucleic acid
EMBRAPA	Empresa Brasileira de Pesquisa Agropecuária
FAO	Food and Agriculture Organization of the United Nations
GATT	General Agreement on Tariffs and Trade
GTZ	German Agency for Technical Cooperation
HYV	High-Yield Variety
IARC	International Agricultural Research Centre
IBPGR	International Board for Plant Genetic Resources
ICARDA	International Centre for Agricultural Research in Dry Areas
ICGEB	International Centre for Genetic Engineering and Biotechnology
ICRISAT	International Crops Research Institute for the Semi-arid Tropics
IITA	International Institute of Tropical Agriculture
IRRI	International Rice Research Institute

KSC	Kenya Seed Company
MIRCEN	Microbiological Resources Centre
NSSL	National Seed Storage Laboratory
NTBs	Non-tariff barriers
PBI	Plant Breeding Institute
PAHO	Pan American Health Organization
PBRs	Plant Breeders Rights
PPA	Plant Protection Act
PVPA	Plant Variety Protection Act
R&D	Research and Development
UNCTAD	United Nations Conference on Trade and Development
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNIDO	United Nations Industrial Development Organization
UPOV	Union for the Protection of New Varieties of Plants
WHO	World Health Organization
WIPO	World Intellectual Property Organization

Glossary*

Biological diversity	The variety and variability among living organisms and the ecological complex in which they occur.
Biotechnology	The application of science and technology to the processing of materials by biological agents to provide goods and services.
Cell	The smallest unit of living matter potentially capable of self-perpetuation; an organised set of chemical reactions capable of self-reproduction. Cells contain DNA, where information is stored, ribosomes, where proteins are made, and energy conversion mechanisms.
Centre of diversity	The region where most of the major crop species were originally domesticated and developed. These centres may coincide with centres of origin.
Chromosome	In any cell, the DNA-bearing structure that carries the inheritable characteristics of the cell.
Clone	A group of genetically identical cells or organisms derived from a single ancestor.
Cultivar	An organism developed and persistent under cultivation.
DNA	Deoxyribonucleic acid. A long, chainlike, thin molecule that is usually found as two complementary chains. The chain is arranged in subunits repeated many times. The arrangement is used to store all the information necessary for life.
Embryo transfer	An animal breeding technique in which viable and healthy embryos are artificially transferred to recipient mothers for gestation and delivery.
Equilibrium	The absence of net movement one way or another.
Ex situ	Pertaining to the conservation of organisms in places where they normally do not occur. This is associated with storage facilities such as gene banks, botanical gardens, or zoos.

* Based on Drlika, 1984; OTA, 1987b; Bent et. al., 1987.

Gene	A small section of DNA which contains information for making of one protein molecule; a unit of hereditary information that can be passed from one generation to another.
Gene-pool	The collection of genes in an inter-breeding population.
Genetic diversity	The variety of genes within a particular species, variety, or breed.
Genetic engineering	The manipulation of information in the DNA of an organism in order to alter the characteristics of the organism.
Genetic resources	The useful characteristics of plants, animals and micro-organisms that are transmitted genetically.
Genome	The genetic endowment of an individual or organism.
Germplasm	A non-specific term used to refer to the genetic information of an organism or group of organisms; the total genetic variability of a species.
Hybridoma	A cell type produced by the fusion of two or more different types of cells.
In situ	Pertaining to organisms in their native environment.
In vitro	The growing of cells, tissues, or organisms in vessels under sterile conditions on artificially prepared medium.
Micro-organisms	Organisms not classified as plants or animals. These include bacteria, fungi, viruses, mycoplasma, protozoa, and cyanobacteria.
Molecule	A group of atoms tightly joined together.
Morphology	A taxonomic description of an organism, or a detailed analysis of its form and structure.
Mutation	Any change in the structure of DNA or number of genes or chromosomes in a cell.
Recombinant DNA (rDNA)	The hybrid DNA produced by joining pieces of DNA from different organisms *in vitro*.
Recombination	The breaking and rejoining of DNA strands to produce new combinations of DNA molecules.
Species	A group of closely related, morphologically similar individuals which interbreed or have the potential to interbreed; a taxonomic subdivision of genus.
Taxonomy	The study of the theory, procedure, and rules of classification of organisms according to similarities and differences between them.
Tissue culture	A technique in which portions of plant or animal are grown on an artificial culture medium.

Introduction

In his analysis of the impacts of Old World animals and plants in the Americas, Crosby described in detail the major ecological oscillations that resulted from the introduction of new life forms. He concluded: 'This wild oscillation of the balance of nature happens again whenever an area previously isolated is opened to the rest of the world. But possibly it will never be repeated in as spectacular a fashion as in the Americas in the first post-Columbian century, not unless there is, one day, an exchange of life forms between planets.'[1] These words were written in 1972. A year later, US scientists cloned the gene. Since then, scientists have marshalled enough knowledge to modify existing life forms and create new plants and animals. The world is on the verge of receiving life forms whose economic and ecological implications are likely to rival the effects of the Columbian exchange.

Writing almost at the same time, de Janvry pointed out that '[B]iological innovations have relatively little effect on labour and management requirements. They are slightly capital using and moderately yield increasing when used outside of complete packages of techniques.'[2] This assertion has neither been supported by the experiences of the Green Revolution nor advances in biotechnology. The potential impacts of advances in biotechnology will not only be irreversible, but they will also introduce major and unpredictable transformations in the global organization and distribution of production which will have far-reaching implications for Africa. This, together with its historical antecedents, is the theme of this book.

In the last decade the world has experienced major advances in technological change. The use of micro-electronics or information technology has moved from the consumer sector to the capital goods sector – the very heart of industrial production. Biotechnology, on the other hand, promises to make major inroads into the productive sector. These changes are likely to have profound effects on the world economy and the agricultural sector is likely to experience some of the earliest effects. Countries which rely on the export of high-value agricultural commodities are likely to be affected by these advances. African countries, for example, will be required to make adaptations in their agricultural practices. Their responses will depend largely on their capacity to use some of the modern techniques in biotechnology as well as conserve biological diversity as a basis for renewed agricultural production. In order to understand the advances in biotechnology and their implications, it is necessary to place the developments in a historical perspective.

Three major events related to historical botany took place exactly 200 years ago. In 1788, the ill-fated crew of the *Bounty*, under Captain William Bligh, landed on Tahiti with special instructions to move the breadfruit tree to the West Indies so as to establish a new source of food for slaves working in British colonies. The same year, the First Fleet of British colonists arrived in Australia and thus the Antipodes were turned into an extension of the European culture. In another development, British amateur scientists formed the Linnean Society in London to promote the work of the Swedish botanist, Carl Linnaeus. These three significant events were associated with Joseph Banks, a longtime president of the Royal Society and botanical adviser to royalty. It was Banks who recommended that British convicts be shipped to Australia and suggested that Linnaeus's papers and notes be purchased and brought to London. Banks also organized the mission of the *Bounty*. These events represent major landmarks in the role of genetic resources in socio-economic evolution.

In 1884-85 the European powers converged on Berlin for a conference that was to change the future of Africa. The continent was divided into numerous colonies and a long process of domination ensued. The Berlin conference was a culmination of what was later referred to as the 'scramble for Africa'. Historians have not fully explained why the scramble for colonies took place. What is clear, however, is the fact that it was partly associated with the expansion of economic activities in Europe. The scientific and technological resources available to the European powers not only contributed to local industrial and agricultural development, but it also enabled the countries to extend production to other parts of the world. These events have been used by historians to explain Africa's poor economic performance.

Most historical studies on Africa have examined the long-term changes in the control over land, labour and capital. These factors, though admittedly important, do not adequately account for the main sources of agricultural and industrial growth. Recent ecological and economic crises in Africa have led to a questioning of the validity of existing modes of analysis and the related development policies. This book aims to recast the picture by emphasizing two of the main sources of agricultural growth – plant genetic resources and the related technologies, and the accompanying institutional reorganization. The scramble for African colonies was only part of the story of European economic expansion. The other part, which is often ignored by historians, was the introduction of new genetic material and the related technological know-how into the economic system. The introduction required the reorganization of existing institutions to provide suitable conditions for the success of the proposed changes.

This book will show that colonization could have been meaningless without access to genetic resources as sources of agricultural growth. This historical legacy still dominates economic growth and has received renewed impetus from the recent advances in the capacity to modify plant and animal life. These changes, as will be shown later, pose new challenges to African economies. Africa failed in the last 100 years to benefit from the major technological advances in agricultural and industrial production. The emerging techniques in biotechnology offer both prospects and problems for the continent. While the restructuring of the global agricultural sector is likely to affect African high-value, low volume commodity exporters, the potential responses lie in the capacity to apply some of the emerging techniques to farm and industrial adjustment. The capacity to benefit from biotechnology will depend largely on the ability to conserve and utilize existing genetic resources as well as formulate science and technology policies that facilitate the process. This shift in policy focus will also require a change in the epistemological basis for the anaylsis of African events.

This study has drawn from a wide range of subjects to build a case for the conservation of genetic resources and their introduction into the economic system. The first chapter outlines the African situation and suggests an alternative approach of analysing the situation. It is suggested that the static and equilibrium notions underlying neo-classical thought are not adequate to deal with a continent that is undergoing fluctuations in a world of rapid technological change. The current conditions of technological discontinuities and socio-economic reorganization require an analytical approach that can deal with uncertainty, novelty and long term dynamics.[3] Chapter 1 traces the roots of the modern agriculture in early Western epistemology and identifies those key principles which have led to agricultural uniformity and reductionism.

In chapter 2 the reader will be introduced to the subject of historical botany. The role of genetic material in socio-economic evolution will be presented. Illustrative examples will be drawn from the use of genetic material to support the British empire. It will also be shown that the rise of the United States as a global agricultural power was as a result of the persistent efforts to introduce new genetic material and the related technology into the economic system. It is the success of this programme that has given the US the power to dominate world agricultural output.

The relatively poor performance of the Soviet agricultural system is also associated with the destruction of scientific and technological capability in plant genetics during the Stalinist era.

The US agricultural model (and the related social and political features) was later exported to a large number of Third World countries under the banner of the 'Green Revolution'. The model has taken root but has also resulted in a large number of social, economic and ecological problems. This is the subject matter of chapter 3. Chapter 4 examines the implications of recent advances in biotechnology for the Third World countries in general and African countries in particular. These innovations are likely to shift the production of high-value commodities from Third World farms to industrialized countries' laboratories. Chapter 5 deals with intellectual property issues related to genetic resources and biotechnology and their potential impact on the African countries. The new patterns of patent protection are likely to limit the flow of scientific information at a time when African countries need to build their scientific and technological capability to respond to the discontinuities analysed in Chapter 4.

The ability of African countries to take advantage of the emerging technologies depends largely on the prevailing policies on genetic resources and technology. Chapter 6 examines the history of Kenya and identifies some of the major legal and institutional obstacles to the expanded utilization of genetic resources and biotechnology. The final chapter provides policy guidelines on genetic resource conservation and biotechnology development.

This book illustrates the role played by science and technology in socio-economic evolution. It shows that economic change is largely a result of the introduction of new information or knowledge into the economic system. The manner in which that information is generated and used depends very much on the prevailing political ideology and patterns of institutional organization. African countries' capacity to undertake the required adjustments will, therefore, depend on the ability of the political leadership to grasp the significance of technological change and institutional reorganization. This will also require a shift from dependence on economic advisers and planners who still accept moribund economic theories that fail to take into consideration long-run social and economic dynamics.

The study is intended to show the options available to African countries, given their current economic and ecological crises. The continent is at the crossroads at a time when new technological and scientific advances are being made. Unlike previous technological revolutions, biotechnology offers the potential to be applied to decentralized production. It is also amenable to popular participation and can therefore be applied to the African situation. Moreover, the fact that biotechnology is science-intensive suggests that the capital-related entry barriers are minimal and the main requirement is the building of human resources through education, training and skill acquisition. But to fully comprehend the implications of biotechnology, it is important to place the subject in a long-term perspective.

Africa has found itself at a critical moment in world history. While the continent searches for alternative development strategies to deal with changes in the world commodity markets, the industrialized countries are making institutional reforms and technical advances which tend to narrow the range of development options open to the African countries. Moreover, the pace at which these changes are occurring requires African countries to make equally rapid adaptations. The future lies in the application of some of the very biotechnology innovations that are leading to the restructuring of world agriculture. Africa must innovate at technological, institutional and political levels: conventional agriculture and industry must adapt to the emerging transformations as must the intellectual as well as the policy environment.

Notes

1. Crosby, 1972, p. 113.
2. de Janvry, 1978, p. 307.
3. A full account of the proposed approach is provided in Juma, 1986 and Clark and Juma, 1987.

1. Genetic Resources and Socio-economic Evolution

US President Thomas Jefferson once said that the greatest service that could be rendered to any country was to add a useful plant to its culture. This statement underscores the importance of genetic resources in socio-economic and cultural evolution. Economic history has often focused on technological development and ignored the role of genetic material in economic change. This chapter presents a brief overview of the role of genetic resources in socio-economic change and prepares the ground for subsequent analyses of historic botany. The Jeffersonian view of the world was based on a detailed understanding of the prevailing development in the US at the time. The lessons, however, have not been adequately learnt by most African countries.

This chapter will show that the introduction of new genetic material and the related technological knowledge into the economic system is one of the most crucial sources of economic growth. To illustrate this point, however, requires an alternative epistemological basis for social analysis. Most conventional approaches are based on static notions that are inherently incapable of dealing with socio-economic systems which evolve under conditions of uncertainty. A non-equilibrium systems approach captures the destabilizing effects of new genetic material and the related technology on the socio-economic system.

Epistemology and environmental expansionism

The rise of inanimate technology and the increased use of genetic resources are closely linked. The shift from hunting and gathering to agriculture required changes in the knowledge base and the introduction of new technologies. Technology enabled mankind to introduce new modes of interacting with the environment in order to meet nutritional needs. Thus, knowledge and the prevailing material conditions were closely tied together in a non-deterministic manner. The material conditions enabled mankind to formulate a range of institutional arrangements (including traditions, myths, rituals and codes of social behaviour) which embodied some of the rules that governed mankind's interaction with the natural environment. Some of these institutional arrangements, however, acquired autonomy and became a source of instrumental power in themselves.

Knowledge of the botanical and zoological base increased the range of options available for providing nutritional needs. At this early stage of socio-cultural evolution, mankind was already showing the tendency to expand and influence the natural resource base. The decision on whether to seek control over the natural environment differed from region to region. While the American Indians, for example, adopted an ecological cosmology that avoided the need to drastically transform and control the environment, Western thought is associated with various forms of expansionism and control. One of the earliest forms of expansionism was the application of genetic resources to expand economic activities and control other human beings, a narrower domain of social behaviour that can be referred to as genetic imperialism.

Modern historians have mainly presented a truncated understanding of expansionism, often emphasizing the recent events associated with the political and economic expansion of Western Europe and the creation of colonies. Much of this has been based largely on the materialistic interpretation of the world. In order to understand the historical role played by genetic resources in social change and economic expansion, it is necessary to examine the broader philosophical basis for expanionism in a non-deterministic manner. It is understood here as the view that the role of mankind is to extend control over the rest of nature. This view is well articulated by Aristotle who conceived of a divine hierarchy over which a supreme being, God, presided and the rest of the creatures followed in a descending pecking order. Humankind, more specifically man, ruled over all the creatures below him — women, children, koala bears, snails, phytoplankton and rocks.

Aristotle flourished during the era of Alexander the Great, a significant period in Hellenic imperialism. That his philosophy should reflect such thinking is not surprising. Aristotle may have influenced his pupil, Alexander, but the extent of that influence is uncertain. Aristotelian scholasticism carried all the major elements of expansionism. He argued that the conquest of 'natural slaves' was right and therefore war against barbarians was justified. His thoughts later became central doctrines of the Judaeo-Christian tradition in which the natural environment existed mainly for the purposes of meeting human needs. Christianity became inherently expansionist in practice and philosophy.[1]

The view that humankind was supreme to all other life forms was strongly advocated by the Catholic Church. When some residents of Rome planned to organize a society to protest against the slaughter of bulls for amusement and sport, Pope Pius IX refused them permission on the grounds that animals had no souls and therefore did not deserve man's moral sympathies. Although St Francis of Assisi provides a counterpoint to the mainstream Catholic worldview, the church still remains antagonistic or indifferent to nature. With this kind of belief, all expansionists needed to do was to be convinced that other races were inferior and they could therefore justify their exploitation and even extermination.

The philosophical strand of Judaeo-Christian thought was consolidated by other notions that led to the mechanistic world in which genetic expansionism flourishes. One of the earliest advocates of expansionism was Francis Bacon. He saw the rise of science as a major source of power and tools for the control of nature. Bacon stressed that for all their pompous claims, the Greeks has not performed any experiments which led to improvements in the human condition. For him, the main goal of science was to endow human life with new discoveries and powers. He advocated the search for objective knowledge which would enable mankind to have control over all natural things.

The Baconian appeal to rationality and expansionism was furthered by René Descartes who sought to reduce all phenomena to mathematical expressions. The Cartesian world was precise and followed neat mathematical laws. With Baconian rationality one was able to identify the mathematical laws that governed the behaviour of all phenomena. The Greek view of the world as a series of chaotic events and decay was deemed irrational by Descartes and therefore dismissed as false. With the Cartesian method, the world could be reduced to separate entities which represented the whole; the behaviour of the sum of the parts was equal to the functioning of the whole. This mechanistic view of the world, which received new impetus from Galileo and Bacon, was now on its way to theoretical dominance.

Descartes compared human beings and animals to clocks composed of springs and wheels. A combination of the mechanistic view and the need to accumulate experimental knowledge led to the disregard of compassion towards animals. He defended vivisection and other cruel experiments conducted on animals in Paris and believed that the crying of animals was no more that the creaking of a wheel. Like Pope Pius IX, he saw no reason why animals deserved human compassion. Science and religion worked closely to promote expansionist attitudes.

It was Isaac Newton who consolidated the mechanistic world view in his *Principia* in 1687. He also presented a methodological synthesis of the opposing empirical, inductive method represented by Bacon and the rational, deductive method of Descartes. Newton was a strong believer in God and creation. Since God had no beginning and end, his worldview was equally timeless. What mattered for Newton was the existence of some form of equilibrium in which separate entities existed. The entities remained in balance through their mutual attraction. Gravity was the ultimate force in the Newtonian universe. It was constant and was the most fundamental of all laws. Newton's world was thus a mega-clock that worked according to some grand design — God's handicraft. The world was also reversible since it was in equilibrium and timeless. The equilibrium could be disturbed by the attraction between the constituent entities but the divine relentlessly returned to equilibrium.

Because of being timeless, Newton's worldview disregards history since events occur instantaneously and can be analysed through comparative statics. In addition, this mechanistic worldview is deterministic since all that happens is already predetermined in the initial conditions. In Newtonian systems, spontaneous emergence is severely curtailed and things change through linear progression. The Newtonian synthesis has given us a seemingly orderly world without surprises. Every entity has a predefined place in a larger constellation. And as in Aristotle, entities are defined by their fixity of form and their boundaries are clearly marked. Their positions are predetermined and do not easily change. If there are any changes, they are predictable. There is a strong causal relationship in the Newtonian worldview; for every effect there must be a discernible cause. One of the aims of research is to identify the cause-effect correspondence. In most cases, researchers look for single causes.

This mechanistic worldview has had a major influence on the development of world agriculture. Let us examine in detail the impact of Cartesian-Newtonian metaphors on botany, genetics and agricultural production. The pursuit of Aristotelian scholasticism led to a strong need to classify plants so as to understand more fully their potential contribution to human needs. And since the external form of plants was presumed to be static and discernible, an analytical method that could capture their key features could be used for classification. The belief that plants were created by God in the form they existed made it seemingly easy to classify them according to their distinctive morphological features. This mechanistic and reductionist programme was implemented by Swedish botanist Carl von Linné, popularly known by his Latinized name, Linnaeus.

The method of Linnaeus was simple, neat and appealing: one simply counted the pistils and stamens in a flower to establish its position in God's divine arrangement. With further calculation, the Cartesian part of the programme could easily be achieved and plants could be classified and neatly organized on shelves. In a few years after the system was introduced, most of Europe abandoned previous attempts to classify plants and adopted the method of Linnaeus. Like most heroes, Linnaeus succeeded in synthesizing and rationalizing existing methods of classification and analysis. His binomial nomenclature was already in use when he came to the scene. But why did Linnaeus' method prevail over the previous attempts to classify plants? The answer lies in the rise of genetic imperialism.

The clear-cut Cartesian nature of the method was extremely appealing to the scientific community. Linnaeus blossomed during the era of abstraction and reason. His method also conformed to the growing need to base botanical studies on herbarium specimens as it was becoming increasingly difficult to deal with a large body of botanical information, some of which was on plants from all over the world. It should be noted that by then imperialist countries such as Britain were already sending botanists and plant collectors to all parts of the world and the accumulated stock of specimens needed to be classified. Classification was therefore necessary if the empire was to utilize some of the plants in its expansionist designs.

In 1749 Linnaeus had written an academic thesis, *The Oeconomy of Nature*, which became a popular text in Europe and America. The book reiterated the Judaeo-Christian view that nature existed to meet the needs of mankind. His worldview was clearly Newtonian. The mechanistic and static nature of Linnaeus' work is captured by Worster: 'Essentially [the book] presents a thoroughly static portrait of the geo-biological interactions. All movement takes place in a single confined sphere, planetary in scope. Like the classical Greek naturalists, Linnaeus allows only one kind of change in the natural economic system, a cyclical pattern that keeps returning to its point of departure.'[2] According to Linnaeus, species are constantly circulating in the economy of nature with the precision of clockwork. In order to keep the system rational, God has set limits to the geographical range of each species and assigned its peculiar food. He conceived of a divine demarcation between the species and did not concern himself with variability within species.

According to Linnaeus, man must exercise his expansionist responsibility:

> All these creatures of nature, so artfully contrived, so wonderfully propagated, so providentially supported . . . seem intended by the Creator for the sake of man. Everything may be made subservient to his use; if not immediately, yet mediately, not so to that of other animals. By the help of reason man tames the fiercest animals, pursues and catches the swiftest, nay he is able to reach even those, which lye hidden in the bottom of the sea.[3]

Linnaeus' thus conformed to the Baconian ideal. With the application of science to the study of botany, mankind was able to utilize the natural endowment to fulfil his needs. As his experimental knowledge grew, so did his capacity to control and utilize nature. By doing so mankind would have realized his imperial objectives. In a rather Machiavellian fashion, the end would justify the means; the rise of human welfare, as measured by the accumulation of material wealth, would vindicate the instrumental and utilitarian ethos.

The utilitarian approach adopted by Linnaeus was also consistent with the prevailing managerial practices of British industrialists. Nature was seen largely as a storehouse for raw materials for industrial and agricultural production. This view greatly influenced the thinking of economists such as Adam Smith and led to economic theories which assumed that natural resources were inexhaustible. In addition, Newtonian equilibrium notions led to the view that pollutants and waste released into the environment would gradually dissipate as the system returned to equilibrium. The costs of ecological damage were treated as factors external to the units of agricultural and industrial production. This legacy has led to extensive environmental damage and the naive unwillingness to adopt environmentally-sound development strategies.

Linnaean thought was very popular among the Anglo-Americans. Upon his death in 1778, his books, papers and herbarium sheets were bought for £1,000 and shipped to London by James Edward Smith at the suggestion of Sir Joseph Banks, a leading advocate of the use of genetic resources for the expansion of the British empire. In 1788 amateur botanists formed the Linnaean Society to promote Linnaeus' work. The mechanistic view of botany that Linnaeus promoted faced new challenges from Darwin's *Origin of Species*, published in 1859. The theory of evolution challenged the view that species were a product of God's handiwork and did not change through time. But Darwin's concepts were easily incorporated into Linnaean thought. It was botanical business as usual.

The mechanistic and reductionist approach in the biological sciences was given renewed impetus by the discovery of hereditary factors by Gregor Mendel. Although Mendel published his work a few years after Darwin's *Origin of Species*, it went unnoticed until 1900 when it was rediscovered. The view that there were 'units of heredity', later called genes, was consistent with the reductionist Cartesian philosophy. The genes, according to Mendel, did not become diluted through progeny but were preserved; they did not change their identity but only recombined. With the rediscovery of Mendel's work, the discipline of genetics, as William Bateson called it, was born.[4] Genetics became the ultimate realization of the mechanistic and reductionist programmes in the biological sciences.[5] It was believed that every gene corresponded to specific traits in a linear way. The understanding of the functioning of the whole system was subordinated to the imperatives of genes.

Mendel's work was used to promote 'genetic determinism'. Life forms were treated as machines controlled by linear chains of cause and effect. The correspondence between genes and traits has led to simplistic interpretations of human behaviour as exemplified by socio-biology in which human behaviour is seen largely as a result of genetic make-up.[6] This deterministic interpretation of natural phenomena has been used to justify such expansionist practices as racism and sexism. Agricultural production was the first major beneficiary of genetic determinism. With Mendelian genetics, plant breeders were able to make major advances in the field. The expansionist nature of the application of genetics to agricultural production is reflected in the emergence of monocultural agricultural production. Monoculture is, indeed, genetic imperialism with all the reductionist and mechanistic underpinnings. Further advances in genetics led to new knowledge on the functioning of enzymes. This knowledge was extensively applied to industrial production, especially fermentation in the 1940s.

The most significant breakthrough in genetics research was the discovery of the physical structure of deoxyribonucleic acid (DNA) – the self-replicating molecule that carries genetic information and forms the basis of chromosomes – in 1953 by Francis Crick and James Watson. Molecular biologists have since then unravelled the basic language of life as coded by DNA. Two decades of research led to techniques that allowed scientists and industrialists to transfer specific genes from one organism to another. With these techniques, first applied in 1973, mankind is now able not only to control and use life forms, but also to modify and create new life forms. Genetic expansionism has become a pervasive phenomenon whose consequences are irreversible. This is the epistemological heritage of the biological sciences in general and agriculture in particular. The rise of biotechnology is helping push this expansionist programme further, with untold benefits and risks.

Genetic sources of social change

On 26 October 1788, the ill-fated British ship, HMS *Bounty*, under Captain William Bligh, dropped anchor in Matavai Bay, Tahiti. The ship's only mission was to collect the breadfruit tree (*Artocarpus altilis*) and introduce it into the British West Indies colonies.[7] The plant was intended to be a source of food for African slaves, or 'pieces of the Indies' as they were then called, true to the mechanistic worldview of the day.[8] The idea of sending the breadfruit tree to the West Indies was advanced by Joseph Banks, who was with Captain James Cook on his first voyage to the Pacific.[9] Banks had funded the scientific expedition, which had yielded enormous botanical and zoological knowledge on the South Pacific, including Australia.

After the voyage, Banks discussed the findings of the expedition with King George III and convinced him that the plant would be a cheap source of food for slaves in the West Indies. Then Britain had lost its American colonies and was starting to rely more on scientific activities to find alternative ways of sustaining the economy. Convinced of the potential benefits of the tree, King George III commissioned Bligh, who had sailed with Banks on Cook's second voyage on the *Resolution*, to undertake the mission. Banks made all the plans to transform the ship into a floating garden and prepare instructions for plant handling. The Royal Botanic Gardens at Kew appointed David Nelson, who had served as botanist with Cook, to accompany Captain Bligh. William Brown, another gardener from Kew, was chosen to serve as Nelson's assistant.[10]

The mission had problems right from the start. Banks and Nelson took over its running and marginalized the Admiralty. Banks provided Nelson with his own instructions, forcing the Minister of War, George Yonge, to complain that they did not expect the Captain to take orders from a gardener. Banks rejected outright the proposal that Captain Bligh be taught gardening, arguing that he had seen so much mischief done by dabblers. The entire ship was transformed into a floating garden. Even the Great Cabin, 'traditionally sacrosanct to the captain, had been taken over and enlarged, a false deck had been laid throughout the cabin and in it hundreds of round holes had been cut to receive plant pots.'[11] Botanical fanaticism ruled the place: the Great Cabin was renamed the 'Garden'.

The ship was very crowded as a result of the modifications. With a crew of 44, the gardeners could hardly find enough room to do their work. The ship sailed from Spithead on 23 December 1787. Two days later a fierce storm broke, filling the Great Cabin with water and completely ruining a large quantity of stored bread. By January 1788, the crew's allowance was reduced by 33 per cent and water was being filtered because of its bad condition. The ship was supposed to go to Tahiti by Cape Horn but the rough sea forced Captain Bligh to change course and go by South Africa arriving in October 1788. On 4 April 1789 the *Bounty* left Tahiti with 1,005 breadfruit trees for the West Indies. Crammed in an already reduced space, the crew experienced great discomfort and were also unhappy with the fact that much precious water was being given to the plants. In addition, they resented Captain Bligh's overbearing manner.

On 28 April 1789, there was a mutiny on the *Bounty* and Bligh and Nelson were put in a 33-foot open boat by the crew. The mutineers delightedly threw the plants into the sea. With their screams of 'Good riddance', they had succeeded in putting to an end the first major state-supported attempt by the scientific community to relocate economic plants. Nelson died in 1789 on Timor where *Bounty* finally landed.[12] Brown, who was kept aboard the *Bounty* because the crew needed the services of a gardener, later helped found a colony at Pitcairn. He was later shot during a land ownership dispute.

Britain did not abandon the effort to take breadfruit to the West Indies. In his second attempt, Captain Bligh watered the 1,200 plants well before leaving Tahiti. When he landed in Jamaica in 1793, the *Providence* was described as a floating garden. The breadfruit scheme, however, did not prove as successful as expected as the slaves preferred plantain and other plants.[13] It was not until the emancipation of the slaves in 1838 that the plant began to be used on a large scale; previously breadfruit was mainly eaten by pigs. Despite the fruitless efforts, Captain Bligh was honoured for his work; he was made Governor-General of New South Wales in 1805. Although he had good ideas for running a colony, his arbitrary and harsh approach led a section of the navy under Major George Johnstone to rebel. Captain Bligh was deposed and gaoled, and eventually left the colony and returned to England in 1810. Botanists have immortalized him in the genus, *Blighia*, although he is better known for the mutiny.

The breadfruit scheme demonstrates the role of genetic resources in economic development. With the help of Kew Gardens and support from the state, a major attempt was launched using the military to move a plant, whose economic value was only hypothetical, from Tahiti to the West Indies. This attempt has received little attention in history, an illustration of the failure of conventional analytical approaches to focus on the major agents of social change. Most academic traditions have paid excessive attention on the broad paths of social change and have ignored the key factors which led to social reorganization. The introduction of new genetic material into the economic system and the related technological knowledge has played a significant role in socio-economic evolution. It has taken a series of agricultural crises for this fact to be recognized. Even so, decision-makers in most African countries have not fully grasped the implications of the role of genetic resources in human welfare.

The fact that methods of moving plants have so much changed since the days of Captain Bligh has also made the role of genetic resource less obvious. Unlike mechanical technologies, which have high visibility, the genetic potential is obscured in plant material and its impact is not so obvious to the public. The contributions of genetic resources to human welfare are so widespread that they are taken for granted, and problems such as loss of biological diversity have remained unnoticed for a long time.[14] In the case of food, the range of useful resources has been narrowed to a handful. It is estimated that throughout human history over 3,000 plant species have been used for food.[15] This has been reduced to a few crops: most of the world's food comes from 20 species. Part of the reduction in the species used for food was a result of external conquest and domination which was associated with the suppression of local food crops and the introduction of exotic varieties. More recently, plant breeding programmes have reduced the number of crops used for food. In India, for example, out of 50,000 known varieties, scientific programmes focused on developing less than ten.[16]

Table 1.1

Annual production of world's major crops (1985)

Crop	Production (Million Tonnes)
Wheat	450
Corn	400
Rice	395
Potato	295
Barley	180
Sweet potato	155
Cassava	115
Soybean	105
Grapes	80
Oats	65
Sorghum	60
Sugarcane	55
Millets	50
Bananas	45
Tomato	40
Sugar beet	35
Rye	35
Oranges	30
Coconut	30
Cottonseed oil	30
Apples	30
Yam	25
Peanuts	25
Watermelon	20
Cabbage	15
Onion	15
Beans	10
Peas	10
Sunflower seed	10
Mango	10

Source: Food and Agriculture Organization, Rome.

One of the plants still suffering from prejudice is grain amaranth (*Amaranthus cruentus, A. caudatus* and *A. hypochondriacus*), which was an important food to Central and South American Indians 500 years ago, revered by both the Aztecs and Incas. When heated, the seeds burst and take on a flavour of popcorn. But, because Aztecs created idols out of popped amaranth and ate them in their religious ceremonies, the Spaniards banned its cultivation and drove it into obscurity. Although this act helped bring down their religion and culture, a few farmers continued the old tradition of growing amaranth. In the 1970s it was learnt that amaranth seeds have unusually high levels of total protein and of the nutritionally essential amino acid, lysine. This amino acid is usually deficient in plant protein, including the protein in all common varieties of major cereals such as wheat, corn and rice. Today, amaranth is being reintroduced although most cereal researchers have still never heard of it and some are cynical about its potential contribution to agriculture.[17]

The rediscovery of amaranth represents recent concern over the narrowing range of the genetic base for agricultural, industrial and pharmaceutical genetic resources. The decline of biological diversity has gradually become an issue of international concern. In the 1960s the matter seemed to interest only scientists and environmentalists. Today the subject has become a major item at various international fora, despite the limited knowledge of the extent of the problem. The 'consequences of changes in diversity cannot be forecast because our knowledge of earth's biological fabric is uneven and incomplete'.[18] The uncertainty surrounding the loss of biological diversity and its potential contribution to human welfare has led to renewed conservation efforts. Countries such as the US that have for a long time relied on the importation of genetic material for agricultural renewal have taken the lead in genetic resource collection and conservation. It is largely the understanding of the role of genetic resources and the related technological knowledge that gave the US its global lead in agricultural production.

The historical botany of the US differs remarkably from that of the Soviet Union. The Russian economy went through similar imperatives that made the need for genetic resource collection necessary. Indeed, Russian botanists, under the leadership of Nikolai Vavilov, made the hitherto most systematic global collection of economic plants. Vavilov identified eight major regions with high genetic resource diversity which he termed 'centres of origin'. He stressed that the 'enormous quantity of field and vegetable crop material discovered in these centres should be widely used in breeding work in the [Soviet Union].'[19] In order to utilize the global genetic stock, Vavilov noted, it was necessary to improve the state of Soviet climatological knowledge. Using his theory of climatic analogy, Vavilov argued that in 'selecting species and varieties of the [Soviet Union] one has to take into account the climatic conditions under which the plants introduced were growing and, wherever possible, to select varieties from regions more or less similar climatically to our country.'[20]

Vavilov's efforts were rendered fruitless by the abstractionist philosophy that dominated the Soviet Union under Stalin. With Lysenko's connivance, experimentation as a mode of scientific and