Genetically Modified Organisms

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A Scientific-Political Dialogue on a Meaningless Meme

By

Giovanni Molteni Tagliabue

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For Lisetta

"Great is the power of steady misrepresentation"
Charles Darwin[1]

[1] *On the Origin of Species*, Chapter XV: "Recapitulation and Conclusion", 421, http://darwin-online.org.uk/content/frameset?pageseq=449&itemID=F391&viewtype=image

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PREFACE

BY ROBERT PAARLBERG

I first met Giovanni Molteni Tagliabue in the lovely town of Ravello, on the Amalfi coast, when we both were attending an international conference on the political economy of agricultural biotechnology. The focus was specifically on controversies surrounding so-called "genetically modified organisms," known as GMOs. This new book from Giovanni, titled "GMO": A scientific-political dialogue on a meaningless meme, makes a convincing case for the position he expressed at this conference. He explains that the term "GMO" is worse than just confused and unscientific; it is wittingly as well as unwittingly deceitful.

Others have constructed some parts of this argument before, but none has presented the whole case with such grace, wit, and detail. Each chapter begins with a brief and convenient summary, using standard expository prose, but the reader then discovers that the chapters themselves are presented in an inviting dialogue form. Giovanni's delightful dialogues (between the fictitious characters Marcello, Veronica, Andreas, James, Norberto, and others) could almost be acted out on a live stage. Plato's Socratic dialogues deliver the same seductive learning pleasure. Giovanni's tone is conversational, the mood is convivial, and the language always accessible. He knows the science and explains it with technical precision, then lays out the psychology, economics, and politics through one case or example after another, all suitably annotated for those who want to learn more.

The author is not afraid to call out the errors of others, nor does he hide his own indignant conclusions. He correctly describes the pseudo-category of "GMO" as a frustrating and damaging Gordian Knot, caused by "a strange and complex tangle of psycho-sociological, political and, last but not least, economic motivations." It was Alexander the Great who used his sword to cut the original, mythical Gordian Knot. Giovanni Molteni Tagliabue's artful pen is taking a powerful swing at the all-to-real GMO Knot in the pages of this fascinating new book.

Robert Paarlberg
Emeritus Professor of Political Science, Wellesley College
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NOTICES

The six chapters which make up the text (plus the Annexes), each preceded by a summary, are not completely independent, but the division may help direct the reader to the issues they are particularly interested in.

Quotations, both in the main text and the notes, when they are not originally in English, are translated by the author.

Citations from valuable websites and blogs ("grey literature") are used when they can add or emphasise something or are particularly interesting.

A Very Brief Prelude

The reader may well wonder whether there is any sense in a long and detailed text whose very title states the meaninglessness of the main theme. Yes, there is: unfortunately, in documents of all ages we have countless examples of idle and simpering discussions, of banal arguments which have been given an endless series of treatments. However, we believe that our situation is different because, while it is true that "Genetically Modified Organism" ("GMO") in a real sense does not mean anything coherent, the issue is very complex, has many different aspects, sees an overlapping of levels—scientific, psychological, sociological, political, economic—the investigation of which requires a fair torrent of words: analyses which is largely aimed at taking apart some basic, powerful and ill-fated misunderstandings. For this reason, we hope that the dialogue we have imagined, instead of being inconclusive and make-believe such as the proverbial discussions about angels dancing on the head of a pin, may achieve the goal we have set.

This text addresses the intricate labyrinth by treating the various aspects rigorously, trying to achieve the necessary dynamic between a rational approach and continuous factual and empirical findings. The abundant specialist scientific literature—whose fruits the author has tried to "distil", hopefully in a way that is largely understandable to the layperson—is indicated in the notes and References, for those who want to go directly to the source.

Our hope is that the subject matter of this debate will be as stupefying to a future observer as we today find ridiculous the fact that in the past there were heated discussions about irrelevant or nonsensical philosophical questions. Moreover, we are sure that all this fuss over a non-existent category seems surreal to the Rational Alien, an imaginary inquisitor of earthly matters, whose reactions we have sought here and there to imagine, especially where the paradoxes are truly disconcerting.

ACKNOWLEDGMENTS

I am grateful to a number of colleagues and friends for useful discussions; they are scholars and researchers, whose works are quoted or referred to in the text: Klaus Ammann (University of Bern, Switzerland), Gilberto Corbellini (University of Rome "La Sapienza"), Jon Entine (Genetic Literacy Project), Klaus Jany (Wadi-International University, Syria, and Leibniz Institute of Plant Genetics and Crop Plant Research, Germany), Drew Kershen (University of Oklahoma), Marcel Kuntz (Centre National de la Recherche Scientifique, Grenoble, France), Alan McHughen (University of California at Riverside), Henry I. Miller (Pacific Research Institute, San Francisco, California), Piero Morandini (University of Milan), Robert Paarlberg (Harvard University), Pamela Roland (University of California at Davis), C.S. Prakash (Tuskegee University, Alabama), Matin Qaim (Georg-August-Universität Göttingen, Germany), David Zilberman (University of California at Berkeley).

I have been helped with the translation and revision of the English text by Emanuela Croci, Paul Garwood and Filippo Rizzi.

Beyond the papers and articles indicated in the References, the complete list of my publications—in English and Italian—is available at www.researchgate.net/profile/Giovanni-Molteni-Tagliabue.

INTRODUCTION

"Genetically Modified Organisms" ("GMOs") are a solid nothing[2]: a deceitful meme, a category error, a false concept, a harmful and persistent intellectual and political boil; they form an illogical and disordered pile of almost all the products from biotechnologies which derive from certain techniques which target genomes in some spots (DNA recombination). "GMOs" are the focus of ceaseless propaganda which lumps them all in together as harbingers of risk for health, the environment, food sovereignty, supposedly arising from an intrinsic, indefinite, non-existent common denominator; but similar varieties of vegetables or cereals or pulses or fruits, which have been obtained with similar methods (for example *in vitro* cultures or induced mutagenesis), are strangely immune from such charges, as are all pharmacological or industrial biotech products and some food ingredients, including those from organisms whose genome has been directly tweaked. Nor do the ferocious critics distinguish among the vast range of characteristics that are obtained, a myriad of different traits (for example resistance to insects, immunity to viruses, tolerance to weed killers, an increase in nutrients, an ability to prosper with less water, increased yields, better flavour), many of which can often be generated without directly pinching the genomes: therefore, these enhanced plants, legalistically speaking, are not "GMOs". Why is a heterogeneous list of cultivars selectively and arbitrarily attacked? Why do opponents tar all "GMO" crops with the same brush and tirelessly and aggressively demonise them? Why rail against a bogeyman that can't even be unarguably identified?

This enmity is not justified using sound arguments: those which are typically adopted are invalid. "GMOs" as such do not threaten biodiversity, because extensive monocultures which deeply alter, or even destroy natural environments are a phenomenon which does not depend on whether plants are recombinant DNA or not. Vice versa, these techniques can help biodiversity: in many areas of the world, just a small helping hand for the genomes of various typical and local crops would be enough to save them from extinction, which is looming due to pests that have become desensitised to traditional methods of defense. Not even the development of

[2] We borrow this expression from the great Italian Romantic poet, Giacomo Leopardi, who used it with reference to the whole of reality.

resistance to pesticides or tolerance to weed killers is purely a "GMO" phenomenon, because it has always existed, it is an eternal, biological and ecological fight: it is called competitive co-evolution.

The only grounds for some perplexity which makes any sense is the fear that some "GMOs", those obtained by transgenesis, i.e. from the transfer of short DNA sequences between distant species, represent an illicit violation of the natural order: but the unease seems unfounded when one understands that the genetic code is a universal language, that the genomes of microorganisms and plants and animals are made with the same building blocks, that all living beings share numerous genes, that the "jumping" of genes from an organism to another (e.g. from a microbe to a plant) is not so uncommon in nature.

Attempts to manipulate organisms date back to the start of civilisation: farmers and breeders have always changed, until a few decades ago without being conscious of the fact, the genomes of plants and animals which they used to cross and select in the search for the desired characteristics, in a utilitarian or aesthetic sense. During the 20th century, the traditional results of hybridisations and purely empirical selections were joined by effective laboratory techniques, the products of which—above all plants—were welcomed by agri-food entrepreneurs and the public: numerous new varieties enriched fields, industry and dining-tables, to the profit of producers and to the benefit of consumers. Also the first commercial "GMOs" were viewed favourably, but an opposition movement then arose in many nations that was as bizarre as it was arbitrary.

So almost everywhere deaf ears have met the reiterated appeals of scientists to establish laws which should impose assessment of any biotechnological intervention (whether "GMO" or not) according to actual levels of risk: for human/animal health, i.e. toxicity or allergenicity and/or for the environment, e.g. invasiveness; similarly, the important socio-economic and legal considerations, with the consequent legislative and regulatory frameworks, which are linked to "green" biotechnologies and to agriculture in general, should not be connected to the genetic makeup of the products, or to the techniques and processes used by scientists and animal/plant breeders to obtain them. Assessments should be made individually, case by case: the environmental impact, the health risks, the economic cost-benefit ratio, the social impact, must be established for each individual product in every given geographical-historical situation, and not *a priori* and in relation to the methodology used to create it. Geneticists, agronomists, ecologists, and biologists do *not* recommend that the checks are bland: we have a lot of examples of failed experiments ("GMOs" and others), in which collateral effects have been generated (for example

allergenicity or toxicity), and therefore these cultivars have simply been abandoned. Let us repeat: the traditional biotechnologies can also generate unsuccessful plants, but the failures do not depend on whether one method or another has been used; individual unsatisfactory results must be discarded, not the techniques. The pluralisation of single cases is wrong: if we ascertain that one mushroom is toxic, do we abhor them all? Being "anti-GMO" means falling into a semantic trap; being "pro-GMO" means coming out in favour of well controlled recombinant DNA crops: but it is an expression to be avoided, an ambiguous and misleading abbreviation. Similarly, the societal impact related to the exploitation of new ag products, with the important legal and legislative-regulatory facets, should leave aside as irrelevant the DNA composition of a plant or animal or micro-organism—whether it is believed to be a "GMO" or not.

Following the moods of a public which is too often misinformed, both due to dogmatic activists and to many uncritical members of the mass media, domestic and international lawmakers have built flawed and bizarre rules: almost identical products are immune from checks if they are considered "traditional" (including very sophisticated laboratory techniques), but instead burdened with redundant analyses, pointless bureaucracy, and related abnormal costs, if they are classified as "GMOs", using contorted and incoherent attempts to define an object which does not have a consistent meaning. The law, which is almost everywhere irrational, anti-scientific and botched, creates pointless obstacles and causes serious damage to scientific research, to agricultural progress, the environment, the economy, all of society—above all in less developed countries; it is unjust prohibitionism, which is often underpinned by a protectionist intent that dare not speak its name: instead, the freedom to conduct business must be guaranteed, in a well regulated free market, in which adequately tested "GMOs" are freely available for production and consumption, just like all the other agricultural products. Any form of excessive, unjustified state control is not only anti-economic, but anti-democratic too.

Those who believe they are combating the agribusiness—a legitimate socio-political struggle—by demonising some particular products, which are unjustifiably and confusingly lumped into a pseudo-container, have picked the wrong fight, i.e. they are dazzled, because the area covered by "GMOs" does not coincide with the one that opponents target: the ostracism imposed on DNA-recombinant crops, while it hampers the public and philanthropic researches and activities, has no impact on the revenues of the big seed companies, whose customers are the farmers who, untouched by the propaganda, buy "GMO" seeds in enormous quantities (this happens, where it is allowed, also and above all in developing countries); in the

meantime, the dogmatic anathema favours other capitalists, the traditional manufacturers of more harmful pesticides and more aggressive weed killers. Vice versa, ill-considered hostility puts a block on public or philanthropic "GMOs": this harms the poor above all, when they are denied some valid agricultural biotechnologies and the related benefits, whether small or large. On their part, dealers of "organic" food encourage "anti-GMO" fixations and draw economic benefits from the action of protestors, using and exploiting them as useful idiots.

Environmental activists who are in good faith, if they were to note their error, should wipe out their counterproductive incoherence, abandon their flailing attack on "GMOs" and concentrate their efforts on the healthy part of their struggle (fighting pollution and fossil fuels, supporting renewables, protecting biodiversity, mitigating the inevitable downsides of agriculture in general); in doing so, they would see their values held up as true and valid: as we will try to explain, they would no longer be "half-baked" or "two-faced" environmentalists, they could fruitfully refocus their action on real problems.

In any case, those who see intrinsic negativity in what they call "GMOs" are free to avoid them: they just must stop to impose this approach on everyone. In various cultures, philosophies, and visions of the world there are prescriptions on foods that must be avoided, conduct that must be followed, beliefs that must be embraced or rejected: modernity tolerates different points of view—as arbitrary and dogmatic as they can be. Whoever wants to exalt or demonise differences which for most of mainstream science are not differences at all, is free to do so, but wanting to turn that into law is illiberal, despotic: both in moral terms and in the economic field, it is illicit to force legitimate but not universal points of view on the whole of society.

PARTICIPANTS TO THE DIALOGUE

Andreas, philosopher
Veronica, biologist
Marcello, geneticist
Arturo, anti-biotech activist
Sofia, curious citizen
José, farmer
James, psychologist and anthropologist
Norberto, legal expert
Maynard, economist
The Rational Alien, inquirer visiting the Earth

1.

THEORETICAL BACKGROUND

Summary of the chapter

Every living being is by definition *genetically modified, derived from a very long intergenerational series of "descent with modification", in which the genome of its ancestral lines has undergone, over thousands or even millions of centuries, genomic mutations which have slowly accumulated, while the organisms are constantly put under tremendous strain in the Earth's changing environments: this is* natural selection*. Some thousands of years ago, Homo sapiens began to domesticate certain plants and animals, directing crossbreeding and picking out, as necessary, the samples which best met mankind's requirements; to eat or use, even for aesthetic and recreational applications: this is* artificial selection*. In so doing, and up to a few decades ago, the domesticators unwittingly modified the genotypes, i.e. the DNA "recipe" that the biochemical mechanisms follow to produce, to "cook", phenotypes, the organisms with their various anatomies and traits, the "final dishes". In the meantime, primitive doctors tried to exploit the therapeutic properties of many products originating from the animal and vegetable worlds.*

To these empirical and rudimental manipulations of nature, in the middle of the 20th century numerous laboratory techniques were added: in vitro cultures of cells and tissues, a double methodology of inducing mutagenesis in vegetal genomes (by exposing cells to radiation or particular chemical elements), and the ability to directly modify DNA, to "recombine" or "splice" the genomes of various micro-organisms, plants and animals, using a variety of procedures. In all cases the aim is to create or accelerate the expression of selected characteristics, or to silence/delete unwanted traits, into "prototypes", to be later mass produced. The manipulations of the living being, i.e. biotechnologies, from the traditional to the most recent (be they "GMOs" or not), are divided into areas: medical-pharmaceutical ("red" biotechnologies), industrial ("white"), environmental ("grey"), and agricultural ("green").

The latter, particularly when applied to a number of plants, aim to provide this or that cultivar with traits that enhance them from two points of view: the producer is interested in increasing yields (also in conditions of abiotic stress: drought, frost, flood), resistance to pests (insects, virus, fungi, moulds), and tolerance to herbicides (the crop is immunized to the product which kills off the competitor weeds besetting it and vying for space, water and nutrients), and in reducing labour (the ability to germinate with only light ploughing or none at all); on the other side, the consumer is interested in the quality of the product (organoleptic characteristics, prolonged shelf-life, hypoallergenicity, nutritional value), and that it is reasonably priced.

The aim of this book is to demonstrate that the pseudo-category "GMO" is a false concept, deceitful and misleading, the existence of which—with the theoretical and practical damage it causes—is due to a strange and complex tangle of psycho-sociological, political and, last but not least, economic motivations: it's a Gordian knot, and to cut it, we have to acknowledge that not only is it useless and harmful, but it is also counter-productive for the objectives of many of those who continue to use and fuel it, not always in good faith.

1.1. Every, every living thing!

Veronica—Do I look disgusting to you?

Sofia—…Pardon me?

Veronica—I am asking whether you find me loathing, repugnant; or at least whether you look at me with annoyance, suspicion.

Sofia—My dear, I don't know where you are going with this, you know very well that you are rather likeable—to use a mild understatement… ☺

Veronica—Because you have to know that—speaking seriously—I am a genetically modified organism!

Sofia—What?!

Andreas—Our beautiful biologist has chosen to start today's discussion in very provocative fashion. Before letting her explain the reason for this strange preamble, and the related important considerations, I invite you to try a little thought experiment.

Sofia—We're all ready, go! ☺

Andreas—Visualize a person, either friend or relative or acquaintance, or your favourite athlete, your cult actress or performer. Someone you like very much, in any sense: tenderness, admiration, sex-appeal, whatever.

Sofia—Done, boss! Although at least a dozen faces came to my mind… ☺

Andreas—Very well. Now recall to your mind a pet you particularly love: dog, cat, canary, hamster. And also your favourite fruit: feel the exquisite taste, perfume, flavour. Then: visualize a poisonous mushroom, a noxious insect, some peculiarly repulsive beast.

Veronica—Are you ready? Well, now be aware that all the images you have evoked, whether people or plants or animals, beautiful or ugly, attractive or detestable, friends or enemies—are genetically modified organisms!

Andreas—That's because—we need to understand it well—all the organisms, from the most remote microbe to the mightiest oak, from the most insignificant little spider to the greatest human being, are *by definition* genetically modified.

Marcello—Every living being, whatever species or biological kingdom it belongs to (animal, vegetable, bacteria...) comes from an almost endless lineage: in Darwinian terms, it is called "descent with modifications".

Veronica—Modifications of what? Simplifying a bit, the answer is: of 1. genome, and 2. epigenome. That is: 1. the ensemble of DNA molecules (i.e. the genes), which are in every cell, containing the instructions—"written" in a biochemical code that it is fairly well known—for the creation of the myriad different proteins; these "building bricks" form tissues, organs, apparatuses, during the development and life of the phenotype, i.e. the entire organism; and 2. the epigenetic "trimmings", other substances and processes which, while constantly interacting with the genes, play an essential role in modulating their expression and effects, also reacting to the very different environmental stimuli. Each living being has its own anatomic, physiological and behavioural characteristics, according to the environmental situations in which it finds itself during its development and its existence; and these numerous "phenotypic traits", in biological jargon, which are very different depending on this or that microbe or animal or plant (from eye colour to blood clotting; from fruit shape to escape instinct; from production of poison to contour of leaves), have their roots in the genome and epigenome: such molecules and mechanisms, inherited from the long, long lineage of one's ancestors, modulate forms, functions, actions of bodies, in the continuous dialectics of encounter and confrontation of any organism with life events, conspecifics, predators, parasites, food and energy sources, in the wider or narrower area where their life takes place. The integration and flow among genotype (plus "epigenotype"), phenotype and environment happen both in fairly simple unicellular individuals and in more complex multicellular ones, with their whole system of distinct organs

and apparatuses: from the invisible bacterium to the small cockroach to the immense whale; from yeast to fern to sequoia.

Veronica—During the natural history of life on Earth, which unfolded over unimaginably long eras—hundreds of millions of years!—the "descent with modifications" of living beings produced countless hereditary lineages which were increasingly slowly divergent, due to small genetic mutations, basically happening by chance. From time to time, these processes have made the offspring a little different from their parents; the very tangled aggregate of these changes over geo-biological aeons gave life—and death—to an extraordinary number of very different species, which have differentiated and branched off in astonishing ways, often then disappearing. This has occurred in parallel with the ever-changing natural environments, which constantly remodel in capricious and unforeseeable ways: in this great mess of life, innumerable organisms have found themselves existing, surviving, breeding, and dying.

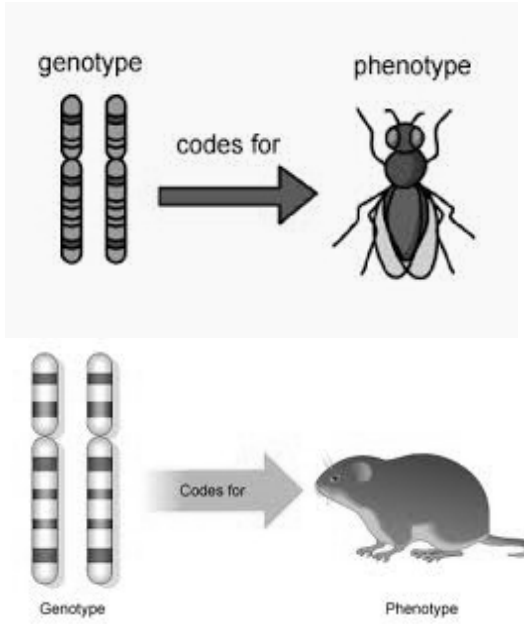

Figure 1-1. Genotypes and phenotypes. A certain system of DNA sequences (a genotype) dictates biochemical mechanisms (life!) as to produce a fly (a phenotype); from a different genotype a mouse will derive; etcetera...
Source: Internet.

Sofia—In summary, you are telling us that all living beings—from shrimps to lichens to orchids, from worms to lizards to monkeys, are the way they are—or were the way they used to be—because their genome and epigenome are—or were—different from those of other species…

Veronica—That's it! We can think of the whole DNA of any organism, which is contained in every cell, as the "recipe" followed by the machinery of life to attain the final "dish", i.e. this or that living being of one or another species; or, if you want, you can imagine that the genotype is the "instruction handbook", put in place by the biochemical dynamics to produce and reproduce each organism's cells, from conception to death.

Marcello—In a more precise sense, it is not wholly correct to refer to the biological category of species: individuals of a species have inside them a very similar genetic make-up, but the DNA and the epigenetic endowment of the single organism are actually unique; the differences are minute and often not relevant within the gene pool of populations of the same species, but over the generations each descendant brings with it a singularity, deriving from complicated recombination of its parents' genome and from the interactions of the epigenetic settlement, the genes and the environmental actions and reactions: that's why each living being is different from any other in some trait, whether small or large, of its genotype and epigenotype. Since even identical twins (whose DNA is exactly the same) are exposed to slightly different environmental inputs and their bodies show diverse reactions to those stimuli, the small differences showed by their phenotypes (i.e. the totality of their morphologic, physiological and behavioural traits) make any living being distinct from every other, even within the same species. Again, every organism is—and must be!—genetically modified!

Andreas—This short introduction to some basic concepts of biology and genetics is due to three interconnected reasons. First of all, it is good to remember that any living organism cannot but have a genetic make-up; while this statement is not necessary for many, we must refer to opinion polls on so-called "GMOs": many interviewees show that they know simply nothing about what they then declare to oppose, to the point that the common layperson often thinks that a vegetable or an animal becomes "genetically modified" only when scientists insert some genes in a certain organism, while it would be naturally devoid of them; similarly, many think that persons possess no genes at all, but let them into their body if they ingest a "GMO" food! More than the 60% of respondents show a similar level of disinformation, both in Europe ("By eating a genetically modified fruit, a person's genes could also become modified"; "Ordinary tomatoes do not contain genes, while genetically modified tomatoes do." Gaskell et al. 2006,

59) and in the USA (Hallman 2003). Secondly, we just want to underline that the unfortunate expression "genetically modified organisms"—that we will always quote inside inverted commas, to mark its weirdness—is very misleading, because such a label is usually applied—with quite a few terminological-conceptual difficulties that we will note—to a very limited sub-category of organisms on which human intervention has produced some direct and wilful modifications with precise aims, inside their genomes; while in the wild, on the contrary, the casualness of genetic mutations is the rule. Lastly, the polemical and ironic start to our colleague's talk wanted to indicate one of the targets of our criticism, i.e. the widespread and confused attitude of suspicion and distrust, or even open and unjustified hostility, against so-called "GMOs".

Veronica—Let me see if you have understood, my dear… If I plan to open a restaurant declaring that only "GMO" food and ingredients will be used, which foods and ingredients am I actually supposed to utilize?

Sofia—Any food and ingredients, from vegetables or animals both bred and gathered or hunted in the wild, that is produced in any way!

Veronica—Perfect!

Sofia—OK. But… would you please clarify why you asked—clearly ironically—whether we saw you as repugnant?

Veronica—Because we often see an attitude of rejection and disgust, when not actual abhorrence, to "GMOs", i.e. the living beings—mostly crops—whose genome is intentionally and directly modified in labs, for various purposes that we will discuss; we will try to explain that genetic modifications are not only quite common in nature, but have also been practised by human beings for millennia, through various kinds of biotechniques: operations whose results must be very attentively checked, yet without letting prejudices influence us.

Andreas—Before tackling this multifaceted and complex subject and having a closer look at what genes "do", we'd better explain some background elements, which are the premise to the following discussion.

1.2. Natural selection and artificial selection

Veronica—All living beings have always had the same problems, which are easily understandable: surviving (i.e. finding sources of food and energy in their environments, avoiding predators and parasites) and breeding (by scissiparity, as bacteria do; via mating with conspecific partners, for sexual species). And individuals producing more or less numerous offspring have always left their DNA in the descendants' bodies, with small or large modifications, substantially due to chance, in the gene makeup and

expression; genetic variations which, being inherited, can dictate phenotypic differences: those varied traits (anatomic, physiological, behavioural) are most often unfavourable or irrelevant, they do not help the carriers in the struggle for life, influencing the odds against their survival and reproduction. From time to time, the somewhat different characteristics of some individuals in the progeny, with respect to former generations, entail an advantage for organisms expressing them, above all if the environmental context is changing: slightly thicker hair allows to better face the rigours of winter; a little enhancement in running ability is useful to better escape predators, or to hunt prey more effectively; a minimum improvement in metabolizing water supports life in dry areas; brighter feathers attract more sexual partners. Put simply, this is the mechanism of *natural selection*, i.e. the constant action of "sifting" carried out by the environment on the individuals and populations of organisms of any species: according to the traditional expression, there is an ongoing phenomenon, in the history of life, called "survival of the fittest", or at least of those which are minimally able to keep alive and are lucky in breeding. Thus, in trying to make best use of its anatomic, physiological and instinctual tools, any individual of whatever species seeks to survive and reproduce in the environment into which it is thrown at birth.

James—Such basic biological dynamics dominated most of the history of *Homo sapiens*, a species which appeared in Africa one to two hundred thousand years ago from an ancestral hominid lineage; until a few thousand years ago, our predecessors survived by hunting wild game and fish and gathering wild fruits, not so differently from other species of great apes (such as chimps and gorillas), but experiencing much greater success than their "cousins"—as far as demography and geographic spread are concerned. In doing so, our ancestors were strongly favoured by their ability to master fire, by their skills in manufacturing primitive but effective tools, above all hunting weapons, and also by the gift—unique in nature—of conceptual speech. Starting some ten to twelve thousand years ago, in limited areas of the planet, some human populations, while still hunting and gathering, began something new. With gradual yet determined rhythms, certain animal and vegetal species were *domesticated*, initiating the ground-breaking phenomenon of the so-called *neolithic revolution*. Various human cultures, independently from one another, in far-flung places and without being in contact, began to imagine that breeding pigs could be less dangerous than hunting wild boars, and growing cereals more convenient than gathering them where they happened to be available. Anthropologists and psychologists, historians and archaeologists have been debating for a long time about the advantages and disadvantages of such an epoch-making

breakthrough, which is the basis of civilization. What is certain is that, although hunting and gathering were an important way of life also while agriculture was spreading (let's not forget that even today small groups of hunters and gatherers still survive!), the exploitation of animal breeding (cattle, sheep, pigs, poultry) and crops (cereals, vegetables, fruits) gradually became the rule.

Veronica—Here's the first point that really interests us: in more or less conscious and thought-out ways, the multi-millenary effort of domesticating crops and animals, used for human nourishment and work (indeed, sometimes just for pleasure, e.g. pets and flowers), led the succeeding generations and populations of breeders and farmers to perform various kinds of *artificial selection*, i.e. to constantly try to multiply the individuals which best showed the desired characteristics: it was not difficult to realize that crossing sheep with fluffier wool among those in a flock, or dogs better able to point prey in a litter, or stronger and faster horses in a herd, or hens which laid more eggs in a brood, often generated a little improvement of the preferred traits in the offspring of successive generations. Similarly, raising cereal plants whose seeds were less prone to fall on the ground, but rather to remain on the ear even when mature, favoured the farmer with a richer harvest; likewise, repeated crosses of similar plants could give birth to hybrids with bigger or juicier fruits; and so on.

Marcello—So our ancestors started the genetic modifications of several living species, without being aware of the biological mechanisms involved: choosing and crossing the best phenotypes, domesticators nurtured the heredity of certain underlying genomic make-ups more than others. Natural selection is a process by which organisms of the various species survive and reproduce in virtually casual, non-directional ways, often as a consequence of changes in the environments, which are always unpredictable and sometimes catastrophic. Differently, artificial selection, as the work of breeders and farmers, tries to achieve certain aims: the explicit intention—although the results are never guaranteed!—is to steer the creation of new vegetal and animal varieties, endowed with the qualities men want: not infrequently, certain traits are sought out not for reasons of nourishment or support for work, but for aesthetic purposes (e.g. birds endowed with shapely forms and rich plumage, flowers with new colours and stronger scents, beautiful ornamental plants…). Over many centuries, during thousands of generations of animals and plants, the induced modifications are amazing: without knowing about the relentless work of breeders, who would say that the Basset and the Dane are distant descendants of domesticated wolves? Or that wheat and tomatoes, peppers and peaches

come from wild ancestors which were itsy-bitsy and almost inedible (Kennedy 2014), whose original forms sometimes we don't even know?

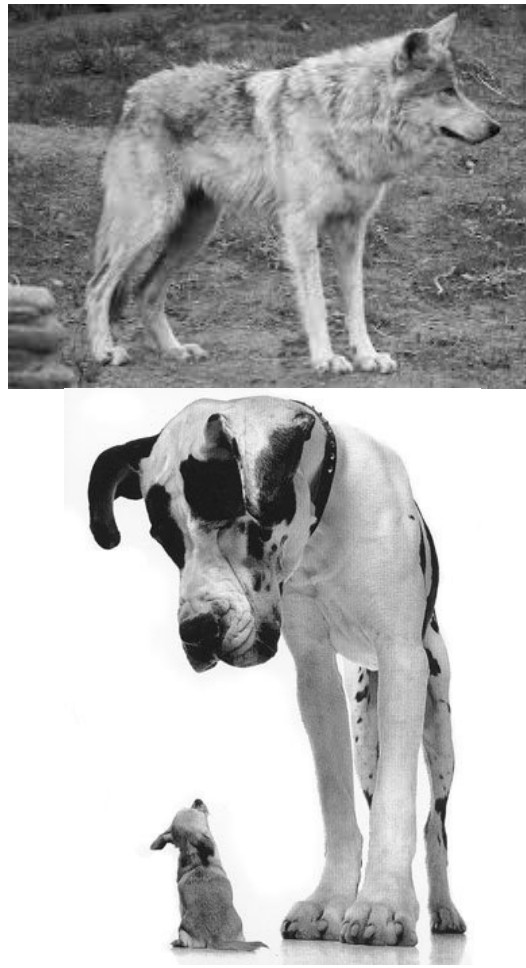

Figure 1-2. Artificial selection: from the wolf to the Great Dane; or to the Chihuahua. Source: Internet.

Figure 1-3. Artificial selection: from teosinte to maize. On the right a modern variety of maize, on the left its natural ancestor, teosinte. The images of the two varieties are in different scales, but can be compared by looking at the size of the dollar coin. Source: Internet.

Veronica—This means that organisms whose genotypes, over generations, were modified via natural dynamics have been increasingly joined by "GMOs" created by domesticators. Artificial selection, over the millennia during which mankind has been practising it for utilitarian or aesthetic purposes, relied on the empirical competences of breeders, farmers and floriculturists: still at the beginning of the 20th century, not even biologists knew what secrets were hidden in the phenotypic modifications which appeared by chance or were the result of hybridizations and crosses from experimental trials. However, the fertile combination of Darwinism and genetics provided an impressive boost to the process of scientific understanding about heritable variations in animal and plant lineages, and, consequently to the practical use of such new knowledge. The central concept of *biotechnology* is defined by the United Nations Convention on Biological Diversity: "any technological application that uses biological systems, living organisms, or derivatives thereof, to make or modify products or processes for specific use." (CBD 1992, Art. 2). Briefly, it means techniques, methods and processes aimed at the manipulation of living beings; constantly applied in a crude way since the beginning of domestication, it was revolutionized by the new, immense possibilities