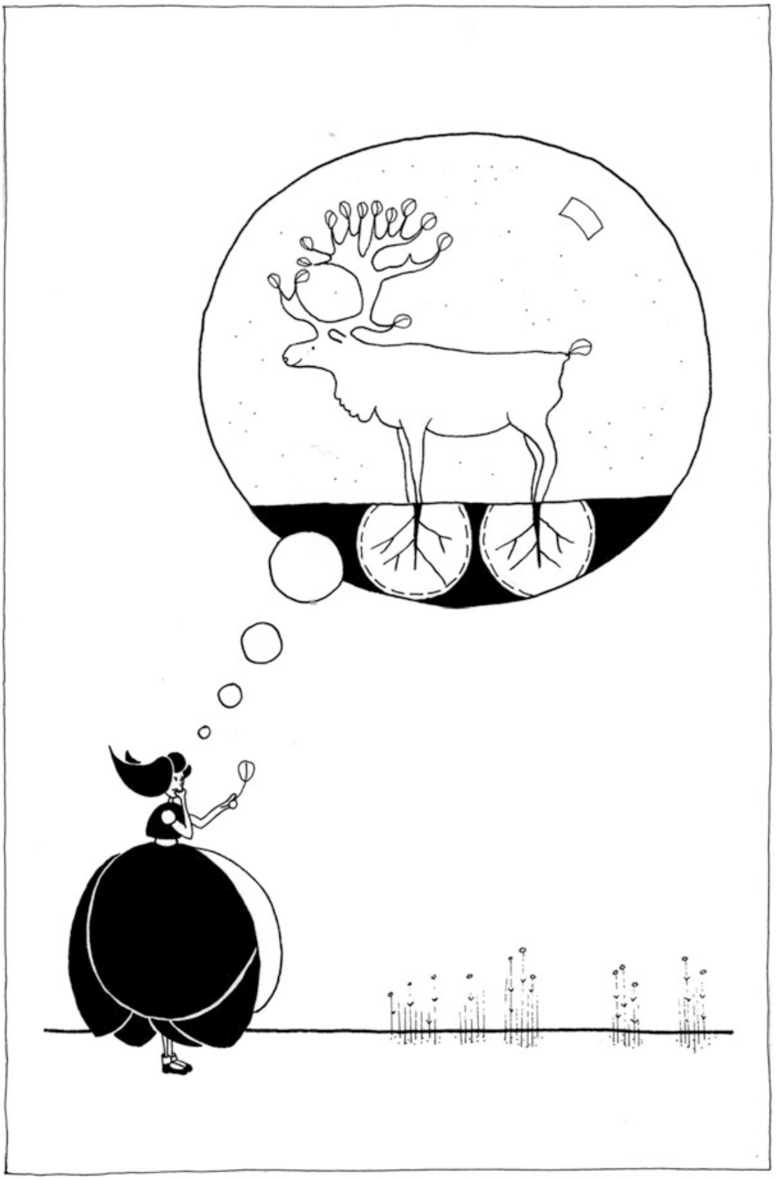
Chapter 1
Introduction



Plants are no Less Complex than Animals: They are Just Different

If the average person were asked how important plants are, it is more than likely he or she would not underestimate them. Who could dispute their importance as a source of food when 35 % of the dietary protein in the developed world and 80 % in the developing world comes directly from plants? Indeed, all our food comes from plants because they are the base of the food chain. Moreover, 25 % of all medicines in the West include at least one plant extract, and this percentage increases sharply if calculations include traditional medicine in the Third World. Those better informed might add that civilisation – whether in antiquity or in the industrial era – was based on plants. As for literary and scientific masterpieces, these were recorded on plant products, such as Egyptian papyrus and Chinese paper. Those who are more sensitive might refer to the aesthetic value of plants or the deep emotions aroused by their wide range of colours, hues, and scents. Others may remind us of the delight plant condiments add to food, the merriment following a glass of wine among friends, or the ecstatic harmony of a violin made from the right wood.

The significance of plants is not limited to their use by humans

One could carry on *ad infinitum* along these anthropocentric lines and write page upon page about the usefulness of plants; however, that is not the aim of this book. The aforementioned list of various plant uses refers to only a few hundred plant species, a tiny minority, that have been "tamed" and cultivated by humans or that provide their products and services as indigenous wild species. We share the planet with at least 260,000 other, insignificant plant species that need support and are truly significant merely because they exist. Even if people are oblivious to them, such species have shaped and continue to shape the state of affairs on Earth and

Plants keep shaping the biological state of affairs on planet Earth will do so as long as the planet exists. This is because plants are the only organisms on Earth that can easily exploit a virtually inexhaustible, extraterrestrial energy source, and because the process selected for this successful exploitation, photosynthesis, has to a great extent determined the climate, the composition of the earth's atmosphere, the carbon cycle, the water cycle, food production, and so on. Photosynthesis shaped the history and evolution of life to an extent that we have only begun to grasp in recent decades. It is easy to imagine a world that is exclusively vegetal, without humans or even animal species, such as those that exist or used to exist on Earth. However, it is impossible to conceive the opposite. In their search for elementary life forms in the universe, the first thing scientists look for is water. Small pockets of bacteria, with limited exploitation of local chemical energy sources and an equally limited capacity to propagate far from these sources, may be invisible at first glance, buried in the depths of underground or surface water masses. This hardly looks like the blue-green planet. A rich terrestrial life as complex as that encountered on Earth, covering the whole available surface, is inconceivable without some form of plant life. During nine tenths of our planet's history, life was limited to water while the earth's terrestrial surface was a grotesque, inhospitable lunar-like landscape. Only after the gradual (yet exceptionally speedy in geological terms) colonisation of the earth by plants did life as we know it today become possible. Because of this colonisation, we have inherited a world with millions of animal species that find habitat, food, and protection thanks to the 260,000 plant species in every possible nook and cranny of the planet. This precious heritage deserves our appreciation and protection, but first we must become acquainted with it.

A world without animals is possible, but a world without plants is inconceivable…

…particularly on dry land

Let us, therefore, get to know the food and protection providers

Natural versus Human Selection

Wild and cultivated plants or natural and human selection

This book is not about cultivated plants, which in any case are quite different from their wild ancestors. This difference lies in the fact that wild plants are the result of natural selection whereas cultivated plants are the products of human selection. Of course, the latter originated from wild ancestors, but human intervention in their evolution has been so effective that today they bear little resemblance to their ancestors, which in many cases are unknown. Human selection is aimed mainly at changing the natural properties of a species to serve human purposes rather than to benefit the plant itself. Cereals are a typical example. Like all plants, the wild ancestors of wheat, barley, and maize scattered their grain (contained in their fruit, i.e., their ears) away from the mother plant, so the offspring would grow at some distance. In this way, vital territory increased and the new plants were not faced with competition from their progenitors. It would be a great reproductive failure if the grains did not leave the mother plant: What would be the point in their growing on it? Grain dispersion is controlled genetically by several genes that are activated when the seed has matured. In some cases, however, random mutations may result in unsuccessful dispersal, causing the seed to remain on the plant's ear, where it would be pointless to germinate. When humans recognised the nutritious value of cereals, they started collecting their grains and, obviously, collected those still on the plant, which was much better than picking at the soil like hens. This is how the first grains were selected. They were mutants, probably the first mutants consumed in history. Nonmutated grain had already fallen to the ground, forming the basis for the next harvest.

How were cereals selected?

When humans were still food gatherers, there was no point in keeping leftover grain, that is, grain that had not been consumed. Therefore, after they ate their fill, they got rid of the rest because refrigeration did not yet exist to preserve food. Eventually, some of the more observant people among this group of early humans noticed that these same nutritious plants were growing at sites where human rubbish had been disposed.

The First Gardens

The first gardens of humanity

Contemporary common sense dictates that if one wants to confirm that a phenomenon is not an accident or a miracle, he or she must repeat the manipulation to determine whether the phenomenon occurs again. In other words, one must perform a controlled experiment. Although this was not an easy task for our primitive ancestors, some charismatic individuals did perform an experiment, resulting in the first gardens. Now, instead of foraging for wheat, they could cultivate it on site, transforming themselves from food gatherers to cultivators with a fixed abode. What did our ancestors cultivate? Obviously, mutant individuals. Unknowingly, they selected plants that could not reproduce on their own, as the grains remained fixed on the mother plant. As a result, wheat has not been able to survive without humans since then; it has become symbiotic and cannot exist independently. It separated from its wild ancestor; it can grow as a plant but cannot leave offspring behind unless humans sow its grain.

Most cultivated plants are, in a sense, mutants

Other cultivated plants had similar destinies. The wild ancestors of lettuce, for example, have hard, bitter leaves, which serve as a defence system to protect the species from being overconsumed by its predators. This property is very useful for the plant; it was tested and naturally selected to achieve a balance in which predators can avoid famine while the plant species avoids extinction. Occasionally, random mutations occur in the genes responsible for tough cellular walls or for the biosynthesis of bitter phenols. Such mutations may lead to the appearance of plants with limited mechanical and chemical defences. These mutants cannot compete with their bitter, tough relatives unless they are selected by humans. Of course, such disadvantaged and handicapped lettuces are preferred not only by humans, but also by other herbivores and pathogenic microorganisms, which humans must eradicate with fungicides, insecticides, and other cultivation practices. If left without protection, such lettuce types may not reach reproductive age, nor will they leave many offspring behind.

Human selection produced plants incapable of surviving on their own. Since then, they have been symbiotic with humans…

For the aforementioned reasons, cultivated plants do not escape easily from their crops and are unlikely to be encountered growing on their own. They are strictly symbiotic with humans. If people decided to feed on pills, such plant species would disappear within a few years and their present-day artificial habitat would soon be overtaken by wild species. Cultivated plants are like pet dogs, aquarium fish, and canaries in cages: to survive, they need an artificial ecosystem provided by humans; they would not survive natural competition. They are biotechnology products with an expiration date, a topsy-turvy selection. Their significance is of concern only to humans, in a direct and exclusive way. They will collapse as soon as humanity collapses. They are useful for the here and now but of no importance for life's continuum.

…and cannot easily escape from cultivated crops

This book, therefore, does not examine the plants humans spend time cultivating, consider valuable, and describe as useful. Rather, it focuses on the insignificant plants, those we pass by every day without noticing, those we look at without seeing, those we step on with no protest on their part, those we cut down to improve the view from our windows, those we consider unworthy of being viewed (although we *should* consider them worthy), those that existed before us and will continue to exist when we are gone. If these plants all have a role

This book studies wild plants and their functions, which are important at the planetary level to play, both as a group and as individuals, if they have a significant function that escapes us, if the state of our planet would be completely different if these plants did not exist – which is what this book posits – then it might be worth paying greater attention to them. The prerequisite for appreciating these plants, of course, is that we become acquainted with them.

Plants versus Animals

When contemplating Alice's entrance into Wonderland, certain intellectual difficulties arise that also must be faced when encountering the world of plants. Like humans, plants are organisms, yet they are quite different from us. Plants also differ from organisms that, because of their similarity, are more familiar to us (i.e., animals). It is understandable that humans easily comprehend animals, with which we share a basically similar lifestyle. We are familiar with this lifestyle because each person's body – including its form, functions, and behaviour – is an inevitable part of his or her experience and is needed to maintain health and physical conditioning. However, the structure, functions, and behaviour of plants are fundamentally different; therefore, comprehending them requires a mental shift. The most effective way to think about plants is to compare animals (which are more familiar to us) with plants (which are not) to identify basic similarities and, more importantly, the basic differences that impose a different structure, organization, development, function, and behaviour.

To enter the world of plants, we need to get rid of our anthropocentric view of things

If the average reader finds the aforementioned difficulties justified, or even self-evident, he or she would expect them to have been overcome by experts, such as students of biology and related disciplines. Unfortunately, this does not seem to be the case.

The relevant literature appears to consider the basic organizational and functional philosophy of the plant world to be self-evident, although it is not. This philosophy is bypassed to leave room for otherwise useful details that, however, are not examined within the context of the essential pattern of plant behaviour. In other words, the general prevailing sense is that because plants are not structured, are not organized, and do not behave like humans, they are incomplete organisms and so are unworthy of our curiosity, observation, and study, as opposed to animals or, more importantly, to humans. In this view, 99 % of the earth's biomass is of no consequence and hardly deserves scientific attention.

Plant Blindness

Plant blindness: a mental attitude that condemns plants to discredit

A decade ago, some biologists in the United States tried to scientifically explain the low esteem and modest interest humans have for plants. They coined the term *plant blindness* to describe an attitude that fails not only to explain the life of plants, but also to even recognize their existence around us. Since then, a series of Gallup polls of students, biology teachers, and the general public have shown that the reputation of plants is disproportionately low in relation to their significance as living organisms. Yet scientists are still at odds as to the reasons behind such blindness. Some report there is a physiologic explanation for plant blindness: the human eye receives 10 million information bits per second, but the brain processes and focuses attention on only a few (around 10). This unconscious choice on the part of the brain is based on its detection of three characteristics of objects: movement (plants do not move), bright colours (although flowers attract attention, they appear only seasonally), and potential danger (who is afraid of plants?). Because we cannot overcome our inherited

Physiologic basis for plant blindness

characteristics easily, this physiologic view provides us with an alibi. In other words, plants are objects we see but do not pay attention to; they do not arouse our curiosity.

Others, however, maintain that the physiologic basis for such blindness is reinforced by social and educational prejudice. A biology teacher who is asked to describe a basic biologic function using an example in most – if not all – cases will choose an animal or, better still, an anthropocentric example, probably because he or she is more knowledgeable about it. Perhaps animals are more familiar to the biology teacher because during the teacher's studies, he or she did not make the necessary mental shift to see plants in a different light.

Social and educational bias

In any case, this blind attitude towards plants, whether inherited or acquired, clouds one's judgment and degrades plants to organisms that deserve less attention. Yet, the greatest fathers of modern biology were inspired by plants and dedicated the main part of their scientific work to them. One of the great naturalists of all time, Alexander von Humboldt (1769–1859), was (among other things) an enthusiastic collector of plants and a keen observer of the effect of climate on the geographic distribution of plants. The father of the theory of evolution, Charles Darwin (1809–1882), supported his views by observing both plants and animals, but his descendants isolated and highlighted the example of finches on the Galapagos Islands. Few are aware that the greatest part of Darwin's scientific work concerned plants. Gregor Mendel (1822–1884), the father of classic genetics, formulated the laws of heredity based on his experiments with peas. What happened in the meantime to lead us to the current state of affairs? Why are universities around the world offering fewer and fewer courses on plants? Why is funding for plant research decreasing? Why do biology books at secondary schools and universities contain fewer chapters dedicated to plants as each new edition

The most important fathers of modern biology studied plants carefully

Why do the descendants of scientists ignore plant studies?

is published? Why do students rarely choose to study plants during their postgraduate studies? Why does the average person consider plants "third-class citizens?"

In the struggle for survival among scientific branches the winner is: molecular biology

It is not the aim of this book to analyse this phenomenon, and the author might not be fully qualified to do so. However, plant biologists may not have marketed their products effectively, and they are not the only ones. Many other (equally interesting) objects of biological study are gradually sinking into obscurity, failing to counterbalance the prevalence of molecular genetics, especially its applied branch of biotechnology. The latter indisputably has exploited its fundamental success at the basic research level to promise, probably prematurely, radical solutions to human health and nutritional problems. There is a widespread impression that the initial and justifiably sensational optimism of this discipline soon led to the childhood disease that almost inevitably accompanies every quick success story: a sense of supremacy and a loss of perspective.

Popular Science

Comments on the communication of research

In the Middle Ages, alchemists convinced rulers – because they were convinced themselves – to provide them with the funds they needed in their quest for the philosopher's stone, which would turn humans into immortal beings and base metals into gold. This activity proved to be a futile attempt that consumed both wealth and human effort. However, the alchemists' pursuit had important results. During the initial, heroic period, a wealth of knowledge was generated about the nature of metals, along with methods for studying them. Although the philosopher's stone was never found, the research methods discovered were useful in the ensuing development of chemistry. In time, the number of crooks and charlatans grew so much that the rulers were forced to ban the practice of alchemy.

Although things might not be exactly the same today, *mutatis mutandis,* several similarities exist. Research no longer is funded by arbitrary rulers accountable only to themselves but by governments whose leaders want to be reelected or by private enterprises accountable to their shareholders. Still, supporters of science today, as in the past, expect some sort of compensation – reelection or direct financial gain; therefore, they must be convinced their investment will pay off. Medieval alchemists had to convince only the local rulers, at the risk of losing their heads if they failed. Although modern scientists do not face such a drastic fate if their research ends in failure, they have to convince more people, that is, they must sway public opinion in their favour. Today, public opinion is influenced by the media, and when one secures a few minutes of publicity, he or she achieves the glamour of being famous and is automatically labelled an "expert" by the public. Countless times a day, we hear the statement "I saw it on TV." We do not hear "I read it in a book," or "I know from a reliable source," or "I researched it on my own," but simply – and effortlessly – "I saw it on TV" (so it must be true!). A scientist appearing in the popular media may fume when his or her statements are distorted by journalists, yet the exposure may lead to a publishing contract for his or her book, the ability to influence public opinion, and recognition of his or her views.

The glamour of being a "celebrity"

Experts in molecular biology and biotechnology played this communications game well: they built their myth; marketed their product effectively; promised signs and miracles; monopolised the interest of the public, students, and scientists; and marginalised the other branches of biology. As far as public opinion is concerned, biology is now synonymous with DNA, which has become a household term. Any characteristic considered inherent is now said to be "written in one's DNA," and there are people preparing to tell us our

Myths and promises…

. . .when the degree of ignorance is many times that of knowledge

destiny and predetermine our future based on a genetic sequence. Although such a sequence might be known mechanistically, more serious and discerning molecular biologists contend that what we do not know – the how and why of genomic regulation and function – is infinitely more than the smidgen we do know.

This book's aim, however, has nothing to do with research communication; it has to do with the fact that plants are considered inferior organisms. To the physiologic or sociologic explanation of this attitude towards plants, I would add the view – justifiable at first glance – that plants are simpler organisms than animals.

Complexity

Criteria for the complexity of organisms

What determines an organism's complexity? A system is complex if the whole cannot be explained based on the properties of its components. Although these properties are easier to analyse, their sum is hardly ever sufficient to explain the whole, because the parts are interdependent in various, and not always predictable or easily accessible, ways. Therefore, one of the parameters of complexity relates to the organism's size and form. Obviously, the more cells, tissues, and organs an organism has, the more complex it is. In this sense, microorganisms must be simpler than other organisms.

Size and complexity

Within each distinct kingdom, complexity should increase with size, that is, with the number of cells and their need to communicate with one another. If one adopts this view, a horse is more complex than a worm and a plane tree more complex than a dandelion plant. However, is this actually true?

Behaviour and complexity

If, for a moment, we ignore form and examine behaviour – that is, an organism's action and reaction to environmental challenges – we reach a similar conclusion. Animal behaviour is more complex than that of plants, which, after all, do not move – but is this actually the case?

Although it may be premature at this point for the reader to believe plants are no less complex than animals, the hope is he or she will be convinced through further reading. However, it must be stated at the outset that plants have all the component biological properties that characterise behaviour. They perceive the environment, they literally measure it, they record and respond to stimuli, they regulate the chemistry within their bodies and the physics and chemistry of their surroundings, they feed in a characteristic and self-sufficient manner, they perform cellular metabolism at their discretion (or, to avoid such teleologic views, in accordance with their developmental programming, as this is modified by the environment), they develop, they differentiate, and they reproduce. As for their apparent lack of motion, indeed they do not get up and leave when threatened – for example, if they become too hot or cold – they simply change their properties where they stand to cope with the threat; this is typical plant behaviour. Although this behaviour pattern would be impossible for humans or animals, it is successful for plants, as proven by their presence everywhere on the planet. Yet, plants do not completely lack movement. Plants do move in a certain way and often enough to fully serve their needs, but we cannot see their motion because we are not used to perceiving such slow movement. One may detect plant motion by careful observation and technical means, as well as through an effort to ignore the anthropocentric concept of motion, which says, “Flee when threatened, approach if you expect a reward.” The penetration of roots towards selected soil regions is spatial movement, as is the upward growth of the shoot towards light – and there are more examples, as the following pages reveal.

Do plants have “behaviour patterns”?

And yet, in their way, they move

Even if we accept that plants are indeed complex organisms, how do we respond to the question of whether they are more or less complex than animals? Is there a quantitative criterion for complexity? For this, we can turn to molecular genetics and its central

Molecular criteria of complexity

doctrine that the form and functions of an organism are determined and controlled by material informational bits called genes. Recent technologic advances have made it possible to determine the number of genes for some organisms, including humans. It would be reasonable to expect that more genes exist in more complex organisms. For decades this reasoning was accepted although it could not be proven experimentally that the number of genes, generally speaking, is lower in plants, higher in invertebrates, and still higher in vertebrates. However, modern molecular biology has confirmed that this is not necessarily the case. Although determining the number of genes is a difficult and controversial task (as indicated by frequent revisions), it is generally accepted that around 21,000 to 23,000 genes exist in humans. *Anopheles gambiae*, the mosquito that carries malaria, is indisputably a less complex organism, with around 14,000 genes. Is this difference in the number of genes a measure reflecting the difference in complexity between a human and a mosquito? Are the 7,000 additional genes enough to account for the human condition? Is a human only four times as complex as the microbial pathogen *Escherichia coli*, with its 5,500 genes? Molecular biology keeps surprising us: a dog has as many genes as a human, whereas a sea urchin has a few more (24,000). The humble roundworm *Caenorhabditis elegans*, which is only 1 mm long, has as many genes as the so-called capstone of creation. What about plants? *Arabidopsis thaliana* has 28,000 genes. Is this a giant of the animal kingdom? No, it is an herb that is scarcely 20 cm in height. Rice has about twice the number of genes as humans and the poplar tree even slightly more (44,000 genes). Therefore, we need to revise our views of what exactly biological complexity means or accept that complexity is not related (or not related only) to the number of genes.

How is it possible that a sea urchin has as many genes as a human being…

…and rice has twice as many genes as humans?

Of course, molecular biology has provided more important information, for example, that the protein products of some genes function as switches that awaken certain genes or lead others to dormancy. Technically, these products are called *transcription factors*. Might this be where the quantitative expression of complexity lies? It is reasonable to assume that organisms that appear more complex have a greater need for gene function regulation. Yet, this does not seem to be where the secret lies. Humans have around 2,000 genes that codify transcription factors, whereas the humble *A. thaliana* plant has around 1,500. Nevertheless, it is known that protein products of genes are edited later so that a gene ultimately produces many more than just one protein. Therefore, the key might well lie in the maximum number of proteins produced (i.e., the proteome). Nevertheless, the comparison favours plants.

Transcription factors and post-transcription modification of proteins: plants prevail on all counts

One may wish to leave the issue open, expecting the question as to which organisms are more complex to be answered in the future. However, there is at least one reasonable explanation for the apparent wealth of genes, transcription factors, and proteins in plants. This explanation may be related to plants' immobility and their need to face head on, with no means of escape, seasonally changing environmental conditions, attacks by predators and enemies, and competition from neighbouring plants. These issues are discussed again later. For now, following the fluidity of criteria imposed by recent discoveries in molecular biology, the least we can say is that plants are not necessarily less complex than animals. Moreover, plants are not less successful as organisms; therefore, they are as complex as their lifestyle and life pace dictate. They simply are different. The aforementioned phrase "they are not less successful" actually may be an understatement. In effect, plants are *more* successful – on an evolutionary and geologic scale. The average time plant species have been present on the planet is many times that of animal species.

Is it immobility that requires more genes?

In other words, plants are no less complex; they are just different and, in evolutionary terms, more successful

Animal species come and go and have a shorter "sell-by" date. If we could travel to the distant past or distant future, we would meet more or less the same plant forms, but quite different animals. The reasons should become clear in the course of this book.

Springer
http://www.springer.com/978-3-642-28337-6

Alice in the Land of Plants
Biology of Plants and Their Importance for Planet Earth
Manetas, Y.
2012, XVIII, 374 p., Hardcover
ISBN: 978-3-642-28337-6