PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Introduction

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THE ROYAL SOCIETY

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Introduction

'Photosynthesis: the plant miracle that daily gives us bread and wine, the oxygen we breathe, and simply sustains all life as we know it.'

(Theme statement; 12th International Congress on Photosynthesis, Brisbane, 2001)

Research in photosynthesis continues to uncover surprising new phenomena. In these Discussion Meetings we drew attention to some of the paradigm shifts in contemporary research by concentrating on the importance of photoprotection, and of alternative photon and electron sinks, in the highly energetic primary processes of photosynthesis. We are most grateful to The Royal Society, and to the Novartis Foundation, for this opportunity to do so.

Much of the progress described has arisen from research in plant ecophysiology, from observations on wild plants in natural habitats. It has provoked major re-evaluation of what determines the stability of the photosynthetic apparatus in the real world, and is giving new perspectives for agriculture. We begin to understand how, lacking sophisticated mechanisms for homeostasis, plants cope with the vagaries of the physical environment through compromising the efficiency of light use. In most plants, much of the time, a high proportion of absorbed photons is wasted as heat in the antennae of the photosynthetic apparatus, thereby preventing potentially damaging photochemistry.

Achieving a high efficiency of substrate use in the dark and light reactions (CO_2 and H_2O, respectively) is evidently also a low priority. One of the unavoidable consequences of photosynthetic CO_2 assimilation in the present atmosphere, the simultaneous evolution of CO_2 in photorespiration, reduces the efficiency of carbon acquisition in most plants. The photochemical oxidation of H_2O to O_2 and electrons sometimes initiates electron transport to O_2 with the generation of reactive oxygen species that are detoxified to H_2O. These inefficiencies permit loose coupling between the highly energetic primary photo events and the many constraints that subsequently arise in the course of carbon reduction. This loose coupling seems essential to plants that alone transform the stuff of life.

Advances on all of these fronts are reviewed in the papers presented here. Progress has been driven by questions born of our imagination, by availability of new instrumentation, by advances in data analysis and modelling, and especially, by access to genetically modified plants. Ultimately, progress depends on our freedom to responsibly conduct tests with 'designer plants' that will provide answers to questions of plant performance in the field. This freedom has been taken for granted in the past, but is now potentially under threat as the application of molecular genetic techniques, and especially the testing of genetically modified plants, meets public anxiety. As David Walker argues later in the introduction, we can but hope that reasoned discussion can devise a *modus vivandi*.

Two broad advances in plant science research may actually help achieve better professional recognition and public understanding of photosynthesis in the first decades of the 21st century. First, the thin green veneer of the planetary biosphere is now firmly recognized as a critical component of, and primary respondent to, global climatic change. Autotrophic functions of plants account for a significant part of global CO_2 and water vapour exchange in the atmosphere, and of nutrient fluxes in the biosphere. Second, and at the other pole in the scale of research, the facility of molecular genetic intervention, and information from genome projects, open up previously unimagined possibilities. However, at present, plant research is experiencing the blunt impact of public anxiety about, and hostility to molecular genetic interventions, domination of plant genetic resources for food production by multinational corporations, and sustainability of biodiversity and habitat.

Professional recognition seems to be no problem. In the last half of the last century chemists saw fit to recognize advances in photosynthesis twice, awarding Nobel Prizes for insights into the dark reactions of metabolism (in the early 60s), and into the molecular infrastructure that sustains the primary light reactions (in the late 80s). There is a warm feeling in the field that the soon to be resolved photosystem II complex, the core of oxygenic photosynthesis, may once again attract attention in Stockholm.

To our knowledge, few interventions in photosynthetic processes have yet delivered a breakthrough in plant performance or product quality such as would attract the attention of either multinational corporations, or of those determined to trash experiments. The real fear is that both interest groups now have the power, and are already using it, to prevent legitimate research questions from being evaluated. Big questions, such as the functional significance of the over-expression of C_4 pathway genes in C_3 rice, may well attract such attention before they are resolved. In the meantime, our research is also likely to attract another sort of unwanted attention if 'breakthroughs' are released to the press before peer assessment and publication in the scientific literature of field-evaluated, genetically modified plants.

So why focus, as we did during these Discussion Meetings, on molecular mechanisms of photosynthetic processes when such weighty matters increasingly command public attention? There is one good reason alone. Confronted with these concerns at the start of the 21st century, we remain frightfully ignorant of many of the fundamentals of photosynthesis. Much seems simply miraculous. In spite of professional recognition, but perhaps because of poor public understanding, photosynthesis research has always travelled hard class, in relative terms, so far as research funding is concerned. As David Walker made clear in his after-dinner speech (published in the remainder of this introduction), the public misunderstanding of photosynthesis and genetically modified plants generally, gives cause for grave concern. For a discipline that underpins all life processes on the planet, all these situations need to be remedied.

Despite the famous experiments by Van Helmont in the 17th century, the man in the street, the producers of television gardening programmes and some scientists in non-biological fields still believe that plants derive the bulk of their substance from the soil. There seems to be little appreciation that photosynthesis is the principal contributor to the production of food or biomass. Why? Is it because gardeners are exhorted to 'feed' their plants? Is it inadequate education or is it a common human tendency to read too much into apparent cause and effect relationships? Is it simply that we have a reluctance to disbelieve what we are told by 'experts'. Is it that, in some circumstances, there are hidden agendas and blatant manipulation? Certainly there seems to be blatant manipulation in relation to the perceived dangers of genetic manipulation of plants as discussed below.

It is important that we make clear that photosynthesis research has a critical role in finding new paths to securing the global food supply and sustaining the human habitat. We have to do this in a world assailed with eyebrow-raising statements such as

> 'The world today produces more food per inhabitant than ever before. Enough is available to provide 4.3 pounds to every person every day: two and a half pounds of grain, beans and nuts, about a pound of meat, milk and eggs, and another of fruits and vegetables—more than anyone could ever eat.'

This statement could be dismissed, but, in my view, it is deeply offensive, even cruel in its implications and its effects. Anyone can hear the denial of this statement on the television news, nightly. Yet statements such as this seem to have persuaded most of the British population, at least, that there is no 'need' for genetic manipulation of crop plants; that 'organic' agriculture is not only desirable, but sufficient to meet all our requirements.

Acceptance of the associated suggestion, that it would be possible to grow all the food that the world needs, at a price that it can afford, without the use of current technology, demands credulity comparable to that which accepts the world was created by a supernatural power in seven days. If scientists are ever to widen public understanding of their subjects they must first realize that the syndrome 'don't trouble me with the facts, my mind is made up' is as prevalent amongst pressure groups (and the public at large) as it is on the Kansas Board of Education. The facts are self-evident but the arguments in favour of organic farming, and the notion that there is 'no need' for genetically modified food plants, are based on belief, not facts.

The Food and Agriculture Organisation of the United Nations takes a different and altogether more realistic view, thus

> 'In the developing world, 790 million people do not have enough to eat, according to the most recent estimates (1995/97). That represents a decline of 40 million compared to 1990/92. At the World Food Summit in 1996, world leaders pledged to reduce the number of hungry people to around 400 million by 2015. At the current rate of progress, a reduction of 8 million undernourished people a year, there is no hope of meeting that goal.'

Cereals constitute about one-half of the world's food. The North American wheat crop has provided most of the world's requirements since 1950 and has struggled to keep pace with demand. Even though wheat yields per unit area have doubled during the last 20 years, wheat consumption has matched production.

Wheat reserves have been known to fall as low as 10% of consumption in recent years; a margin for error which one relatively modest drought could readily tip into deficit and famine. Yield improvements achieved by conventional plant breeding, mechanization, herbicides, pesticides and nitrogenous fertilizers are remarkable, but a further doubling of output in the next 20 years seems most unlikely. The fact that it might be achieved without modern agricultural practice is patently absurd. It is the lack of realism in the arguments put forward by pressure groups that create real dangers for society and wherein lie the worst consequences of the lack of public understanding of science.

Given the opportunity, most would buy carrots that have never been near lindane. Realistically, the possibility is remote that 'organic' farming could do more than still such anxieties and concerns of a handful of relatively wealthy people in countries such as Britain. Recent events suggest we have a propensity to take 'organic' farming to absurd lengths. Was an informed scientific community asked if it was a good idea to feed dead sheep to live cows? Had the question been put, the answer must surely have been 'no'. As we all know, beef grows best on rubisco, but in photosynthesis research, as in biology generally, repercussions of the BSE and other affairs will compromise our credibility in the eyes of the public for years to come. Intensive agriculture, however deplorable and distasteful from many points of view, does feed most of the world's population. Organic farming, in many ways as attractive as intensive agriculture is unattractive, does not *and could not*.

There must be a place for realism in debates of this sort. Scientists are widely believed to be either in the pay of commercial organizations or government (and therefore manifestly corrupt), or so unworldly that they cannot recognize mendacity when it stares them in the face. It is great fun, no doubt, to describe Fellows of The Royal Society as 'idiots savants' and 'paid mercenaries'. Conversely, those who head, or are employed by, pressure groups, those who miss no opportunity to denigrate the scientific community in the media, are perceived to be pure, disinterested and infallible. Both perceptions are unrealistic, and much effort is required to inject some reality in the debate. Surely, pressure groups have scientific advisors who share our values. It is hard to believe that they are not aware that maintaining food production *at present levels* can only be achieved by persisting with intensive agricultural practices and advancing research with new technologies.

Some of these practices have been properly questioned for decades because of their adverse effects on the environment in general and on human health in particular. Agricultural practices (like the use of cars and aircraft) cost lives and damage the environment. New risks, real and imagined, are associated with the introduction of crops modified by new rather than traditional genetic manipulation. However by now it is probable that we have all ingested some genetically modified food and pesticides. Experience to date suggests that the latter are orders of magnitude more dangerous than the former. However tragic, BSE has killed fewer people than herbicides such as paraquat, and far fewer than food poisoning, or road transport of the food itself. But how many would have starved to death, worldwide, had it not been for intensive farming? It is hard to believe that all are not aware that intensive agriculture comes at a price, but a price that must be paid if greater evils are not to follow.

Genetically modified food plants, first derived from natural, unconscious selection by the dominant mammal, and later by artificial selection and scientific breeding, are the foundations of agriculture. The Nuffield Council on Bioethics concluded that genetic engineering could not be regarded as more unnatural than conventional plant breeding. The US National Academy of Science found

> 'There is no evidence that unique hazards exist either in the use of recombinant DNA techniques or in the transfer of genes between unrelated organisms.'

Emphasis on risks associated with new technologies tends to be presented with conviction, but with little authority. Even if modern agricultural practices can be sustained, we start to run into other constraints that will not be readily overcome. Colleagues in global climate change tell us that the availability of arable land is likely to diminish and that the availability of water per head of world population (except when it is delivered in unwelcome ways by hurricanes) is not likely to increase (except at the expense of other areas which will receive less). Beyond this we run into walls as impenetrable as those erected by the laws of thermodynamics. In short, as Ginsberg would have it 'We can't win. We can't break even and we can't stay out of the game.'

Always conscious of the fabled Astronomer Royal who said that space travel was bunk, it would be foolhardy to declare that there is no prospect of improving the photochemical apparatus of photosynthesis itself, in ways that might improve plant performance. Yet we do have to confront many hundreds of measurements of quantum yield for example, none of which reveal variations that would gladden the heart of one bent on improvement. We may have to drastically revise our thinking about photosynthesis. How far would we have come in air transportation had we allowed our thinking to be constrained by bird flight? Experience suggests that some photosynthetic cycle mechanic will discover novel ways to exploit emerging technologies that will give flight to our imagination.

With about a billion hungry people in the world and evidence that it is most unlikely that world hunger can be abated by present agricultural practices, we cannot allow ourselves be hamstrung by failing to explain the need to responsibly apply all of the tools at our disposal. As Smarrelli pleaded recently

> 'Let us not threaten, with unfounded allegations that have no basis in science, a technology that could save the lives of millions of people and improve the lives of all of us.'

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