Aspects of genetics and plant breeding

Inra Versailles
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Georges Pelletier, Inra Versailles

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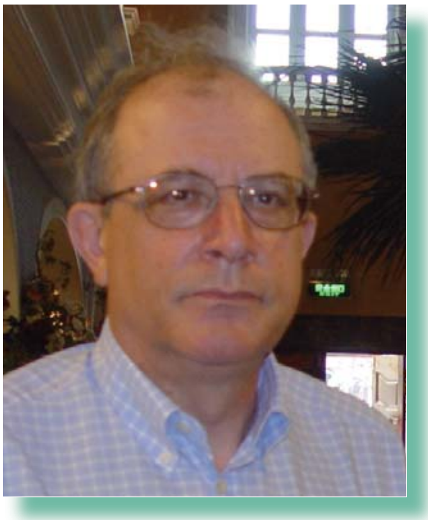
Marc van Montagu, University of Gent (Belgium)

Georges Pelletier



Aspects of genetics and plant breeding

As animals, plants were domesticated by selecting mutations which increase the mutual dependence between human societies and plants. This process of selection of new mutations has been continuing for thousands of years and explains the diversity of our crops. Sexual reproduction was scientifically discovered at the end of the 17th century, and has since then been exploited. First plant breeders try systematically to hybridize species with the purpose of creating new species. Interspecific hybridization had not been fully exploited until the second half of the last century as, for example, the triticale, the creation of a new species.

Since the eighteenth century it was observed that progeny of crosses between plant species are systematically more vigourous than their parents. This phenomenon, named heterosis, has been exploited in the past decades through the production of F1 hybrids cultivars in a great number of species like maize, rice, sunflower, sugar beet, rapeseed.

With the introduction of scientific methods and elaborated tools in plant selection, plant breeding has became an integration of diverse disciplines in the building of new genotypes to answer specific questions.

Complex enzymatic machineries elaborated billion years ago are responsible of transgenesis which consists of the insertion of extra DNA sequences in a genome and meiosis which, by dividing by two the chromosome number in order to produce gametes, is at the basis of sexual reproduction. Both, are the main ways to genetically modify plant and to produce new varieties from the knowledge accumulated by the functional analysis of genes and by high throughput technologies of genomics.

Gareth Hudson Jones

Gareth Jones was born on June 13, 1941 in Abergele,
a small town in North Wales.
His early education was gained at Ysgol Eifionydd Porthmadog, also in North Wales.
He attended the University of Wales Aberystwyth from 1959 to 1965
where he gained the degrees of BSc and PhD (Agricultural Botany).
In 1965 he joined the Department of Genetics at University of Birmingham,
now merged into the School of Biosciences, as an Assistant Lecturer.
He have remained at Birmingham all his working life,
apart from sabbatical periods at the MPI fur Meeresbiologie, Tübingen,
and the Department of Genetics, University of Copenhagen.
He was appointed to a Readership in Cytogenetics
in 1986 and he is currently a Senior Research Fellow.

Meiosis and plant improvement.

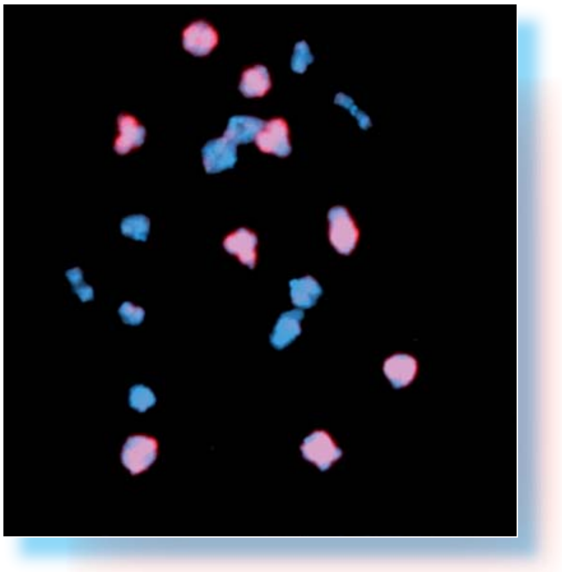


Photo : G.H. Jones

Metaphase I of meiosis in *Brassica napus* following genomic in situ hybridization (GISH) to differentiate the A (blue) and C (red) genomes.

Meiosis is a specialized form of cell and nuclear division that occurs at designated points in the life cycles of sexually reproducing plants and animals to compensate for the summation of chromosome sets during fertilization and to prevent the accumulation of genomes.

Chromosome reduction is achieved by combining two successive cell divisions with a single round of chromosome replication.

It is designed to ensure the orderly and accurate distribution of chromosomes to gametes and zygotes to minimise the incidence of aneuploidy (eg Down's syndrome in humans).

At the same time meiosis generates genetic variation through the process of recombination which forms an integral part of the process.

Our understanding of meiosis is based on research that extends back to the 19th century and continues to the present day. Indeed we are now witnessing an exciting period of meiosis research that is unlocking the detailed molecular mechanisms involved. This current progress is based on utilising a number of model organisms, including the flowering plant model *Arabidopsis thaliana*.

However, in this talk I will focus on the role of meiotic studies in plant improvement.

Historically, plant improvement has benefited from a partnership between breeding practices and cytogenetic analyses of meiosis, certainly from the 1930s onwards. This probably reflects the fact that a large proportion of plant species, including crop plants are polyploids, a situation that can compromise meiosis and hence the fertility and stability of plants and adversely affect crop yields. Meiotic studies have the potential to ameliorate these problems and contribute positively to crop plant improvement. This will be illustrated by reference to two case studies, the "autotetraploid" *Allium ampeloprasum var. porrum* (leek) and the allotetraploid *Brassica napus* (oil-seed rape).

Thomas Altmann

Dr T. Altmann received his PhD degree in 1991 at the Faculty of Biology of this university after the study of insertion mutagenesis by Ac/Ds transposons in *Arabidopsis thaliana* (L.) Heynh. under the supervision of Prof. Dr. L. Willmitzer. From Project Leader in 1991 he became Group Leader in 1995 in the Department of Prof. Dr. Lothar Willmitzer, Max Planck Institute of Molecular Plant Physiology at Golm. Professor of Genetics at the Potsdam University, Institute of Biochemistry and Biology since 2001, he will move as Professor of Molecular Plant Genetics in the Martin Luther University of Halle-Wittenberg and Head of the Department of Molecular Genetics at the Leibniz Institute of Plant Genetics and Crop Research, Gatersleben, next April. He was member of the Multinational Arabidopsis Steering Committee and chaired the Scientific Co-Ordination Committee of the BMBF-funded German Plant Genome Program `GABI´.

Heterosis in a wild species.

Heterosis, the superior performance of F1 hybrids in comparison to their inbred parents, was demonstrated to occur widespread among crosses of *Arabidopsis thaliana* natural accessions with respect to growth/biomass accumulation.

Detailed histological, molecular, and metabolic analyses of the Col-0 and C24 parents and their F1 hybrids revealed the occurrence of critical processes during early stages of seedling development.

Increases in (epidermal) cell sizes were detectable in the hybrids at 4 days after sowing (DAS) and higher cell numbers at 6 DAS.

Metabolite (GC, GC-MS) data indicated enhanced metabolic activity in the hybrids at the same time points (4 – 6 DAS). While a substantial fraction of metabolites exhibited overdominant patterns (levels in hybrids higher than in both parents), genes with over- or underdominant expression levels (higher or lower in the F1 hybrids than in both parents) appeared to be extremely rare and hybrids showed a more balanced (and thus probably more favourable) gene expression than the parents, which exhibited more extreme gene expression patterns.

The genetic and molecular basis of heterosis for biomass accumulation and the mechanisms causing this important phenomenon are investigated using correlation analysis and QTL mapping in *Arabidopsis*. Particular emphasis is given to the investigation of the relation between plant growth / biomass accumulation and metabolism. To this end, a population of 429 RILs and 97 ILs derived from crosses of the Col-0 and C24 accessions and test crosses thereof have been analysed for vegetative growth / biomass accumulation and metabolic composition (determined by GC-MS). Correlation analyses showed weak relations between growth and levels of individual metabolites, but a close and highly significant link between biomass and a specific combination of metabolites was observed, which allowed the prediction of biomass on the basis of metabolic composition. Six biomass QTL and 157 QTL for metabolic content were detected. Two biomass QTL coincide with significantly more metabolic QTL than expected for a random distribution and 3 of 6 biomass QTL can be simulated purely on the basis of metabolic composition. This observation furthermore supports the interconnection of metabolism and growth. Extension of the QTL analysis to the test cross data resulted in the detection of QTL for biomass and metabolite heterosis, respectively.

These data provide a solid basis for the detection of functionally relevant variation in known genes with metabolic function and for the identification of genes with hitherto unknown roles in the control of growth and metabolism and in the expression of heterosis.

Herman Höfte

Dr H. Höfte received his PhD degree at the University of Ghent in 1988 on the study of the insecticidal crystal proteins from *Bacillus thuringiensis* and the generation of the first insect-resistant transgenic tobacco plants. His thesis supervisor was Marc Van Montagu and his work was carried out in the, at that time, start-up biotechnology company Plant Genetic Systems. He then moved to the laboratory of Maarten Chrispeels at the University of California, San Diego in 1989, where he worked as a post-doctoral fellow on the intracellular targeting of vacuolar membrane proteins in plants using aquaporins as a model system. In 1992 he took up a position as a research scientist at the National Institute of Agronomic Research (Inra) in Versailles, France where he has been studying the synthesis and assembly of cell walls using a molecular genetic approach in the model plant *Arabidopsis*. In 2002 he became the director of the Laboratory of Cell Biology at the Versailles center.

Biomass and biotechnology.

The need for renewable energy and raw materials for industry and society has become a pressing issue for the 21st century. Plant biomass (or 'lignocellulose') is one of the greatest untapped reserves on the planet and is mostly composed of cell walls. Energy-rich polysaccharide polymers make up about 75% of plant cell walls and, in theory, these can be broken down to produce sugar substrates (saccharification) from which a whorange of useful products can be made (e.g. bioplastics, fine and bulk chemicals, food and feed ingredients), including bioethanol. Even more value can be added by using integrated processing systems that allow multiple different products to be produced from the same biomass – the biorefinery concept. In this presentation, I will discuss how recent revolutionary developments in plant genomics and the advent of plant systems biology will contribute to the development of novel agricultural feedstocks optimized for the sustainable industrial production of biofuels and bioproducts, while preserving the security and quality of food chain.

Photos : Maryse Brancourt, Inra Mons

Clockwise from left to right : A transverse section through a pine tree trunc shows the cell walls that constitute the biomass ; High magnification shows bundles of cellulosic microfibrils that constitute the cell wall ; *Miscanthus giganteum* is a vigorous perennial C4 grass and an excellent candidate for a dedicated biomass crop in temperate climate.

Marc Baron Van Montagu

Em. Prof. M. Baron Van Montagu,
president of the European Federation of Biotechnology (EFB),
is a pioneer in plant molecular biology.
With his colleague, Jeff Schell, he discovered the mechanism of DNA transfer
from *Agrobacterium tumefaciens* to plants, and constructed the first chimerical plant genes.
B. Van Montagu used this new technology to study gene regulation
and to discover the molecular basis of several plant physiological processes.
He has made major contributions to the identification of genes
involved in plant growth, development and flowering.
He ranks among the 100 top living contributors to biotechnology
and is one of the most cited scientists in the fields
of Plant and Animal Science, Molecular Biology and Genetics.
His laboratory raised two spin-offs, Plant Genetic Systems (PGS),
and CropDesign. At PGS, he drove front-line innovations for biotech agriculture,
such as plants resistant to insects or tolerant to more environmentally friendly herbicides.
In 2000 he created the Institute of Plant Biotechnology for Developing Countries (IPBO)
at Ghent University. Its mission is training, technology transfer and
plant biotechnology research oriented towards the needs of less-developed countries.
He has received numerous awards. In 1990, due to his scientific accomplishments,
he received the title of Baron, he is member of several academies of science,
and holds numerous Doctor Honoris Causa degrees.
M. Van Montagu holds a Ph.D in Organic Chemistry/Biochemistry
and earned a B.A. in Chemistry from Ghent University.

Importance of GM crops for environment, industry, and food and feed production.

More then 70% of Europeans are reportedly suspicious or afraid of GMO's despite the fact that there has never been any detrimental effect substantiated, caused by GM-crops, on the health of humans or animals. Furthermore the GM-crops so far commercialized have been shown to have substantial beneficial environmental effects.

In a democratic society the opinion of the fellow citizens' must be respected, and it is therefore essential that scientists take an active role in explaining to policy makers and the interested public that a GM is not a product but an important technology to improve plants. To support this argument, it must be stressed that during probably ten thousand years man has domesticated and improved today's modern crop varieties by much less precise genetic modification. Reshuffling genes is the base of evolution and an ongoing event in all our food and feed crops. GM technology is simply a refinement and improvement upon traditional means for crop improvement. Indeed, GM technologies allow breeders to create new varieties and tackle complex traits such as drought tolerance that were not possible through conventional means.

It is imperative to do so, since the world population tripled, from 2 Billion to 6 Billion in the fifty years after World War Two. Innovation is needed since not only will there be an increased demand for food and feed, world-wide there is a growing concern that the practices of management and utilisation of natural resources are unsustainable. The amounts of waste and pollution generated by human activity – industrialisation, urbanisation, agriculture, fishing, aquaculture, forestry, petroleum and mineral extraction – must be reduced on a large scale. As a result, there is considerable emphasis on how to make industry more sustainable in ways that reduce environmental impacts or even improve the environment while yielding goods and services that can provide jobs, reduce poverty and improve the quality of life for a growing world population.

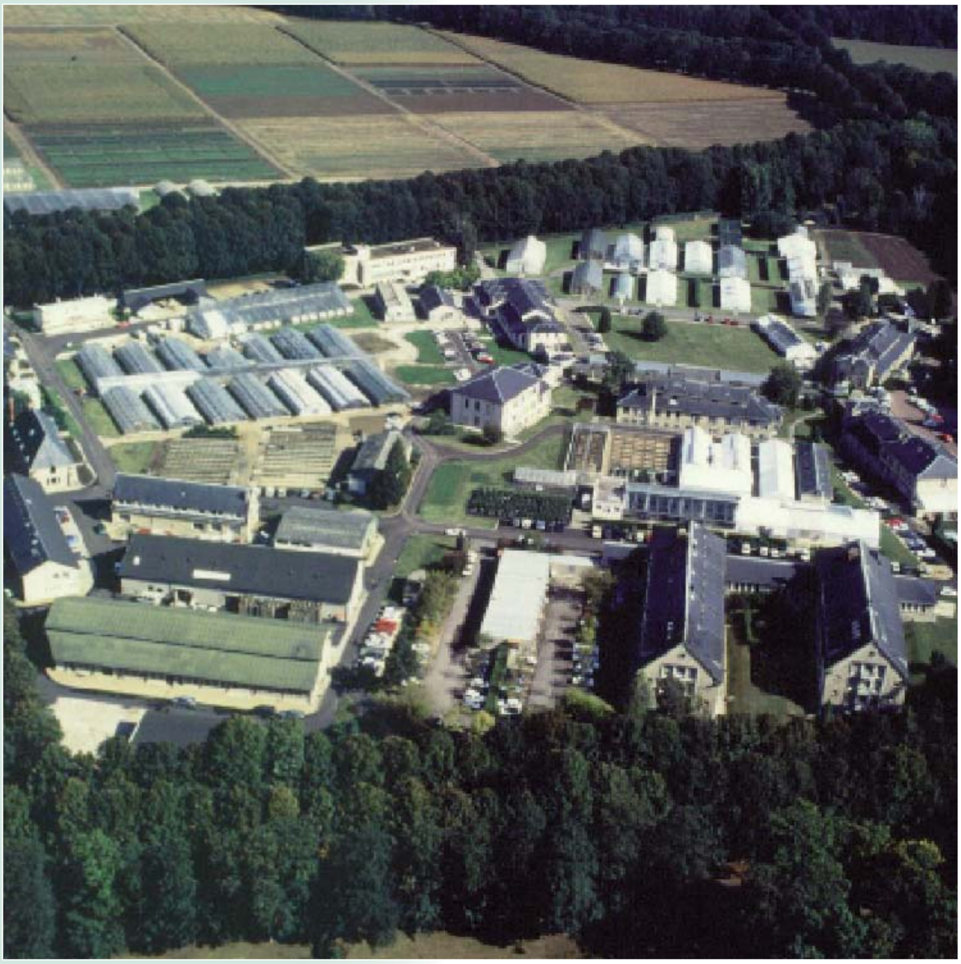
The need for intensive agriculture for food and feed and for growing plants for industrial uses due to petroleum shortage, form a major threat to our environment. Only the best of science can help to construct crops that deliver double or triple yield, are better resistant to biotic and abiotic stresses, better post harvesting, transport and nutritional properties and have reduced environmental impact.

Due to historical experiences and ideological prejudice against industry, it is difficult for the large scale multinationals to foster the dialogue with society. Hence, it is the absolute mandate of scientists from the public sector to do these efforts. They have to become articulate in explaining to the media the importance, the moral and economic value of science. They must communicate to the younger generations the fascination for science.

A good 25 years ago plant gene engineering conveyed for the first time new properties to laboratory plants. For plant scientists, a new area opened up. This technology brought them the tools to explain plant growth and development in molecular terms. Start-up companies were formed to try to construct improved crops through gene engineering. Today, 110 Mi hectares of GM plants are planted every year by 12 Mi farmers, the majority living in developing countries. At the same time, scientists from the public sector have remained focussed on competitive fundamental research and were not drawn into public debate on the achievements of plant molecular genetics for society.

Unfortunately, the result of this has been that until recently, the public sector was absent from negotiations on international regulations relating to biosafety. The result of this is that current developments in the regulation of plant biotechnology, particularly in the Cartagena Protocol, represent a serious threat to the efforts of public research to create sustainable solutions for food security in the future[1]. The costs of the regulatory procedures that have resulted from years of impasse over these regulations and well-funded campaigns of misinformation have escalated to the point where it is impossible for SME's and developing countries to apply public sector scientific breakthroughs to the staple crops based on the many prototype constructs already available.

[1] De Greef, W. (2004). The Cartagena protocol and the future of agbiotech. Nature Biotechnology 22: 811-812.



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