Preface by
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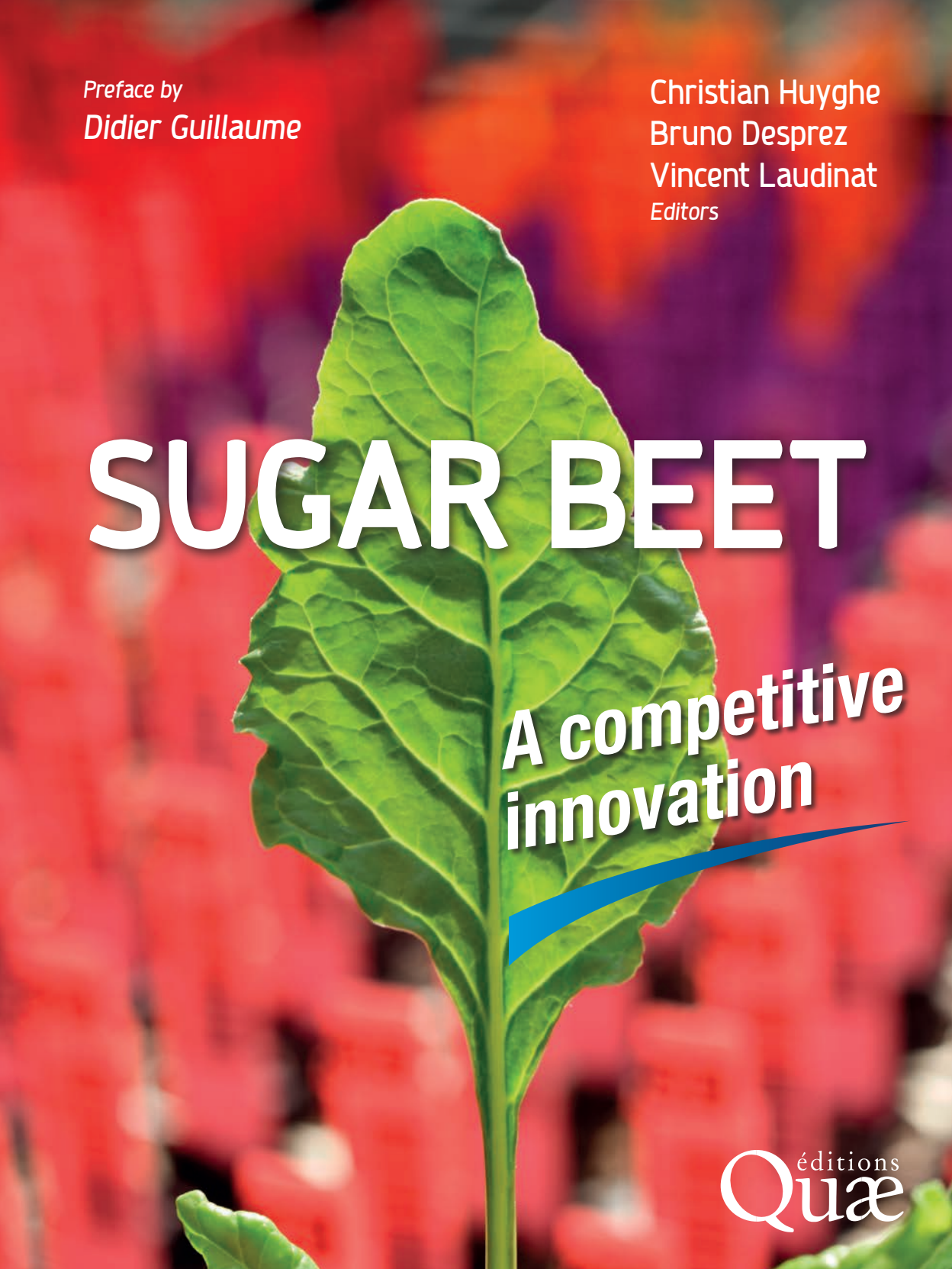
SUGAR BEET

A competitive innovation



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Éditions Quæ
RD 10
F-78026 Versailles Cedex, France
www.quae.com

ISBN (print edition): 978-2-7592-3184-3
ISBN (pdf): 978-2-7592-3185-0
ISBN (ePub): 978-2-7592-3186-7

Contents

New genetic material

An open programme

Preface

Sugar beet is an essential contributor to the French agriculture and agri-food industry. Located in the fertile plains where it contributes to maintaining a diversity of production, the sugar sector is being transformed to meet economic and environmental challenges.

The industry has focused on innovation to optimize production and processing, by exploiting economies of scale to the maximum, with the objective of keeping factories at the heart of production areas.

The innovation is paying off. Over a decade, the significant yield improvements have been achieved while reducing environmental impact, with a sharp reduction in the use of nitrogen fertilisers.

Advances in agricultural equipment are also remarkable: not only harvesters, but also laser-guided mechanical weeding with weed recognition—technologies that may soon move into other crops.

But, most of all, the genetic progress has been truly remarkable in this recently-domesticated species.

The AKER programme, selected in 2012 as part of the French Biotechnologies-bioresources Investments for the Future Programmes, has made a major contribution to these innovations. The new varieties that emerge from this programme, more productive and more resistant to disease, offer great prospects for the whole sector. By harnessing high throughput genotyping and phenotyping technologies, and exploring genetic diversity, the AKER programme is recognizing the major role of biodiversity, which is at the heart of agroecology.

Innovation is one of the pillars of our country's agroecological transition. The AKER programme also reminds us that innovation and this transition are based on our capacity for collective action. It has brought together a particularly dynamic and creative French company, INRAE teams, universities and Grandes Écoles, and an agricultural technical institute, together constituting a French exception in innovation that accelerates progress and its take-up.

Thus, the AKER programme has been emblematic of what public-private research partnership makes it possible to produce in the service of an economically efficient and environment-friendly agriculture and agrifood industry.

Didier Guillaume
French Minister of Agriculture and Food

Context

The first beet sugar refinery in Silesia built by Frédéric-Charles Achard.

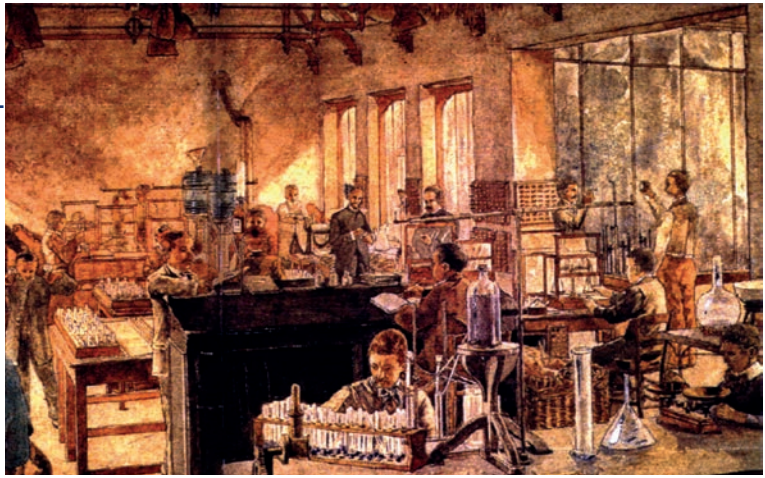
A short history of sugar beet breeding

Sugar beet (*Beta vulgaris* L.) appeared in Silesia, at Cunern in 1802, thanks to the work of Frédéric–Charles Achard. It is the first plant to have been systematically selected because the beet has a biennial reproductive cycle (one year in vegetation, one year in seed production), which makes it difficult for the farmer to reproduce.

In 1806, during the Continental Blockade, the measures taken by the Emperor Napoleon 1st to stifle the maritime trade of the United Kingdom led to the first developments of beet cultivation on 30,000 ha in France, in order to find a source of supply in sugar other than cane. At that time, Benjamin Delessert industrialized the process of making beet sugar. This "ersatz" of imported cane sugar has experienced considerable growth since then, not only in France but in many regions of the world.

Selection methods have evolved over time. Long before Gregor Mendel's arrival, mass selection (best individuals are kept) had become genealogical or pedigree selection (progenies are separated) thanks to the Vilmorin family in the 19th century. In addition, at the request of Florimond Desprez, and under the impulse of Louis Pasteur and Charles Viollette (successive deans of the Faculty of Sciences of Lille), the quantification of sugar by density gave way to the chemical method by reduction of copper salts.

Napoleon 1st, initiator of sugar beet and protector of industry (Museum of Fine Arts of Lille).



The Florimond Desprez laboratory at its beginnings (watercolour painted in 1893).

The discovery by V.F. Savitsky in 1948 of monogerm beets on the one hand, and the description by F.V. Owen in 1952 of the cytoplasmic male sterility of the plant on the other hand, offered to the breeders the possibility of producing monogerm hybrids. The latter made it possible to carry out regular sowing and to mechanize the cultivation of beets by eliminating the labour which was required for the thinning, essential for multigerm beets.

WHAT DOES AKER MEAN?

Aker is an Egyptian god represented by two lions back to back, one watching the sun rise (in our context, genetic resources) and the other watching the sun set (in our context, elite germplasm). Aker is the "Saint Christopher" of the Egyptian gods, carrying the sun from one world to another on his back, which, according to ancient beliefs, was sinking west into the Earth. The symbolism of the two lions can also be associated with the partnership between the Public and the Private, and the phonetics of the name AKER sounds like "Hacker", the one who breaks the (genetic) code.

The beet visual is positioned between the two lions, whose leaves are entangled in the manes. It highlights that AKER is a research programme to improve the competitiveness of sugar beet, the deadline for which is included in the signature "Beet 2020".

AKER

Betterave2020

The genetic improvement in beet is a good reflection of the improvement in cultivated plants, to which the breeding company Florimond Desprez has contributed for five generations. Today, with high-throughput genotyping and phenotyping, with sequencing and the use of molecular markers, with bioinformatics and genomic selection, as well as systematic exploration of genetic diversity within cultivated beets and the *Beta* genera usable in crossing… the AKER programme brings its stone to the building of this construction that is always in evolution.

The objectives of the AKER programme

When it was launched in 2012, the AKER programme corresponded to the wish to put beets at the centre of the field of field crops; the desire to remake one of the scientific supports for agricultural research; the opportunity to enrol in the Investments for the Future Programmes and benefit from the dynamics of the "Grand Emprunt" launched by the French authorities at the time.

Two strands

The first part of the AKER programme aims to identify genetic diversity, build an allelic reference collection and crossbreed with elite material (material with agronomic performance corresponding to market expectations), so as to broaden the diversity of exploitable genetics, accelerate genetic progress and obtain new varieties with high potential.

Concomitantly, the second part consists, in an original way, in valuing all the diversity acquired, in controlling it and in evaluating it by new phenotyping and genotyping methods based on high-throughput tools.

Four steps

In terms of biological material, the AKER programme was deployed in four stages and is now approaching the production of improved varieties, which can be registered in the Official Catalogue of varieties and cultivable plants:

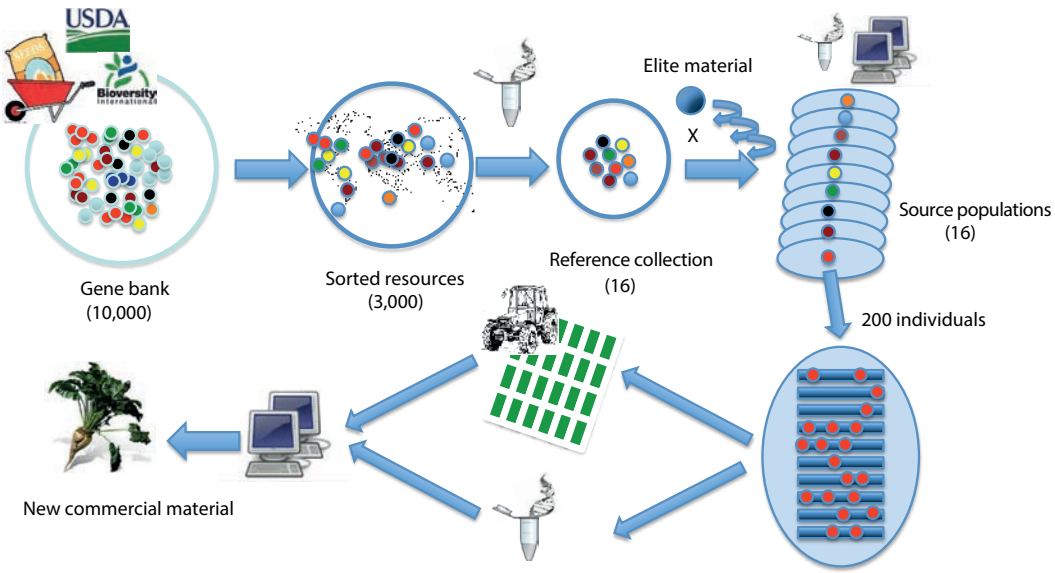
- the first step (2012 and 2013) consisted in identifying sixteen reference plants from 10,000 genetic resources collected that summarized the diversity available for all frequent alleles;
- the second stage (2013 to 2016) implemented crossing of the reference collection with elite germplasm to obtain variable source populations;

• the third stage (2017) focused on obtaining and multiplying these source populations;
• the fourth step (2018 and 2019) consisted in evaluating and analyzing the source populations, taking into account of the year and the place effects;
• finally, the AKER programme has resulted in the selection of new varieties and the associated new knowledge, from 2020.

HOW EFFECTIVE ARE INVESTMENTS FOR THE FUTURE PROGRAMMES?

"The action 'Biotechnologies–bioresources' of the French Investments for the Future Programme, initiated in 2011, funded nine major projects, on crops of major economic interest for our agriculture and our country. These projects have above all made it possible to improve knowledge of these species through the exploration of the diversity of the multiple varieties, drawing in particular on the achievements of the scientific interest group Genoplante. They have also made it possible to consolidate public–private partnerships, by encouraging business investment on the national territory, and to develop for the coming years new varieties better able to meet the needs of farmers, industrialists and consumers, as well as the major challenges of climate change. Finally, these long–term projects have fostered the training of a new generation of researchers, through the involvement of numerous doctoral and post–doctoral students."

Guillaume Boudy, General Secretary of the SGPI
(General Secretariat for Investment)



General diagram of the AKER programme, as designed at the origin of the project.

AKER in brief

AKER aims to improve the competitiveness of sugar beet by 2020 by doubling the annual growth rate of its sugar yield per hectare.

AKER is part of French Investments for the Future Programmes; it is supported by eleven public and private partners representing the entire French beet industry.

AKER is an original and innovative programme which concerns at the same time research, development and training; it confirms sugar beet as a reference plant and sector.

AKER is also:

- 16 reference plants;
- 40 million molecular data points;
- 8 km of hybridization cages;
- 3,000 selected hybrids;
- 63,000 phenotyping plots in the field;
- 11 partners;
- 100 collaborators (including 60 researchers);
- €18.5 million budget (including a €5 million in state grant).

In addition...

The AKER programme has highlighted the entire genetic diversity of beet on the basis of sixteen reference plants.

It is developing a new approach to selection that places genotyping (analysis of genetic composition) before phenotyping (evaluation of traits).

It uses a new selection method (genomics) that relies on plant DNA and new selection techniques (labeling, genome sequencing).

It manages a large number of data (by bioinformatics) to make predictions.

It uses technologies (imaging, robotics) from other research sectors (physics, medicine).

It is interested in the sugar yield of beet, but also in all its components, including resistance to diseases and nitrogen recovery, while respecting the environment.

AKER is a research, development and training programme. It contributes to ensuring the generational renewal of researchers.

WHAT IS THE INTEREST OF THE AKER PROGRAMME FOR INRAE?

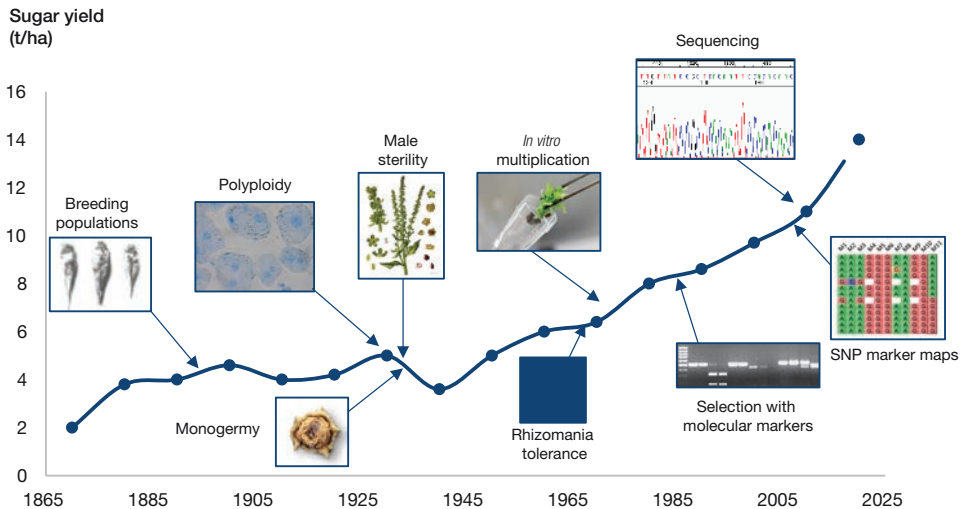
"At the time when the AKER programme was launched, Inra, now INRAE, did not have a dedicated sugar beet programme. And yet the contributions of laboratories and teams from our establishment were very important, whether it was studied in genomics and bioinformatics in Évry and Toulouse, developments in high-throughput phenotyping in Montpellier in interaction with the Capte mixed technology unit in Avignon, or studies on seeds and seedlings at Inra in Angers and Geves. Scientific knowledge has progressed, as shown by the numerous publications of these teams.

But, beyond science, the AKER programme demonstrated the capacity we had to implement, on a new species, all the resources, methods and knowledge developed within the Institute. This considerably widens the scope of the research carried out within INRAE and the scope of the partnerships. Cognitive advances, the quality of the genetic material created within the framework of AKER and partnerships with the Florimond Desprez company, the Technical Institute for Sugar Beet, the universities of Lille and Angers or Agrocampus Ouest are remarkable demonstrations."

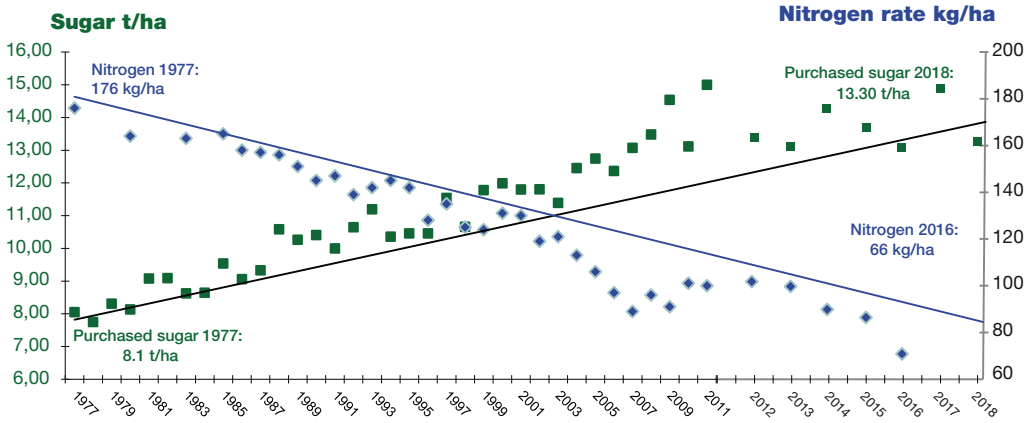
Philippe Mauguin, CEO of INRAE

Sugar beet today

Beet is a cultivated plant which appeared at the beginning of the 19th century, boosted by the Continental Blockade. Since then, yield and quality have improved steadily, while the various inputs required for cultivation decrease over time.



Evolution of beet yield regarding to the technical evolutions (tonnes of sugar/ha).



Evolution of mineral nitrogen inputs (kg/ha) and sugar yield (t/ha).
Sources: CGB, 1977-1996; ITB, 1997-2018.

Sugar yields from beet have increased more than twenty-fold in France. They have gone from 700 kg/ha of raw sugar with a sugar content of 7% from the crop, to 14,800 kg/ha of white sugar with a sugar content of 18% in the best recent years. Mention should also be made of the improvements in the industrial process, which have ultimately enabled the extraction of much higher quality sugar. Finally, energy consumption per ton of beet has been halved in 40 years.

But genetic progress is not measured only considering the "simple" character of sugar productivity. Reduction of the environmental impacts of beets has become particularly remarkable. Since 1983, there has been a 50% drop in the quantities of phytosanitary products used (fungicides, insecticides, herbicides), part of this drop being linked to the development of active ingredients at the end of the 1990s. The trend continues with a strong investment by beet growers towards rational cultivation methods. Over the past 40 years, the amount of nitrogen supplied to beets has dropped by 68% per ton of sugar produced. All of this progress is the result of an interdependent improvement in cultivation techniques, agro-equipment and variety selection.

What has changed since the launch of AKER

Since the launch of the AKER programme in 2012, the beet industry has undergone major transformations by subscribing to a process of continuous progress both in terms of productivity and economic and environmental efficiency.

These changes affect the entire production chain, from the beet seed to the marketing of sugar, including cultivation and processing into sugar and alcohol. They have a direct impact on the economy of the sector and its agricultural practices.

The end of European quotas

The first of these transformations, and certainly the most important for the organization of the sector, is the end of sugar quotas. On October 1, 2017, the system that regulated the European sugar sector ended. The quantities produced are no longer controlled and the liberalization of the market allows each actor in the sector to produce as much sugar as he or she wishes, with a view, among other things, to exporting it.

Thus, from the following marketing year, even as third countries continued to increase their volumes in unprecedented proportions,

Hoeing beets as an alternative to chemical weeding.