CHAPTER 6

INNOVATION AND KNOWLEDGE TRANSFER IN THE DUTCH HORTICULTURAL SYSTEM

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INTRODUCTION

The horticultural industry is an important economic sector in the Netherlands. Internationally, the sector has a leading position in vegetables, fruits, ornamentals, flower bulbs and trees. Within these product groups long-lasting experience in breeding and production is combined with extensive industrial activities in support, logistics and services. The strong position of the Dutch horticultural industry is founded on an intensive interaction between governmental research institutions and private companies. Over the past fifty years, the high quality of plant sciences has been a continuous resource for innovations. In this paper we describe and analyse the success factors of Dutch horticulture, with an emphasis on the organization of knowledge transfer.

THE ECONOMIC POSITION OF THE NETHERLANDS IN GLOBAL HORTICULTURE

The strong position of Dutch horticulture can be illustrated by some impressive figures. All horticultural products (vegetables, fruits, flowers) together represent a production value of approximately € 7.5 billion, and an export value of over € 13 billion (all figures for 2006; source: Product Board for Horticulture). The two large horticultural sectors, the production of ornamentals and the production of food, have developed very well over the past 25 years (Figure 1). Since 1980, the export value

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has increased dramatically in both sectors, from around € 1.4 billion to more than € 6 billion in 2006. In 2006, the export value of all ornamental products was € 6.28 billion, including the two most important products of cut flowers (€ 3.2 billion) and potted and garden plants (€ 1.8 billion). Horticultural food products account for an export value of almost € 7 billion, mainly based on the production of fruits (€ 2.5 billion) and vegetables (€ 3.8 billion).

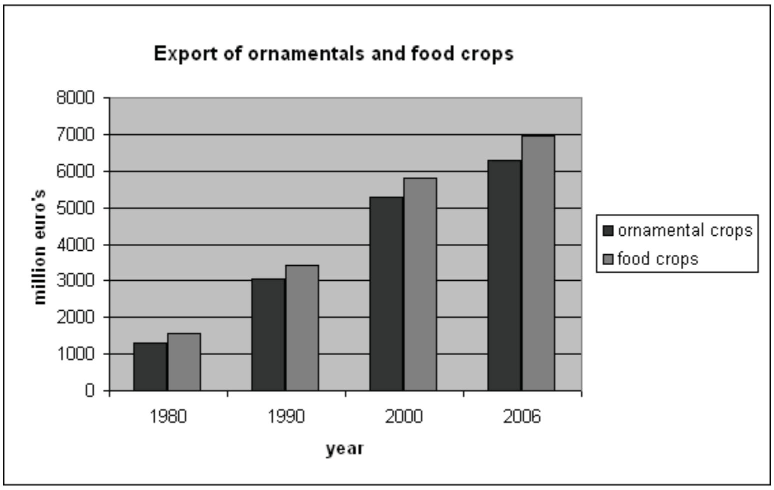

***Figure 1**. Export of ornamentals and food crops*

In the horticultural industry it is not only the production and export of plant-based consumer products that represent an important economic value. A surplus of over € 2.5 billion can be added due to the activities of breeding companies, plant producers, tissue culture companies, traders, etc. Moreover, the Netherlands has a strong position in the high-tech industry of greenhouse construction and greenhouse logistics, with a turnover of more than € 1 billion. If we compare the various sectors in the agricultural sector of the Netherlands, the efficiency and the added value raised in horticulture is impressive: the sector only uses 7% of the nation's agricultural area, but delivers over 40% (€ 7.5 billion) of the overall economic value of Dutch agriculture (€ 18.8 billion) (see Figure 2, data of 2006 from the Product Board for Horticulture). The sector employs over 500,000 people (5% of the nation's overall employment), and over 40,000 entrepreneurs (growers, traders, excluding retail and food processors) are active in this sector.

Within the European Union, Dutch horticulture plays a leading role in the export of ornamental crops and food crops. The Netherlands is responsible for about 28% of the total export of horticultural products within the EU-15 and with countries outside the EU. Ninety percent of ornamentals like cut flowers and flowerbulbs are exported by the Netherlands, whereas for vegetables (33%) and fruits (9%) the percentages may be lower, but they are still considerably above the average for the EU-15 countries. The conclusion is that the Netherlands has a leading position in horticultural industry, both in flowers and in food. It is, therefore, not surprising that in 2004 the Dutch government, through its Innovation Platform, has nominated ‘Flowers and Food’ as one of the key areas of the Dutch economy (www.innovatieplatform.nl). In fact, this particular key area combines the horticultural sector, Food Valley and Green Genetics (Van Oosten and Kropff 2005). In line with the Dutch policy of ‘backing the winners’, this initiative will lead to a further stimulation of innovation, knowledge transfer and business creation in the sector. In this paper we explain why the Dutch horticultural sector has achieved such a strong position and how this position will be maintained or even extended in the coming years.

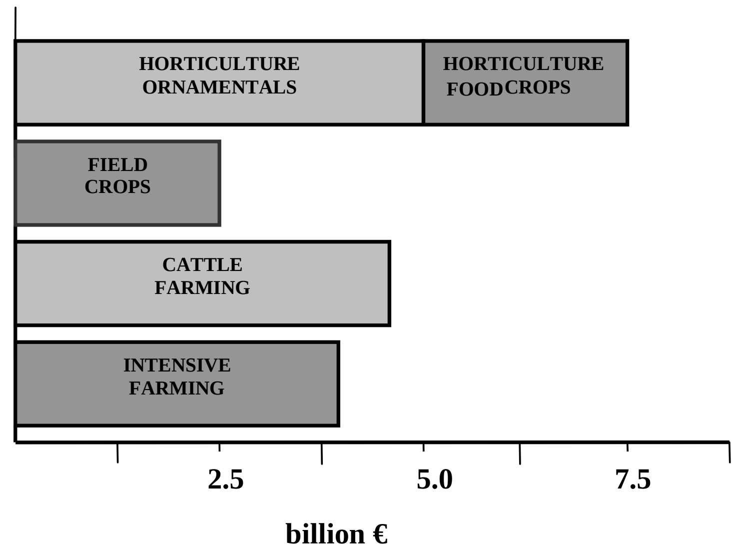

Figure 2. *The position of horticulture in Dutch agriculture; annual production (in billion €) in 2006 (Source: Product Board for Horticulture (PT), Agricultural Economics Institute (LEI) Wageningen UR.)*

FOCUS ON VEGETABLES

Within horticulture, several sectors can be recognized – vegetables, fruits, trees and ornamentals (e.g., cut flowers, pot plants, flowerbulbs) – each with its own history, organization and position. In this paper our main focus is on the vegetables sector. Vegetables include a large variety of plant species. Most of them are annual plants that are cultivated because of their edible parts. Depending on the species, various parts of the plant are used for consumption: fruits (e.g., tomatoes, cucumbers, melons), leaves (e.g., lettuce, cabbages), roots (e.g., carrots, radishes), bulbs (e.g., onions, garlic), flowers (e.g., cauliflower). Vegetables are grown all over the world, in most countries in open fields, but also in controlled environments, such as plastic tunnels or greenhouses. Although there is a great variation in vegetable types, the top five (tomato, watermelon, cabbage, onion and cucumber) account for about half of the total vegetable production worldwide. Tomato is the most important vegetable crop, with a global production of 125 million tons in 2005.

Most of the world's production of vegetables is located in Asia. Of the 880 million tons produced in 2005, 646 million tons were grown in Asia, and its share is increasing very rapidly, especially thanks to China. Europe has a share of approximately 11%, with major production located in Italy, the Russian Federation and Spain (Baas 2006). While the production of vegetables in Europe has grown by about 11% over the past ten years, an increase in production of 75% was realized in Asia over the same period. As may be expected when we take into account the small size of the Netherlands, only a small percentage of the total production of vegetables is grown in this country. For instance, 660,000 tons of tomatoes are produced in the Netherlands, accounting for about 0.5% of the world's production. However, the Netherlands is leading in the production of vegetables (and flowers) in glass greenhouses (more than 10,000 hectares, representing about 25% of the total area of glass greenhouses worldwide). Although the production of vegetables in glasshouses is much more expensive than open-field culture or covered culture using non-permanent plastic coverage, the use of glasshouses allows for a very good control over the culture conditions, leading to optimal performance, reliable and constant production and high quality. Although currently less than 3% of the world's production takes place in controlled environments, this figure is increasing each year. If we look at the trade of fresh vegetables, only a small percentage (less than 3%) is traded globally. This is a reflection of the short shelf life of most products. Here too the Netherlands is among the leading nations (number two, after Spain) in the worldwide list of vegetable-exporting countries, mostly to Germany. Because of its position as a trade centre, the Netherlands is also relatively important as an importer of fresh vegetables.

A FASCINATING HISTORY OF DUTCH HORTICULTURE

Professional horticulture started in the Netherlands more than a century ago, in specific parts of the country where growers found an ideal combination between soil type and climate conditions. In those regions there are still high concentrations of activities in vegetable growing (e.g., around Enkhuizen, the region north of Amsterdam), flowers (e.g., around Aalsmeer), trees and shrubs (around Boskoop) and mushrooms (e.g., around Venlo in the south-eastern part of the country). Vegetables and flowers are also grown in the well-known 'Westland' area, the greenhouse region between Rotterdam and The Hague.

In the second half of the last century the horticultural sector developed into large, so-called Greenports, a combination of intensive and large complexes of cultures, transport, trade, logistics, supporting industries, auctions, etc. Due to a need for economies of scale and globalization, the horticultural industry has developed into a strong concentration of various industrial functions in a small geographic area. The short distances have enabled a fast and efficient communication between various partners in the chain, exchange of information on markets, technologies and societal changes.

The strong position of the industry can be typified as a business model in which Cooperation, Competition and Continuous innovation in products, processes, systems and markets are integrated into a chain of individual partners. The Dutch greenhouse industry is generally considered one of the world's leaders in horticultural production and trade. By investigating a large number of innovative companies in this industry, it has been possible to identify the critical success factors in entrepreneurial innovation (Pannekoek et al. 2005). As expected, superiority in product or process appeared to be by far the most important factor. Furthermore, insight into the needs of the market provides the opportunities needed in a production chain in which the various partners sometimes are not closely linked (e.g., breeders versus retailers or consumers). In greenhouse cultures the introduction of a process that has a positive effect on the environment can be a key success factor. Processes that lead to a more sustainable type of culture and environmentally friendly crop production or reduction in energy consumption are important success factors. It has also been shown that the 'clustering' of companies (e.g., in the 'Westland') stimulates the diffusion of innovative ideas. Strong relationships within the chain appeared to be prime sources of innovative ideas, downstream relationships were used to obtain market and consumer information and cooperation within the production chain reduced the uncertainty of innovation (Pannekoek et al. 2005). To increase the environment-friendly production of crops even further, new innovative greenhouse systems that combine low energy need, limited CO_2 emission and no light disturbance are being developed (see http://www.kasalsenergiebron.nl/).

VALUE CREATION IN THE PRODUCTION CHAIN

The entire production chain for vegetables, from seed companies to the consumer, consists of several stages (Figure 3). Typically, most suppliers within the chain do

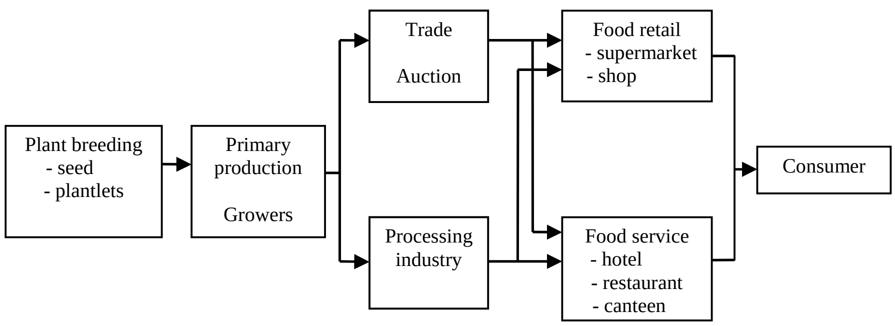

***Figure 3**. The production chain of fresh and processed vegetables (Source: Baas 2006)*

not have a direct contact with the consumer. This may have a negative impact on the interplay between the quality and costs of the goods. However, what the consumer needs should determine the behaviour of all suppliers, and it should influence their specific role in the supply chain. Over the past decades this has become a major issue, and nowadays the ‘reversed chain’ concept is generally accepted and the needs of the consumer are taken into account.

Depending on the type of crop, vegetables are produced by the grower in the open field or, as usually is the case in the Netherlands, in a covered production area, mainly glass greenhouses. The harvested vegetables will reach the consumer in various ways, via a complex trading and distribution system. Two mains streams can be recognized. One possibility is for the fresh produce to be traded first via wholesale or auctions and then to be delivered to retailers (supermarkets, vegetable shops) or food services (restaurants, catering). The second route is via food processors to the food industry, after which the processed vegetables, either canned, dried, salted, frozen or as part other food, are delivered to food retail or food services. A new and fast-developing variation in the processing of fresh vegetables is that of convenient pre-cut and specially packed vegetables.

To illustrate the value creation in the vegetable supply chain, the tomato is used as an example. A quality tomato seed costs the grower 20 eurocents. For one kilogram of seed the grower has to pay € 50,000 (keeping in mind that gold sells at € 12,000 per kilo). In a good production system, e.g., the greenhouses in the Netherlands, one kilo of seed will yield a harvest with a value for the grower of € 3.5 million. Further down the chain, the total value of these tomatoes in the supermarkets reaches a value of about € 7 million, an increase in value of 140 times, from seed to consumer.

FOCUS ON PLANT BREEDING

Seed companies are the starting point of the vegetable supply and value chain. They deliver the high-quality seeds that the grower needs for a profitable and guaranteed production. The main activity of the seed companies is plant breeding. New cultivars of crop species are created by using the genetic variation that exists in nature or by inducing genetic variation (e.g., via mutation induction or genetic engineering). Through a continuous process of crossing and selection, new cultivars are developed that contain genes that code for traits that are important for the production process throughout the chain and for the quality of the final fresh produce that lives up to consumer requirements. Hence, the genetic composition of the plant directly affects its phenotype, and many consumer traits, such as taste, freshness, colour, etc., are in the hands of the plant breeder. Plant breeding, therefore, can affect all partners in the chain: grower, trader, processor, retailer and consumer (Figure 4). The seeds have to meet the needs of all these actors in the production chain.

In 2006, the global seed business realized a turnover of approximately € 25 billion. Compared to the large size of the field crops seed business (maize, cotton, canola, etc), the vegetable global seed market is much smaller but still accounts for about € 3 billion. The Netherlands holds a unique position in plant breeding, plant propagation and plant production. Internationally, the Dutch plant industry is recognized as a leader in the breeding of vegetables, ornamentals, potatoes and grasses, and it is responsible for 46% of the overall worldwide export value. The vegetable-seed business has experienced continuous shifts over the past decades.

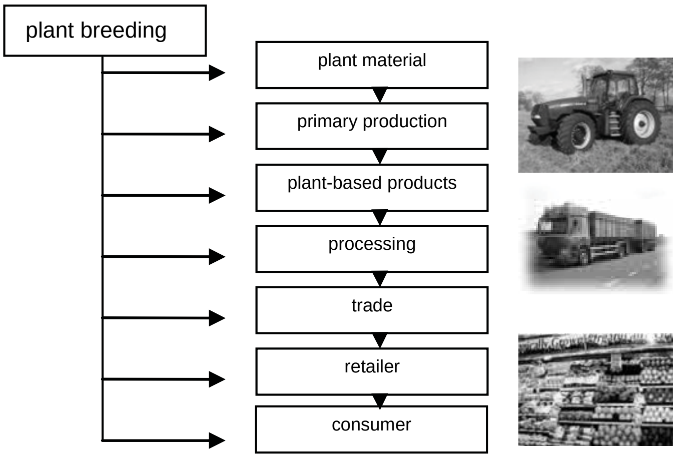

***Figure 4**. Impact of plant breeding in the food chain*

Most companies originally started many years ago as family-based small companies and have a long and successful history. A famous example is Monsieur Vilmorin, who started selling plantlets and seeds in a small shop along the Quai de la Mégisserie in Paris as early as 1766. The company Vilmorin & Cie is now one of the largest seed companies in the world. The major Japanese vegetable seed company Takii & Co was founded as early as 1835, when Mr. Takii started selling his first seeds in Kyoto. It is interesting to note that these pioneers started selling their products many years before the monk Gregor Mendel discovered the laws of heredity (Mendel 1865). Since their re-discovery (around 1900), these laws form the fundamental basis for plant breeding.

In the Netherlands, the primary commercial activities in the seed and plantlet business started at the beginning of the nineteenth century, by pioneers like Nanne Groot and Nanne Sluis. They were in fact the founders of a seed business that still exists, although their names now live on only as a brand name (S&G Seeds) of the large multinational company Syngenta (NTZ 1992). There were many more pioneers in the Dutch seed business in the previous century, and their vision resulted in the establishment of more than twenty vegetable-seed companies. Several of these companies are now successful commercial entities that operate at a global scale. Most Dutch companies kept their independence, committed as they are to their entrepreneurship and responsibility. The sector is characterized by creativity and craftsmanship, and is present in the first part of the value chain. Although family ownership continues to be an important feature of the vegetable seed business, several companies have been taken over or merged into larger entities. Over the past twenty years an extensive consolidation has taken place. Nowadays, the world vegetable-seed business has consolidated in such a way that over 80% of the market is in the hands of ten companies (Figure 5).

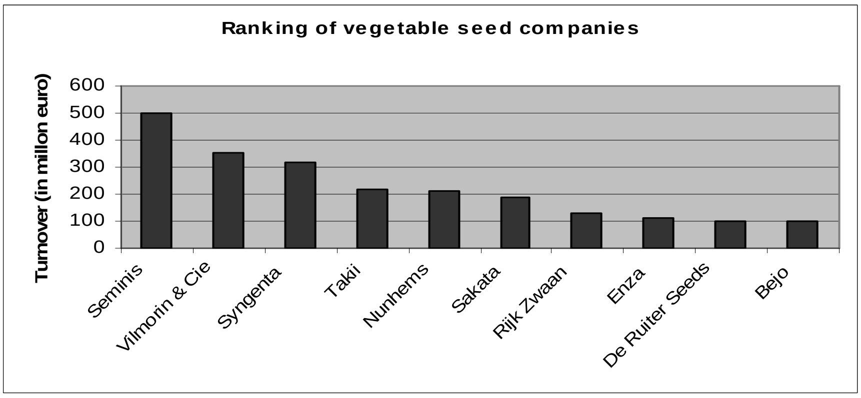

***Figure 5**. Ranking of vegetable-seed companies; turnover of professional vegetable-seed sales (2005)*

Most of these companies have their main offices and/or their R&D facilities in the Netherlands, which illustrates the country's important role in the plant-breeding sector. Some recent changes are the acquisition of the largest vegetable seed company, Seminis Vegetable Seeds (approx. 30% share) by Monsanto in 2005, and the merger of the field-crop division of Limagrain and the vegetable division Vilmorin Clause & Cie into the new large company Vilmorin & Cie (in 2006), the fourth largest seed company in the world. The top three largest vegetable seed companies (Monsanto/Seminis, Vilmorin & Cie/Limagrain and Syngenta are now part of large entities, including field-crops seed breeding and production. Moreover, another top-10 player, Nunhems, is part of the Bayer Group. Nevertheless, there are still a number of independent (family-owned or at least family-based) companies, e.g., Takii & Co, Rijk Zwaan, Enza Seeds, De Ruiter Seeds and Bejo Seeds.

CONSOLIDATION AND COOPERATION

One of the reasons for the consolidation in the seed industry, as exemplified in the vegetable-seed business, is the need for financial resources to incorporate new innovative technologies in the development of new cultivars. The need for innovation in this industrial branch is impressive. In the Netherlands, the breeding companies on average spend 14% of their budget on R&D (including research to find new genotypes and the breeding and selection process itself). Some companies spend as much as 25%, which is even more than the pharmaceutical industry spends on R&D. The reason for this is that breeding companies are continuously challenged by the need to develop new varieties of a large series of crops. These new varieties have to meet various demands made by growers (good yield, reliable and uniform production, resistances to pests and insects) and consumers (taste, appearance). Globalization also leads to the requirement of cultivars that are adapted to the agronomic needs of the various regions in the world.

At a global level, the seed industry is well organized. The main organization, the International Seed Federation (ISF), represents the world seed trade and plant breeders' community, with members in over 70 countries (www.isf.org). This organization is the international forum for the world seed industry and deals with important issues concerning the international regulation and legislation of seed production, trade and sales. High on its list of priorities is the protection of intellectual property rights (IPR). Because innovations are the basis for the development of new cultivars and require high levels of investment in labour and finance, companies need a lead period in order to have sufficient return on investments.

In the Netherlands, the companies active in plant breeding and plant reproduction work together in an organization called Plantum.NL, the Dutch association for breeding, tissue culture, production and trade of seeds and young plants (www.plantum.nl). Plantum.NL is one of several organizations that play a role in the strong institutional framework that is the basis for the Dutch seed sector. These organizations are part of the variety development chain in which new cultivars of crops are developed and which ranges from genetic-resource organizations to organizations that recognize a new variety on the basis of Plant Breeders' Rights. Recently, an overview of the organizations involved in this process was provided by Kamphuis (2005).

The seed industry is characterized by fierce competition as well as intensive collaboration. A good example is BioSeeds, a strategic alliance between a number of vegetable-seed companies, founded in 1989, at the onset of the integration of biotechnology in the seed business. To be able to develop and incorporate the new technologies within the breeding processes a number of seed companies in the Netherlands decided to establish a strategic alliance (which is called BioSeeds) and founded Keygene, a biotech company whose main focus is on the development and application of marker-assisted breeding technologies. The Dutch seed companies Rijk Zwaan, Enza Seeds and DeRuiter Seeds form part of this consortium, and its success has attracted other companies. Vilmorin & Company (VCO), which originated in France, became a shareholder in 2001, and in 2005 the Japanese company Takii & Co joined the alliance. All of these five companies are among the top-10 companies of the vegetable-seed industry (Figure 5).

FROM CONVENTIONAL BREEDING TO MOLECULAR BREEDING

As a result of the development and application of biotechnology, the plant-breeding process has changed enormously. Biotechnology has revolutionized the industry from what is now called 'conventional' or 'traditional' breeding towards the application of 'molecular breeding'. The technological development that has enabled this change is based mainly on important scientific breakthroughs in the 1970s. The discovery of restriction enzymes for the fragmentation of complex DNA molecules, the development of methods for amplification of DNA fragments and the introduction of large-scale DNA sequencing are examples of this. All these technologies led to the creation of a new and innovative toolbox that plant breeders can use to unravel and visualize the genetic variation in the plant germplasm. One of the major technologies (AFLP) was developed in 1990 by Keygene (Vos et al. 1995). This technology enables breeders not only to gain a clear insight into the genetic variation of their breeding lines, it also allows them to use genotyping instead of phenotyping in the selection process. Nowadays, such DNA-fingerprinting technologies are routine in all breeding companies and they are used in the breeding of all vegetable crops. This really has revolutionized plant breeding (Peleman and Rouppe van der Voort 2003).

Another biotechnological tool that has been introduced is genetic modification, which has the potential to reshape the way crops are grown. Genetic modification implies the addition of genetic information with the aim of developing a plant with a new trait or character. Again, this technology is based on scientific research carried out in the 1970s. In a collaboration between the groups of Schilperoort at Leiden University, The Netherlands, and Schell at the University of Ghent, Belgium, it was discovered that the soil bacterium *Agrobacterium tumefaciens* was able to transfer part of its genetic information (a piece of DNA) to plant cells (Van Larebeke et al. 1974). This 'natural' system of genetic modification has been engineered into a tool that has been used extensively over the past ten years. Since the first commercial culture of genetically modified maize in 1996, within 10 years the area of land on which such genetically modified crops are grown has increased tremendously, up to an area of over 90 million hectares in as many as 21 different countries in the world (ISAAA Report 2006). The introduction of a genetically modified plant on the market requires an intense and very costly analysis of its safety, both in terms of consumer health and its potential ecological effects. Except for the introduction of canned tomato paste based on GMO tomato some years ago in the USA and Great Britain, hardly any genetically modified vegetable product has reached the market in Europe and North America. However, recently, genetically modified long-shelf-life tomatoes have been marketed in China and it is expected that insect-resistant *Brassica* species, based on the introduction of *Bacillus thuringiensis* (Bt) toxin genes, will be introduced in India soon, via a collaboration on insect management for brassicas in Asia and Africa (e.g., www.cimbaa.org).

THE SCIENCE OF PLANT BREEDING: THE IMPACT ON INNOVATION IN THE VEGETABLE PRODUCTION CHAIN

Plant breeding became real science soon after the rediscovery of Mendel's Laws at the beginning of the 20th century. Since then, plant breeding has evolved by absorbing approaches from different areas of science, allowing breeders to increase their efficiency and exploit genetic resources thoroughly. In their interesting review 'The Future of Plant Breeding', Gepts and Hancock (2006) describe how plant breeding has evolved as a multidisciplinary science, combining areas of expertise such as agronomy, botany, physiology, pathology, biochemistry, genetics, molecular biology, genomics, bioinformatics, etc. Thus, plant breeding is a vibrant science, with continued success in the development and deployment of new cultivars on a worldwide basis. In Wageningen, plant-breeding research and education is a core theme of the Plant Sciences Group of Wageningen University and Research Centre.

The plant-breeding group is a multidisciplinary research team that combines fundamental and more strategic research lines and offers a vital education program. In Wageningen, plant breeding focuses on vegetables such as cabbages (Brassicaceae), tomatoes and potatoes (Solanaceae) and some ornamental crops (roses, tulips, lilies), based on three major research themes:

- Growth and development: Crops need to perform optimally under a variety of conditions. The main scientific challenge is to gain greater insight into the physiology of the plant and the genetic regulation of processes involved in growth and development, including seed germination, plant architecture, fruit ripening and senescence. Results are used for genetic improvement and for the development of culture conditions and culture regimes that guarantee a high, uniform and controlled growth and development of seeds and plantlets.
- Plant health: Crops are continuously threatened by pathogenic organisms such as viruses, bacteria, fungi and insects. Changing culture conditions, new crops and new culture regions require continued research into the development of new resistances against insects, viruses, bacteria, fungi and nematodes. The scientific challenge is to improve our insight into the regulation of the interaction between plant and pathogens, and to develop expertise and methods to interfere in this relationship. Results are used for the pathogen-free production of seeds, cuttings, bulbs and plantlets and for the genetic improvement of cultivars that are more resistant to pathogenic organisms.
- Quality for the consumer: Products derived from the culture of crop plants have to fulfil all the various needs of the different partners in the product chain (from grower to consumer). The scientific challenge is to improve our understanding of the complexity of components that determine aspects such as colour, fragrance, taste and health-promoting effects of plant products, to unravel the genetic basis of the biochemical pathways involved, and to show that this will lead to plant products with improved contents. Results allow breeders and producers to exploit the existing genetic variation and to create plants that meet the needs of the various partners in the chain.

The Wageningen research program has been very successful and has generated some fine examples that provided the Dutch horticultural system with many innovative new products. Basic research in plant–pathogen and plant–insect relationships has led to an understanding of the genes responsible for resistances in crop plants. This has made it possible to create cultivars that are resistant to several major pests and diseases. For instance, it has led to cultivation systems for major crops like tomatoes, in which the application of chemical treatments has been reduced to zero. Another example of the application of fundamental knowledge is the ornamental crop lily. *Lilium* L. is a genus of the monocotyledonous family

Liliaceae, which comprises over 80 species classified into six sections. The most important hybrid groups cultivated for cut-flower production are the Longiflorum, Asiatic and Oriental hybrids. Crosses within a section can be made with relative ease, but for interspecific hybridization, pre- and post-fertilization barriers have to be overcome. For commercial reasons, there is a special interest in such interspecific crosses, as such hybrids may combine the resistance to *Fusarium* and viral diseases of Asiatic hybrids and the *Botrytis* resistance of some Oriental types. In Wageningen, a research team headed by Dr. Jaap van Tuyl has succeeded in developing a series of combinations of Asiatic and Oriental types, each with some important traits for production (e.g., resistances) and floriculture (e.g., colour, shape, vase life) (Barba-Gonzalez et al. 2006). These are just a few examples of the impact of plant sciences on innovations in the breeding industry.

THE AGRICULTURAL KNOWLEDGE SYSTEM

The Dutch agricultural system not only developed through the entrepreneurship of the individual breeders, growers and retailers or the well-organized institutional framework, but it also has been strongly supported by the agricultural knowledge system. This system was put into place in the second half of the 20th century and consisted of a close interaction between the agricultural education system, the agricultural research system and the agricultural extension system (Kamphuis 2005). The so-called OVO-triptych (see Figure 6) shows the close interrelations between Education, Extension and Research (in Dutch: Onderwijs, Voorlichting, Onderzoek).

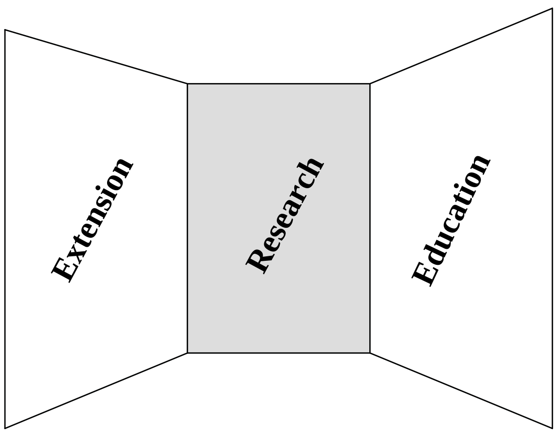

Figure 6. *The agricultural knowledge system: the OVO triptych, the relation between research, education and extension*

The exchange of information and transfer of knowledge, based on a strong infrastructure for scientific research and education, has led to a tremendous improvement of our knowledge basis and to a corresponding high level of innovation. The Ministry of Agriculture was responsible for the entire agricultural education system in the Netherlands. The OVO tryptich in fact reflected the need for strong links between education and the agribusiness. Professional education and training were given by Agricultural Education Centres, which provided programs from lower to higher education, for students between the ages of 12 and 20. The Agricultural College (later Agricultural University) in Wageningen was devoted to education in agriculture-related sciences at an academic level. It was founded in 1876, first as a State Agricultural School in 1876, with the intention of improving agriculture on the basis of increased knowledge via research and education. In addition to academic research, more strategic and applied research was carried out at various institutes within the Agricultural Research Organization (DLO), also under responsibility of the Dutch Ministry of Agriculture, Nature Management and Fisheries. Since then, 'Wageningen' has developed into an internationally recognized centre of knowledge and expertise in agriculture.

FROM A COMPLEX ARRAY OF ORGANIZATIONS TO ONE LARGE ORGANIZATION

The organization of agricultural research has changed dramatically over the past twenty years. One of the main drivers for change was the required transformation from knowledge-driven toward demand-driven research. The development of research, innovation and practical application was no longer the main responsibility of the government, but became much more dependent on the needs (and inputs) of the industry. Another driver for change was the increased globalization of research, the required investments in technologies and the more multidisciplinary arrangement of research. To remain competitive on a global scale, it became important to improve the efficiency and the efficacy of the agricultural knowledge system in the Netherlands.

This all has led to a major reorganization of agricultural research in the Netherlands, which took place incrementally between 1987 and 2004, and culminated in the creation of Wageningen University and Research Centre, an alliance of Wageningen University, all the applied research institutes of the Dutch Agricultural Research Department DLO and the experimental stations in the Netherlands (Beemer et al. 2006). Moreover, recently the agricultural technical college Van Hall Larenstein also became part of Wageningen UR. Nowadays, the complex array of the sector's research organizations has been transformed into a single large complex organization covering most agricultural research and education. Wageningen University and Research Centre is now organized in five expertise groups, Agrotechnology & Food Sciences, Animal Sciences, Environmental Sciences, Plant Sciences and Social Sciences. In 2006, the entire organization employed about 5,600 people, boasting some 4,500 BSc and MSc students, over 1,100 PhD students and approx. 4,000 professional bachelors, representing a turnover of approx. € 700 million.

Wageningen UR is in fact the largest education and research organization in the Netherlands. In each expertise group, the university groups are directly linked to strategic and applied research, and research at all these different levels is directly connected to education programs. Internationally, Wageningen UR holds a prominent position, as can be deduced from the scientific publications and citation indices. According to ‘Essential Science Indicators’ (Thompson Corporation, Web of Science), Wageningen UR is among the world’s top five when it comes to agricultural sciences, plant and animal sciences and environmental sciences.

FROM OVO-TRIPTYCH TO PPP (PUBLIC–PRIVATE PARTNERSHIPS)

The agricultural knowledge system is considered a critical success factor with regard to the strong development of Dutch horticulture. Over the years, significant changes have taken place, not only in the organization of the knowledge system, as we described above, but with regard to the interaction between the companies and the research organizations. In the past, the classical flow of information began with fundamental University research, via strategic and applied research at governmental research institutes and experimental stations, to implementation in practice via the agricultural extension system (Figure 7a). Nowadays, we are in the middle of a transition from this classical transfer model towards new concepts of co-innovation, in which industries and research centres operate together in new and more open forms of collaboration. This co-innovation model affects collaboration in R&D as well as in education.

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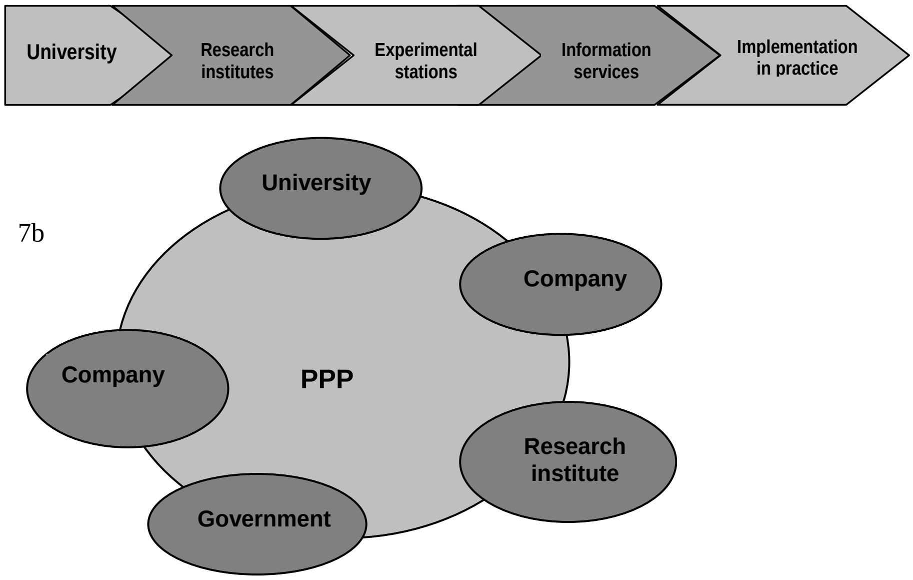

Figure 7. *The agricultural knowledge system: 7a: the classic flow of information; 7b: the new public-private partnerships*

In education, the transition is from the OVO triptych towards an OOO (*Onderwijs*: education, *Onderzoek*: research, and *Ondernemerschap*: entrepreneurship) network in which academic research, education and industries all work together in a network system, to establish effective education programs. In research, the transition is from a linear flow of information, from fundamental research via applied research towards implementation, in practice to a so-called public–private partnership (PPP), in which various stakeholders work closely together in a more dynamic and open system (Figure 7b). The close interaction that has existed for many decades within the agro-food research and agro-food industrial complex in the Netherlands is seen as a good example of a so-called 'cluster' approach (Porter 2000; 2001).

Such collaborations are in line with current observations that well-established Industry Science Links (ISLs) are very important in the transfer of scientific knowledge and the transfer of technologies to companies. As described by Debackere and Veugelaars (2005), the effectiveness of these ISLs depends very much on and is fostered by the quality of the technology-transfer organization (TTO) established within the research organizations. At the home base of Debackere, the Catholic University (K.U.) Leuven, the technology-transfer unit plays an important role as an intermediary between researchers and commercial entities. Over the past thirty years this university has developed one of the best practices in the field of knowledge transfer and spin-off creation. Only recently, in 2005, Wageningen University and Research Centre has founded the Wageningen Business Generator, which fulfils a similar role. And this organization will facilitate the transfer of know-how and technology to existing companies, through licensing or joint ventures, and for the foundation of new ventures, based on the results of research from the research organization.

New, innovative collaborations between universities and private companies are important to drive the value creation of knowledge. In general, Dutch universities are less commercially oriented than those in other countries, especially in comparison with the main universities in the US (e.g, University of California, Cornell University, Massachusetts Institute of Technology). There are a number of attitudes that hinder value creation of scientific research. In his analysis of the innovativeness and competitiveness of the Netherlands, Porter (2001) presents a number of observations. First of all, science is curiosity-driven and its application is considered less important. Secondly, the commercialization of science is not seen as a critical factor and is even expected to threaten the independence of a university. Finally, the importance of establishing relationships with industry has for a long time been insufficiently recognized. Porter argues that for the Netherlands to play an important role, the scientific culture must be adapted to modern requirements, and scientists must be encouraged to explore new avenues of research. We are presently in the middle of a transition towards more 'entrepreneurial universities', and the responsibilities and tasks of the universities have been extended. The two traditional key activities of the university – academic research and academic education – have been extended (formally by law) to include a third key activity: creating value for society. There are two targets: increasing the societal responsibility of the individual researcher and the university as a whole and stimulating economic factors to assure the continuity of the research organization. This also means that the patenting of intellectual property is now becoming an important asset of universities, and will become an important indicator for success (Mowery et al. 2001).

EXAMPLES OF NOVEL PUBLIC–PRIVATE PARTNERSHIPS IN PLANT SCIENCE

Within the field of plant breeding and plant biotechnology a number of such new PPP collaborations have been installed. As an illustration, we will describe two research programs that were established recently in the Netherlands: the Centre for BioSystems Genomics (CBSG) and the Technological Top Institute Green Genetics.

The Centre for BioSystems Genomics (CBSG)

In 2001, the Dutch government decided to invest considerably in genomics research and created the Netherlands Genomics Initiative, with a total budget of € 300 million for four years. The principle aim and target of this initiative was to turn the Netherlands into an international leader in genomics research, and to link high scientific quality to economic and social returns. The Centre for BioSystems Genomics (CBSG) was selected as one of the five Centres of Excellence within this program. As posted on their website (www.cbsg.nl), the mission of CBSG is "to exploit the potential of biosystems genomics to realize new opportunities for sustainable agro-production systems of tomato and potato and to contribute to the improvement of the quality of these food crops and their derived products for consumer, processor, producer and the environment". CBSG is a public–private partnership between Dutch scientists in the field of plant sciences and genomics, and the major Dutch companies in plant genomics and breeding in tomato and potato. Although the program is coordinated by Wageningen University and Research Centre, it includes all the major scientific groups of the Netherlands. The 53 m€ research program will be in operation between 2002 and 2007, and a new research program covering the period 2008-2012 to establish further a critical mass of effort and resources is now put into place. This unique collaboration comprises all the main research groups working on plant genomics. The aim of the program is "to exploit the potential of genomics to create new opportunities for sustainable agro-production systems for potato, tomato and *Brassica* which shall have clear socio-economic implications for producer, processor and the consumer through improved crop production, enhanced food quality and reduced environmental impact" (Stiekema 2007).

Technological Top Institute Green Genetics

In 2004, the Dutch Government selected a few number of key areas of high economic importance, and the horticultural sector in the Netherlands was one of them. In this key area the Dutch Government made it possible to found the Technological Top Institute Green Genetics. Green Genetics comprises all the activities in the breeding and propagation of horticultural, floricultural and agricultural crops. The Green Genetics sector provides the starting material for the entire agribusiness and occupies a strategic position in the knowledge and production chain of the agro-food business (Figure 8). To strengthen the position of the strategic research of TTI Green Genetics further, a strong interaction with fundamental and utilization-oriented academic research has been installed that combines ‘upstream’ and ‘downstream’ research. Within TTI Green Genetics, the government supports fundamental and utilization-oriented research in plant sciences and the development of various instruments for valorization and knowledge.

The central theme of TTI Green Genetics is ‘Innovative plants for sustainable flowers & food’. This theme expresses the main aim of TTI Green Genetics: to utilize knowledge and expertise of research organizations and industry for the development of innovative crop varieties – plants that are optimized for a sustainable growth under various environmental conditions. The results will enable breeders and growers to use the full genetic potential of plants for optimal and sustainable growth under existing and new production systems. The research topics, which are demand-driven, are prioritized by the industrial partners, and research is carried out by selected top-quality research groups in close collaboration with industrial partners. The projects have creating know-how and expertise as their primary objective, with the aim of strengthening the competitiveness of the Dutch industrial and the country’s technological position in the Flowers & Food sector. All cluster research projects contribute to the central theme ‘Innovative plants for sustainable flowers & food’, which is divided into three sub-themes: Growth and development, Plant health, and Quality for the consumer. The TTI Green Genetics program started in 2007 and will be in place for the next four years, with an overall budget of € 40 million, co-financed by industry, research organizations and government as expected for a real public–private partnership.

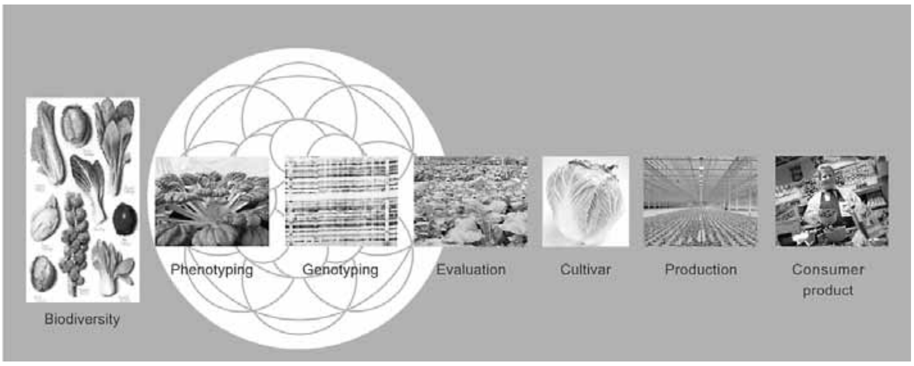

Figure 8. *Plant breeding is the basis for all food*

CONCLUSIONS AND OUTLOOK

The Dutch horticultural industry is a good example of an economic sector that is successful as a result of ongoing innovations. The sector has a long history and it has succeeded in developing its position thanks to a number of key success factors. Firstly, its unique position is based on the industrial entrepreneurship of the breeders, producers and traders. The country's entire production chain of vegetable and ornamental produce has reached a high level of efficiency, logistics and quality control.

Another important factor is the renowned research environment that has led to the generation of fundamental knowledge in plant sciences, in particular plant genetics. The exploitation of the results and technologies derived from fundamental and strategic research leads to new innovations in the various parts in the production chain. This is most obvious in the breeding and production of horticultural, floricultural and agricultural propagation material, where Dutch companies play a leading role. This forms the basis of the food production chain, and breeders are very successful in using genetic information to create crops that have an improved performance and quality. Essential for such an implementation of new knowledge via innovations and applications is an effective and efficient interaction between various partners in the field. The recent examples of public–private partnerships as described in this paper are illustrations of this approach. Nowadays, because of increased competition due to globalization, the recognition and assessment of the value of scientific knowledge is a key issue for success. Universities, research institutes and companies will have a competitive edge if they are able to value the knowledge they develop. Unfortunately, the Netherlands, like many other European countries, is lagging behind when it comes to the commercialization of knowledge, and this could threaten the position of the Dutch agro-food cluster in the future.

As described in this paper, there are a number of key elements that are of crucial importance and that have to be changed or improved. The most important ones are:

- a culture that fosters innovation and an awareness of opportunities;
- universities that are not only excellent in terms of academic research and education, but also in terms of creating value for society;
- researchers who see the protection of intellectual property as a major responsibility;
- a positive attitude among students and teachers towards entrepreneurship and commercialization; and
- a further stimulation of global interaction and the transfer of knowledge between industry and knowledge centres.

Although the current economic situation in the Dutch agro-food sector looks very healthy, it is important to look to the future. Globalization and consolidation of the industry and the explosive increase in knowledge from scientific research requires a close interaction between industry and science. To remain competitive it is important to resolve the European paradox and to bridge the gap between science and industrial application. Historically, there has always been a close link between the Dutch agro-food cluster and the nation's main agricultural research organization, Wageningen University and Research Centre. As a result of this, this cluster is therefore in a very good position to pursue the changes needed to improve innovation, entrepreneurship and value creation.

WEB-SITES CONSULTED

- Centre for BioSystems Genomics: www.cbsg.nl
- Collaboration on Insect Management for Brassicas in Asia and Africa: www.cimbaa.org
- www.innovatieplatform.nl
- International Seed Federation: www.ISF.org
- International service for the acquisition of agri-biotech applications: www.ISAAA.org
- Plantum.NL, www.plantum.nl
- Technological Top Institute Green Genetics: www.greengenetics.nl

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