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The History of Dutch Potato Breeding 1888–2018: from Hobby to Industry

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Abstract

The Netherlands has a world-leading position in potato breeding, but little is known about the factors that led to this success. This paper analyses the factors that have influenced the development of potato breeding in the Netherlands. This study is based on research of the grey and scientific literature and interviews with various representatives from the Dutch potato breeding sector. We distinguish four periods: (i) Before 1888, no potato breeding in the Netherlands existed whereas in other countries first crosses occurred. (ii) 1888–1940, more individuals started breeding out of interest and hobby to overcome the commonly observed degeneration of potato. (iii) 1940–1967 the emergence of a corporate set up of breeding by private companies collaborating with small breeders. (iv) 1967–present, towards full-fledged breeding industry supported by the new Seeds and Planting Materials Act (ZPW) in 1967 including the breeders' rights. Many factors including cultural practices, diseases, and market that determine the strategy of breeding have been analysed. The development is most of all 'crop driven' to maintain the level of production. But it was also 'export driven' leading to the development of an export-oriented seed potato sector. The conclusion is that three elements were dominant in the development of a strong potato breeding sector: (1) the broad cooperation among all players in the potato chain, (2) the design of the institutional infrastructure, and (3) the remuneration of the breeding work through legislation regarding plant breeders' rights. The study ends with an outlook on future trends, one of them leading from an open to a more closed business culture.

Keywords Agricultural history · Plant breeding · Plant breeding factors · Potato

Abbreviations

COA	Commission for the Advancement of the Breeding and Research of New Potato varieties
FMvL	Frisian Association for Agriculture
FSS	Farm Saved Seed

Extended author information available on the last page of the article

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IVP Institute for Plant breeding
IVRO Institute for Research on Varieties of Cultivated Plants
NAK Dutch General Inspection Service for Agricultural Crops
SVP Foundation for Plant Breeding
ZPW Seeds and Planting Materials Act

Introduction

Potato is one of the most important crops in Dutch agriculture (CBS 2022). In potato breeding and potato seed production, the Netherlands has a leading position in the world (Table 1). This concerns many aspects of the sector, from research and breeding to cultivation, processing, and export. The dominant factor is the availability of improved varieties for all segments of the market: consumption, (seed potato) export, processing industry, and starch production. There is much literature about the potato, its agronomic research, breeding research, and research into all kinds of potato diseases and pests, but little is published about how potato breeding developed into a permanent and indispensable part of the Dutch potato industry. There are some publications on aspects of the Dutch plant breeding history and more specifically potato breeding, mainly written quite extensively and generally descriptive about several early periods until the mid-twentieth century (Dorst 1957, 1964; De Haan 1949, 1962, 1965; Thijn 1964; Zingstra 1968, 1983). But a complete overview until recent times is lacking.

Potato acquired great significance to society in more than four centuries since its introduction into Europe. With respect to the history of the potato, there is certainly literature available (Roze 1898; Burton 1948; Salaman 1985; Oliemans 1988; Kolbe 1999; Van der Zaag 1999; Haverkort 2018; Campos and Ortiz 2020; Earle 2020). The history of potato is discussed in all these books, but the role of breeding is certainly not central. There are, however, references to breeding, especially to the first approach to the problems in cultivation. These arose because of viral diseases, often referred to by the English term 'Curl' (Salaman 1985). In the Netherlands, the name '*Krul*' was used (Dorst 1943); the cause was

Table 1 Area of seed potatoes (ha × 1000) of the largest seed potato producing countries in the Western world over the years 2002, 2007 to 2020 (source: NAO 2014, 2017, 2021; USA 2020; CND 2020)

Country	2002	2007	2012	2016	2017	2018	2019	2020
The Netherlands	37	36	37	41	40	42	42	42
Germany	18	16	16	16	17	17	18	19
France	14	15	17	20	21	22	23	24
United Kingdom	16	14	14	14	14	14	14	14
Denmark	5	5	6	4	5	5	5	6
Canada	33	25	25	21	22	22	23	23
USA	54	43	46	42	43	40	42	40

not yet known at the time. However, the climax is the catastrophe in Ireland after the outbreak of the late blight (*Phytophthora infestans*) epidemic in 1845.

The potato grower who must make choices regarding varieties for cultivation plays a significant role to match with its soil type, the use of plant protection products, the storage, the mechanisation and the organisation, and marketing of its harvest. In all these aspects of cultivation and processing, potato breeding and research have played and still play a key role by continuously participating in the development of appropriate varieties. Breeding is in fact the basis of the complete potato column (from crossing to consumer), and thus, a description and analysis of the history will provide a clear picture of the complexity of potato breeding and of lessons learned for better management of potato breeding in the future. (Potato) breeding is more than just improving variety traits. In a much broader sense, the breeder must deal with the economy, the environment, applicable laws, and regulations, in short corporate social responsibility (Nijhof 2008; Carroll and Shabana 2010).

Starting points for the study are the developments that push along potato breeding, as well as the interplay between the problems that arise and the action or reaction of breeders and researchers to this. The focus of the study is from 1888 onwards, when in the Netherlands, the goal-oriented potato breeding starts, an easy and sharply delineated starting point. However, to be able to put the beginning in a broader, international context, we also briefly picture the period prior to 1888. The basis of this study is the description of the shift from potato breeding by small private breeders to breeding by companies.

This article is based on the dissertation of the first author (Van Loon 2019). The study draws on an extensive literature review, including scientific and grey literature, documents from archives of institutions and companies, and the personal archive of the first author. The search in literature was done with a range of keywords, such as potato, breeding, the different potato diseases, company names, and market segments. In addition, data was collected through many years of participant observation and through informant interviews with more than 25 key persons from the potato breeding sector. The interviewees were a representative group from across the industry, scientific research, potato breeding and cultivation, and trade. A similar group of people was brought together in a workshop setting to discuss the provisional results of this study. This method can be defined as triangulation: the use of multiple data collection methods to improve the quality, reliability, and validity of the findings (Patton 1999).

The aim of this study is to understand the factors that have influenced the development of potato breeding in the Netherlands, to analyse their interrelationships, and to learn what have been the most determining factors in the development of potato breeding. We analyzed the following three specific areas: (i) the development of potato breeding over time, between 1888 and present. (ii) The role of government, in governance, research, and education. (iii) Other driving factors, such as occurring diseases, developments in cultivation, and market. In the last section, we reflect on the key factors and perspectives to the success of the Dutch potato breeding.

The Development of Potato Breeding over Time, Between 1888 and Present

The history of Dutch potato breeding shows that it coevolved with developments in government policy and the potato industry. Several distinct periods can be discerned, which together demonstrate how potato breeding in the Netherlands developed into a fully-fledged agricultural industry. This begins with the start-up to cross breeding in Europe before 1888 with no potato breeding in the Netherlands. This is then followed by the development in the Netherlands in which three periods of activity can be distinguished: (i) 1888–1940, the individual breeder. (ii) 1940–1967, private companies start breeding. (iii) 1967–present, towards full-fledged breeding industry. The first period in the Netherlands deals with the time when individuals started breeding out of interest and hobby, and the field developed further. The second period depicts the emergence of a corporate set-up alongside the small breeders. The third period coincides with the coming into force of the Seeds and Planting Materials Act (ZPW), leading to a change in the mode of working and the establishment of an actual industry.

Before 1888: No Potato Breeding in the Netherlands

At the end of the eighteenth century, people began to search for improved potato varieties in the Netherlands as well as in neighbouring countries. The first major problem was degeneration caused by ageing. As this was the basis of degeneration, regeneration from true seed could thus renew the old varieties (Dorst 1943; Salaman 1985). Salaman assumes that in the UK, skilled farmers took the first steps towards improvements by sowing seeds derived from spontaneously formed berries. This approach triggered the development of new varieties. The problems of degeneration were reported in different countries, and the same approach was adopted. In the Netherlands, already in 1783, Derk de Vries in Alkmaar was developing new varieties in this way (Addens 1952; Zingstra 1983). At the time there were many varieties being used, as mentioned by Zingstra (1983), e.g. Jam and Wolkammer (1850), Schoolmeester and Zeeuwse Blauwe (1860), Botergele, Hamburgers and Fransen (1870), Berlikumer Geeltje, and Hallumer Gele and Munstersen (1890). Dorst (1963, 1964) mentioned some 170, partly due to synonyms. Marshall (1796) describes in detail how one should proceed to breed from seed, both in the field and in greenhouses. He describes the occurrence of a large variation in the seedlings, to which even separate selection was applied. This can be considered a first step on the path to systematic breeding. Burton (1948) describes that the raising of seedlings was widely practised in the UK, at least from the end of the 18th century onwards, and this led to large numbers of new varieties, called populations or mixtures of clones. The question is whether this seed was a result of self-fertilisation or of spontaneous crossings in the field caused by bumblebees (Bradshaw 2007; 2021; Lammerts van Bueren and Van Loon 2011).

Crossbreeding as a Basis for New Varieties

An initial wider and deeper interest in cultivating and breeding of potatoes arose at the beginning of the nineteenth century. Salaman (1985: 159): 'It is difficult to say when and where the first deliberate attempt to create new potato varieties occurred'. Salaman mentions that Andrew Knight in England tried to breed early maturing varieties from early maturing parents. Bradshaw and Mackay (1994) also mention Knight who reported on artificial pollination in 1807. It is not clear when one switched to making specific crosses. Noteworthy is that the transition to crossbreeding probably started in the USA, between 1860 and 1880. Roze (1898) and Thijn (1949) presume that in Europe, crossing first started in Germany.

After crop failures in the years 1845–1847, the need for improved varieties increased and purposeful crossbreeding was practised, resulting in a number of varieties that appeared on the market during the second half of the nineteenth century (Roze 1898; Dorst 1943; Burton 1948).

There were certainly international contacts. This is evident from the import of seeds and the use of each other's clones (Roze 1898). Goodrich, from Utica in the state of New York, is especially mentioned in this context as American breeder (Salaman 1985). It is evident from all the descriptions that the start of systematic breeding in all countries was initiated by interested and enthusiastic farmers and gardeners (Thijn 1949; Mackay 1987). In the Netherlands, such passioned people have remained active in potato breeding until today. The start of purposeful breeding in the Netherlands did not have *Phytophthora* resistance as its first aim, but improved varieties for the starch industry (Velthuis 1916; Addens 1933).

1888–1940: Individual Breeders

At the end of the nineteenth century, the first potato breeders emerged in the Netherlands. In 1888, Geert Veenhuizen (1857-1930) was the first to start crossing potatoes out of interest. Veenhuizen is considered the founder of potato breeding in the Netherlands (Kok 1931; Bekius et al. 1957; De Haan 1958). Veenhuizen was owner of a flower and tree nursery in Sappemeer. He initiated a layout for comparative field trials for potatoes. The choice for more productive varieties was especially important. Already in his first year as field trial manager, he made multiple crosses (Kok 1931; Addens 1952; Bekius et al. 1957). After 4 years, the first new varieties were on the market. Geert Veenhuizen's objective was to create an excellent starch potato, as well as varieties for the export of ware potatoes and seed potatoes. Veenhuizen took a dynamic approach to crossing, selecting, and releasing of the promising new selections in the market, with the accompanying information. The results of this first 'real' breeder were impressive. In 1929, the Veenhuizen varieties occupied 66 % of the potato acreage in the Netherlands, with the Eigenheimer variety at the absolute top (Bekius et al. 1957).

Moreover, his work proved to be stimulating for others (De Haan 1956). As early as 1892, the Frisian Association for Agriculture (FMvL) started a potato breeding

field. K. L. de Vries (1854-1929) started in 1898, besides his work as a teacher, as manager of the breeding field of the FMvL. He was the breeder of the famous variety Bintje (parent varieties: Munstersen and Fransen). The number of breeders remained limited until the discovery of the wart disease in 1915. This stimulated the breeding of new varieties with immunity to the disease, first in the North-East of the Netherlands and Friesland, and later also in the southwest of the country. The breeding objectives were a good and high marketable yield, but that was translated into resistances (Smits 1911).

Information and Consultancy

After Geert Veenhuizen started breeding in 1888, every breeder depended on his own knowledge and experience. As potato breeders were motivated amateurs, often without any knowledge of heredity and selection methods, a structure of advisory was urgently needed. Because of improved seed potato cultivation at the beginning of the twentieth century, interest in new varieties had declined. However, the discovery of the wart disease around 1915 caused a revival of potato breeding work. The main varieties Bintje, Eersteling, and Eigenheimer, were all susceptible. Therefore, Prof. Broekema strongly recommended expanding potato-breeding activities (Hogen Esch 1953; Nijdam 1958; Hogen Esch and Zingstra 1963). In the 1930s, more and more new breeders started, probably due to the incentives and support of the Dutch General Inspection Service for Agricultural Crops (NAK) of breeding. The expansion of the breeding work called for coordination. Broekema was able to gain NAK's interest in breeding, partly because the chairman of the NAK, Dr. Oortwijn Botjes, was as passionate about stimulating breeding as Broekema. Broekema repeatedly insisted on intensive supervision of research by the NAK and wished to place the breeding of new varieties under central management (Hogen Esch 1939). In 1938, the NAK Board agreed to the proposed structure and the establishment of the Commission for the Advancement of the Breeding and Research of New Potato varieties (COA). The board of the new committee was made up of persons from the NAK, the Institute for Plant Breeding (IVP), the Ministry of Agriculture and, after its establishment in 1942, also from the Institute for Research on Varieties of Cultivated Plants (IVRO). This composition reflects how broad cooperation in our country took shape in promoting breeding and research (Hogen Esch 1953; Hogen Esch and Zingstra 1963).

For making crosses, a collection of genetic resources was of significant importance. To this end, in 1938, it was agreed to maintain a collection as complete as possible (N.N. 1946). This can be considered the first collection of genetic resources. The collection included over 200 old and existing varieties, mainly from European countries, but also from USA and India, collected by researchers. To provide breeders with information about the value of certain varieties as a crossbreeding parent, it was decided in 1954 to publish such information as a booklet (Hogen Esch and Zingstra 1954). This first booklet contained over 330 varieties and the advice to contact researchers when there was interest in *Solanum* species. For 40 years, thirteen editions appeared, the last in 1991. These booklets have been extremely useful for the breeders, they were used as 'the breeding bible' when making crosses. The start

of a gene bank, The Wageningen Potato Collection, came after the first expedition to South America (Toxopeus 1955).

Centralised propagation began in 1922, well before the COA was founded. The purpose was healthy maintenance and propagation of varieties, seedlings, and crossing parents. In addition, there was central multiplication of seed potatoes for the official testing of varieties for cultural and practical value, to be able to decide about inclusion in the list of varieties. The system of official variety testing was developed partly due to the COA's efforts. The COA took care of the pre-screening through field trials to reduce the influx of seedlings to 20 to 30 for official variety testing (N.N. 1967).

1940–1967: Private Companies Start Breeding

After Veenhuizen started in 1888, it took almost 50 years before commercial companies started breeding. After that, there was a continuous development of potato breeding by the companies. The first companies started just before World War II, during the crisis of the 1930s. It is remarkable that only a limited number of companies started breeding. This was due to the high number of existing small breeders, reaching the highest number of 243 in 1956. Of the starting companies, the first were organised as cooperatives. Later, private companies followed. Important in this regard was the establishment of the Foundation for Plant Breeding (SVP) in 1948 for continuous supply of starting material. SVP became a key player in this period with providing knowledge and material to the breeders. The breeding method was the classical system of crossing and selection, whereby SVP played an important role in crossing, allowing the breeders to do the selection. Breeding companies were separate organisations, either outside or inside a trade company. In the latter case, newly developed varieties are passed on to the sales department for market introduction and commercialisation within their own organisation. If there is no sales department, this is done by another company, which then takes the variety into representation.

When companies decide to start breeding, it is with a vision drawn up in advance and usually on a significantly larger scale than of a small breeder. Of the business considerations that underlie the corporate approach, the possession of own varieties is the most important one. For the starch industry, the driving force was also that they experienced a too large risk to remain dependent on what small breeders offered. The wide spread of the potato cyst nematodes needed a joint effort for improved starch varieties to secure a constant volume of potatoes to the factory. This led to establishment in 1954 of the Breeding Institute of Potato Varieties for the benefit of the Dutch Potato Starch Industry (Karna).

The group of small breeders does not consider the breeding work as its main occupation but breeds out of interest in addition to their own farm activities or other job. That is why the term hobby breeder is often used. Most small breeders worked independently, due to the availability of advice and provision of start-up material by COA and later by SVP. But when it came to market introduction, they collaborated with trading companies on a contractual basis. Some small breeders with successful

varieties have developed into medium-sized breeding companies. In the period 1940–1967, simultaneously with the development of private breeding companies, the scale of breeding increased from a total of all Dutch breeders together from 50,000 to approximately 700,000 seedlings per year.

The breeding objectives were simply finding a replacement of the main variety Bintje with improved resistance to several diseases.

1967–Present: Towards Full-Fledged Breeding Industry

From 1938, a limited number of private companies started potato breeding. This process was accelerated in 1967 after the new ZPW came into force, replacing the Plant Breeders' Decree of 1941. The introduction of the ZPW in 1967 caused a major turnaround in the trade in seed potatoes due to the exclusive rights of a breeder (the monopoly) on his varieties. This resulted in a different structure of the relationship between the breeder and the trading company.

The structure and organisation of variety testing through COA and IVRO changed in the 1970s. In 1976, expansion in breeding led to a limitation in the number of entries for the preliminary testing. In the end, this led in 1989 to a preliminary test conducted entirely by the breeders. Clustering of small breeders around the larger breeding companies during the reorganisation helped to shape the new set-up.

Simultaneously, a realignment of the SVP's relationship with breeders began. This created problems for small breeders, and it led them to an often exclusive cooperation with commercial trading companies, laid down in a contract. The practical side was that the companies took over the role of the SVP in providing seeds or clones and genitors to the small breeders (Almekinders et al. 2014). The need to shift to more fundamental research was a bridge too far for many potato breeders. Small breeders often lack the knowledge for this and the opportunities to invest in research and pre-breeding. As a result, differences among breeders put pressure on the open relationship in the sector. The companies themselves also adapted to the changing situation in Wageningen by slowly starting-up in-depth investments in pre-breeding. At the end of the 1980s, the close and direct involvement of IVP and SVP in practical, publicly funded potato breeding ended. One of the consequences of this was that breeders took initiatives for contract research.

The current organisation of potato breeding in the Netherlands is remarkably diverse. The small breeder still exists. He is mostly a seed potato grower. Their number is now rather stable and remains currently around 150. About 90 % are exclusively affiliated with a larger breeding company/trading house. All large and medium-sized trading companies, approximately fifteen, have now incorporated breeding into their business. During this period, the organisation changed, and some companies became key players due to cooperation among companies and mergers. Agrico was established in 1973 as a merger of several regional cooperatives and later on with a company. The second one is HZPC, the merger in 1999 of Hettema, a private company and ZPC, a cooperative, both from Frisian origin. Thanks to their breeding programmes all companies have their own varieties, the so-called 'monopoly varieties' (a term typical for the potato). Lammerts van Bueren and Van Loon

(2011) and Almekinders et al. (2014) described the cooperation between the small breeder and the companies. The most common principle is based on 'no cure, no pay' agreed by contract. When a variety is successful in the market, the received breeders' fees are shared between the trading company and the breeder.

The breeding objectives broadened during this period. Much more attention was given to export varieties, resistance for pests and diseases, especially late blight, potato cyst nematode, and wart disease. A new goal became breeding for the processing industry. In general, the breeding methods remained classical. But new techniques became available and were introduced in breeding, first through contract research, such as in-vitro culture and marker-assisted selection.

The Role of Government

Development of Governance of the Breeding

Varietal Testing and Recommended Variety List

A first plea to conduct trials with new obtained varieties came from Pitsch (1918), director of IVP. Based on these trials, recommendations could be made about the potential for their large-scale cultivation. The next director of the IVP, Broekema, proposed a descriptive list of varieties in 1923, as a guideline for the selection of varieties, and at the same time, as means to promote the propagation material of these varieties.

In 1924, the first variety catalogue was published (De Haan 1949; Maat 1998; Van Wijk 2005). This publication consisted of 70 plant varieties of which ten consisted of potato varieties. Three of them were recommended for testing, including the Bintje variety. The sixth edition also included tables and a list of parentages of the varieties. The table for potato showed 34 characteristics. From 1932, foreign potato varieties were included for the export of seed potatoes. The export of seed potatoes grew quickly from 2000 tonnes in 1923 to 75,000 tonnes in 1930. At that time, the Netherlands already took the first position in the world market for the export of seed potatoes and has maintained this position until today.

Variety testing in potatoes was conducted in a structured collaboration between the public and private sector. Compared to other countries, this resulted in a unique system of guidance, consultancy, and testing. The preliminary testing and the official testing merged seamless (Van der Woude 1985).

The potato has played a significant role in the long history of the variety list. There was a steady increase in the number of potato varieties included in the variety list, from 10 in 1924 to 140 in 2007. Each trading company wanted a wide range of monopoly varieties, and the diversification of the market also had its influence. The introduction in 1993 of a National Catalogue of Varieties, in which all registered varieties are listed according to European criteria, accelerated the intake of new potato varieties and gave a reduction of variety-testing. Finally, from 1999 to 2007, this led to the listing of a selection of potato varieties from the National Catalogue

in the recommended catalogue. After 2007, potato is no longer mentioned in the recommended list of varieties.

In the 1970s, retrenchment and reorganisation of research in Wageningen began, in which the COA was also involved. After consultation with the potato industry, the entire testing system was reduced to the minimum European standards for admission of a variety to the market. Since 2008, the registration process and testing for the value for cultivation and use have been conducted simultaneously. The old system was reduced to 2 years of official testing. This brought an end to COA's task and objective in 1990.

Laws and Regulations

Two notable points can be mentioned regarding the developments after the new ZPW came into force in 1967: (i) interest from the potato trade companies in the breeding work increased significantly, to obtain their own exclusive varieties and (ii) the cultivation of a variety could be better regulated based on exclusive rights (Trip 1968). The remuneration under the new act remained the same during the entire duration of the plant breeder's rights, a clear improvement. On the other hand, breeder's rights expired after 25 years, which was not seen as a major objection compared to the old regime.

The ZPW has been revised several times. For potato breeders, one change of significant importance was the extension of the duration of plant breeder's rights from 25 to 30 years in 1991. The development of European (Community) plant variety rights started in the 1980s and resulted in a final regulation in 1994. This regulation is also strongly based on the international UPOV-Convention 1991. A term of 25 years of plant variety rights was included in the regulation, but it changed in 1996 for potatoes to 30 years.

The second major change in the ZPW concerns the Farm Saved Seed scheme (FSS), also known as Farmers' Privilege. The FSS is regulated differently in each country, but it can be said that it runs well in countries where breeders are well organised. Almost 25 years before an FSS-scheme was incorporated into the ZPW, a regulation was made in 1974 in the starch potato area of the North-Eastern Netherlands (Hilbrands 1976). This was an exceptional situation arose because a Dutch and European scheme would not be introduced for years. A remarkable effect of the ZPW was a substantial increase in the Dutch variety package for potatoes from 1967 onwards. A continuous increase can be seen over the entire 50-year period (Fig. 1). Just as in 1967, a limited number of varieties are responsible for a large part of the seed potato acreage. In 2022, there were 11 varieties (out of 479) with more than 500 hectares declared for inspection, which collectively represented almost 50% of the total area.

The extensive range of varieties illustrates that each trading company desires to have its own varieties for the various markets. During the entire period from 1924 to 2007, 326 varieties were admitted to the Dutch catalogue of varieties. In the subdivision by market segment, table potatoes account for 36 %, export varieties for 41 %, and starch varieties for 23 %. These proportions are constant over time. The share of varieties that come from small breeders is also stable over the entire period but

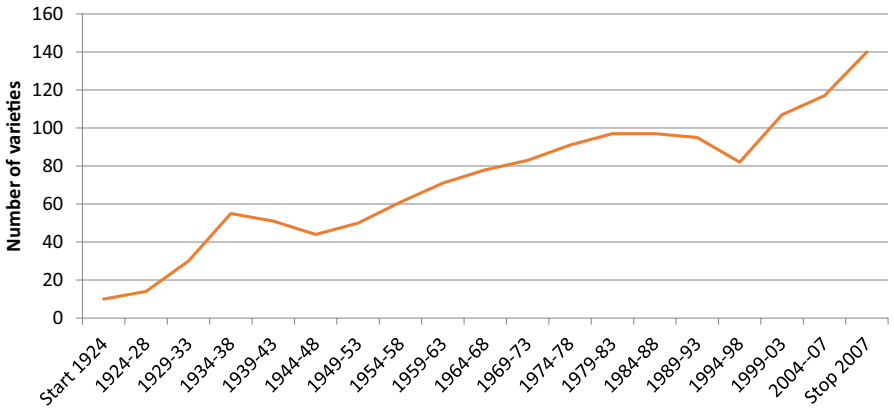

Fig. 1 The number of potato varieties in the Dutch variety list (source: Descriptive Varieties of Agricultural Crops from 1924 to 2007)

has declined slightly in recent years; on average, they make up for 66 % of the total number of Dutch varieties. Because the small breeder works with a programme of small size, it can be concluded that they select effectively. Normally, more than 40 % of the varieties will be deleted from the variety list within 10 years after the market introduction, due to unfavourable experiences when growing the variety on practical scale. Four varieties have been on the variety list for more than 80 years, Eersteling, Eigenheimer, Bintje, and Alpha. This is a remarkable result of the pioneers among the breeders.

Remuneration

A new aspect of legislation is the (financial) remuneration of the breeder. One of the first to suggest a remuneration for the breeder was Mayer Gmelin in 1922, deputy director of IVP. However, his proposal did not receive support. The demand for a good remuneration of the breeders' work did not originate from the breeders themselves (Van der Kooij 1990; Maat 1998). The first steps to reward the breeder for his labour have been taken by the NAK, established in 1932. The government introduced legislation forbidding the export of seed potatoes that were not inspected and issued a decree that a national inspection service, NAK, was necessary. The need for good varieties increased. On NAK's initiative, a system of breeders' compensation was introduced in 1937, later known as the Plant Breeders' Fund. This has been described by various authors from different angles (Van Leeuwen 1957; Roosenschoon 1960; Zingstra 1983; Debets and Hammink 1988; Geersing 1990; Van der Kooij 1990; Wiskerke 1997).

Breeders' Decree 1941

From the very beginning of its existence, the NAK has recognised the need for compensation for the breeders (Van Leeuwen 1957; Debets and Hammink 1988).

Therefore, a ministerial committee was set up in 1940 leading to the 'Breeders' Decree 1941 (Siebenga 1949b; Addens 1952; Van Leeuwen 1957; Roosenschoon 1960; van der Kooij 1990; Wiskerke 1997). The Plant Breeders' Fund fee regulations were adopted in the Plant Breeders' Decree 1941. Incentive schemes also continued to exist. The Breeders' Decree of 1941 allows the breeder to obtain ownership of his new variety. It grants the breeder:

- The exclusive right to put propagating material on the market.
- The right to remuneration for the breeder from contributions by those who deliver propagating material (under the classification of the inspection authority).

The plant breeder's rights are valid for 25 years but could be extended by 10 years each time. A fundamental change took place when the Breeders' Decree 1941 came into force. The catalogue of varieties became binding, requiring a variety to be new, distinguishable, and true to type (Van Rees 1949; Van der Kooij 1990). New varieties can only be introduced to the market once the value for cultivation and use has been assessed. The catalogue of varieties was given a legal basis, and its implementation was transferred to the newly established Institute IVRO and ceased to be part of the IVP. Only the varieties listed in the variety catalogue were accepted for inspection, and only seed and seed potatoes approved by the NAK were allowed on the market. Inferior varieties were therefore no longer admitted to the market (De Haan 1949; Van Wijk 2005).

On the 25th anniversary of the catalogue of varieties, the changes after the introduction of the Breeders' Decree 1941 were pithily summarised: *'in the past the catalogue of varieties could wait for practice, now practice must wait for the catalogue of varieties'* (Dorst 1950). The catalogue of varieties developed steadily and became a very useful booklet.

Roosenschoon (1960) writes that at the time when the initial draft of the new ZPW was presented to the Dutch parliament in 1959 as the follow up of Breeders' Decree of 1941, the work of the breeder was poorly rewarded, while the whole of Dutch agriculture benefited. A lengthy parliamentary process followed. Under the new law, the 'monopoly system' was introduced, meaning that only those growers who obtained a cultivation licence from the breeder were allowed to propagate seed potatoes (Mol 1967; Van den Bosch and Veerman 1981). The law came into force in 1967 (Van der Kooij 1990; Wiskerke 1997).

Development in Research and Education of Breeding

Plant breeding as object of research and education started with teachers at the agricultural school in Wageningen, already at the end of the nineteenth century. The increasing interest led to the establishment of the Institute for Breeding of Agricultural Crops (IVL) in 1912, later known as IVP. At the time of its establishment, it was explicitly stated that the government would not compete with the private breeders (Addens et al. 1953: 4). Agricultural education and research in Wageningen were elevated to the level of an Agricultural College in 1918. IVP became part of this.

The foundation of the IVP can be seen as the starting point of the structure and organisation of plant breeding. Prof. C. Broekema became the first professor in plant breeding in 1923; he participated in many activities related to the inspection and breeding of potatoes. However, the IVP did not primarily work on potato breeding. Potato breeding was simple, and gifted private breeders, such as Veenhuizen and De Vries, were able to outcompete existing varieties (Nijdam 1958). But the substantial number of small potato breeders did require support of the breeders' work to result in good varieties. Over many years, the IVP provided seeds of crosses and parental lines to the breeders, in addition to providing technical information (Wiersema 1944; De Haan 1962).

Research on Scientific Basis

IVP Shortly after his appointment as professor of plant breeding in Wageningen in 1941, Dorst introduced breeding research of potato at the IVP (De Haan 1962). From 1943, the promotion of potato breeding started on a scientific basis (Zingstra 1960). Main objective was to cross the existing potato varieties with wild and primitive varieties from Central and South America to find genitors with resistance to *Phytophthora*, and among others, to viral diseases, scab, and unfavourable influences such as cold and drought. Dorst (1947a, 1947b) strongly emphasised the need for a national programme for potato breeding, similar to the pleas of Broekema (1930; 1938; 1939). With the establishment of the SVP in 1948, potato research intensified. Bakker (1948) summarises potato breeding research at IVP into three main components: (i) stimulating flowering, ii) introgression from wild relatives, and (iii) research on *Phytophthora* resistance. With the establishment of the SVP, potato research accelerated and followed by broadening to other research areas. In 1956, plant breeding was recognised as a subject and resulted in a discipline at the Agricultural College in Wageningen.

SVP The desire for a comprehensive approach to the problems of the potato existed long before the establishment of the SVP (Broekema, ibid). The general opinion in the 1940s was that a replacement of the variety Bintje was necessary for our export position. Although it has excellent qualities, the variety also has several negative characteristics; a central institution will have to do the work which the individual breeder is not able to do in a sufficient way. The much-desired Potato Breeding Institute was established in 1948 as SVP, but the scope was on more agricultural crops. The possibility of self-breeding by the SVP was discussed; breeders wanted the SVP to cooperate with them (Siebenga 1949a). To promote cooperation, the Dutch Plant Breeders' Association (NKB, now Plantum) established new working groups for seven (clusters of) crops. The guidelines included the provision of SVP-breeding material only for Dutch breeders (Veenstra 1958). The first and most important task for the SVP was potato breeding research. Almost one third of the annual budget was used for potato (Lamberts 1966). Initially, the research focused on the provision of breeding material, seeds and clones, of such a level that varieties could be selected directly from them (Veenstra 1958). Thijn (1965) provides an overview of the delivery of material to the breeders. Many small breeders worked entirely with

clones originating from the SVP and about half of them with no more than 100-300 clones per year (Zingstra 1960).

The SVP cooperated with the COA and took part in providing information to the breeders through articles and lectures by its researchers. In addition, independent regional Potato Breeders Associations (AKV's) were established in the 1950s. These have played a key role in exchange of knowledge among the small breeders.

Lackamp (1966) recalled how the SVP developed in good cooperation with and for the benefit of the breeders. Looking back at the developments in potato breeding in the Netherlands, the SVP has played an especially important role.

The development of plant breeding in education, research, and extension, especially at the institutes IVP and SVP, followed the developments in the business sector. The search for new sources of resistance was a recurring theme. The IVP/SVP partnership continued to search for resistance to *Phytophthora*. The wild species *S. bulbocastanum* stands out. In 1973, there was a breakthrough which meant that the resistance of *S. bulbocastanum* could be exploited (Hermsen and Ramanna 1973).

From 1941 onwards, when potato cyst nematode was first identified in the Netherlands, most of the research effort was focused on finding resistance (Oostenbrink 1950). In 1951, IVP received a small quantity of seeds of *S. andigena* from Cambridge (UK), with a request to test them for cyst nematode resistance (Toxopeus and Huijsman 1953). After confirmation of resistance, research at SVP was conducted successfully for many years, in intensive cooperation with breeders to develop resistant varieties.

Annual reports and project reports show that SVP has worked on an impressive range of diseases, problems, and other features. In 1978, at the 30th anniversary of the SVP, the director recalled that in that year the 10,000,000th seed was supplied to the breeders. Later, the strategy shifted to the development of usable parental lines for the breeders. Three phases can be distinguished: (i) Delivery of material to breeders. (ii) Material resulting from research. (iii) More fundamental research. Since 1966, parental lines have been issued to self-crossing breeders in addition to seeds and clones. The 1980 annual report already indicates the third phase, a gradual shift towards more fundamental research. At the same time the political changes were becoming increasingly important in research. 'Wageningen' was confronted with a long-term period of reorganisation and reorientation that affected all research institutes. The last year of the SVP as an independent institute was 1989. The growing distance between breeders and SVP and its successors was caused by the elimination of issuing material and the long-lasting reorganisations.

The impact of the breeding strategy of the SVP has been large from the beginning (Zingstra 1983). In 1982, 'SVP-offspring' was found in more than half of the potato varieties, together these varieties accounted for half of the Dutch cultivated area (Van Dijk 1984). Even 23 years later, based on the 2007 variety list, the impact of the SVP is still as great. In both years, 1984 and 2007, direct and indirect progeny counted for 75% of the varieties. Attention is drawn to this successful cooperation in a highly effective system (Huijsman and Lamberts 1972; Van der Wal 1978).

Over the years, an intensive cohesion and cooperation arose between institutes and the Agricultural College in Wageningen. The political changes around 1980

brought them finally together, in 2016 with a new name: Wageningen University & Research (WUR). Plant breeding is united in the 'Laboratory for Plant Breeding'.

Breeding Process and Technology Development

Several authors describe the breeding process over the years (Dorst 1943; Bekius et al. 1957; Mastenbroek and Schnieders 1963; Haverkort 2018). The method based on phenotypic assessments, and in the early selection years rather ineffective, has been used from the very beginning of the breeding process until today (Bradshaw and Mackay 1994). Regularly, there is criticism that the method of working in potato breeding is still the same as it was 150 years ago, when purposeful potato breeding began. Nevertheless, there have been innovations over time. We have learnt to use all kinds of techniques and resources, varying from greenhouses, laboratories, and well-equipped kitchens for determining cooking and baking quality, to computers and possibilities for data processing. More new techniques are at our disposal today, such as the gene map of the potato, cisgenesis and genome-editing, and molecular marker-assisted breeding can be useful tools, but they still have to prove their value. In the past, the high expectations often had to be adjusted.

Eenink (1988) mentions the major and minor developments, changes, and adaptations, of which three stand out: (i) polyploidisation in the 1930s, (ii) induced mutations in the 1950s, (iii) the rise of cell and molecular biology from around 1970. The first two played no significant role in potato breeding. Genetic variation comes about exclusively through crossbreeding. The attention of the breeder is focused on a more efficient selection process. The Wageningen research of especially IVP, IVRO, SVP, and COA has played a key role in the development of tests, methods, and the transfer of knowledge to the breeders (Dorst 1957; Prummel 1975).

A brief overview of examples is given on the period since 1940 of the interaction between research and application by breeders. Crossing was initially done in the field where one was particularly dependent on weather conditions and of unintended pollination. In the greenhouse, new methods were developed. Stimulation of flowering by grafting potato stems on to a tomato rootstock and planting out tubers on a brick to prevent the formation of new tubers or to remove them easily (Wiersema 1944).

Raising seedling plants was done by the Dutch light method to grow plants for transplanting in the field. The main drawback of this method was the frequent occurrence of viral diseases (Thijn 1954; 1964; Thijn and Brink 1954; Zingstra 1955). It changed to the production of small tubers in greenhouses, the so called 'greenhouse clones' for planting the year after. Potato seed from crosses is not always sown the following year. Reduction of germination and germination energy of the seeds was experienced as a problem by the breeders. COA therefore set up a multi-year germination trial and followed this for 10 years (Zingstra 1958).

The sprout that develops on the potato in diffuse daylight is called light sprout. This sprout is unique for each variety due to its colour and shape and therefore an important part of the variety description to distinguish the potato varieties. In the nineteenth century, the light sprout was already a means of recognising varieties (De Vilmorin 1881). The method was first applied in the Netherlands in 1934 and

described by Verhoeven (1940). From 1950, the research was conducted by IVRO as a distinguishing mark for all varieties in the list of varieties (N.N. 1967). An inconvenient problem was that the light sprout method was not reproducible. Research set-up for this purpose using artificial light resulted in an easily usable and reproducible method (Houwing et al. 1986).

Wiersema (1959) notes that breeders had little interest in breeding for virus resistance. Many breeders were also seed potato growers and considered it too risky. Slowly infection tests in the field, greenhouse tests and serological tests were introduced.

The use of wild species did not actually begin until Dorst became a professor (De Haan 1962; Zingstra 1983). Both IVP and SVP worked intensively with wild species to make desirable characteristics available for the breeding of new varieties (Dorst 1964). The developed genitors could be used directly in commercial breeding programmes. The use of wild species was focused on achieving resistance to *Phytophthora* and potato cyst nematodes. Larger breeding stations also started crossbreeding with wild species in the 1940s, at that time aimed at *Phytophthora* resistance using *S. demissum* (Mastenbroek and Schnieders 1963; Poos 1967; Sterk 1967).

In 1961, the use of haploids was first described (Rozendaal 1961). From that same year onwards, targeted efforts were made at IVP/SVP to obtain haploids from varieties and genitors (Van Suchtelen 1966a, b). It was unclear at the time whether breeding at the diploid level would offer possibilities and whether doubling back from diploid to tetraploid level would be necessary to achieve the desired yield level (Lamberts 1966). However, it can be assumed that larger breeding companies worked at diploid level at that time, and today in their pre-breeding programmes. Fairly recent is attention to the development of hybrid potato varieties at diploid level (Lindhout et al. 2011; Bethke et al. 2022; ter Steeg et al. 2022).

Spontaneous mutations, sudden changes that are called bud mutation or somatic mutation, received a lot of attention in the beginning. Dorst (1924) states that most of the bud mutants are not improvements. However, there are bud mutants of the potato included as a variety in the list of varieties. At IVP, mutation research of the potato began in 1961 (Van Harten 1987). Efforts were made to obtain favourable mutations of Bintje by irradiation (Zingstra 1968). Several hundreds of mutations were tested for resistance with negative results (Van Harten 1978, 1987).

The SVP worked on good instructions for the breeders. This was particularly useful for small breeders. A good example is the extensive research of Maris (1962) and Neele (1991) on selection in the first field generation. Researchers often object to the extremely strict selection by breeders. Up to 95% is discarded already in the first year. But this research did not lead to an adjustment of the breeding programmes.

The reason for investigating alternative propagation methods was two hot summers of 1975 and 1976 resulting in severe virus infection in seed potato crops. There was a fear for a shortage of seed potatoes of the main variety Bintje for the processing industry. In 1977, a working group ‘Fast propagation techniques of seed potatoes’ was set up to further investigate the possibilities (Marinus and Bakker 1980). The propagation in test tubes quickly became popular. (Mini) tubers were harvested from the plants planted in aphid-free greenhouses. The Foundation Guidance for Rapid Potato Propagation (SBSA) was set up in 1980 and functioned until 1994. In 2023, the production of plants

and mini tubers takes place on specialised companies with different methods. Mini tubers have almost replaced the clonal selection as starting point for basic seed (pers. information NAK 2018). The assumption that in vitro propagation could be applied in breeding proved to be unrealistic.

On the NAK's 25th anniversary, Dorst (1957) already listed the progress made towards modern breeding methods. Now, more than half a century later, this again results in an extensive list of tools. From which, after its introduction in the 1960s, the computer for data storage and processing became an indispensable tool. The first application took place in field trials with a hand-held terminal (Van der Wal and Post 1980). A special tool valued by breeders is the website with the pedigree database (Van Berloo et al. 2007).

Despite the above improvements, crossbreeding has long been done with little insight into the heredity of very many traits (Bradshaw 2021). However, technological developments have brought us to a turning point. From around 1940 onwards, scientific breeding methods emerged (Dorst 1942; Bradshaw 2021). On the 100th anniversary jubilee of plant breeding at Wageningen University & Research in 2012, Prof. Jacobsen highlighted the following developments in a lecture: (i) around 1960, cell biology and in vitro techniques; (ii) around 1980, plant biotechnology with genetic modification and molecular marker-assisted breeding; and (iii) around 2000, the unravelling of the plant genome to allow genomic selection. Now in the twenty-first century, the core of potato breeding is the same, but we have learnt to use all kinds of techniques and resources, varying from greenhouses, laboratories, and well-equipped kitchens for determining cooking and baking quality, to computers and possibilities for data processing. The new techniques at our disposal today, such as the gene map of the potato, molecular marker-assisted breeding, and genetic modification tools including cisgenesis and genome-editing, are promoted as useful tools. With respect to the genetic modification techniques, the new genomic technologies (NGTs) are still restricted under the European rules for genetic modification. These rules are currently under discussion in Europe.

Another important attempt to speed up the breeding process is the development based on hybrid breeding in potato. Delleman (2013) and Lindhout et al. (2011) argue that progress in the potato breeding process is slow and that the potato needs more innovations, certainly compared to cereals and sugar beet. They came up with ideas to develop a hybrid potato. In the Netherlands, a new programme for TPS (true potato seed) was set up by Bejo in 1995 for a hybrid potato variety at tetraploid level. In 2017, plant breeder's right was granted on their first F1 hybrid potato variety Oliver (N.N. 2017). The Dutch company Solynta, established in 2009, has the aim of developing and marketing a hybrid potato variety, based on homozygote lines at diploid level (Lindhout 2011; Lindhout et al. 2011, Stemerding et al. 2023, Struik et al. 2023). Now in 2023, more breeding companies are working on hybrid varieties to speed up the potato breeding process.

Contract Research; Breeders' Cooperation

After the reorganisation and termination of practical research in Wageningen, not all companies had the potential for further investment in research, which is why cooperation in contract research was chosen in differing partnerships of companies.

This marks the transition from classical breeding to the use of biotechnological techniques in research and breeding. In 1989, the Dutch Potato Association (NAA) decided to conduct a strategic study into the developments in the field of biotechnology with regard to plant breeding. Bijloo and Hermsen (1989) conclude that the Dutch business community does not seem to be able to incorporate knowledge and material in their own company. With the shift to more fundamental research, the gap with practical breeding was widening. This put pressure on the good cooperation and relationship of trust between the companies.

In the 1990s, the first applications of biotechnology became known. In the Netherlands too, the expectations among researchers were high. In the field of research, various institutes were active with biotechnology of the potato. At the same time, a big question mark was placed over the expectations of genetic modification (Parlevliet 1982; Stoutmeijer 1982). Plant breeding is extremely complex. Genetic modification will be part of it, but not in the immediate future. It was against this background that the business community and breeding companies came into action in the 1980s.

In varying compositions of companies and research institutes, contract research was set up in different projects and the various investigations led to a series of dissertations:

- Diploid breeding opportunities for practice (Hutten 1994).
- Reducing black spot sensitivity (Bachem et al. 1994).
- Development of the amylose-free (so-called waxy) potato (Kuipers 1994; Flipse 1995; Kortstee 1997).
- Somatic hybridisation for possibilities of resistance from related species (Horsman 2001).
- Introgression of resistance to *Meloidogyne spp*. (Draaistra 2006).
- Resistance against the potato tuber moth. Report of a trial in Tunisia (Khamassy and Ben Salah 1996).
- The working mechanism of *Phytophthora* resistance from new sources (Vleeshouwers 2001).

According to the 'prohibition by default' system, licences were granted for field trials. At the same time, environmentalists were concerned about technological developments (Hagen 1988). There was also growing unease in society about biotechnological research and its applications. In some years, action groups even destroyed experimental fields with genetic modified plants.

The genetic modification for the amylose-free or amylopectin potato using the antisense inserted gene for Granule Bound Starch Synthesis (GBSS) was successful. The first modified varieties Apriori and Apropos were admitted to the described list of varieties in 1999. Continued cultivation has been forbidden because of the presence of resistance to the antibiotic kanamycin, used as a selection marker during the modification process.

The transformed potato varieties in the USA and Europe were technically a success and could provide added value for growers, end-users, and the environment. The societal pressure against the development and use of these varieties blocked

market approval (Halterman et al. 2016). In Europe in 2023, the situation is still unchanged. In the USA, the first varieties have been admitted to the market.

Other Driving Factors

Besides the primary driving factors which describe the historical development, there are many other factors influencing the potato breeding process. The most crucial factors concern disease resistance, cultivation, and market segments. Several authors describe the major changes that influenced the approach to potato breeding and speak of stimuli and impulses (Broekema 1938; Dorst 1941, 1943; Salaman 1985; Jellis and Richardson 1987; Scholtz 1987; Van Loon 1987; Van der Zaag 1999). Dorst (1964) gives a review of the development of potato breeding in the Netherlands until 1964.

Disease Resistances

Of the many diseases in potato, only the most important are mentioned here. Although a choice is arbitrary, virus as the first problem, and late blight, wart disease, potato cyst nematode, and common scab are briefly described.

Virus Salaman (1926, 1985) describes that around 1775 the infestation by Curl (i.e. viral diseases, as we now know, and mainly leafroll and Y-virus) was so severe that people feared for the continuity of potato cultivation. Oortwijn Botjes (1920) discovered the transmission of leafroll by aphids, especially the green peach aphid *(Myzus persicae)* and its infectiousness. Oortwijn Botjes (1942) describes the possibility of immunity and less sensitive varieties and makes a plea for this. This brought breeding back into the picture.

Rozendaal (1957), Hille Ris Lambers (1957), and Van Slochteren (1957) wrote the solution to the virus problems was mainly to be found in the inspection of the seed potato crop. Initially, the susceptibility to the virus was not considered so bad, but this changed after the year 1939 with a lot of leafroll (Oortwijn Botjes 1941) and with a new race of the PVY, called Y^N in 1959 (De Bokx 1964). Attention to virus was the main work of SVP, right from the start in 1948.

The question arises as to whether all this effort actually improved the level of resistance to the various viruses. First there was the difficulty to introduce field resistance, besides there was no urgency to improve the level of resistance due to available chemical protections. The descriptive lists of varieties for agricultural crops over the years give a good but disappointing picture of this. For leafroll virus, the average resistance rate over the 70-year period is almost unchanged. For mosaic, from the 1960s onwards, there is a small continuous increase in the average resistance figure (Table 2). Nowadays, breeding companies are paying more attention to virus resistance.

Table 2 Variation and average resistance rate for three viruses (leafroll, mosaic/Y virus and TRV), measured at 10-year intervals (source: Dutch Descriptive Lists of Varieties of Agricultural Plant Species 1929–1998)

Reference year	Number of potato varieties	Leafroll variation in resistance	Average	Heavy mosaic variation in resistance	Average	TRV variation in resistance	Average
1929	19	3–9	6.26	4–9	6.68	2–9	6.63
1939	31	4–8	5.74	4–8	6.35	2–9	6.20
1949	35	4–7.5	5.74	3–8	6.68	3–9	6.16
1959	56	4–8	6.03	3–8	6.62	4–9	6.66
1969	76	4–8	6.16	2–9[1]	6.49[1]	4–9	6.81
1979	88	4–8	6.00	2–9[2]	6.74[2]	2–9	7.00
1989	97[3]	4–8	5.96	2–9	7.13	4–9	6.78
1998*	81[3]	4–7.5	6.07	3.5–9	7.31	3.5–9	6.61

[1]From this year onwards Y virus

[2]From 1977 onwards Y^N virus

[3]In these reference years respectively 2 and 1 varieties are insusceptible and not included in the average figure

*Reference year 1998 because in 1999 the structure of the tables in the catalogue of varieties was changed

Phytophthora It is generally accepted that the epidemic in 1845 was a turning point in the search for improved varieties and resulted in the first big impulse for breeding of the potato (Salaman 1985; Jellis and Richardson 1987; Van Loon 1987). Until about 1920, all breeding work aimed at acquiring resistance to *Phytophthora* was based on *S. demissum.* Prof. Dorst initiated research at IVP (De Haan 1962), in order to try to develop genitors with, among other things, resistance to *Phytophthora*, because of the large annual yield loss of 10 to 15% due to the disease.

Breeding for late blight resistance started late, around 1940, with the first commercial approach (Koopman 1963). The first two varieties with R(esistance)-factors from *S. demissum* appeared in the variety list in 1955 both with the R-factor 1 (Hogen Esch and Zingstra 1957). Mastenbroek (1952) records his research in a dissertation and concludes optimistically, even though new races of *P. infestans* have appeared. Nevertheless, breeders continued and turned additionally to the so-called field resistance (Toxopeus 1964). SVP supplied large numbers of true seeds and clones with the R-factors 1 and 3 from *S. demissum* to the breeders (Veenstra 1958). In addition, genitors were issued with the R-factors 1, 2, and 3 and preferably with the trait in duplex or triplex. In the early 1960s, the enthusiasm for resistance based on the R-factors from *S. demissum* was diminished because of the constant occurrence of new breakthrough races. From that time onwards, reliance was placed on chemical agents (Hawkes 1990).

The search for new sources of resistance was a recurring theme. The wild species *S. bulbocastanum* stands out. In 1973, there was a breakthrough (Hermsen and

Ramanna 1973). In the 1980s, the A2-mating type of *Phytophthora infestans* was found all over Europe. Problems arose in the epidemiology of *Phytophthora* due to the possibility of sexual reproduction of the A1 and A2 types. Similarly, there was an explosion in races and quite soon resistance of *P. infestans* to some fungicides appeared (Drenth et al. 1993).

At the same time, there was growing aversion in society against the use of pesticides. All these developments contributed to the renewed attention for breeding for resistance to *Phytophthora*, with particular attention to resistance from *S. bulbocastanum*. In early 2000, two new varieties were introduced with resistance based on this material (Haverkort et al. 2009).

More than 150 years after the outbreak of *Phytophthora* in 1845, the disease is still a major problem. The belief of protecting the potato against the disease through resistance is as great as ever but different from scientific and social point of view. In 2006, a 'Sustainable Resistance to *Phytophthora*' (DuRPh) project, using cisgenesis, began (Haverkort et al. 2009; Boonekamp et al. 2010). The aim of this project was a proof of principle for genetic modification by using cisgenesis to make existing potato varieties resistant to the potato disease. However, the regulation for organic agriculture does not allow GM techniques in organic agriculture. That is why, almost in parallel, the government supported classical breeding with new late blight resistance genes from wild relatives. This was conducted in a 10-year project *Bioimpuls* as a collaboration between research institutes, company and farmer breeders, to accelerate the availability of *Phytophthora* resistant varieties through classical breeding (Lammerts van Bueren et al. 2009; Keijzer et al. 2021). A covenant (2017) between the organic umbrella organisation Bionext and all the Dutch supermarkets to only use late blight resistant varieties for the organic segment to avoid the use of copper sprayings in organic farming systems, stimulated breeding companies to come up with more late blight resistant varieties. Now in 2023, more than 30 'robust' varieties are available for both organic and conventional markets (Bionext 2023).

Wart Disease There was no effective control against wart disease. The government in England had decided to stop the cultivation or to cultivate non-susceptible varieties, such as the not affected Snowdrop variety (Salaman 1985). Research demonstrated that immunity dominantly inherited over susceptibility but was influenced by several factors (Salaman 1926). In the Netherlands, wart disease was found around 1915. Twenty-five years later, Oortwijn Botjes (1941) mentioned wart disease as the best example of the significant importance of breeding work because there were no other means of combating it.

The group of small breeders was successful in selecting immune varieties. Already in the variety list of 1925, eight new resistant varieties were included, and from 1930, only non-susceptible varieties were listed in the catalogue. The rapid development of resistant varieties was because resistance was already present in the existing material. In 1973, race 2 was definitively established (Baayen et al. 2002). In the late 1990s and early 2000s, new suspect finds were made, and

it turned out that races 6 and 18 were involved. Even in 2021, a new race, characterised as race 38, was found. The disease can be kept under control with resistant varieties and through legislation and regulations (Wanders et al. 2004).

Potato Cyst Nematode Potato cyst nematodes are often referred to as the greatest enemy of the potato, due to the insidious nature of the disease. Resistant varieties could mean the preservation of the crop, or even the 'salvation' of the potato crop (Van Dijk 1984). In the Netherlands, the disease was first identified in 1941 as 'potato fatigue' caused by the potato cyst nematode (Oostenbrink 1950). Legal measures were quickly taken (Zingstra 1983). In 1950, there was little perspective on the possibility of breeding resistant varieties (Ten Houten 1961).

The search for resistance began as early as 1946 and 1947. In total, 18 South American *Solanum ssp.* were tested without finding any resistance. Subsequently, 358 potato varieties were tested for resistance in 1948. All were susceptible (Oostenbrink ibid). In 1948, Ellenby (1952) found resistant clones in various sources of *S. tuberosum ssp. andigena*. In 1951, Toxopeus received at IVP from Cambridge (GB) self-fertilised seeds of three clones of *S. andigena* (Toxopeus and Huijsman 1953). About half a year later, the presence of resistance was confirmed. As *S. andigena* is closely related to *S. tuberosum*, crossing with each other was easy.

Soil sample analysis in the Netherlands has proven to be one of the strongest weapons in the fight against potato cyst nematodes. (Oostenbrink 1950). The other powerful weapon became the resistant variety. Massive efforts were being made with scientific support from the SVP. Seeds, clones, and genitors were issued containing resistance genes. In the spring of 1954, 80 to 100,000 seeds of hybrids (AT x variety) were distributed to about 200 breeders (A stands for *andigena* and T for *tuberosum*). In 1963, the first two varieties with resistance to potato cyst nematode pathotype A (Ro1) were placed on the catalogue. But after success came the setback. The first breakthrough in the Netherlands, of resistance from clone CPC 1673, was already reported only 5 years after its discovery (Toxopeus 1956). Much has been published on the search for various sources of resistance (Huijsman 1957, 1964; Hogen Esch 1961; Mastenbroek and Schnieders 1963; Van Suchtelen and Huijsman 1966; Vinke 1983; Phillips 1994). The wild species *S. vernei* emerged as one of the most important, especially for pathotypes of *Globodera pallida*. Once again, the close cooperation of SVP with research and the breeders with practical breeding work led to rapid results. In 1973, the first variety with wider resistance, pathotypes ABC (Ro1, 2, 3) appeared on the list of varieties. Research for pathotype D (Pa2) started in 1974/75; the need in cultivation was high. The first variety with ABCD-resistance (Ro1, 2, 3, Pa2) was admitted in 1975. In 1983, the SVP made an offer for rapid release of seven new genitors with E-resistance (Pa3) to the breeders. In 1995, Seresta was the first variety with resistance to all five pathotypes ABCDE (Ro1, 2, 3 and Pa 2, 3) in the list of recommended varieties. Twenty-five years later, all varieties for the starch industry are resistant to Pa3 and moderately to highly resistant to other

pathotypes. Now in 2023, several varieties with a high degree of resistance are also on the market of ware potatoes. But there is an uncertain future, because of the variation in the nematode population, especially with *Globodera pallida*, (Mulder et al. 2008). Various authors indicate that integrated pest management is the best way of keeping the nematodes below the detection limit (Guskova and Gladkaja 1974; Spitters and Ward 1988; Mulder and Van der Wal 1997; Mulder et al. 2008). A recommendation to this effect was already made by Oostenbrink (1950).

Common Scab Common potato scab was first mentioned in 1825 (Roze 1898; Millard 1923). An improved level of resistance to common scab has been urged for years. However, it has only received the real attention of Dutch breeders in the last twenty years. A larger variety range with good resistance is the challenging task of the breeder. This difficulty lies in the complex heredity of resistance or tolerance (Trip 1979; Dees and Wanner 2012). The SVP also paid attention to scab resistance; the need for resistance was increasing, and efforts were made to develop a testing method (Lamberts 1966). A sharp selection for scab resistance was almost impossible because the correlation coefficient is only 0.06 (Maris 1966). He recommends working with negative mass selection. Despite all the research, breeding for resistance to common scab has not led to a significantly higher level of resistance in our potato varieties. The average resistance figure has fluctuated between five and six for 70 years (Table 3).

Table 3 The number of varieties in the list of varieties with their mean, their range, and the level of resistance to common scab at 10-year intervals (source: Dutch Descriptive Catalogue of Varieties of Agricultural Plant Species 1929 to 1998)

Year	Number of varieties	Mean rate of scab resistance	Variation in rate of scab resistance	Percentage resistant varieties**	
				≥ 7	≥ 8
1929	15	6.50	4–8	53	6
1939	31	5.29	3–7	13	0
1949	35	5.06	3–8	20	3
1959	56	5.63	3–9	18	9
1969	76	5.83	4–8	24	7
1979	88	5.87	4–8	26	3
1989	97	5.51	4–8	11	1
1998***	81	5.68	3–9	12	1

*Half figure rounded down

**Rating on the scale of 1–9; 1 is very susceptible, 9 is resistant

***Last year that scab resistance rating is included in the variety list

Cultivation

Every potato grower wants to reduce the occurrence of diseases, pests, and other problems to minimise the loss of yield and quality. Addens (1933) gives a good overview of the multitude of experiments carried out to improve the cultivation.

Yield A main problem in potato breeding is the difficulty of creating a broad genetic variation for yield (Trip 1979). The genetic complexity of tuber yield is apparent from the multitude of factors that determine tuber yield (Van der Zaag 1999; Kadijk 2003; Tiemens-Hulscher et al. 2016).

In potatoes, there is a strong emphasis on eliminating defects to ensure profitable yields, also historically. Vos (1992) describes breeding successes but notes that production technology has contributed more to increasing yields than the genetic potential of the varieties, but breeding is and remains necessary.

Toxopeus (1954) was one of the first to realise that wild species had a broader potential than just the introduction of resistances. He observed a heterosis effect for yield. Sneep (1977) writes about a considerable improvement in yield, especially in starch potato varieties with PCN-resistance from *S. vernei.* Lamberts (1975), Zingstra (1983), and Vos (1992) reach the same conclusion.

Mechanisation More than half a century ago, mechanisation brought about an enormous change in the cultivation and handling of the potato (Hesen and Kroesbergen 1960; Van der Poel 1967; Dendermonde 1979). The downside of mechanisation for the quality of the product became clear later on (Massey et al. 1952; Hesen and Kroesbergen 1960; Sawyer and Collin 1960; Maas 1966; Hunnius and Fuchs 1970). Simply summarised, these reduced to two main problems, mechanical damage, and bruising. The SVP conducted research in the 1960s on tolerance to mechanical damage. An apparent reason for research lay in the demands made by the processing industry (Hesen 1974), because in practice bruising mainly occurred after sorting (Van Loon and Meijers 1980). The results achieved by the breeders are evident from the figures for mechanical damage and bruising in the list of varieties for the years 1962–1994 (Fig. 2).

Market and Society Social changes and an increase in the level of prosperity influenced the breeding strategy to a considerable extent. The export of potatoes always played a key role in the Netherlands. Over a period of almost 100 years, Van der Waal (1961) calculates that about half of the harvest is exported. Factory production of starch is important in North-East Netherlands, the so called Veenkoloniën. The increase in the level of prosperity, especial in the second half of the last century, changed consumers' eating patterns towards a more varied diet and more convenience food.

Seed Potatoes Export In the Netherlands, FMvL took the initiative in 1903 to introduce field inspection of cereal seed (Addens 1952; Minderhoud 1957; Van der Zaag 1999). Potatoes followed in 1908. The first export of seed potatoes in the autumn

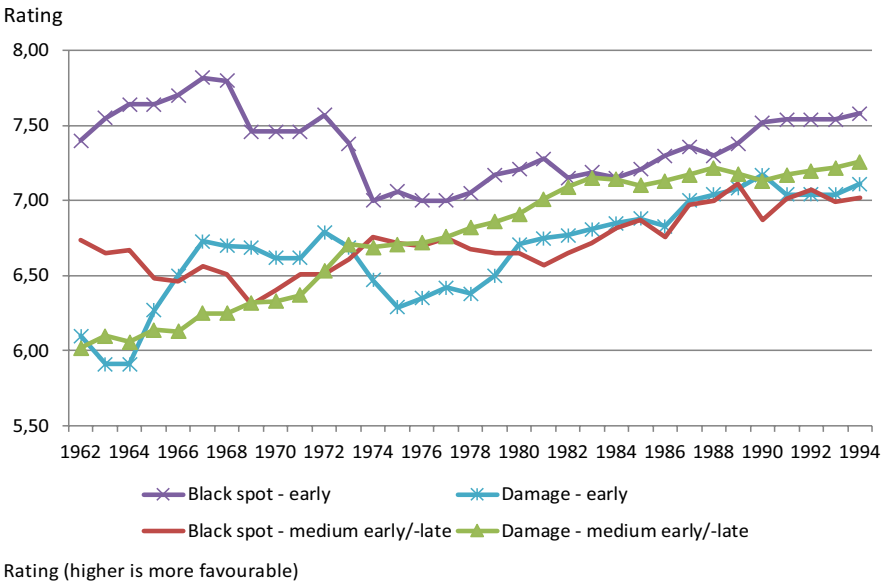

Fig. 2 The development of black spot and damage resistance of potatoes in the period from 1962 to 1994, for early varieties, middle-early and late varieties, with a rating between 1 (low) and 9 (high) (source: Dutch Descriptive List of Varieties of Agricultural Plant Species 1962–1994)

of 1920 was of the Eigenheimer variety to Belgium. The potential for export was discovered then. The breeding scheme of the FMvL was directed towards export varieties, despite criticism of this change (Sterk 1967). When the 'United breeding stations' (VK), now known as Agrico Research, was set up in 1958, the mission was 'to breed export varieties' (N.N. 1998). This mission has a twofold purpose: to grow seed potatoes profitably in our own country and ware potatoes in the export country.

Export of seed potatoes was the power behind the potato breeding industry. Until 2021, there has been a steady growth in tonnage of seed potato exports with an average of about 750,000 tonnes in the last 5 years (Fig. 3).

Table Potatoes In the long-term frame of more than 100 years, the consumer's supply with ware potatoes has changed enormously, from 130 kg per capita around 1900 to approximately 83 kg in 2000 (CBS 2022). Two-thirds consist of fresh consumption potatoes and one-third of processed products. From 1994, the responsibility for the control of potato cyst nematodes lays with the individual grower. The expectation was that this would result in a demand for other varieties (Table 4).

Potatoes for the Processing Industry The second half of the last century witnessed the rise of the processing industry. The Bintje variety was excellent for the French fries industry as was the Saturna for the crisps industry. The dominance of Bintje and its suitability resulted in little interest from breeders to work towards varieties suitable for processing (Hesen 1974; Meijers 1981). The dry summer of 1976 can

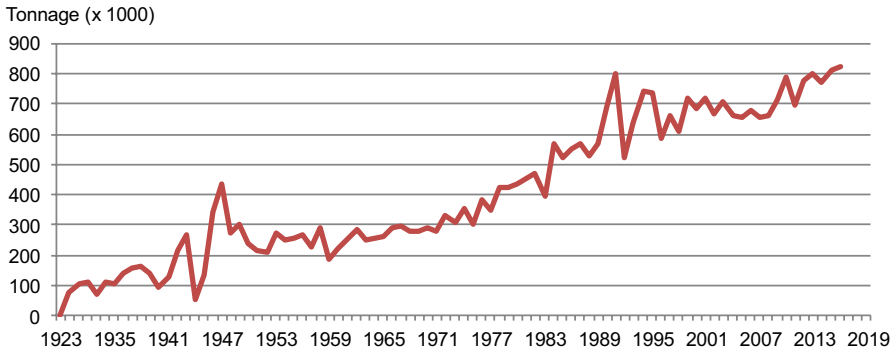

Fig. 3 Tonnage (× 1000 tons) export of seed potatoes per year from the Netherlands (source: NAO)

Table 4 Share of PCN-resistant varieties in the Dutch seed potato acreage between 1962 and 2016 (source: NAK, NAO)

Jaar	Percentage
1962	0
1972	10
1982	17
1992	42
2002	45
2016	72

be characterised as accidental start to breed for French fries' quality, because of an imminent shortage of good propagation material, particularly of the Bintje variety.

The breeders have been successful and complied with the wishes of the industry. Most new varieties for this segment were developed by Dutch breeders after 1970 (Keijbets 2008). In 2022, the top ten French fries varieties included 13,026 ha of seed potato cultivation, which was 31.55 % of the seed potato acreage in the Netherlands.

The developments for the crisps industry are like those for chips. Initially, mainly Bintje was used, and later Saturna, a starch variety that was found to be very suitable for crisps. In 2022, the top ten crisp varieties comprised 2170 ha of seed potato cultivation.

Starch Potatoes About 25 % of the total Dutch area of potatoes is grown for starch production. In 1841, W. A. Scholten founded his first potato starch factory (Sneeuw 1942; N.N. 1957). The nineteenth century saw the establishment of many factories, private and cooperative. Through mergers, takeovers, and economies of scale, one company emerged, Avebe (Dendermonde 1979; Van der Werf 1980). The threat of potato cyst nematodes to cultivation was so serious that the joint industry set up its own breeding station, Karna, in 1954 (Toxopeus en Huijsman 1961).

For a long time, protein was the cause of the wastewater problem with pollution and stench. As early as 1872, a competition was held to find a solution to this (Van der Werf 1980; Pepping 1982). Now, protein is a by-product of regular processing and has breeders' attention. Breeders have been successful, and the yields per hectare of starch potatoes also show a trend increase to over 50 tonnes per hectare over the last few years (De Bont et al. 2007). The top ten starch varieties in 2022 whose seed potatoes were inspected by the NAK, consist of highly resistant varieties for potato cyst nematodes and wart disease.

New (Niche) Markets In recent decades, a trend towards new small (niche) markets has emerged, from various sides, cultivation, trade, and consumer. This market is of interest to breeders, breeding companies, and trade. Niches are baby potatoes, salty potatoes, truffle potatoes, coloured potatoes, and potatoes with low carb or a particularly good taste. Growers often revert to old varieties. A few small breeders started breeding for the organic market at the end of the last century. Now, all breeders understand that this market could be interesting and are looking for improved varieties that can serve both for the conventional market and the organic market. As the rules for organic farming demand organically produced seed potatoes, many companies provide such nowadays.

Keys to Success of Dutch Potato Breeding

Over the past century, potato breeding in the Netherlands has developed into one of the world's leading breeding industries in the world. This study argues that several factors have influenced the development of potato breeding: interest, cooperation, remuneration, legislation, structure, organisation, research, diseases, cultivation, technique, monopoly, market, and variety. It can be concluded that three of these factors have been of decisive importance for innovation in potato breeding: cooperation, structure, and remuneration. This is reflected in the continuous flow of new varieties for all segments of the market.

Cooperation

This study covering a period of more than 100 years shows how the involvement of and close collaboration between government, industry, researchers, and breeders has advanced potato breeding in the Netherlands since 1888. The history of the chain development is distinguished into four periods. With great regularity, the unique cooperation between government and business in the Netherlands is confirmed and expressed. (Dorst 1947b; Hogen Esch and Zingstra 1963; Nijdam 1964; Thijn 1964; Huijsman and Lamberts 1972; Huijsman 1975; Lamberts 1975; Van der Wal 1978; Eenink 1988; Van der Zaag 1999).

Cooperation is a keyword in Dutch potato breeding. Potato breeding in the Netherlands can be regarded as a distinct way of cooperation between small breeders and commercial companies, and between public and private actors and interest, as well

as an integration of an informal and a formal system, also called participatory plant breeding (Morris and Bellon 2004; Almekinders and Hardon 2006; Gildemacher et al. 2009 and Almekinders et al. 2014). Four elements of the Dutch system fit this definition:

- Extensive testing of promising new varieties and clones with farmers in many countries.
- The method of testing for the variety list together with large-scale practical testing at farms.
- One public breeding company (SVP) with many small private breeders (selectors), each with their own breeding objective.
- Cooperation of small breeders with the breeding stations of the trading companies.

More precisely, the Dutch potato breeding system can best be characterised as Participatory Variety Selection, which corresponds with the advice of Morris and Bellon (2004) to collaborate between breeders and farmers, see also Almekinders and Hardon (2006). Louwaars (2018) argues that centralised breeding alone cannot provide the necessary diversity, it requires collaboration with farmers. The starting point is good varieties for farmers (in the Netherlands and abroad) and for trade. There is a central directed breeding from the commercial breeding companies for the strategy, but the collaboration with the group of small breeders, each in different regions and with their own objectives, ensures a large diversity of selections.

Small farmers and gardeners were the first to start breeding potatoes (Earle 2020; Salaman 1985). Special and unique is that the small breeder still plays a key role in Dutch potato breeding, more than in any other European country. It is easy for a small breeder to start breeding in this important arable crop. His motivation is passion and specialisation in one crop, the potato. Although small breeders are inexperienced in genetics, they are very much the experts in practical potato cultivation and selection.

The guiding principle for this collaboration is the continuous and urgent need for improved varieties to cope with the many diseases in this crop, which was jointly recognised and supported. That means the breeding strategy is ‘crop-driven’. Olmstead and Rhode (2002, 2008) come to the same conclusion with their research in crop technology innovation for wheat breeding in the USA. They argue that breeding is not so much aimed at increasing production but at maintaining production under changing conditions. The findings of Douches et al. (1996) on the productive potential of potato varieties confirm the research of Olmstead and Rhode and this study. They compared potato varieties from before 1900 to 1990 in field trials and found no difference in yield. Yield improvement has been and is achieved by improving the cultivation method (Vos 1992; Haverkort 2018). Trip (1979) writes that in potato breeding, a stable yield has priority over a high yield potential.

Dutch potato breeding has a second strong guiding principle for collaboration: the joint interest in serving export of seed potatoes, which means that the breeding process can also be characterised as ‘export-driven’. Adaptation of the potato varieties to the climatic conditions in the respective export countries is of decisive

importance to maintain a profitable cultivation there as well. This too corresponds with the findings of Olmstead and Rhode (ibid) in their study on the wheat cultivation to the Midwest.

Improving varieties of potatoes is becoming increasingly difficult due to the high level of many desirable characteristics of the current varieties and is a challenge for the future.

Institutional Infrastructure

A crucial part of this unified cooperation is the *institutional infrastructure* of institutions, organisations, foundations, and legislation. The strength of the joint public and collective approach in the potato breeding sector has played a crucial role in the development of this industry and the individual companies.

In the first half of the 20th century, there was hardly any business development in the potato breeding sector as it was dominated by individual small breeders. However, an institutional infrastructure started almost straight from the beginning of this century with field inspection of seed potatoes. In 1932, through legislation forbidding the export of seed potatoes that were not inspected, this led to the establishment of NAK. The importance of good varieties was recognised and NAK together with IVP stimulated breeding. COA became the organisation of guiding and supporting the breeders.

The best way to characterise the potato breeding sector, as it emerged in the last century, is as a platform, defined as 'the common basis of technologies, technological, economic, and social rules, and arrangements (such as standards) on which multiple players together can innovate and develop complementary technologies, products or services' (Kreyveld 2014). This model in which the SVP centralised the pre-competitive research with an open relationship between breeders and companies, was characterised as 'Holland Ltd.', which means all jointly in one company. The strength of the joint public and private approach in the potato breeding sector has played a crucial role in the development of this sector and individual companies. The approach to potato cyst nematode is an excellent example of this. Potatoes received a strong business boost after the breeder obtained exclusive ownership of his varieties, when the ZPW came into force in 1967 and led to an immediate increase in scale of private breeding. Potato breeding as an open platform reaches its peak in the 1970s. From then on, a long-lasting reorganisation started. The withdrawal of public practical research triggered the private breeding sector to set up breeding on a more scientific basis.

A second decisive aspect for building up a supporting infrastructure is the export of seed potatoes. The most important drivers for the Dutch success and international position in the production and sale of plant reproduction materials are plant breeder's rights, the variety list and inspection (Wiskerke and Oerlemans 2004). Louwaars (2007) distinguishes two seed systems regarding production and trade in seeds: an informal farmer system and the formal, commercially regulated system. The Dutch system of seed potato export has combined both systems at an international level. The Netherlands has a formal, strict system

with plant breeder's rights, inspection, and trading companies. In many of our export countries, there is free reproduction of the imported seed potatoes. This can be seen as the informal farmers' seed potato system. The Dutch system was developed with a twofold aim: profitable cultivation in the Netherlands and in the relevant export country. Louwaars opposes against restricting the admission of varieties for other ecological areas, risking that local and regional wishes and adaptation to the prevailing conditions are not sufficiently considered. Therefore, in the Netherlands, varieties for the export of seed potatoes have been included in the variety list because they are desired in certain countries.

It seems to be a quest for the potato breeding industry to continue to grow internationally under its own power, expansion of scale through the internationalisation of the potato breeding companies and trading companies themselves and an increase in licensed propagation in order to remain profitable. The increase in scale in agriculture in general started with Mansholt's plans in 1968 (Bieleman 2010). However, the effect on the cultivation and trade of seed potatoes follows years later with the search for cooperation and merger in the 1990s. Expansion of scale in breeding also has another cause; breeding is becoming more complex and technological. This is applicable to the use of new molecular and genomic technics in breeding, and most likely also to breeding hybrid potato varieties at diploid level. Both, increase in scale and ever more complex breeding, have a cost-increasing effect, due to the required facilities and more highly trained and higher educated breeders. Howard (2009, 2015) describes the concentration over the past 40 years in the seed industry. De Vriend and Lammerts van Bueren (2014) argue that the low net yielding of potato breeding is not of interest to multinationals. Such concentrations of power as in the seed industry of other crops are not yet visible in the potato sector. As a result of the Dutch reorientation from public applied research to commercially organised research, increasing the costs of breeding, the open platform is now clearly eroding and moving towards more closed platforms.

Remuneration

Remuneration as laid down in legislation for the work of the breeder is a crucial factor: without reward, no incentive. This is for the potato determined by the low propagation rate and the long payback. The variety as exclusive property of the breeder (the monopoly variety) is a strong stimulating factor.

The principle of good (financial) remuneration of the breeders' work did not originate from the breeders themselves but was initiated by NAK in the 1930s. First support came from incentives, later developed in legislation through the Breeders' Decree on initiative from the government. This provided the breeder the exclusive right to introduce propagating material to the market. The ZPW brought even more, the exclusive right (monopoly) on the variety. This created a turnaround in the marketing of seed potatoes and also a considerable increase in private breeding.

The ownership of monopoly varieties stimulated breeding much more than compensation based on legislation. Extension of plant variety rights legislation

in the EU and other countries, based on UPOV-regulations, stimulated breeding for different climate zones, sales of seed potatoes and production of seed potatoes under license.

Concluding Remarks

Even with the changes from an open to a more closed platform, we conclude that the government's involvement should remain, not so much in a controlling role, but in a facilitating and stimulating role. In contrast to the increasing closed culture among the larger companies, finding new forms of open platform cooperation is essential for smaller potato breeding companies (De Vriend and Lammerts van Bueren 2014). The long history of Dutch potato breeding has taught us that the broad diversity of breeders and trading companies has been a guarantee for a broad and good package of varieties (Van der Zaag 1999).

This study shows that the potato breeding sector relatively slowly incorporates new elements into the strategy. It is recommended that the signals of change be recognised in that there will be action. The growing attention for a more sustainable crop, or as recently called 'circular agriculture', makes this necessary. To be able to steer the future policy regarding breeding strategies even more sharply, it is also recommended to investigate in which the Dutch potato sector differs from the organisation of the potato breeding sector of other seed potato–exporting countries. Comparative studies of the breeding sectors of other crops can also contribute to a deeper understanding of the historical development of Dutch agriculture.

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