

The potato sector in The Netherlands: players, current challenges and opportunities with particular reference to the differences between conventional and organic potato

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1. Background of potato sector in NL

1.1 Brief overview

Potato cultivation in the Netherlands started in the 17th century at a larger scale as it provided relatively cheap food and was easy to cultivate. Today, the Netherlands is recognised as one of the main potato producing countries in the world and leading in the export of seed potato (Van Loon, 2019). In the EU, Dutch total potato production ranks third, after Germany and France (Govaert et al. 2022). Dutch potato growers achieve very high yields, among the highest in the world. The last decades, a further process of mechanisation and specialisation in production occurred, in particular in regards to storage facilities, and as a result the number of potato growers decreased, but total annual production remained quite stable over the years.

The Netherlands have a unique system of potato breeding in which farmer breeders work together with professional breeders (Almekinders et al. 2014). In the earlier part of the 20th century, government subsidised farmers to be actively involved in variety development (Van Loon, 2019). Most of the farmers involved in breeding are potato seed producers. The potato breeding companies are also commercializing potato seed who contract farmers to produce seed potato for them. As a result, potato breeding and seed production are tightly connected, both at the level of the involved farmers as the breeding companies. Today, there are three associations with in total 150 farmer breeders (Lammerts van Bueren and Van Loon, 2011). About 50% of the potato varieties grown today have been developed by farmers (Lammerts van Bueren and Van Loon, 2011; Almekinders et al. 2014).

Dutch potato production is differentiated into three main categories: Ware, seed and starch (described in more detail in section 1.3). Ware production includes both fresh and processed potato. Potato production can be found in all parts of the countries, with more intensive production in the provinces Groningen, Friesland, Drenthe, Flevoland, Zeeland and Noord Brabant. The region of Tholen in the Southwest part of the Netherlands is known for early potato production with the first harvest usually already available in April. The Northeastern part (eastern part of Groningen and Drenthe) are known for starch production. Seed production and variety development mostly take place in Flevoland and Friesland, but in other regions as well (Groningen, Drenthe, Noord Holland, Zeeland).

Of the domestic ware production (approximately 3.8 million ton based on CBS data) about 65% is processed of which 70% stays in the EU and 30% is exported worldwide (VAVI, 2022). Additional ware potato for processing is imported from Germany and Belgium (Kik et al. 2024). Annual processed potato totals 4 million ton and is exported to 150 countries (Vavi 2022). Of the ware potato production today only about 20% is exported as fresh potato (NAO, 2022). Export of fresh ware potato is shifting: whereas in the 1990s, most ware potato was exported within the EU (Rademakers and Mcknight, 1998), today only about 60% is exported within the EU (NAO, 2022). New export markets are West Africa and Central America. The last few years showed a small decline in export, probably because of a lower demand from countries whose domestic production has improved.

The breeding and seed companies with a base in the Netherlands and their associated farmers also have a strong position in seed potato production with a total annual production of approximately 1,5 million tons. Seed export is an important value chain: about 50% of the total seed production is exported, of

which only about 55% in the EU (NAO, 2022). Apart from the EU, seed potato is exported all over the world: Eastern Europe, Middle East, Asia, Africa and Central and Latin America.

Organic ware potato production is relatively small, about 3% of total potato production. The main market for ware potato is table potato. In the past *Phytophthora* was considered the main problem for organic potato cultivation. The development of *Phytophthora* resistant varieties and two covenants that stimulate cooperation in the value chain helped stabilise production. However, market demand remains another important problem for Dutch organic growers.

1.2 Organisation and actors of the value chain/potato sector

The Dutch Central Bureau for Statistics (CBS) organises the potato grown by farmers into three main separate products produced via three sometimes interconnected value chains:

- Ware (which includes fresh and processed)
- Starch (including other products for industrial and food purposes)
- Seed (for both ware and starch)

These value chains include both conventional and organic potato. Since 2015 the Dutch Office for Statistics also keeps records regarding organic cultivation using the same three categories. Notably, conventional potato production involves more players than organic potato production (Table 1).

Each of these value chains are organised in different ways. The seed value chain involves breeders, and farmers who grow seed potato. The starch value chain is made up of a cooperative called Avebe that includes farmers, breeding and seed production, and the processing industry. The ware value chain can be subdivided into two parts: suppliers and customers. The suppliers include the breeders, seed multipliers, farmers, wholesalers and processors. The customers include retailers, fast food corporations, supermarkets, restaurants and consumers (see Rademakers and McKnight, 1998).

Many important actors of the supplying part of the potato value chain have specialised in potato decades ago, like breeders, wholesalers of seed potato and processors. However, there is an on-going process of vertical integration, meaning that specialised potato chain actors (like breeding companies and wholesale in seed potato) can be active in other parts of the potato value chain as well (like wholesale and packaging of ware potatoes). There are also growers who do the packaging themselves and may sell to shops directly. They could be considered niche-players.

Particularly the 1980s and 1990s saw an intensive process of change that can be described as concentration (through mergers and buy-overs), inter-firm cooperation, and various ways of horizontal and vertical integration (Rademakers and McKnight, 1998). A change in consumption towards more processed potato started in the late 1960s (Hak, 1998). This resulted in a larger role of supermarkets and fast-food chains in the market and they became an important driver of change, as they favoured reliability in quality and supply and a larger diversity in products to sell.

Nowadays, a number of specialised players in the potato value chain have joined forces in several types of associations which are all linked to each other in various ways. As a result potato production, processing and trading has become a very efficient and integrated process in the Netherlands (Smit et al. 2008). The NAO (Nederlandse Aardappel Organisatie) represents the interests of the Dutch potato trade worldwide from seed to processing (for all three value chains seed, ware and industry). Important linked bodies are the NIVAP (Netherlands Potato Consultative Foundation) responsible for the quality and

trade of seed potatoes, LTO (Land- en Tuinbouw Organisatie) which is a farmer union representing the majority of the Dutch farmers and VAVI (Vereniging voor de Aardappel Verwerkende Industrie) that represents 95% of the ware potato processing industry. VAVI consists of six processing companies: McCain, LambWeston, Agristo, Peka, Aviko and Farmfrites. Except for LTO, the involved organisations are all highly specialised in potato. PotatoNL, in which NAO and VAVI are involved is founded in 2017 to provide a better overview on daily prices for potato.

The potato breeding and seed companies form the only part of the potato supply chain that is not directly represented by the NAO. The biggest Dutch potato breeders are Agrico, HZPC, Meijer and STET. Farmer breeders are organised in three associations (Lammerts van Bueren and Van Loon, 2011).

Twice a year potato growers and the ware processing industry meet, through joint meeting of the farmer organisations LTO and the smaller NAV (Nederlandse Akkerbouw Vakbond) and the association of the ware processing industry VAVI (NAO 2023). These so-called tripartite strategic meetings are meant to define the main interests of the various actors of the potato value chain to be represented. At European level the organisation Europatat has the role to protect the interests of the potato supply chain (Europatat, 2023). Originally set up by national organisations to protect the interests of the wholesale potato traders, today also individual companies can be member such as currently the Dutch companies Agrico, HZPC, Landjuweel, Meijer, Nedato, Schaap and Stet.

The importance of potato in Dutch agriculture shows by the fact that three of the twelve members making up Branche Organisatie (BO) Akkerbouw (the interbranch organisation of arable farming in the Netherlands set up in 2014) are specialised in potato, i.e. Avebe, NAO, and VAVI. Since April 1 2024 organic arable farmers, are represented in BO Akkerbouw via Bioplant (BO Akkerbouw 2024).

Because of bacterial ring rot in potato (caused by the quarantine pathogen *Clavibacter michiganensis subsp. Sepedonicus*), hygiene protocols have been developed for traders and washers. The NAO has lists of accredited traders, transporting companies and washing places (respectively about 25, 60 and 90 in the Netherlands). More information on quarantine diseases is presented in section 2.2.2.

In particular the Dutch ware processing industry developed strong horizontal cooperation in order to address peaks and dips in the orders by their customers, e.g. the supermarkets and fast food chains (Rademakers and McKnight, 1998). Today, there are also value chain players with high levels of vertical integration, such as Meijer that integrated breeding and processing, and Agrico that integrates breeding, seed production and ware production. It can be expected that in the near future more so-called vertical integration can take place. Vertical integration is in particular important for those companies involved in industrial processing in order to be able to put specialty products on the market (a trend visible for other crops as well). Avebe, an important player in the processing of potato starch and other products, is a case in point. Avebe represents a different value chain in potato processing compared to ware processing: Avebe uses potato to develop a wide range of products, based on starch, protein and fibre (in total over 20) for different markets: industrial use, animal feed and human food. In addition to the processing plant in the Netherlands, Avebe has processing plants in Germany and Sweden.

Averis seeds is part of Avebe and responsible for breeding and seed production, Avebe Commerce is responsible for innovation, marketing and sale, and Avebe Operations is responsible for production and purchase from growers. In 2001, Averis Seeds was formed by merging the KARNA Cultivation Institute

and the Seed Potato Department of Avebe with the Starch Seed Potato Department of HZPC Holland B.V. (Averis 2024).

1.2.1 Organic potato

The large mainstream organisations (like the NAO) in the supply part of the potato sector do not make any explicit mention of organic potato. Only one ware processing company is currently involved in organic potato. Smit et al. (2006) explain the absence of organic through the structure of the market and the dominance of processors in the supply chain, efficiency as major driver, the interdependencies between the value chain actors and an asymmetrical distribution of power. The processing is dominated by five companies and the retail by 7 purchasing organisations (see also Table 1). Because of the asymmetrical distribution of power change is difficult to achieve (Smit et al. 2006).

Interestingly, whereas the NAO makes no mention of organic potato, various potato breeding and seed companies (Agrico, Den Hartigh -now called Solana -, Plantera amongst others) distinguish organic as a separate value chain. Agrico has a separate program (called BioSelect) for the organic growers that are member of the cooperative. With this program, Agrico claims to be the supplier of roughly 25% of the organically grown potato seed potato in the Netherlands. The Dutch breeding and seed company Geersing, that initially started as farmer breeder in the Bioimpuls breeding program, mentions they are specialist in varieties for sustainable and organic potato cultivation. Part of their breeding takes place on an organic farm. Other breeding companies that do not mention explicitly breeding under organic conditions have several varieties for organic cultivation are the Dutch company Plantera, the German company Europlant and the French company Sementis. Companies that have one or two varieties suitable for organic are Den Hartigh, Meijer, Schaap Holland, and the German Interseed Holland BV. The company HZPC has stopped making their varieties available for organic cultivation as they are afraid of a rapid breakthrough if cultivated under organic conditions.

Of the conventional supply value chain relatively few value chain players are involved in organic potato. Regarding the customer side of the ware potato, the supermarkets sell both conventional and organic potato and potato products. However, until recently supermarkets had little interest in selling newly developed potato varieties more suitable for organic production (Nuijten et al. 2018): they preferred to sell the varieties they were familiar with. In 2017 a covenant was signed with the supermarkets to sell only fresh produce of Phytophthora resistant varieties cultivated in the Netherlands by 2020. The percentage of produce from Phytophthora resistant varieties sold in the Dutch supermarkets increased from 25 % in 2017 to 90% in 2020. Hence, the covenant is considered very successful. In the last few years, Phytophthora resistant varieties suitable for chips have become available. The hope is that in the next few years also varieties suitable for fries become available. In November 2022 a new covenant was signed to reach 100% Phytophthora resistant varieties in all value chains (table, chips and fries) (Bionext 2022). The development of the second covenant was led by Bionext. The following value chain actors are part of it:

- Retailers: Albert Heijn, Jumbo, Aldi, Lidl, Superunie (conventional and organic) and Ekoplaza and Odin (100% organic)

- Traders and packers: Schaap Holland, Leo de Kock, Landjuweel, Van Kampen Aardappelgroothandel, 3 Point Potato (all conventional and organic), Green Organics and BioNederland (organic)
- Breeding and trading companies: Agrico, Meijer Potato, Plantera, Geersing Potato Specialist, Danespo, HZPC, Agroplant, Europlant, Agroplant, Sloot Agri (conventional and organic) and Carel Bouma (100% organic)
- Grower Associations: Bdeko, Biowad, Vereniging Zuidwest, Nederlands Biologische Aardappelpool, Biohuis, Biolimburg, Bio-NH (all 100% organic) Nedato (conventional and organic)

Table 1: Overview of the number of actors involved in the potato sector, subdivided in conventional and organic production.

Value chain actor	Conventional	Organic
Breeding and seed commercialization	19 companies and 148 farmer breeders	11 companies and 12 farmer breeders linked to various breeding companies
Wholesale seed potato	Often linked to breeding companies	11
Licensed seed potato growers	1505	
Potato growers	9550	259
Accredited traders	25	?
Accredited transport companies	60	?
Accredited washing stations	90	?
Wholesalers ware for supermarket	7	7
Wholesalers ware for organic shops	NA	2
Processing industry (ware and starch)	6	1
Packaging stations	many	5
Large supermarket chains	12	5?
Greengrocers	Many	Many
Other retailers	Many	3 main groups and many small

Source: Dutch Central Bureau for Statistics (CBS), Smit et al. 2006, Lammerts van Bueren and Van Loon 2011; Janmaat, unpublished).

1.3 Current developments and trends

The following sections describe trends in potato cultivation of ware, seed and starch, based on data from CBS (Dutch Central Bureau for Statistics), the government office that collect statistics for a broad range of topics.

1.3.1 Conventional potato production

Yearly production

Regarding yearly conventional cultivation in kg produced (Figure 1), seed potato shows an increasing trend, but starch a decreasing trend and ware production a slightly decreasing trend. Regarding the

ware potato, an increasing percentage is being processed into chips, fries and other easy-to-eat products. Potato processing companies have several processing plants in Northwestern Europe (e.g. The Netherlands, Belgium, Germany, France and the UK) and Dutch produce is exported within the region depending on the availabilities of the crop in the Netherlands and the neighbouring countries. The Netherlands is still the biggest exporter in seed potato and exports seed potato across the world. Starch is mostly processed in the Netherlands, or alternatively in Germany.

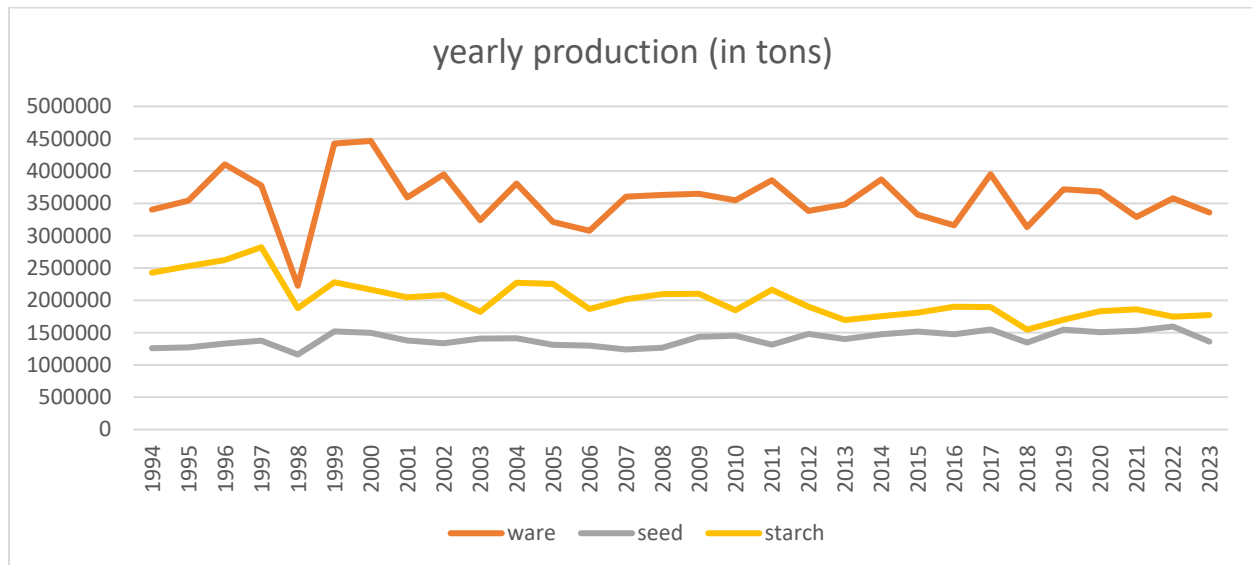


Figure 1: Yearly potato production in the Netherlands, subdivided for ware, seed and starch, from 1994 till 2024 (based on data from CBS, Dutch Central Bureau for Statistics).

Area under cultivation

The area for ware potato is much larger compared to starch and seed potato (Figure 2). Total area under cultivation shows a stable trend over the years for seed potato, a decreasing trend for starch and more dynamics for ware over the years.

Acreages for organic vary between 1100 and 1500 ha for ware and between 400 and 600 ha for seed potato. Both show an increasing trend between 2015 and 2024. Regarding potato for starch, there were only a few farmers who cultivated only a few hectares over the years 2016-2024.

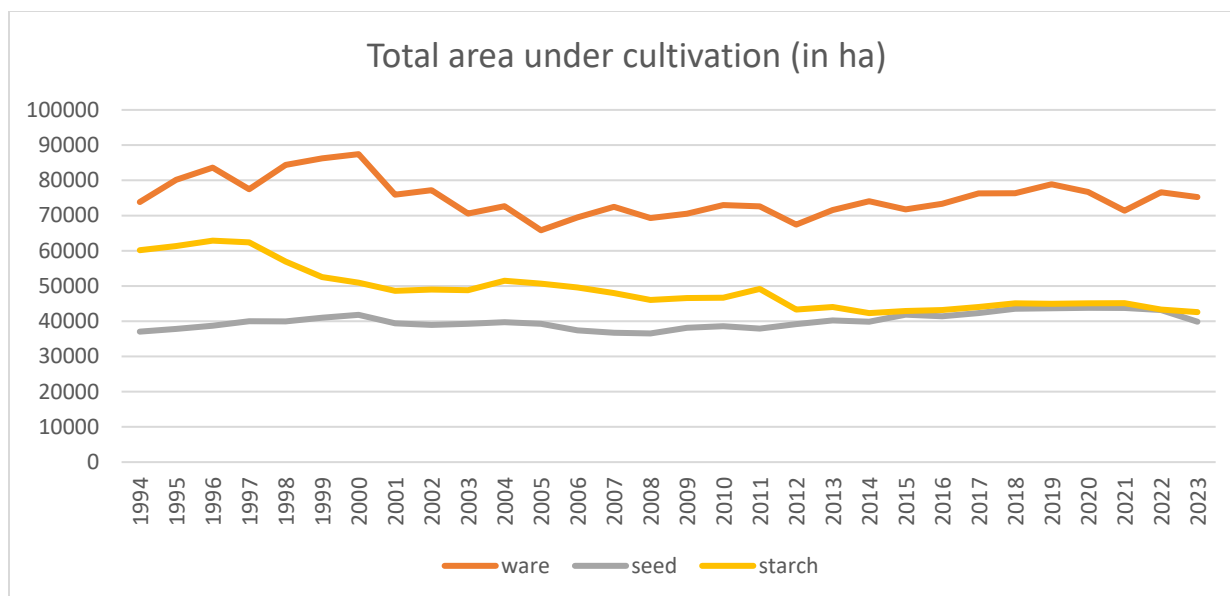


Figure 2: Total area under potato cultivation in the Netherlands, subdivided for ware, seed and starch, from 1994 till 2024 (based on data from CBS, Dutch Central Bureau for Statistics).

Average acreage per farmer

The area of starch potato is largest and that for ware potato the smallest (Figure 3). The average potato area per farmer has increased between the years 2000 and 2023 for all three categories. The increase in area per farmer shows a gradual trend for ware and seed potato, whereas the increase for starch went from 17ha in 2000 to 28 ha in 2023. This change is mostly related to the fact that the number of growers has decreased over the same period: for ware potato from an estimated 10.890 farmers in the year 2000 to 6.410 farmers in the year 2021. Starch shows a similar trend, although the total number of farmers was and remains smaller. The number of seed potato growers also decreased but to a lesser extent, from 3.270 in the year 2000 to 2.330 in the year 2021.

For organic, the average areas per farmer for ware and seed potato are, respectively, similar and much lower compared to conventional potato cultivation. The average acreage per organic farmer is approximately 7 ha for both ware and seed potato, compared to 11 and 18 ha / farmer for respectively conventional ware and seed potato. There is very little organic starch potato cultivation, often conducted by only one or two farmers.

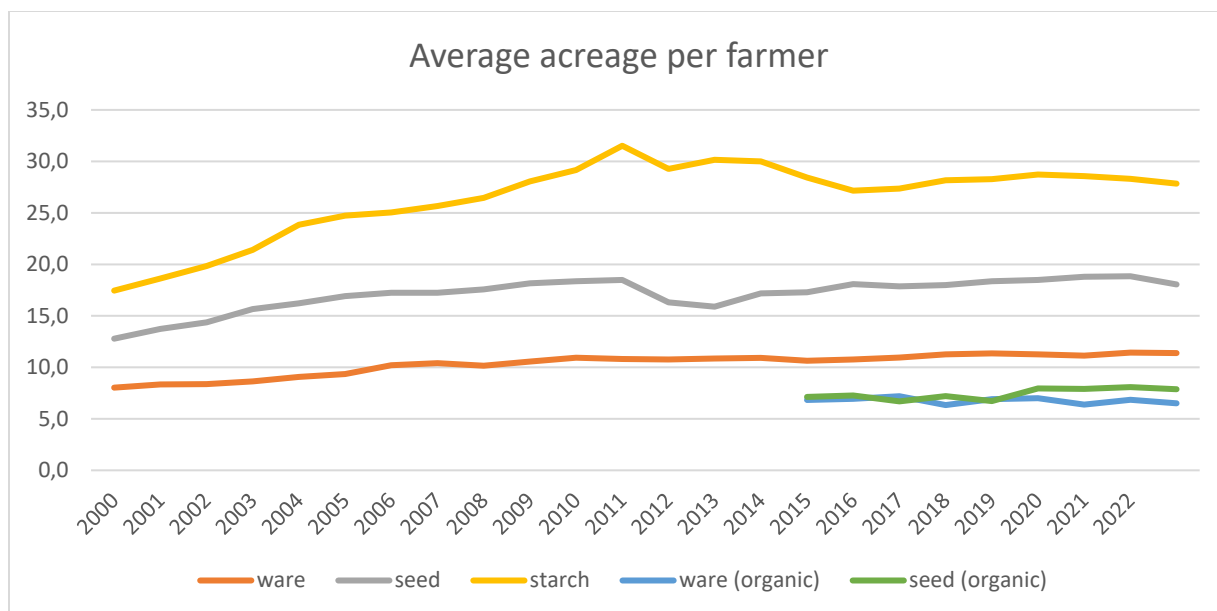


Figure 3: Average potato area per farmer in the Netherlands, subdivided for ware, seed and starch, from 1994 till 2024 and for organic average potato acreage per farmer from 2015 to 2024 (based on data from CBS, Dutch Central Bureau for Statistics).

Average yield per hectare

Average yields are highest for ware, followed by starch (Figure 4). Lower average yields for seed potato are explained by the fact that they are harvested earlier. Over the period 1994 to 2023, yields slightly increased over time for ware but since 2014 rather show a decreasing trend in yield. Average yield for seed potato seems relatively stable with small fluctuations over the years compared to ware and starch potato. Fluctuations in yield are mostly weather related with the worst yields in 1998. More recently, the dry weather in 2018 had clear impact on yield for all three categories.

Statistical data for organic potato have only been collected since 2015. These data show much higher fluctuations in yield as compared to conventional potato. Organic ware potato has much lower yields except for the years 2017 and 2018 which generally were very dry years and low *Phytophthora* pressure. In the years 2016 and 2023 *Phytophthora* pressure was very high.

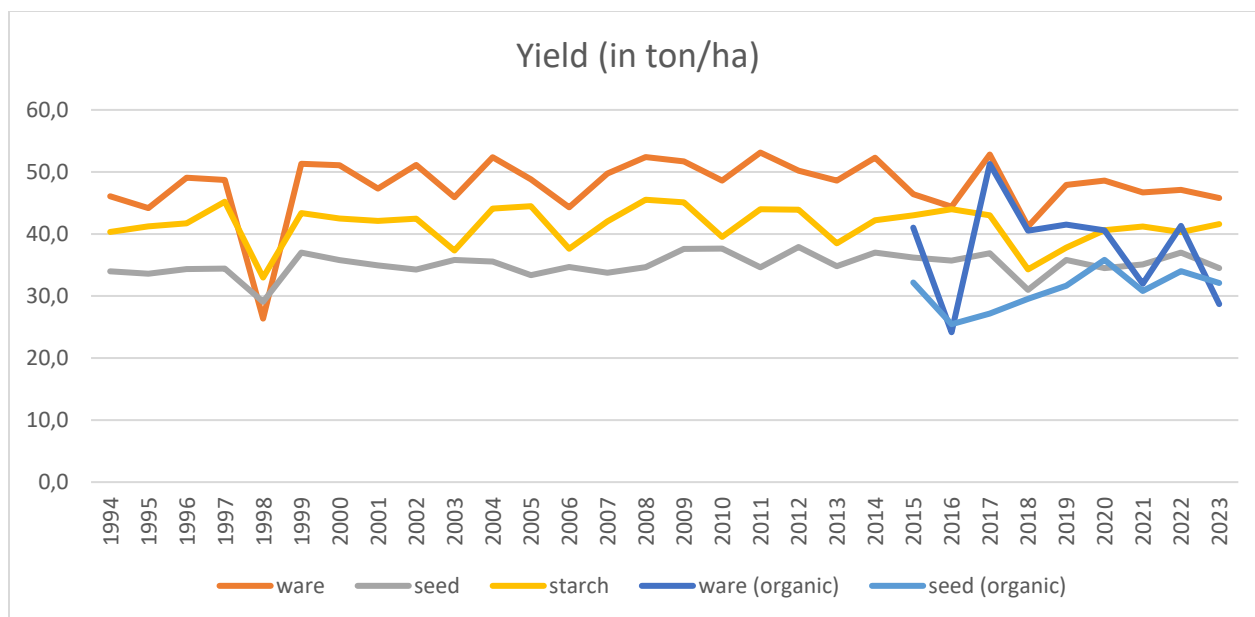


Figure 4: Average yield for potato in the Netherlands, subdivided for ware, seed and starch, from 1994 till 2024 and for organic potato, subdivided for ware and seed from 2015 to 2024 (based on data from CBS, Dutch Central Bureau for Statistics).

1.3.2 Summary

Conventional potato cultivation

Production levels of potato are high in the Netherlands. They need to be high for farmers to cover the high costs related to potato cultivation. All three categories (ware, seed and starch) show trends of specialisation and increasing scale, shown by the increase in area per farmer and the clear decreases in number of farmers. However, the three categories of potato production show clearly different trends: Seed production shows increasing trends in total area and total production. Over the last ten years ware potato shows a decreasing trend in yield but an increasing trend in area. Starch shows decreases in total area, yield and total production. These figures suggest that there is still possibilities for increasing seed potato production, but less so for ware potato.

Organic potato cultivation

For organic potato cultivation fewer data are available. After a decline in 2009, a gradual increase showed in the following years. With only data available over the last 10 years it is more difficult to draw trendlines for all the parameters presented for conventional potato cultivation. Yields in organic vary much more between years compared to conventional. The smaller area for organic potato growing are partly related to wider crop rotation cycles compared to conventional potato growing. For comparison: in conventional farming in the Netherlands, potato is the second crop after cereals with the total acreage with potato nearing the total acreage of cereals: from approximately 70% in the early 2000s to 92% in the late 2010s.

Table 2: description in numbers of conventional and organic potato farming in the Netherlands (data for 2020, based on data from CBS, Dutch Central Bureau for Statistics).

Category	Conventional	Organic
Total number of farmers	51417	1742
Total number of potato growers	9550	259
Consumption	6810	210
Seed tubers	2370	72
Starch	1570	1
total area (in ha)		
Consumption	76709	1472
Seed tubers	43807	572
Starch	45104	1
total production (in tons)		
Consumption	3.681.626	59740
Seed tubers	1.507.199	20510
Starch	1.831.237	-
average yield (in ton/ha)		
Consumption	48,6	40,6
Seed tubers	34,5	35,8
Starch	40,6	-
average field size per farmer (in ha)		
Consumption	11,3	7,0
Seed tubers	18,5	8,0
Starch	28,7	-

Although organic agriculture has a long history in the Netherlands, it still makes up only a small part of agriculture in the Netherlands. The number of organic growers has increased with 40% in the last six years, but the number of organic potato growers has only increased with 30% over the same period. Whereas the number of organic farmers make up about 3% of the total number of farmers, the acreage of organic potato has grown to only slightly over 1% of the total area of potato production in 2021. The last few years showed an increase in area, which can be attributed to the efforts made to increase production due to the increased availability of late blight resistant varieties and an agreement with the supermarkets to sell organic potato produced in the Netherlands from 2018 to 2020. However, table 3 shows that organic farmers engage more in vegetable crop with high profit margins and do not require much use of chemical pesticides.

Table 3: Total number of arable farms engaged in various crops, the percentage of organic farms per crop, the total surface cultivated with a particular crop and the percentage of the surface cultivated under organic (Averages shown over the years 2018-2022 based on data from CBS , Dutch Central Bureau for Statistics).

Agricultural activity	Number of enterprises total (x 1000)	Organic enterprises in %	Total surface cultivated x 1000 ha	Surface organic in %
Arable farming (totaal)	18,7	3,8	527,0	2,7
Potato (total)	9,5	2,6	164,3	1,2
Ware Potato	6,7	3,0	76,0	1,8
Seed potato	2,4	3,1	43,6	1,3
Starch potato	1,6	0,1	44,7	0,0
Vegetables grown as arable crops (total)	5,4	6,3	63,9	10,6
Onion	4,0	4,4	37,0	4,3
Carrot	0,9	19,7	6,4	20,5
Peas	0,5	23,1	3,8	24,2
Chicory roots	0,4	12,0	3,1	12,2
Fresh beans	0,4	19,6	2,9	18,8
Spinach	0,3	33,8	2,2	30,4
Sellery	0,3	14,2	1,9	9,6
Surgar maize	0,2	36,7	1,3	39,1
Red beet	0,1	46,3	0,9	51,2
Other vegetables grown as arable crop	0,7	8,3	4,5	5,0
Cereals (total)	11,9	3,5	176,5	2,5
Wheat	7,9	2,1	117,3	1,0
Barley	4,3	3,3	35,1	2,7
Maïze	1,9	1,4	18,2	0,8
Rye	0,5	17,7	2,0	35,5
Oat	0,3	35,1	1,5	47,8
Triticale	0,3	27,3	1,2	38,2
Other cereals	0,4	15,9	1,2	25,2
Grass seed	1,1	1,1	10,1	0,7
Commodity crops (total)	1,6	5,0	11,9	3,4
Leguminous crops (total)	0,7	9,4	3,9	7,4
Other arable crops	8,6	1,0	88,0	0,4
Fallow	3,6	4,1	8,4	3,4

2. Challenges for the potato sector: conventional - organic

2.1 Summary

For an overview of the main challenges for conventional and organic potato production in the light of climate change, published information news on two news portals was reviewed: agf.nl and biojournaal.nl, both hosted by the same organisation, from January 2023 till August 2023. Emerging from the analysis, the main challenges in potato are related to market developments for both the conventional and organic potato sector (**Table 4**). A number of challenges are gradual (and predictable) developments: A continuing shift in the market from table to processed potato, a gradual reduction in potato consumption, increasing dominance of the fries industry, ongoing decreases in the cost-profit margins are a continuous challenge for farmers.

Table 4: Overview of news items on climate change and potato on the news portals biojournaal.nl and agf.nl from January until August 2023

Theme	Topic	Potato		Climate	
		organic	conventional	organic	conventional
Climate	Organic	0%	0%	9%	4%
Climate	Potato	0%	0%	0%	12%
Climate	Other crops	0%	0%	6%	35%
Climate	Production planning	0%	0%	9%	17%
Climate	Sustainability	0%	1%	9%	8%
Breeding	Breeding	9%	7%	0%	2%
Market	Market	61%	54%	3%	2%
Policy	Policy	0%	1%	43%	12%
Society	Society	0%	2%	23%	10%
Potato	Consumers	9%	1%	0%	0%
Potato	Cultivation	4%	12%	0%	0%
Potato	IPR	0%	0%	0%	0%
Potato	Processing	13%	9%	0%	0%
Potato	Research	0%	3%	0%	0%
Potato	seed potato	0%	5%	0%	0%
Potato	storage	0%	2%	0%	0%
Potato	Transport	4%	2%	0%	0%
	Total number of articles	23	244	35	52

An increasing challenge is the volatility of the market related to (increasing) unpredictability of the domestic production as well as foreign production. This is directly related to uncertainty of the developments of prices of domestic and foreign produce in spring when Dutch farmers still have part of their harvest to sell and foreign fresh produce is imported. Due to seemingly changing weather patterns (increases in number of heat waves, droughts and heavy storms) in Mediterranean countries like Malta, Egypt and Spain imports may start earlier in the year when Dutch farmers still have part of their harvest to sell.

A new challenge for both conventional and organic farmers are the recently developed new types of Phytophthora EU 43 and 46 that have higher virulence and are difficult to control with fungicides and have broken various resistance genes already. As a consequence, late blight was difficult to control in the autumn of 2023. In conventional agriculture, the use of new schedules with more alterations of fungicides seems to have suppressed the development of the new Phytophthora types.

Other challenges that conventional farmers are currently facing are, amongst others, envisaged obligatory reductions in use of nitrogen fertilizer and pesticide use, the number of available pesticides, new developments of fungicide resistance by Phytophthora, and increases in salination of the soils in the coastal areas. The latest challenge reported in 2023 is that potato harvested after October 1 is penalized with reductions in nitrogen use in the following year.

Experiments have started with reduced use of nitrogen fertiliser and chemical pesticides. Regarding soil salinisation first trials have shown that some varieties have better salt tolerance and are placed in the market as a unique product (Van de Wadden chips).

For organic farmers, market development and Phytophthora are the most challenging factors they face. Another challenge is finding labour for weeding during the growing season. However, with mechanical weeding potato can be kept weed-free very well.

Climate change

Given the current situation of the Dutch agriculture, worries about the effects of climate change are overruled by other worries. In a survey conducted in 2024 by the farmer journal Nieuwe Oogst together with researchers of Wageningen University farmers responded that the main challenges are at the political, societal and regulations level (50, 33 and 27% of the respondents respectively). Concerns regarding 'environment, climate and animal health' or future perspective scored much lower, mentioned by respectively 17% and 16% of the respondents (Nieuwe oogst 2024b).

The attention to climate risk in agriculture is relatively recent in the Netherlands. Research on farmer risk management in the Netherlands looked at various risks such as input price, market price, supply chain, financial, production, personal, personnel, institutional and societal (Slijper et al. 2020). Climate or climate change was not included. In farmer opinion panels first organised in 2021 by the farmer journal Nieuwe Oogst regarding general trends in agriculture, a question was included whether farmers take measures to limit the effects of the changing climate. The percentage of farmers that take measures to deal with changing climate increased from 48% in 2021 to 66% in 2024 (Nieuwe Oogst 2021, 2024). The responses come from various types of farmers, with dairy farmers being the biggest group, about 40% of the total responses.

In a survey about weather extremes conducted in March 2024 mostly arable farmers responded (839 on a total of 1021 responses). Most commonly cultivated crops were cereals, potato and sugar beet. The rotation for potato ranged from 1 in 2 seasons to 1 in 5 seasons with 1 in 4 and in 3 seasons most commonly indicated.

The biggest risks were related to water, both too much and too little water (Table 5). Of the respondents 74% responded they take measures against increasing weather extremes (Nieuwe Oogst 2024a). Measures most often applied (drainage and irrigation) are directly related to improved water

management as a response to flooding and drought (Table 6). Other cultivation systems (6% in Table 3n0) includes the use of ridges, elevated beds, controlled traffic system, strip cropping or other.

Table 5 Responses of farmers to the question “What are the biggest risks of climate change on your enterprise?” asked in a survey on water extremes organised by the farmer journal Nieuwe Oogst in March 2024 (Nieuwe Oogst 2024a).

Biggest risk	Response (in %)
Drought	59%
Salinisation	8%
Flooding	65%
decrease in soil quality	21%
higher disease and pest pressure	36%
change during the growing season	17%
availability of fresh water	17%
Other	9%
Total number of responses	575

Of the farmers who responded 61% farmers indicated that they are already experiencing reductions in yield because of weather extremes and 18% expects to experience yield reductions in the future. About 15% of the responders expect yield decreases over 20%. In response to the question whether they see the changing climate as an advantage or disadvantage 18% responded they expect an advantage and 40% expects a disadvantage, whereas 42% do not know what to expect. In response to the question whether they will take financial measures, 37% responded expected that this is not necessary. Of those who responded financial measures are necessary almost 50% indicated they themselves need to build a financial buffer, 33% responded they hope fiscal reservation will be possible and 20% responded to have a weather insurance.

Table 4 shows that if there are climate-related worries around potato cultivation, it is about the effect of climate change in other countries and their effects on the international market, which is felt more strongly by the conventional sector than the organic sector.

Regarding climate change in the Netherlands, conventional and organic growers face the same challenges, in particular those related to increased weather variability, which translates in longer periods of drought or heat and periods of rain or intense rainfall. Because of better soil quality resulting in better water retention and absorption capacity, organic agriculture is better positioned to manage with increased weather variability (Migchels et al. 2023). On the other hand, the conventional potato sector has the advantage of having more varieties available, as part of the breeding is oriented towards low-input conditions in other countries, providing more options to adapt to climate change compared to organic.

it is a possibility that increased CO₂ levels can have a positive effect on plant growth and, subsequently, yield. It may also result in reduced evaporation through the stomata, which can help the crop to deal better with low rainfall periods. However, in the case of hot weather, evaporation is a means of the

plant to regulate temperature in the leaves. Heat stress may reduce tuber growth, and hence, reduce yield. Thus, the positive effects of increased CO₂ levels may be counteracted by heat stress (Blom-Zandstra and Verhagen, 2015).

Table 6: Responses of farmers to the question “What measures do you take in response to weather extremes?” asked in a survey on water extremes organised by the farmer journal Nieuwe Oogst in March 2024 (Nieuwe Oogst 2024a).

Measure	Measures already applied	Measures to be applied short term	Measures to be applied long term
Irrigation	60%	32%	23%
Drainage	69%	45%	42%
Levelling (Kilving)	50%	31%	26%
Other / robust varieties	18%	14%	22%
Starting growing season earlier	26%	20%	18%
Other cultivation system	6%	10%	18%
Other soil tillage	40%	26%	22%
Other mechanisation	20%	11%	21%
Adapted crop protection strategy	18%	10%	16%
Adapted manuring strategy	16%	11%	13%
Adapted rotation	20%	18%	27%
Wwater cooperation with nearby arable farmers	1%	3%	5%
Intensified cooperation with water board	7%	9%	7%
Other	11%	17%	13%
Total number of responses	411	201	232

Salt tolerance is likely to become more important in coastal regions in the case of years with lower amounts of rainfall. Salt tolerance seems to differ among cultivars. Breeding with improved salt tolerance for other countries already takes place many years (Van Loon, 2019). Periods with heavier rainfall can result in increased chances of late blight. Longer periods of drought and/or higher temperatures may not only impact yield but also tuber quality in case of limited possibilities of irrigation. Periods of drought can also result in soil salinisation in the coastal areas. Another change in climate is the increased occurrence of easterly winds in spring with increasing chances of night frost. It is also mentioned that increasing temperatures may prolong the growing season for potato. Hence, the effects of climate change may not necessarily result in a yield reduction, but can impact yield stability and quality over the years.

Most often mentioned measures to mitigate these climate-related effects are adapting variety development and agronomic practices (Liu et al. 2025). Variety traits important for developing climate-responsive varieties are improved yield stability, nutrient-use efficiency, root system and tuber dormancy (Keijzer et al. 2022). Suggested agronomic practices by Wageningen University & Research are: drip irrigation, so-called erosion stoppers in between potato ridges, opening the soil in between the ridges, drilling holes, controlled traffic farming and green manure (Knol 2024). Practices often

mentioned by organic farmers are practices that improve soil quality such as reduced tillage, wider crop rotations, green manure and controlled traffic farming.

It is also reported that climate change can provide new opportunities such as carbon banking , which indirectly also means improving the organic matter content of the soil which is an important element of soil quality (See Stichting Nationale Koolstofmarkt (www.nationaleco2markt.nl)).

2.1 Variety development

Dutch potato breeding is based on a unique approach in which breeding-and-seed companies develop new varieties in collaboration with farmer breeders (Almekinders et al. 2014). About 50% of the varieties developed in the Netherlands have been selected by farmers. Roughly 50% of the breeding focuses on ware for export, 20% on starch and 30% on domestic ware (Van Loon, 2019). Today, the bigger breeding programmes of the companies emphasise the importance of molecular markers to make the breeding process more efficient and faster, for both conventional and organic. A recent development is the building of the so-called Netherlands Plant Eco-phenotyping Centre (NPEC) in 2018: High throughput phenotyping in combination with data analysis and plant modelling. So far, only the potato breeding companies Solynta and Averis seeds are partner. Section 3.2 presents further information on breeding research.

Yield is an important trait in breeding for both conventional and organic. For conventional, the focus is on middle early to late maturing varieties whereas the focus for organic are middle late maturing varieties to minimise the effects of Phytophthora in case of heavy infestation and that farmers do not have a complete failure of harvest (Table 7).

Table 7: Agrico potato varieties for conventional and organic categorised according to earliness (based on information from the website of Agrico 2024)

	Varieties for conventional		Varieties for organic	
late	17	25%	1	9%
middle late	27	39%	7	64%
middle early	14	20%	2	18%
early	7	10%	1	9%
very early	4	6%	0	0%
total	69		11	

Van Loon (2019) describes that in starch yield increase was successfully bred for, but not in ware potato in the past 70 years. Although yield remains an important trait, the focus of breeding is changing more towards robustness and disease resistance (Janse et al. 2021). For both conventional and organic production, disease resistance is very important, although priorities are somewhat different (Tiemens et al. 2012, Van Loon 2019, Keijzer et al. 2021). For both farming systems Phytophthora remains the most threatening disease (Table 8). Nematode resistance is also important for conventional starch potato. Virus resistance is more important for organic potato to minimise virus pressure during seed tuber

production. For the future, breeders see virus resistance also becoming more important for conventional which is indirectly related to climate change (Janse et al. 2021).

Table 8: Description of the focus of potato breeders through the count of search terms organised in three main categories, i.e, value chain, potato cultivation and potato breeding, based on interviews in Aardappelwereld 2021 by Janse et al. 2021.

category	search term in Dutch	Translation English	number of hits
general terms	ras	variety	96
	aardappel	potato	41
<i>Search terms related to the value chain</i>			
Activity	kweekwerk	breeding	21
	teelt	cultivation	15
	markt	market	40
	verwerking	processing	18
	bewaring	storage	12
	bewaren	store	7
	consumptie	consumption	4
	koken	cooking	0
product	eten	eating	0
	frites	fries	20
	chips	chips	13
	tafel	table	17
	zetmeel	starch	7
	pootgoed	seed potato	10
value chain actors	kweker	breeder	21
	teler	farmer	21
	klant	client	46
	consument	consumer	1
	handel	trade	6
	industrie	industry	8
<i>Search terms related to potato cultivation</i>			
soil type	grond	soil	2
	klei	clay	0
	zand	sand	2
soil characteristics	mineralisatie	mineralisation	0
	Humus /organisch stof	organic matter	0
	compactie	compaction	0
crop management	bemesting	manuring	3
	kunstmest	artificial fertiliser	2

	gewasbeschermingsmiddelen	pesticides	2
	beregening	irrigation	3
	grondbewerking	soil tillage	0
	input	input	5
	nutrienten	nutrients	0
	stikstof	nitrogen	5
	fosfaat	phosphate	0
	kalium	potassium	0
<i>Search terms related to traits in potato breeding</i>			
Cooking	kooktype	cooking type	2
	smaak	taste	7
	kleur	colour	1
Processing	onderwatergewicht	under water weight	1
Yield related			
traits	opbrengst	yield	18
	stengels	tillers	0
	tal	tuber number	2
	knollen	tubers	5
	vroegheid	earliness	4
	laat	late	5
Disease related			
traits	Phytophthora	Phytophthora	36
	virus	virus	16
	nematoden	nematodes	8
	schurft	scab	3
	resistentie	resistance	29
Robustness	robuust	robust	18
	weerbaar	resilient	0
	grondadaptatie	soil adaptation	2
Efficiency	bemestingefficiëntie	manuring efficiency	1
	water efficiëntie	water efficiency	1
Climate	klimaat	climate	4
	klimaatverandering	climate change	1
	weer	weather	0
	kou	cold	0
	nat	wet	0
	droogte	drought	6
	hitte	heat	3
	weinig water	little water	2
	vocht	humidity	0
	wind	wind	0
Other traits	gewas	crop	1
	blad	leaf	1
	kiem	sprout	6

Other important traits are - apart from yield, disease resistance and robustness - processing quality, storability and good taste. Most breeders categorise the ware market into three subcategories: fries, chips and table potato. Table 8 shows that breeders focus very strongly on the expected client needs. Breeders also expect more reductions in inputs, further underlining the importance of more efficient varieties. In the scope of climate change, traits like drought and heat tolerance are important to improve crop adaptability: they are moderately important for the breeders.

In relation to climate change, other variety traits may become more important to reduce greenhouse emissions, like Nitrogen Use Efficiency (NUE) and good storability (reduction in storage loss and energy for storage). It is expected that varieties that are adapted to climate variability have a smaller ecological food print (as they need fewer inputs and water) and are expected to have better yield stability.

Compared to the fresh market, variety development for processing needs to meet a range of additional traits like high and stable dry-matter content. Furthermore, the processing industry prefers to use a small number of varieties with good stability in quality because it makes processing more efficient. A larger number of varieties used for processing requires more frequent adjustment and cleaning of the processing line. Adoption of new varieties has more hurdles for processing compared to the fresh market. This is a big challenge for conventional breeding companies, but even more so for organic breeding programs because of the small market share of organic. Table 8 shows that the market is very important for breeders to focus their breeding upon.

New value chains are being developed today, such as low calorie potatoes (HZPC) that supposedly have 30% lower caloric value than average potatoes: 'Therefore they are allowed to be marketed as light potatoes' (HZPC, 2023). Another niche development are coloured potatoes which are expected to have higher levels secondary metabolites (Van Loon, 2019).

2.1.1 Organic

The number of potato varieties with late blight resistance and good cropping traits of which organic seed is commercially available is increasing rapidly. In 2024, organically produced seed of more than 30 varieties were available. In the 2010s, the big challenge was to get the market to accept the first *Phytophthora* resistant varieties. Over the last 10 years, many projects have been conducted to improve the acceptance of these varieties, using different approaches (Nuijten et al. 2018). The most successful attempt was the covenant signed by breeders, farmers and supermarkets (Bionext, 2021). The agreement was that during the period 2018-2020 the supermarkets would sell the produce of *Phytophthora* resistant varieties. As a result, the organic ware production increased in area planted till 2020 followed with a decline of 9% in 2021. After the covenant ended in 2020, some supermarkets started to import organic potato from the Mediterranean. In November 2022 a new covenant was signed (Bionext, 2022).

An alternative to breeding varieties with late blight resistance is the development of early maturing varieties that can escape late blight infections. Such varieties, however, need to have good nitrogen uptake and use efficiency because soil mineralisation in the spring is often limited by low soil temperature and the modest manuring levels used in organic. In the 2000s this was a big challenge because such varieties were not yet available. Tiemens-Hulscher et al. (2014) showed that varieties with fast canopy cover development often had better nitrogen uptake efficiency and higher tuber number. A

higher tuber number means smaller tubers which is not a problem so far as the organic market consists mostly of ware potato. In the 2020s new early maturing varieties became available with good yield, although some may have limited canopy cover.

2.1.2 F1-hybrids

A completely new breeding methodology being developed in potato are F1-hybrids. Some companies (like HZPC, KWS and Solynta) have high expectations of this new technology. To what extent this technology can play a role in mitigating the effects of climate change is not yet clear, but expectations are high. Companies involved in the development of F1-hybrid potato varieties argue that they can increase the speed of variety development, and that the technology makes pest and disease resistance breeding easier by using big data and genetic analysis. Currently, the company Solynta has conducted pilot tests in a few African countries like Kenya, Mozambique and Rwanda. HZPC focuses on both Africa and Asia. Preliminary agronomic trials have been conducted in the Netherlands in collaboration with the WUR that suggest that the use of F1-hybrid potato variety would shorten the multiplication from 5 to 8 years to only two generations (van Dijk et al., 2021).

2.2 Seed production

The Netherlands are a net exporter of seed tubers, for both conventional and organic. The export market is very important: about 70% of the seed potatoes is exported.

Stronger fluctuations in weather could impact seed tuber yields, which in turn could impact exports. In the past decades, several problems arose with bacterial diseases which can be spread through irrigation when open surface water is used. The last few years (2018-2020) saw restrictions on the use of water for irrigation in certain regions because of lowered ground water tables and limited rainfall. In the dry year of 2018, the effects on seed production seemed smaller in organic compared to conventional: -3% and -12% reduction respectively compared to the 5 year average of 2016-2020. An explanation could be that organic production is situated in regions with more stable ground water levels (such as Flevoland). An alternative explanation is that higher organic matter content of organically managed soils have a better the water holding capacity.

Throughout the potato production chain, hygiene protocols are applied to prevent the spread of diseases. One measure to prevent the spread of diseases in the field is to harvest the seed potatoes before the spread of in particular virus diseases. Increase in temperature through climate change in winter and spring could improve conditions for survival and foster earlier development and growth of aphids and other insects which in turn can increase the spread of viruses.

An important question is to what extent climate change, through heat waves or drought spells for example, can affect the dormancy, and whether this effect can be variety related. The withdrawal of the chemical Chloorprofam, used to control dormancy in conventional potato cultivation, in 2020 at EU-level may have impact on tuber quality to further away destinations and no good alternatives have been identified (NAO 2023). Some consider F1-hybrid seed production a solution because the botanical seed can be transported and stored much easier than seed tubers. Regarding transport, this is particularly of importance for regions with poor infrastructure. In regions with warm climates, the botanical seed can

be storied easier than seed tubers. On the other hand, the question is whether during the actual farming season similar yields can be achieved from seed compared to seed tubers.

2.2.1 Early generation seed

In conventional production, this topic has been studied for many decades and many multiplication methods and practices are available. To a large extent, early generation seed production takes place under controlled conditions, such as in-vitro and in glasshouses, which reduces the impact of climate change.

For organic, some multiplication methods used in early generation seed production (e.g. tissue culture) do not fit well with the principles of organic culture. Therefore, some consider propagation through true seed to be an alternative.

2.2.2 Seed quality assurance: Certification

The NAK ((Nederlandse Algemene Keuringsdienst) is the Dutch seed certification agency. It checks for diseases that can be transferred with the seed potato. Arount 85 inspectors of the NAK yearly inspect a total of 38.000 ha of seed potato in the field.

Important pests and diseases in seed production, next to Phytophthora, are nematodes, virus and bacterial wilt, are scab and sclerotinia. Wireworms are recognized as an increasing problem (NAO 2023). The NVWA (Nederlandse Voedsel en Waren Autoriteit) has identified the following quarantine diseases and pests specifically relating to potato:

- Brown rot caused by the bacterial disease *Ralstonia solanacearum*
- Ring rot caused by the bacterial disease *Clavibacter sepedonicus*
- Potato fatigue caused by the nematodes *Globodera rostochiensis* and *Globodera pallida*,
- Scab caused by the fungus *Synchytrium endobioticum*

In case of the presence of these diseases in the soil, farmers have to follow specific programs for several years to reduce the disease pressure. Specific crop rotations and the cultivation of varieties with resistance to particular types of the diseases and pests are practices that contribute to lowering the presence of the diseases. The NVWA has lists with potato varieties that are resistant against particular types of potato fatigue and scab. These lists are not only used by farmers but also by breeders to know which old varieties have good resistance against a particular type of potato fatigue or scab.

Compared to potato fatigue, the norms for the quarantine pests root-knot nematodes *Meloidogyne chitwoodi* and *M. fallax* are slightly less strict in potato seed cultivation. Whereas for the cultivation of seed potato, a farmer needs to be able to show that his field is free of potato fatigue, this not the cause for root-knot nematodes. Damage threshold levels are much higher for starch potato compared to seed and ware potato (BO-akkerbouw 2024). The root knot nematode *Meloidogyne enterolobii* has acquired the quarantine status in the EU as of 11 April 2022 and resulted in extra restrictions regarding import of seed potato.

In addition to the field inspections, NAK inspects for various virus diseases (Y-virus and PLRV (potato leaf rolling virus)), bacterial diseases (brown rot (*Ralstonia solanacearum*)), ring rot (*Clavibacter sepedonicus*)

and nematodes (*Meloidogyne chitwoodi* and *M. fallax*). Seed potatoes need to be disease free and are tested by the NAK on the instructions by the NVWA. Under certain condition a waiver for testing for virus is possible: under low presence of aphids, for the E, A and B-class of seed potato and when it concerns seed potatoes for own use. For varieties without symptoms and the seed potato classes PB, S and SE no waiver is possible (NAK, 2023). The testing for PMTV/TRV (potato mop top virus/ tobacco rattle virus) is only necessary for export to certain destinations.

Climate change may induce the growth of aphids which is an important vector of viruses. This could mean that NAK will check more often on the presence of virus. Hitherto unknown viruses may become a problem as well.

Given that the tropical root knot nematode *Meloidogyne enterolobii* has become a quarantine pest in the EU in 2022, other tropical diseases and pests may become quarantine diseases in the future. Although not specifically mentioned, other fungi and bacteria could cause new diseases as well.

2.2.3 Distribution and storage

As the Netherlands are a net exporter of seed potatoes, efficient distribution and good storage facilities are very important. From the 1980s onwards the whole process of distribution and storage has been optimised. Because of problems with the sprouting of ware potato in 2016, NAK conducted a chain wide project to improve the quality of seed potato. Guidelines have been listed for the seed potato growers, the transporters, and the ware potato growers. These guidelines refer to optimising logistics throughout the whole chain, including good communication during logistics, appropriate moisture and temperature conditions, and careful handling during transport and storage (Crkls, 2024).

To improve the quality of seed tubers, optical readers are increasingly used, particularly to identify small spots of disease infections such as *Phytophthora*. This is important for both domestic and export markets.

In the scope of the reduction of greenhouse emissions, improved storage facilities with lower energy use are relevant. Possibly, this is more relevant for organic as ware potato is harvested earlier in organic than in conventional farming.

Another aspect is the improved dormancy: if seed tubers can be stored longer and at higher temperatures, energy use for cold storage can be reduced. However, these aspects are very complex and regulated by various physiological and genetic factors (Celis-Gamboa, 2002).

2.3 Potato production: conventional - organic

Aspects related to potato production are amongst others soil management, crop rotation, control of pests and diseases, fertilisation, variety type and harvesting time. Much has been written about these aspects in detail, for both conventional (Goffaert et al. 2022) and organic ware (Döring et al. 2018) and seed potato production (Hospers, 1996).

An important difference between conventional and organic potato production is the focus of the management practices on the crop and the whole cropping system, respectively. Table 9 summarises the various aspects and differences in practices, amongst others related to the perspective on soil

management, crop rotation and manuring. In regards to soil, conventional practices often target the controlling pests and diseases whereas in organic practices often aim at optimising soil health. The two approaches also show some similarities: Phytophthora is the most important disease for both systems and in both systems hygiene and inspection on the development of the disease are considered important.

The role potato plays in both farming systems is very different. In conventional arable farming, potato is the most important cash crop, whereas in organic arable farming potato has a lower economic importance as organic farmers tend to have many other cash crops in their crop rotation (Table 3). Because of the economic importance of potato, crop rotations in conventional arable farming are more tight compared to organic, and as a consequence the problems with soil diseases and pests are very different. Organic farmers also need a wider rotation (at minimum 1 time potato in 6 seasons) to manage soil pests and diseases in potato and in other crops. For organic farmers improving soil life and organic matter content are important in order to provide sufficient nutrients during crop growth. In addition to a wider crop rotation, reduced tillage and controlled traffic farming help to improve water holding and drainage capacity of the soil. Some conventional farmers also experiment with these practices.

A clear difference in potato production is that in conventional the main potato harvest takes place in September and October, while organic potato is harvested earlier, mostly between July and September. The availability of Phytophthora resistant varieties allow organic farmers to harvest their crop a few weeks later. Conventional potato has a longer growing season because of the use of late maturing varieties, higher fertilisation levels and the use of fungicides in order to control Phytophthora, together resulting in higher yields.

Because of Phytophthora there has been a focus in organic on early to mid-late potato varieties that require an early availability of nitrogen and other nutrients in the soil. Because of the possibility to control Phytophthora in conventional more late maturing varieties are used which have a different nutrient requirement during the crop growth. Consequently, crop physiology is different in conventional and organic farming.

Levels of fertiliser application are higher in conventional than in organic. In recent years experiments aimed at reducing the levels of nitrogen fertiliser in conventional. High levels of nitrogen can have a negative impact on the plant hormone balance which in turn can negatively impact the uptake of minerals and other nutrients important for plant health (Aardappelwereld 2023). Reducing the use of potassium can contribute to a better balance with other minerals like calcium and magnesium in the plant in turn contributing to better resilience against diseases and pests. Bio-stimulants¹ can contribute to a better root system which in turn improve the uptake of nutrients in the soil. But, this only works when levels of nitrogen and potassium in the soil are not too high. Bio-stimulants can also reduce abiotic stress of plants. Recent results show that both bio-stimulants and timely applications with phosphate can reduce resorption of newly formed tubers (Aardappelwereld 2023).

¹ Bioostumplants are described according to EU regulation 2019/1009 as improving plant growth and development. Two main types of bio-stimulants are described: microbial bio-stimulants such as mycorrhizae and bacteria; and non-microbial biostimulants such as plant and seaweed extracts, humic and fulvic acids, digestates from fresh crops and by-products from the food industry, nutrient polymers, inorganic compounds and salts (Engels, 2022)

In organic, factors to optimise potato crop growth are the sequence of the crop rotation, choice of pre-crop, soil tillage, manuring, controlled traffic systems and pre-sprouting. This is done in an integral approach in which potato is one of several crops that are considered in the whole of the farming. For example, when implementing a controlled traffic system, the machinery for all cultivated crops needs to be adjusted.

Table 9: An overview of aspects related to the cultivation of ware potato for conventional and organic farming.

Aspect	Conventional	Organic
Role of Potato cultivation in the farming system	Specialisation /main cash crop	One of many crops
Focus	Crop	Soil / System
Soil	Substrate to hold nutrients and water	Living organ, soil microbiome, organic matter content, C/N ratio
Soil health	Not made explicit	Much attention / multi facets/ holistic
Soil pests and diseases	Focus on nematodes	Not much of a problem
Crop rotation	Mostly 1:3 or 1:4	1:6 to 1:8
Variety type	Mostly late	Mostly early
Harvesting moment	September October	July August
Green manure	Little	A lot
Nutrient supply	Animal and chemical fertiliser	Animal manure, green manure and leguminous crops
Focus of manuring	Crop	Soil
Maximum N application	About 300 kg/ ha	About 170 kg / ha
Main disease problem	Phytophthora	Phytophthora
Main pest problem	Nematodes	Leatherjackets and wireworms, and Colorado beetle
Problem with potato volunteers	Nematodes	Phytophthora
Solution for potato volunteers	Herbicides	Weeding / Harrowing
Weeds	Herbicides and ridging	Ridging
Fungicides	Yes	No
Bio-stimulants	Yes (crop focused)	No /little (soil focused)
Decision support systems	Yes, increasingly important	Minimal, being developed
Controlled traffic systems	Limited so far	Often
GPS	Yes	Yes
Reduced tillage	Being experimented with	Fully implemented or being experimented with
Strip cropping	No (not yet possible)	Being experimented with
Presprouting	Particularly for early crops	Yes
Hygiene	Yes	Yes
Inspection on diseases	Yes	Yes
Main market	Fries	Table

The above comparison focused on ware potato. There are also differences between conventional ware, seed and starch potato. For example, the cultivation season of ware and starch potato is much longer compared to seed potato. In ware and starch potato high yield is very important whereas in seed potato tuber size is guiding towards a shorter cultivation season (next to higher stem densities). Also, in seed potato it is much more important to keep the crop virus free. As a consequence, insecticide applications are much higher in seed potato (Table 10). In ware production quality for fries production is important, whereas in starch quantity is the guiding factor. These different goals translate into different production styles (personal communication P. Struik, 2023).

Table 10: Use of crop protection chemicals for ware, seed and starch potato, subdivided in several categories, in kg of active substance as dosage per year per ha for 2012, 2016 and 2020 (data from CBS, Dutch Central Bureau for Statistics).

Crop type	Year	2012	2016	2020
	Crop protection chemicals	kg/ha	kg/ha	kg/ha
Ware potato	Total of all categories	11,6	13,4	7,8
	Fungicides and bactericides	6,6	8,6	5,1
	Herbicides and canopy killing	5,1	4	2,1
	Insects and mites	0,3	0,3	1,1
	Plant growth regulation, sprouting inhibitor	0	2,5	2,8
	Other chemicals	0	0,8	0,4
Seed potato	Total of all categories	21,3	20,1	24
	Fungicides and bactericides	7,2	5,6	5
	Herbicides and canopy killing	2,3	2,7	1,8
	Insects and mites	12,1	13	18
	Plant growth regulation, sprouting inhibitor	0	0	0,9
	Other chemicals	0	0,2	0,6
Starch potato	Total of all categories	12,9	12	11,6
	Fungicides and bactericides	12,1	10,1	9,5
	Herbicides and canopy killing	1,3	1,9	1,8
	Insects and mites	0,8	0,2	0,6
	Plant growth regulation, sprouting inhibitor	0	0	
	Other chemicals	0	0,7	

2.3.1 Soil fertility

Approaches to improve soil fertility varies amongst farmers, such as decreasing soil compaction, reduction of fungicide use, using animal manure or compost, sowing green manure, controlled traffic systems, reduced tillage and widening of crop rotations. These practices are more or less standard practice for organic farmers (Table 9). Practices to make their farming more sustainable vary widely among conventional farmers and may also depend on local contexts like soil type and availability of machinery and other inputs.

In the context of climate change, improving soil quality and health is an important challenge (Goffart et al. 2022). Increasing soil organic matter, already part of daily practice in organic, is a way to improve water retention capacity of the soil, important to mitigate the effects of prolonged periods of dry weather. Another advantage of increased soil organic matter is its carbon banking. The use of compost increases levels of organic matter. Compared to conventional farming systems, organic systems have higher microbial biomass with higher activity and efficiency (Fliessbach et al, 2024). Fungicides have been shown to affect soil microbial biomass and activity (Verdenelli et al. 2023). This needs to be further investigated because in conventional potato production high levels of fungicide are used.

Ridging and harvesting have strong negative impact on soil quality in both organic and conventional potato. Wide rotation schemes can help restore soil quality. In organic, rotation schemes up to 8 or even 9 years are used. In conventional, rotation schemes of 1 times potato in 3 seasons are still quite commonly used. Conventional farmers who increase their rotation scheme to 1 in 4 or 5 years see a clear improvement in quality (Peter Keijzer pers. communication 4-7-2024).

2.3.2 Pests and diseases

For both conventional and organic, the main disease is the same: Phytophthora. However, organic and conventional have to deal with Phytophthora differently. Until recently, conventional relied heavily on fungicides. But since 2021 the most popular fungicide Mancozeb (active against Phytophthora) is not allowed anymore. With the new more and virulent types of Phytophthora EU-43 and EU-46 conventional farmers have to use different fungicides to be able to control the disease. Conventional farmers see the availability of pesticides as the main bottleneck to deal with diseases (BO akkerbouw 2023).

As a replacement for the fungicide Mancozeb several companies offer supplements to strengthen the robustness and health of the crop in order to better withstand diseases. Mostly, these supplements need to be sprayed during particular growth stages of the crop. One basic formula is the combination of many minerals. Some of these supplements contain specific minerals like Manganese and Zinc which were also ingredients of Mancozeb. Other supplements, also called bio-stimulants, contain amino acids, plant extracts and micro-nutrients. The number of farmers that use bio-stimulants has increased from 25% in 2021 to 35% in 2023 (BO akkerbouw 2023).

To be able to control Phytophthora, conventional farmers are also advised to use decision supporting models to optimise their spraying schedule (Nieuwe Oogst 2024g). About 50% of the conventional farmers use such models (BO akkerbouw 2023). With the new developments in Phytophthora it is seen as one of the measures of Integrated Crop Management to limit outbreaks of the disease. Table 11 summarises the main measures of Integrated Crop Management in comparison to conventional and organic potato farming (BO akkerbouw 2024b).

Organic has now a range of Phytophthora resistant varieties available that need to find their way to the market: the so called robust varieties. The years 2017 to 2022 had growing seasons with long periods of dry weather, resulting in reduced problems with Phytophthora. The years 2023 and 2024 showed many problems with Phytophthora.

Table 11: Summary of the practices dealing with Phytophthora (from Taskforce Phytophthora Actieplan Plantgezondheid)

Measure	Conventional	Integrated Crop Management	Organic
Crop rotation	Narrow	Balance	Wide
Varieties	High yielding	With improved resistance Healthy seed potato	So-called robust varieties Healthy seed potato
Soil management	Eliminate remnant tubers after harvest and cover rubbish heaps	Eliminate remnant tubers after harvest and cover rubbish heaps	Eliminate remnant tubers after harvest and cover rubbish heaps Improve soil health
Monitoring	High frequency Recommended to use decision support systems	High frequency Important measure are decision support systems, strongly recommended	High frequency Suggested to develop decision support systems for organic
Targeted control	Immediate action: spraying, frequent alternation of chemicals, reduction of drift	Immediate action: spraying, frequent alternation of chemicals, reduction of drift use spot spraying if possible	Immediate action: burning

The robust varieties are also available to conventional farmers. So far, not many conventional farmers use the Phytophthora resistant varieties, but their number is gradually increasing. The majority of these Phytophthora resistant varieties are medium late in maturity time which also means a relatively lower yield potential if grown in conventional farming (Table 12).

Table 12: Overview of relative earliness of potato varieties for conventional and organic farming bred by Agrico that are available in 2024.

	Number and percentage of varieties bred for conventional		Number and percentage of varieties bred for organic	
very early	4	6%	0	0%
early	7	10%	1	9%
middle early	14	20%	2	18%
middle late	27	39%	7	64%
late	17	25%	1	9%
Total	69	100%	11	100%

Other important diseases in both conventional and organic are scab and sclerotinia. It seems Alternaria solanii (early blight) may become more important in the future. It was thought that early blight was not prevalent in conventional potato in the Netherlands, but the fungicide Mancozeb may actually have suppressed Alternaria in conventional potato cultivation.

Similar to Integrated Crop Management to better control Phytophthora in potato, Integrated Nematode Management has been developed to better control nematodes like *M. Chitwoodi* or *M. Fallax* in conventional potato cultivation. In regards to nematodes, organic farmers experience fewer problems than conventional farmers, probably due to wider crop rotation schemes. It is also reported that farmers who converted to organic had fewer problems with rhizoctonia (Nuijten et al. 2020). In organic, through an increase in soil life diversity, antagonists can help suppress diseases.

In the case of the Colorado beetle, conventional farmers can spray. Problems for organic farmers may increase with more favourable temperatures. In collaboration with organic farmers the company Fieldworkers has developed a so-called Colorado beetle catcher (Fieldworkers 2024). Research conducted in Germany suggest mulching can reduce Colorado beetle significantly in regenerative potato cropping systems (Junge et al. 2022). The organic demonstration fields with Phytophthora resistant varieties also showed that some varieties are less susceptible to the Colorado beetle than other varieties. The reason behind it is different levels of alkaloids in the leaves.

The effects of climate change on the development of pests and diseases is difficult to predict, but it is generally expected that climate change will increase problems with pests and diseases, particularly in years with more rainfall. However, farmers had fewer problems with Phytophthora between 2017 and 2022 due to drier summers.

2.3.3 Adoption of modern technologies: machinery, new types of inputs, and new practices

There are continuously improvements in the machinery for planting, weeding, spraying, harvesting, transport and storage. Aims are, amongst others, increasing capacity, improving efficiency, combining tasks and/or reducing damages. New storage technologies focus on energy saving. New sorting technologies, important for farmers who produce for export markets, focus on better quality and optical sorting. In the light of climate change, improvements in irrigation to deal with drought and mechanisation in order to reduce soil compaction will become more important.

Currently, Controlled traffic Farming and various approaches to reduced soil tillage are being implemented and/or experimented, particularly by organic farmers: these are beneficial to soil structure, water retention capacity, soil life and soil organic matter. Consequently, these practices can contribute to crop adaptability to wetter, drier and warmer conditions which are the practical consequences of climate change in the Netherlands. In addition, reduced tillage can contribute to increased organic matter content of the soil, and indirectly contribute to carbon banking. Using green manure during the winter period helps catch nitrogen, potassium and other minerals.

In conventional, there are high expectations of precision farming: adjusting fertiliser and irrigation to more local conditions of the fields, in that way reducing inputs. Another approach can be fertiliser that slowly releases nitrogen. Bio-stimulants may support the effectiveness of fungicides against Phytophthora or to optimise crop growth with reduced fertiliser levels.

In 2023 the company McCain started a project to stimulate regenerative agriculture in the Netherlands. Farmers are facing climate change, extreme weather conditions, increasing sales and production costs and more uncertainty regarding regulations and policy. The framework developed by McCain is an

ecosystems-based approach to improve resilience of the farms and the yield and quality of the crops. The aim is to improve soil health, reduce the impact of synthetic pesticides and increase biodiversity (AGF 2023). Financial support to farmers is provided through a three year partnership with Rabobank.

With the prohibiting of various chemical pesticides, plant based fungicides and pesticides can be an option. For example, Chitosan hydrochloride is said to have a positive effect on disease resistance of crops and a microbial toxic effect of fungi and bacteria. It is approved by the label On the way to PlanetProof and by the organic certification body SKAL so also applicable in organic.

Integrated Crop Management

The concept of integrated crop management proposed by BO akkerbouw to work with in the Netherlands includes crop rotation, variety choice and cultivation methods, soil management, monitoring and evaluation and targeted disease management (Riemens and Molendijk, 2022). It includes new developments such as CRISPR-cas, robotics, and precision farming.

Organic

For organic, various new developments are ongoing. New machinery has been developed to pull up the haulm/canopy instead of burning the canopy before harvesting. This also reduces the chances of Phytophthora getting into the tubers. Machinery has also been developed to brush the Colorado beetles off the leaves and then to collect them as they fall.

2.3.4 Harvest and post-harvest management: storage

To mitigate the effects of climate change, improved storage facilities are very important, in particular to lengthen the dormancy of the produce. This is largely the same for conventional and organic farmers, although the volumes in organic are much smaller but need to be stored longer as the time of harvesting is often earlier.

The permission to use chemicals to inhibit sprout development in conventional is recently limited and may be more limited in the future. In organic natural compounds are used to inhibit sprouting: the product carvon, which also reduces the growth of fungi like silver scab (*Helminthosporium solani*). Talent is a carvon-based growth regulator to inhibit sprouting during storage, but can also be used in seed potato cultivation to inhibit the main sprout development, resulting in side-tillers to grow and, depending on the variety, more tubers per plant. Talent is allowed in both conventional and organic. Natural sprouting inhibitors allow higher flexibility in the sales.

2.3.5 Production costs and profitability

Both conventional and organic growers experience a big challenge in making potato growing profitable. For conventional farmers the main issue is overproduction, which is a problem for many decades already, associated with price fluctuations from 30 euro/ton to 250 euro/ton (Goffart et al. 2022). In 2012 the NAV mentioned that prices will improve when total production in the EU would drop with 10 to 15% . The NAV estimates annual production costs for 2022 to be 16 to 20 cents per kilo at a yield of

50 tons/ha, which implies a minimum price per kg of 18 to 24 cents when including a profit margin of 15%. They indicated that an increase of 4 cents per kg is needed in potato contracts due to increased production costs (mainly energy). The main options farmers have to reduce production costs are reductions in seed costs, pesticide use and land rental costs (Goffart et al. 2022). Recently a new production cost calculator (kostprijscalculator) has been developed by the new organisation Producer Organisation Consumption potato (POC). It is a tool that helps farmers to calculate the actual costs for potato on their farm. The tool has been developed on initiative of the POC, in collaboration with the accountants Flynth, Countus and Alfa, extension service Delphy, the bank ABN Amro and farmer representing organisations LTO en NAV (Nieuwe Oogst 2024c). The foundation Hagelunie has provided resources to keep the tool up to date for the coming five years.

For organic farmers there are several challenges to the profitability of potato cultivation. Till 2016, yield uncertainty due to Phytophthora in combination with imports by the supermarkets was an important issue, which was largely solved with the development of a range of table potato varieties with good Phytophthora resistance and a covenant that improved collaboration among organic farmers, supermarkets and breeding-and-seed companies. An improvement in the demand side is that supermarkets like Lidl and Plus aim to only sell organic potato. Predictability on the supply side proved to be more difficult with the high Phytophthora pressure in 2023 and 2024. It is expected that the demand side in organic will improve once there are more varieties available that can be processed. However, the number of varieties suitable for processing is still limited for organic.

In regards to conventional starch potato, the Avebe cooperative published in 2021 that they paid 93.30 euro / ton, which they considered a good price given an increase in production in other countries. They aim for 100 euro /ton in 2024.

Both conventional and organic farmers have three options to sell their potato crop: 1) on the free market, which is only profitable if the potato crop can be stored well, which depends very much on growing conditions and thus not predictable 2) through cooperatives, and 3) through contracts. In options 2 and 3 it is possible to work with 'pools' in which farmers share risk (Smit et al. 2006). Nowadays, most potato is sold through pools. However, a recent price comparison over the period 2017-2023 showed that on average selling the potato crop on the free market is more profitable and that in this particular period contracts meant a small net loss for farmers (Kik et al. 2024).

For both the conventional and organic sector improving margins is very important and a challenge. This is particularly important given the recent increases in price for a range of inputs. In 2019, a study by Litjens showed that one approach to achieve better market prices is by bundling forces through setting up producer organisations. Recently adjusted regulations at EU level provide new opportunities for setting up such producer organisations. This could be particularly relevant for French fries potato producers.

Another indirect challenge is the increase in trade tensions across the world (Goffart et al. 2022). Both conventional and organic potato cultivation is much export oriented and any form of import barrier affecting potato could have a large impact. An additional challenge for organic is an increased demand for locally grown potato in other European countries.

2.4 Marketing and value addition: conventional – organic

Total ware production was 3,7 million tons in 2020, of which according to the NAO 0,7 million ton was exported fresh. The six members of VAVI processed 4 million tons into French fries, chips and other products, for which they used 65% of Dutch ware potato, i.e. 2,6 million tons (VAVI 2022). These data show that processed potato, in particular French fries, shapes the conventional potato production chain. Each processing company has its own laboratory to constantly improve and develop new products and adjust them to particular value chains worldwide. Preferences in looks and bite of the French fries change over time and new combinations of ingredients are tested to find the optimal French fries (VMT 2023).

The conventional potato sector is traditionally export oriented, particularly in processed potato and seed. The NAO keeps track of export figures for the following two categories: 1) seed and 2) ware and starch combined. The last few years showed a slight decline in both ware and seed potato because other countries are improving their domestic production (Van Loon 2019). A related challenge is the increased trade tension across the world (Goffart et al. 2022).

In relation to fresh table potato, value addition comes in two ways: 1) through packaging washed potato in small appealing package units (of 1 or 2 kg), geared towards small households, 2) through ready-to-use packages, by peeling the potatoes, cutting them in small parts, and adding herbs. Varieties with high tuber number and small tuber size are being developed for this purpose.

Another small segment is the sale of specialty varieties, often old well-known varieties which are known for their good taste like Bildstar, Eigenheimer, Frieslander and Doré. Although in the past table potato was sold by the variety name, today most potato is sold by cooking type. It is expected that coloured potatoes will become another niche market (Van Loon 2019).

2.4.1 Certificates

Potentially certificates should improve sustainability and quality of the farm produce. The use of the label 'On the way to PlanetProof' is showing an increase. It is currently used for approximately 8000 ha of ware potato are certified with this label (Planetproof, 2023), representing around 10% of the total ware production. A survey among 162 arable farmers showed that most farmers that signed up to the label hope to achieve better prices or better market access and only 7,8% of the farmers is motivated because of sustainability reasons (Foodlog 2020). Around 33% said to have changed their thinking and practices. Respondents of the survey also wondered what the added value is in addition to GlobalG.A.P. (Trademark and Set of Standards for Good Agricultural Practices) which is a private set of standards for trade and processing. Like GlobalG.A.P. the label 'On the way to PlanetProof' means more administration. But GlobalG.A.P. has the advantage that it is international standard and hence should be preferred (Foodlog 2020).

Organic potato has its own organic label following EU-regulations. Organic farmers who want to export their produce need to consider the requirements of organic labels in other countries. For those organic farmers who had to sell their produce on the conventional market the PlanetProof label has proven to be a hurdle, even though the norms for organic are stricter than those of the PlanetProof label. For organic farmers the GlobalG.A.P. also means additional administrative burden as organic farmers do not use chemical pesticides.

2.4.2 Aggregation and distribution -storage

Aggregation and distribution potatoes involves a range of value chain actors. Wholesalers play an important coordinating role in the aggregation and distribution of seed and ware. They keep track of the volumes, the quality, and the type of variety in storage by farmers in order to organise efficient transport to washing stations, packagers and processors (Smit et al. 2008). Whereas the ware processing industry is dominated by six processing companies and only a few varieties are used, a much larger number of varieties are used for table potato for a wide range of different products resulting in a web of many different sub value chains. In the case of starch potato, the processing industry organises aggregation and distribution and only a few varieties are used, making the logistics relatively easy.

The last decades showed a further concentration and increase in specialisation in storage. This is a consequence of responding to the market as longer storage usually means fetching higher prices for their products. In particular the number of potato growers dropped significantly, from around 40,000 farmers in the early 1970 to less than 10,000 in 2020. The further decline in the last decades can be explained by the need for improved storage conditions and the associated investments in it. Good storage is important in order to sell potato year round and potentially profit from good prices during the season.

The market developments in the 1980s and 1990s, e.g. a shift from a supplier market to a buyer market, had profound impact on the character of competition and cooperation among wholesalers and processors (Rademakers and McKnight, 1998). Hak described that since the 1960s the market of processed potato increased rapidly and became the dominant segment in ware potato that can be attributed to several changes:

- Increase in numbers of fridges owned by consumers
- Increase in demand of convenience food by consumers
- Increase in French fries and chips as snacks
- The consumer need to have more variety in potato products
- Creation of the need for processed potato
- Increase of tourism which want recognisable food

The Netherlands achieved a leading position in potato processing (Hak, 1998) and is able to compete with the US potato processing industry (Rademakers and McKnight, 1998). In order to address the needs of their customers, e.g.. supermarkets chains and fast food chains), in particular the few remaining processing companies developed effective ways of cooperation to meet the peak demands of their customers (Rademakers and McKnight, 1998). Currently, supermarkets implement long term planning regarding the acquisition of fresh potato – with long term planning of dates changing from domestic production to import and back - and it seems plausible that the supermarkets can respond efficiently to market changes related to climate change.

For all segment of potato production, innovation processes are constantly ongoing to develop new machinery and improved automation processes to make storage and distribution more efficient. This is particularly the case for large scale storage and distribution processes.

Organic

In the case of the processing industry, the highly efficient organisation of the supply chain hampers developments in the processing of organic potato (Smit et al. 2006). The table potato market which is much more differentiated has fewer hurdles for a more active organic table potato sector.

Given the slower turnover in organic shops, it can be expected that there is more waste in organic compared to conventional. Another disadvantaging factor for organic potato may be the high market standards for the potato skin, and that organic farmers have fewer means to deal with diseases that affect the skin like rhizoctonia or insects like leatherjackets and wireworms.

2.4.3 Processing-varieties, quality, consistency

Below the focus is on ware processed potato. The processing industry is still expanding and the demand for potato still grows (Nieuwe Oogst 2024d). Quality and consistency in quality are very important for efficient processing, e.g. it decreases the need to adjust machinery settings during processing. As a result the number of varieties suitable for processing are limited. As climate change is expected to affect yield and quality differently because of the varying weather conditions in different years, climate change may have much bigger impact on processing potato compared to the table potato as the quality standards for processing potato are much stricter/well defined and narrower compared to table potato. Farmers are used to the fact that processors and traders adjust/lower quality standards in times of shortage. Some farmers think this seems unfair but they also know this is standard practice (Nuijten and Almekinders 2025b). The big processing companies, together with breeders, collectively fund research to better understand the factors affecting yield and quality in the scope of climate change (see more under research agenda in section 3.2).

In the past decades, processing companies have developed approaches to reduce costs, and that indirectly also contribute to minimise waste and energy use. Today, in the light of climate change, reducing CO₂ output is very important and the aim is to become climate neutral in the future (VAVI, 2022; Avebe 2022). New developments in machinery are also meant to automate processing further and to reduce personnel costs.

New directions in processing still under development are 3D printing, aimed towards easier eating for elderly people, and the use of potato in ice cream (for vegan ice cream).

Organic

Compared to table potato, organic processed potato (e.g. fries and chips) makes up a relatively small part of the market. One reason is that consumers buying organic buy less processed potato as compared to other consumers. The other reason is the lack of good robust varieties for organic that meet the high quality criteria for processing, although there may be some promising varieties in the pipeline. Another aspect is that the big processing plants are not well equipped for the relatively small volumes of organic potato of which processing qualities and quantities are variable and difficult to predict.

2.4.4 Retail market: biggest outlet and niche consumer markets

Compared to the ware processing industry, it is expected that the retail market will be less affected by climate change because of the larger choice of varieties and the lower quality demands compared to processed potato. However, given that the margins in the retail market are small, there is also a certain inflexibility in the retail to work with new or other varieties. The organic sector has already experienced a certain level of 'inflexibility' in the retail market when it comes to working with newly developed Phytophthora resistant varieties.

In order to increase margins, retail is oriented more and more towards semi-processed potato, like microwave or oven ready steamers and roasters with different types of herbs, or different shapes and sizes of potato chunks for different purposes. Another innovation is the introduction of a fast cooking type that only needs 12 minutes of boiling to be ready to eat, like the cultivar Jazzy developed by Meijer. The most recent innovations in the retail market are oriented towards health like low-carb fries and low calorie table potatoes marketed under the brandname Sunlite (HZPC 2024).

Whereas in the past 5 kg bags were commonly found in the supermarket, today table potato is packaged in 1 to 3 kg bags. Processed potato is often found in packages smaller than 1 kg. Product price is not only determined by the product (quantity of potato), but much more the type of packaging and product placement.

Still, a small number of varieties that are known for good taste (like Nicola, Eigenheimer, Doré and Bildstar) are sold through their variety name. They are often sold unwashed and unpackaged on open markets. Traditionally, consumers knew that each variety was fit for particular uses and potato was sold via the variety name. This knowledge is disappearing quickly.

Another change that the retail market introduced is to package potato in bags according to a specific end use, i.e. baking, fast-cooking, fries, mash, etc., even though many varieties can be used for a range of different purposes. As a result, the same variety can be found in bags for different end uses. The explanation given for this trend is that young consumers do not have the knowledge anymore how to prepare potato.

However, the bulk of the table potato is still sold in two main categories: firm boiling and crumbly; varieties are still described accordingly (A = very firm, B = firm, C = crumbly, and D very crumbly). Most varieties fall in the categories B and BC. Type A is meant for salad and Type D is suited for mash.

In the case of organic, it is foreseen that when quantities in sales grow, also this market can become more profitable for processed or semi-processed potato. Potentially, in the future, robust varieties could provide a marketing opportunity.

2.5 Advice and knowledge transfer

Traditionally, a strong collaboration between education, extension and research is considered essential for good knowledge transfer. Whereas in the past extension was a government task, extension has become privatised. Today, a fourth component is considered essential: entrepreneurship.

Conventional farmers see independent advisors (45%) as their most important partners in making their cultivation more sustainable, followed by advisors of companies selling chemicals (29%) (BO akkerbouw

2023). Many farmers have organised themselves in study clubs and/or associations to improve access to knowledge, by learning together through discussions, invite knowledge brokers in meetings, and to organise projects with research organisations and other organisations.

On a yearly or biyearly basis open days are organised by both non-commercial and commercial actors that show new developments in potato farming, such as new machinery (for growing potato, harvesting, transport and storage), inputs (fertilisers, pesticides and bio-stimulants) and new varieties. These open days are co-organised with and hosted at research farms that are part of the public sector research system. There are also variety days organised by the breeding-and-seed companies that are not open to all public.

2.5.1 Non-commercial advisory services (governmental and NGOs)

In the Netherlands, governmental extension services used to provide advice. Today only private organisations exist (see below). A new non-profit organisation is VTA (Verenigde Telers Akkerbouw). It provides information about market developments and prices, aims to make the market more transparent, organises better prices for farmers and lobbies for better trade requirements (VTA 2023). VTA is member of the internationally operating organisation NEPG (Northwestern European Potato Growers Foundation) which describes itself as a non-political foundation: “an exchange platform for market information in the North-Western consumption supply chain” (NEPG 2023)

Universities and NGOs such as the Louis Bolk Institute and CLM may provide advice for free to farmers in the cases that they participate in research projects financed through subsidies. At the WUR-research farm Westmaas potato demo days (aardappeldemodag) are organised biannually. On these days a wide variety of services, input providers and research is present (Table 13).

In the case of organic potato farming, organic field days (Biovelddagen) focus also on the developments in new potato varieties with improved *Phytophthora* resistance (the so-called robust varieties).

Table 13 shows that there is little overlap in the companies that are involved in the potato demo days and the organic field days. Only seven organisations are present at both days which are machine builders, a potato breeding company and the research institute WUR that facilitates both days. The demonstrations with potato varieties is a case in point: whereas at the organic field day *Phytophthora* resistant varieties were presented in various ways, at the potato day the main varieties were presented in combination with various fungicide applications. At both days companies in the category mechanisation are the most represented. The focus of both days is somewhat different, which makes a detailed comparison difficult, e.g. the potato demo day focuses on potato only, whereas the organic field day has a broader focus, namely organic farming. At the organic field day two categories were present more compared to the potato demo day: companies involved in advice and research, and organisations involved in the representation of farmer interests.

Table 13: enterprises present at the potato demo day and organic field day in 2024 organised in categories

Category	Potato demo day		Organic field day		Present both days
Mechanisation	23	20%	19	37%	5
Advice and Research	3	3%	9	17%	1
Breeding and planting material	8	7%	6	12%	1
Data management & artificial intelligence	7	6%	4	8%	0
Fertilisation	11	9%	2	4%	0
Representation of farmer interests	2	2%	5	10%	0
Crop protection	11	9%	1	2%	0
Sorting and packaging	11	9%	0	0%	0
Accounting and insurance	9	8%	0	0%	0
Trade	4	3%	2	4%	0
Other categories (8 and 4 respectively)	28	24%	4	8%	0
total number of categories	18		12		
Total number of organisations	117	100%	52	100%	7

2.5.2 Commercial actors (input suppliers, buyers, traders, other)

Today, input suppliers, breeders and potato traders have a strong position in providing advice to farmers of ware, seed and starch potato in the Netherlands (Table 13). Processing companies have their own advisory services providing knowledge about cultivation practices and the most suitable varieties. For input suppliers, giving advice is strongly linked to selling products. The most common inputs in conventional agriculture are chemical fertilisers and pesticides. As these are not allowed in organic, input suppliers try to sell natural products that can improve the soil, consisting of either minerals or fungi and bacteria. As so-called knowledge partners, input suppliers like Agrifirm, Bayer or Van Iperen also publish articles in farmer journals like Nieuwe Oogst or Boerenbusiness.

In the case of both conventional and organic potato farming, traders and other buyers have a strong say in what crop varieties to grow. In the case of potato, this is particularly the case of processing as the cultivated varieties need to meet certain processing quality criteria.

A new field in advisory services is data-driven cultivation models. Models have also been developed to optimise spraying against Phytophthora. Some of these models have been developed by WUR and consequently updated by commercial actors like Agrifirm. Other models have been developed by companies specialised in data management and modelling like CropX. This prediction model integrates various factors, such as the current weather conditions, weather forecast, growth of the potato crop, measurements of soil moisture and temperature, wind velocity and the history of applied sprayings.

There are also advisory services that do not sell inputs. CLM, Delphy and DLV Advies are advisory and research services that cover a broad range of topics, including potato. They provide advice to both conventional and organic farmers and collaborate with a broad range actors such as input suppliers, traders, research farms and research institutes. Delphy also has a team that works on organic

agriculture. In organic, a new player is Ceres Horti Advice who previously worked for Delphy on organic agriculture.

Organic

As organic farmers use fewer inputs compared to conventional farmers, they have fewer parties that can give them advice. It can also be argued that advice to organic farmers needs to be more tailor-made because of the differences in farming practices between organic farmers and the higher level complexity of their farming, e.g. because of differences in crops grown, rotation schemes, soil management, manuring, etc. Because of the interconnectedness of all these aspects, organic farmers need advice rather at farm systems level than at a specific crop level.

Climate change

The high levels of rainfall in 2023 and the first half of 2024 were ideal conditions for Phytophthora and alarmed the whole potato sector, both conventional and organic. The weather conditions also made differences in growth between potato fields more visible. Differences in growth were attributed to differences in soil management practices and soil quality. For some (mostly organic farmers) organic farming is considered an example to deal with climate change. However, others say organic potato farming needs to be stopped to save future options for conventional farming, in particular the use of robust Phytophthora resistant varieties.

2.6 Legal and regulatory environment: conventional – organic

2.6.1 Policies: government, regional bodies (EU, African) and global ones (WTO, Worldbank)

Policy regarding climate change

Research showed that fresh water shortage in the short term is the most urgent problem in order for the Netherlands to adapt to climate change, apart from increase in rainfall, temperature and sea level increase (Deltaprogramma 2024). Winters become wetter and summers become drier. For agriculture this shortage will have important consequences. Most fresh water is used to minimise salinisation in the coastal provinces and expected is that there are limits to the pushback of salt water. This is also important for agriculture. Also other water uses increase, such as the need for irrigation in agriculture, the use of drinking water, and in nature where the wetting of low peat areas will demand much water to decrease the decline in soil level and the CO₂ emissions.

The years 2018 and 2022 showed that water shortages were difficult for farmers to deal with. Many farmers were not allowed to irrigate their crops (Nieuwe Oogst 2024f). To improve the availability of fresh water measures need to be taken such as: decrease in the use of fresh water, increase ground water tables, more water in the IJsselmeer, and improve soil quality. For conventional potato farmers

this might mean adopting soil management practices that are good for the long term but may have negative financial consequences in the short term. The question is also whether the late harvesting window important in conventional to achieve high yields will remain possible. Already there are regulations that crops need to be harvested before 1 October.

Policy regarding agriculture

The Dutch government does not have a specific research agenda for potato (nor conventional or organic). In general, it has indicated to make agriculture 'future proof' by making it more sustainable and environment friendly. In 2018, the Ministry of Agriculture published a new plan of action titled 'circular agriculture'. Important underlying idea is making agriculture more sustainable but not to reduce agricultural output. A 9-page summary describes how to do that (LNV, 2018). The focus points of 'bringing circular agriculture in practice are:

- Improving soils and water quality
- Reducing emissions and pollutants
- Closing nutrient cycles
- Collaboration at regional level
- Collaboration along the agriculture and food supply chain

The EU recognises the need for these focus points and that research on soil management practices can help address these issues and at the same time maintain high productivity levels (EU, 2020). The identified policy efforts to support circular agriculture are to:

- Promote precision agriculture and farm innovations
- Create more possibilities for experimentation
- Focus Common Agricultural Policy on vision targets
- Utilise public land
- Promote re-usage of food nutrients, a.o. by adapting regulations
- Reward sustainable farming practices
- Support short supply chains

In 2020, the Ministry of Agriculture developed a set of 'Critical Performance Indicators' to provide clarity about the sustainable performance expected of entrepreneurs and how to get rewarded for that. Value chain actors, consumers and government all have a responsibility. The Ministry of Agriculture has identified a budget of 175 million to make the change to a future proof agriculture over the period 2020-2023. In Dutch the so-called 'Contouren van het Omschakelprogramma Duurzame Landbouw' (Kamerbrief 2019). This entails the change to a reduction in the use of nitrogen, amongst others possible through more extensive or sustainable farming methods, organic agriculture and nature inclusive agriculture. Since then, there has been a lot of debate regarding these topics. In general, the critique is that more needs to be done. Currently, the three main goals are (LNV, 2022):

- Increase of sustainable agricultural production
- Prepare agriculture for the effects of climate change
- Reduction of greenhouse gases

The so-called Omschakelprogramma Duurzame Landbouw also included other arrangements such as, the subsidy for agrarian entrepreneurial advice and education. In 2023 the program Investeringsfonds Duurzame Landbouw is prolonged and will have a more permanent character. The investment fund entails 140 million euro and is meant for dairy, arable and intensive animal farming (Nieuwe Oogst 2024e).

Policy related to organic agriculture

Although some of the above policy goals seem positive for organic agriculture, the Dutch organic sector advocated in 2021 for a national research plan for organic agriculture. (Bionext, 2021). The EU commission intends to increase the share of research and innovation (R&I) and dedicate at least 30% of the budget for research and innovation actions in the field of agriculture, forestry and rural areas to topics specific to or relevant for the organic sector (EU 2021).

The Dutch area under organic farming (4,8% in 2023) is low compared to the average in the EU (10,4% in 2023). However, the Netherlands do not use any CAP (Common Agricultural Policy) support to stimulate the conversion to organic (EU, 2020). In addition, no national target or strategy exists in the Netherlands to increase the area under organic farming (EU, 2020), even though the government recognised that, although there are differences between sectors, organic agriculture outperforms conventional agriculture on many aspects of sustainability (LNV 2005).

As organic farming is recognised as environmentally friendly, the current EU Farm-to-Fork strategy aims to increase the organic farming area in the EU to 25% of the total farmland by 2030 (EUa, 2020). The overall aims of the Farm-to-Fork Strategy are to accelerate our transition to a sustainable food system that should:

- have a neutral or positive environmental impact
- help to mitigate climate change and adapt to its impacts
- reverse the loss of biodiversity
- ensure food security, nutrition and public health, making sure that everyone has access to sufficient, safe, nutritious, sustainable food
- preserve affordability of food while generating fairer economic returns, fostering competitiveness of the EU supply sector and promoting fair trade

Accordingly, in December 2022 the Dutch Government published an action plan to stimulate the growth of organic production and consumption to 15% in 2030. The action plan recognises that organic agriculture can play an important role in the transition to a more sustainable and future proof agriculture in the Netherlands (LNV 2022b). The action plan is considered a point of departure for collaboration with value chain actors. This action plan is based on the EU Organic Action Plan. It is part of the European Green Deal and the Farm-to-Fork strategy. Both aim for agriculture to become climate neutral in 2050. Organic farmers are considered to be the front runners of the sustainable agricultural transition, because organic production contributes to many challenges such as climate, nature, animal welfare, water, soil and health. The three main goals of the action plan are:

- 1) More organic consumption and a bigger market, with the following sub goals:
 - Organic products become more familiar

- Increase in sales channels
- Better price for farmer and consumer

2) Increase organic production, with the following sub goals:

- Maintain and expand production
- Stimulate conversion to organic production
- Continuation of existing organic production
- Involvement and input from the value chain
- Access to suitable and affordable land
- Remain distinguishable in terms of sustainability

3) More knowledge and innovation, with the following sub goals:

- Research
 - o Knowledge agenda organic
 - o Knowledge development
- Learning together
 - o Knowledge distribution and education
- Continuous innovation

2.6.2 Relevant regulations: seed laws, plant breeders rights, reductions in input use, more sustainable farming practices

The Commission recommendations for The Netherlands' CAP strategic plan invites The Netherlands to set explicit national values for the Green Deal targets, more specifically “related to use and risk of pesticides, sales of antimicrobials, nutrient loss, area under organic farming, high diversity landscape features and access to fast broadband internet”. Regarding climate change the Commission also recommends “to address the volatility of farm income, risk management tools, which can also play an important role in fostering the resilience of agriculture relating to climate change, should be promoted” (EU, 2020).

In order to “bolster environmental care and climate action and contribute to the environmental- and climate-related objectives of the Union. Greenhouse gas(GHG) emissions require more and stricter measures in the agricultural sector to achieve the goals set out in the Paris Agreement. Emissions of GHG in Dutch agriculture have stabilised in the past 10 years and are currently the highest in the EU” (EU, 2020). In this context, the recommendations also mention the improvement of water quality, reduction of run-off of nutrients, reduction in the use of inorganic fertilisers and manure, and preservation of biodiversity (EU, 2020). The recommendations also mention “To help advance the EU Green Deal, a more integrated policy is needed that combines soil management and nutrient policy, manure management, climate mitigation, biodiversity and landscapes in the Netherlands.” (EU, 2020).

“Given the benefits of organic farming, for e.g. soil quality, and its positive effect on reducing the use of chemical pesticides and inorganic fertilisers, increasing the organic area in the Netherlands would contribute to a more sustainable food production system....To maintain profitability of organic farming, efforts should be made to stimulate the demand for organic products in order to balance the increase in supply.” (EU, 2020).“The intensive use of rural areas by agriculture has resulted in lowered ground water tables by lowering surface water levels (especially in peatlands) and measures to speed up the transport

of surface water out of the capillaries of the sub systems (especially in the sandy areas) by draining land and canalisation of streams and rivers. The sponge-function of rural areas has been reduced considerably. Climate change means that the Netherlands is expected to be warmer and wetter, with more frequent summer droughts and a rising sea level. Many of these challenges are already being felt. Severe droughts have led to considerable economic damage in the last 3 years. (EU, 2020)”

Potato production may be affected by various EU regulations that aim to reduce environmental impacts through reductions in the use of fertiliser and chemical pesticides in the context of the Green Deal and the Farm-to-Fork strategy. Examples are the recent prohibitions of the use of chemicals like the fungicide mancozeb (against *Phytophthora*) as of February 2021 and the herbicide chlorpropham (CIPC) that was used as a sprout suppressant (as of January 2020). Both chemicals were considered important in conventional potato growing as they were cheap, effective and easy to use.

In 2018, the European court of law stated that new genomic techniques need to be considered as methods of genetic modification. Given the new developments for genetic modification, the so-called new genomic techniques, the EU started a procedure to merge about 10 seed directives into a new EU seed regulation. Currently, a consultation is on-going. The Dutch government strongly supports the process to change European directives and regulations in order to allow the use of new genomic techniques (NGTs) in conventional plant breeding.

Organic agriculture

At the level of EU regulations, new policy develops over time that the Dutch government needs to follow and translate into national law and policy if applicable. Since January 2022, the new organic regulation (2018/848) entered into force. It allows, amongst others, the registration and use of organically bred varieties with higher levels of genetic diversity and organic heterogeneous material. The underlying idea is that more genetic diversity within crops provides more buffering potential (Weedon et al. 2023). As potato is propagated clonally, it is not expected to impact potato cultivation and breeding either positively or negatively.

Regarding the use of new genomic techniques, the IFOAM General Assembly approved a position paper in 2017 that states that new genomic techniques are considered GMO and do not fit with the principles of organic agriculture (IFOAM 2017).

3. Research agenda: conventional - organic

In the following sections the development of the research agenda for both conventional and organic are described at various levels.

3.1 Research agenda setting

As potato is an important crop in Dutch agriculture, the research agenda setting at both national and European level are relevant. At the national level many value chain actors influence the research agenda. This is done through umbrella organisations (like NAO, VAVI, LTO, NAV and BO akkerbouw) and directly through the bigger potato processors and breeders that influence the umbrella organisations. Other organisations such as WUR, Plantum, Europatat and SeedNL are involved as well. The WUR also has a Wageningen Potato Centre (WPC) which has as mission “To explore the potential of the potato and to improve its supply chain” (WPC 2025). It provides a platform for collaboration in fundamental and applied research for its approximately 35 partners, mostly breeders, input suppliers, machine builders, processors, and a number of research organisations in Belgium. In addition it aims to strengthen networking.

How these organisations together shape the research agenda is formulated exactly is difficult to determine. In section 2.5 it was mentioned that a strength of Dutch agriculture is that research, education, extension and the corporate sector are tightly interwoven resulting in very efficient interaction.

When it comes to interactions between the ministry of agriculture and the umbrella organisations, there is a strong preference of the ministry that contacts with the umbrella organisations go via a limited number of contact persons to make communication efficient. As a result, the biggest farmer organisation LTO voices the point of view of their conventional members and not that of their organic members. Generally speaking, the various spokesmen who represent the organic sector have the impression little is done with their wishes and input. To them it is clear that the demands of the conventional sector overrule the demands of the organic sector. Put differently, the demands of the organic sector can only be accommodated if they are in line with the conventional sector. As a result, occasionally attempts are made to influence the research agenda via the Dutch parliament. An example is the Bioimpuls project (see further below).

Below the various official institutions are described that apart from shaping the research agenda also provide funding for research.

3.1.1 Topsectoren

Since 2011 the so-called organisation Topsectoren (top sectors www.topsectoren.nl), which falls under the Ministry of Economic Affairs, was created to stimulate innovation. In total 10 top sectors have been formed in which representatives of companies, science and government work together to support innovation and share knowledge (Topsectoren 2024). Regarding agriculture two agriculture-related top sectors have been formed Agri & Food and Tuinbouw & Uitgangsmaterialen (Horticulture and Plant and seed materials). The topsectors consist of a mix of big companies, medium and small companies, start-ups and scale-ups (Topsectoren 2024).

The so-called Topconsortia for Knowledge and Innovation (TKI) conduct fundamental research, industrial research, experimental development or a combination thereof. TKI Agri & Food has described 6 missions to coordinate research (Topsectoragrifood 2024). The missions do not specifically address crops, but do address climate mitigation and adaptation. Of the six missions, the mission 'Agri- and horticulture' mentions the word climate most often (35 out of 3193 words) whereas the mission 'Food' mentions climate only 3 times out of 3418 words. None of these six missions made a specific reference to organic agriculture.

The topsectors Agri & Food and Tuinbouw & Uitgangsmaterialen (Horticulture and Seed materials) have written a letter that policy plans (a so-called 'witboek') developed by the Ministry of Agriculture that includes ways to interweave agriculture and nature do not correspond with their innovation agenda (Trouw, 2024). Also the new Minister of Agriculture as of 1-7-2024 deems a transition in agriculture not necessary (Trouw, 2024).

3.1.2 BO-akkerbouw

BO akkerbouw describes itself as 'Interbranch Organisation Arable Crops'. It has 14 members that represent enterprises that are active in the Dutch arable value chain (the members are: Agrifirm, Royal Avebe, Bioplant, Het Comité van Graanhandelaren, FarmPlus, Royal Cosun, Van Iperen, LTO Nederland, Nederlands Agrarisch Jongeren Kontakt (NAJK), Nederlandse Aardappel Organisatie (NAO), Nederlandse Akkerbouw Vakbond (NAV), Nederlandse Groenten- en Fruitverwerkende Industrie (VIGEF), Plantum NL and Vereniging voor de Aardappelverwerkende Industrie (VAVI). The organic umbrella organisation Bioplant has become member in April 2024. It has published a vision for the period 2017-2030 in a report titled 'Healthy plants for a healthy future' with the subtitle Action plan plant health. The aim is "to develop a resilient cultivation system with healthy and robust plants and a healthy soil, using state-of-the-art information technology. Our main focus will be to minimise environmental impact, develop climate objectives, and strengthen biodiversity, whilst engaging in profitable operations" (BO akkerbouw 2018). Aims are to work together with retail, society and knowledge institutes. From the government an enabling policy is sought (BO akkerbouw 2018). The plan aims to foster more sustainable cultivation methods through achieving a change in behaviour of farmers (BO akkerbouw 2023).

3.1.3 Research agenda setting for organic

Regarding research agenda setting for organic potato, organisations like Bionext, Biohuis, Bioplant and the Louis Bolk Institute are responsible actors at the national level. Bionext is the umbrella organisation for the whole of the Dutch organic sector. Through Bionext, Biohuis and Bioplant are member of IFOAM Organics Europe (a regional sub organisation of IFOAM Organics International, IFOAM stands for International Federation of Organic Agricultural Movements). Biohuis represents the Dutch organic farmers and vegetable growers. Biohuis collaborates with the farmer umbrella organisation LTO at the National and regional level. At European level Biohuis is also member of the farmer organisation Copa Cogena to voice the interests of organic farmers in European policy making (Biohuis 2024). In 2022 Biohuis has presented a 10-punten Groenboerenplan (10 points green farmer plan), together with the farmer organisations Federatie van Agro-ecologische Boeren (BD-Vereniging, Bio-Tuinders Vereniging, Bio-Vegan Netwerk, CSA Netwerk Nederland, Vereniging Toekomstboeren), Caring Farmers en

Herenboeren Nederland. The plan calls for sustainable agriculture without harmful pesticides, chemical fertiliser and much less dairy. The plan is supported by 362 organisations (groenboerenplan 2024).

Bioplant is part of Biohuis and represents 250 organic arable farmers,. Bioplant was set up to coordinate the demands of the five regional organisations that together make up Bioplant. Through Bioplant, arable farmers are able to better influence policy at national and regional level. In April 2024, the organic farmer organisation Bioplant has become member of BO akkerbouw.

3.2 Research support

In the Netherlands, the government currently predominantly funds research through public-private partnerships. The default is that private organisations have to contribute 50%. There are exceptions where the private sector only needs to contribute 30% if provinces contribute 20%, or if NPLG goals are met the private sector only needs to contribute 10%. NPLG stands for Nationaal Programma Landelijk Gebied (National Program Rural Areas). Provinces work together with government and local partners on the goals for climate, water, nitrogen and nature (Rijksoverheid 2024). To reach these goals a transition towards a more sustainable agriculture is necessary (Rijksoverheid 2024).

In order to have significant amounts of funds for research, only large companies can apply for public funding. Regarding potato, it means that only breeding companies and processing companies are big enough to form consortia in order to obtain substantial amounts of public funding. Organisations representing farmers like LTO and NAV can lobby for research priorities, but do not have substantial amounts of money to fund research.

The most common public research organisation involved in potato research is Wageningen University. It is known to be involved on a long-term basis. Other Dutch universities may be involved for specific projects.

Research on organic potato

In regards to research related to organic farming and organic potato production, Bionext and the Louis Bolk Institute are the most important organisations. WUR may also conduct research that can be beneficial for organic. Often this is related to personal preferences and/or initiatives of particular researchers. An example is the project Bioimpuls, which today is part of the program Green Breeding that aims to address problems encountered in both conventional and organic farming (Groene veredeling, 2024). This includes academic and applied research, funded through idiosyncratic ways.

3.3 Research projects on potato

The research projects can be subdivided at national and European level. These are described in the following sections on conventional and organic potato respectively. Projects funded via POP 3 and BO akkerbouw are more applied, whereas projects funded through the Topsectors are more at the fundamental level. Research projects funded through NWO (Dutch Science Organisation) generally have a more fundamental character.

In the frame of the program 'Toekomstvisie Gewasbescherming 2030' (Future Vision Crop Protection 2030) an overview has been made by Thijssen and Huurdeman (2021) of research projects regarding plant health in the widest sense possible, including projects funded through the topsectors, NOW POP and Horizon 2020 amongst others. Table 14 shows an overview of the projects that are funded over the period 2019 to 2022 through public means and through public-private partnerships, the number of projects relevant to potato, relevant to organic potato and potentially relevant to organic potato. The decision whether projects are relevant or potentially relevant is based on the available information. Some project descriptions were more elaborate than others and hence decisions were sometimes easier or more difficult to allocate projects to relevant to organic potato or potentially relevant to potato. The overview is not complete but gives an impression on the number of projects on potato and to what extent they are relevant to organic. Projects on potato funded through public means tend to be relevant to organic potato or potentially relevant, whereas the benefit for organic was less clear of projects funded through public-private partnerships (Table 14). Projects funded through public means were often funded via various types of EU funding schemes. It also needs to be mentioned here that the overview compiled by Thijssen and Huurdeman (2021) does not include the project Bioimpuls that focuses on potato breeding for organic which is funded through a public private partnership.

This overview includes smaller and bigger projects. The overview did not provide information on the project budgets. The overview excludes projects funded via BO akkerbouw as a more elaborate review was conducted on the current set of projects that is shown in Table 15.

Some general trends were visible, such as circular agriculture, reductions on pesticide use, development of alternatives for pesticides, resistance breeding, better interaction between plant and soil microbiome and faster breeding techniques.

Table 14: Overview of the projects that are funded through public means and through public-private partnerships, the number of projects relevant to potato, relevant to organic potato and potentially relevant to organic potato (based on Thijssen and Huurdeman (2021)).

Type of Funding	Funding Program	Sub program	Number of projects	Projects relevant to potato	Projects relevant to organic potato	Projects potentially relevant to organic potato
Public	8	16	74	8	2	5
Projects on potato (in %)			100%	11%	3%	7%
Public-Private Partnership	7	9	129	18	1	8
Projects on potato (in %)			100%	14%	1%	6%

3.3.1 Applied research projects at national level coordinated via BO akkerbouw

Research projects on potato can be organised according to the financing. One channel is via BO-akkerbouw, where the projects are funded via BO akkerbouw and the topsectors (usually Agri & Food and Horticulture & Seed material). BO-akkerbouw is initiated in 2016. Via BO akkerbouw 77 applied research projects on the crops potato, cereals, sugar beet and onion were funded. In addition 75 sector wide projects have been funded. Of the 77 crop specific projects, 52 projects have a focus on potato. In total 41 of these projects fall under the Action plan Plant Health (which counts in total 92 projects), and most are related to nematodes and bacterial and fungal soil diseases (Table 15). None of the potato research projects fall under the Climate Agenda Arable Farming (11 projects in total). The total budget amounts to approximately 16 Million Euro of which approximately 7,5 Million Euro is co-funded via BO akkerbouw. Project funding can vary from 2000 to 3 Million Euro. Contributions from BO akkerbouw ranges from 5 to 100%. Other funding comes amongst others from the Topsector Horticulture & Plant and seed materials, the Topsector Agri & Food, the Topsector Water & Maritiem the Ministry of Agriculture and the private sector. In a few cases all funding comes from BO akkerbouw In most of the research projects WUR is involved. Other organisations that take the lead in the conduct of the research projects are Vertify, Delphy, NAK, IRS,NMS, HZPC and LLTB.

There are also projects that are potentially of interest to organic agriculture (Table 15). Most of these applied projects are related to better understanding crop growth, more sustainable cultivation methods, transfer of virus and climate change. None of these projects specifically mention organic agriculture.

Table 15: Research projects on potato co-funded by BO akkerbouw organised for various topics (overview conducted in September 2024).

Topic	number of projects	potentially useful for organic
Nematodes	22	
Bacteria	7	
Soil fungal diseases	3	
Leaf fungal diseases	4	
Virus	2	1
Sustainability	5	2
Yield	4	2
Quality	1	
Climate change	2	1
Seed potato	2	1
Total	52	8

Source: BO-akkerbouw.nl/kennis-en-innovatie/projecten

3.3.2 Projects addressing climate change

BO akkerbouw has categorised 11 projects under the theme climate agenda and arable farming. **None of these projects specifically targeted potato.** Due to climate change farmers have to deal more often with

periods of extreme drought or heavy rainfall in short periods of time. Also salinisation is becoming a threat for arable farming in some regions. Research must lead to practical solutions and innovations so farmers can minimise the risks. These projects deal or dealt with farming aspects like improving soil management, controlled traffic farming systems, adapting crop rotations, strip cropping, green manure and the potential of leguminous crops. These topics are also important for organic agriculture, and some of these research projects also involved or build upon knowledge generated through organic agriculture.

Other projects under the theme climate change focused on better data management and improving nutrient balances.

3.3.3 Projects for practice oriented research

In the context of Integrated Crop Management the farmer organisation LTO started twelve pilots in 2022 of which one focuses on potato. It is described as a value chain wide project translated as: 'Development sustainable cultivation of ware potato from a value chain perspective' This project falls under the umbrella program 'Weerbaarheid in de Praktijk' (Resilience in Practice), which falls under the implementation program 'Toekomstvisie Gewasbescherming 2030' (Future Vision Crop Protection 2030) that started in 2021. The project is funded by the Ministry of Agriculture and BO Akkerbouw with in kind support from LTO growers and members of the sounding board. The total budget of the project is 691.369 euro (BO-Akkerbouw 2022).

The project aims to connect with a range of other projects, which are amongst others:

- Holland Innovative Potato (HIP): see below
- 7 running projects with involvement of BO Akkerbouw towards more sustainable farming and one project that looks at the effect of biostimulants on drought stress in potato
- Projects related to the cultivation of robust potato varieties in organic and uptake in the value chain
- Research conducted by Agrico
- Innovative techniques related to precision agriculture.

The project aims to achieve a system breakthrough by establishing other forms of cooperation in the potato value chain that contribute to a better income capacity of arable farmers and stimulate more sustainable cultivation practices of potato because fewer chemicals are available and fertiliser use need to be reduced. Expected solutions are so-called robust varieties (e.g. varieties that can do with less fertiliser and irrigation) and robust cultivation (e.g. reduced use of N-fertiliser to 175 kg/ha and use of biostimulants. Below the first results are described.

Robust varieties: In 2023 a trial started with 40 varieties from thirteen potato breeding companies. Apart from nitrogen use efficiency the varieties will be tested for disease and pest tolerance and coping capacity with abiotic stresses (Aardappelwereld 2023). New varieties are compared with a number of older well-established varieties (Innovator, Fontane, Agria, Challenger and Markies). After harvest, and apart from yield and grading, the varieties are compared for shape, peel quality, presence of diseases and various irregularities. Other traits important for the ten table potatoes that are part of the trial are resistance against Phytophthora, tolerance to heat and drought stress and resistance against Y^{ntn} virus. Storing quality will be assessed through the number of treatments with sprouting suppressor the

1,4SIGHT and weight losses. French fries varieties are tested for baking quality and the table varieties for grading by the packing companies. In 2024 the best eight varieties are tested with a number of bio-stimulants.

Robust cultivation: Demo trials on the use of nitrogen and bio-stimulants started in 2022 in three locations with different soils: clay, sandy and loamy soil. The variety Innovator is used as it is sensitive to nutrient deficiencies. High levels of potassium and nitrogen fertiliser disturb hormone balances in the plants and to have a more balanced plant growth particular bio-stimulants are used. The hypothesis is that the combination of reduced nitrogen and application of bio-stimulants results in a more balanced (micro) nutrient uptake and better hormone balance. Fulvine acids are said to improve the functioning of chemicals and silicium is said to improve the immune system of the plant (Schriever, 2023). These trials are repeated in 2023 at two trial farms of WUR: Vredepeel and Westmaas. In both sites two additional varieties Fontane and Markies are evaluated.

3.3.4 Large research projects with a focus on conventional potato

Research consortium HIP-1 (Holland Innovative Potato)

In 2019, a research project started with the aim to improve yield, quality and production stability, with a focus on breeding, agronomy and their interaction (NWO, 2022). Recent develops in science and technology open up new possibilities for variety and product innovation. The total budget is approximately 4,5 million. The project is a private-public partnership. It is partly funded by the Dutch research organisation NWO, the Ministry of Agriculture (LNV) and the so-called HIP consortium (Holland Innovative Potato, founded in 2017) that consists of the following processing and breeding companies: Avebe, Aviko, Bejo, Farm Frites, HZPC, KWS Benelux (daughter company Aardevo), Lamb Weston, McCain, Meijer, Pepsico en Solynta. Associated members are the NAO (Nederlandse Aardappel Organisatie) and VAVI (Vereniging voor Aardappel Verwerkende Industrie). The long term focus of HIP is the nutrient medium, crop protection, the potato plant and processing (Thijssen and Huurdeman, 2021).

Of the processing companies that participate in the project, four are member of VAVI (members of VAVI are the processing companies Agristo, Aviko, Farmfrites, Lambweston/Meijer, McCain and PekaKroef). Together the VAVI is responsible for approximately 95% of all ware potato processed in the Netherlands. Pepsico is the only processing company that is not a member of VAVI. Four breeding companies are part of the consortium as well, namely HZPC, Aardevo, Meijer and Solynta. Other members are Bejo and Avebe. Bejo is a breeding company that only recently got involved in potato breeding. It has an interest in F1-hybrid potato breeding in common with the other breeding companies. The company Avebe is strong in starch production and has its own breeding company Averis Seeds.

Thus, many big potato value chain actors are involved in this project. A few companies that are not part of the HIP consortium are: Agrico, Agristo and Pekakroef. The actual research is conducted by Wageningen University and Research (3 projects) and the University of Amsterdam (1 project).

Research consortium HIP-2

In 2023 HIP phase 2 started because the initial project is considered a success. The announcement argues that climate change is expected to have considerable impact yield and quality (HIP 2022). Hence the 11 consortium members recognise a need to develop potato varieties that can better withstand climate change and at the same time reduce environmental impact of potato cultivation, important in the context of challenges related to the EU Green Deal. To achieve these goals, a better understanding is needed of the potato crop and the interactions with its environment. The aim is to develop potato cultivation models that can predict these effects on quality and yield (HIP 2022). This in turn should support growers for more sustainable cultivation and breeders to develop climate proof varieties. The ultimate goal is to contribute to a future proof potato value chain. Hunger, malnutrition and climate change are the major challenges for agriculture in the coming decades (HIPa 2024).

The project consists of three building blocks (HIPb 2024):

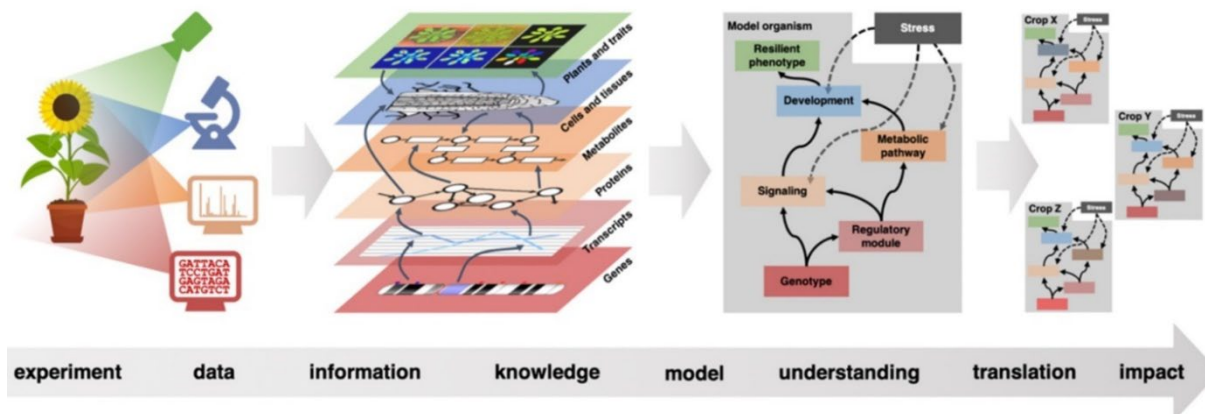
Building Block 1 is about production systems and the interaction of the plant with the soil. The goals are to generate new insights for breeding, develop decision support tools and to optimise the physiological age of seed potato. It consists of 5 sub-projects.

Building Block 2 concerns the content of substances, i.e. metabolites and proteins, in the potato tuber. The content of substances in the potato tuber determines in a broad sense the quality, storability and germination capacity of the tuber.

Building Block 3 concerns the exploitation of disease and pest resistant from crossable potato species. The potato cultivation in the Netherlands and worldwide is continuously threatened by a large number of diseases and pests. It consists of three sub-projects: 3.1 microbial pathogens, viruses, 3.2 nematodes and 3.3 insects.

A new member to the consortium is Agrico. In addition to the research partners, NWO and the Ministry of Agriculture co-fund the research, which is conducted by the Universities of Wageningen, Delft and Utrecht.

The HIP project is part of PlantXR– A new generation of intelligent breeding tools for extra resilient crops. The aim is to use artificial intelligence to analyse big data from experimental plant research to develop models to be used in breeding of improved more resilient varieties (Figure 5). The project PlantXR has started in 2020 with a total budget of 65 Million euro of which 25,4 Million is provided by the private sector and public-private partnerships, total public funding amounts 24,5 Million and 15 Million is contributed by NWO (NWO 2024).



From data to knowledge

Smart data from hypothesis-driven experiments is processed by bioinformatics and artificial intelligence and incorporated into mechanistic models that yield new insights and key regulators of plant resilience in a 'Systems Biology 2.0' approach. These will be translated to other crop species.

Figure 5: work flow description of the research project PlantXR (CropXR 2024)

The project PlantXR is the scientific basis of the virtual CropXR Institute (see Figure 6). Founders of the virtual institute are Utrecht University, Wageningen University & Research, TU Delft, University of Amsterdam and Plantum. Partners are eight vegetable breeding companies, the HIP consortium for potato breeding and processing industry, four vegetable breeding companies, two molecular technology companies and one education partner (CropXRc 2024). The focus of the CropXR institute is the development of extra resilient sustainable climate adaptive crops (NWOb 2024): XR stands for extra resilience. The institute CropXR will develop also educational activities and is committed to quickly and widely translate the 'smart breeding' methods to as many commercial agricultural crops as possible, in the Netherlands and in other countries. The website describes the following (CropXRa 2024):

"In coming decades, three trends converge that will put the agricultural system under even greater stress: changing climates will confront crops with greater stresses, environmental policies will reduce the use of chemical protections, while a growing world population needs further growth in yields.

The three trends stipulate an urgent need for more resilient crops that have the capability to perform under greater stresses and relying less on outside protection. Combined with improved farming practices, they should be able to deliver yields reliably even when confronted with more intense and/or more frequent combinations of stresses such as heat waves, droughts, flooding, pests and disease.

Plant resilience is the outcome of interplay between many biological mechanisms. It involves many genes, many biochemical interactions, and many trade-offs between all of them. It is a prime example of highly complex, polygenic traits, which are still relatively poorly understood and cannot be reliably predicted or managed. Current methodologies have very limited options to efficiently deploy them in breeding. Before we can breed a new generation of more robust,

resilient crops, we need a new generation of smarter technologies and breeding tools, which are capable of improving complex plant characteristics. “

The goal of the HIP association is on breeding more resilient potato varieties. The goal is to reduce the use of plant protection products by 90% by 2030 (CropXRb 2024). Current potato varieties are also not resistant to effects of climate change. CropXR argues that research will help make potatoes more resistant to a wider variety of environmental stresses, such as heat, drought, salinisation, and flooding (CropXRb 2024). According to HIP the two most important stresses worldwide are drought and heat. The HIP association hopes to systematically study the effects of drought stress, environment and genotype on the following aspects: yield and quality caused by plant architecture, tuber development, microbiome mediated resilience (HIPb 2024).

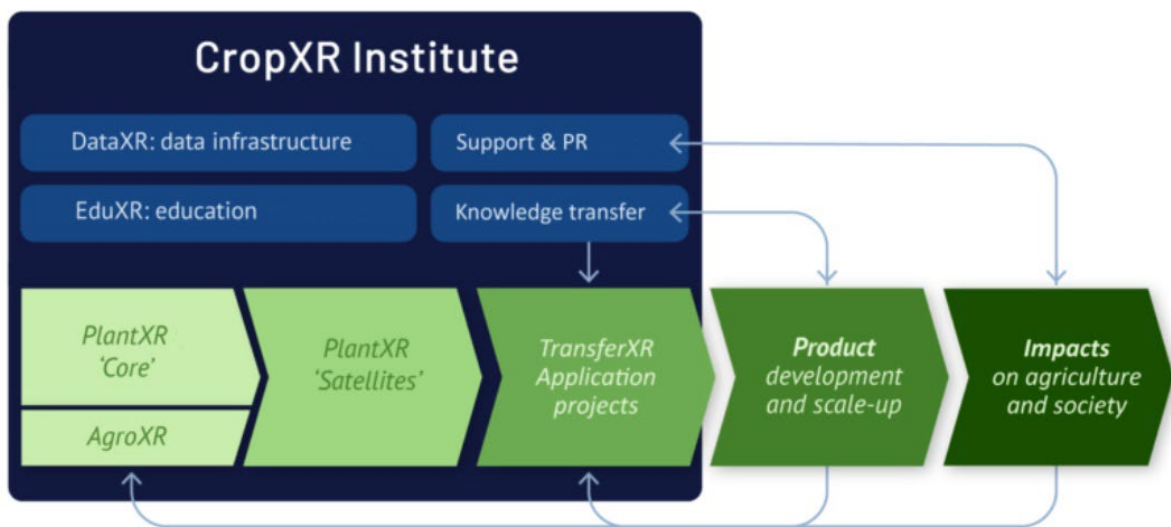


Figure 6: organisational model of the CropXR institute (CropXR 2024)

3.3.5 European Union Horizon 2020 projects with Dutch partners

In this section several EU projects with a strong focus on potato are briefly described.

The project **Accelerated Development of multiple-stress tolerAnt PoTato (ADAPT)** ran from July 2020 to October 2024 with a budget of 5 Million Euro and will study the dynamics of complex signalling and response mechanisms, to identify the molecular mechanisms of adaptation to combined stress in potato. The project will develop new strategies for increased productivity, stability and quality under multiple stress conditions. It will combine molecular biology, stress physiology, systems biology and analytics with engineering and molecular breeding, engaging user-driven agencies for testing and implementation of the project's results.

ADAPT identifies molecular mechanisms of adaptation to combined stress in potato to develop new strategies for the improvement of productivity, yield stability and product quality under multiple stress conditions. Potato is one of the most important food crops worldwide and a major constraint to secure

yield is its sensitivity to environmental stresses, particularly heat and drought, which is often followed by flooding in the field. Whilst limited knowledge of combined stress signalling pathways is available in model plants such as Arabidopsis, this knowledge is almost completely lacking in crops. These adaptation mechanisms require metabolic reprogramming that is triggered by different signalling pathways. To understand the dynamics of complex signalling and response mechanisms our approach will utilise several technological advances (for example high throughput phenotyping and novel sensor plants). These tools will guide us to the key developmental stages and tissues for in depth analysis allowing unprecedented dissection of these processes. The approach requires complementary expertise from 10 leading academic research institutions with 4 major potato breeders (of which 2 are Dutch: Meijer and HZPC), and a screening technology developer. This unique combination of molecular biology, stress physiology, systems biology and analytics with engineering and molecular breeding as well as the active participation of end-user driven agencies for variety testing and potato trading ensure translation of ADAPT results. Arising from our mechanistic understanding, our expected results will include new breeding targets and the potential to match potato varieties to specific environmental conditions. Knowledge from our research will directly reach the most relevant stakeholders and end-users feeding into breeding programmes and guiding technology development for improved crop management strategies. Thus we anticipate that ADAPT will have a game changing impact on potato breeding and management strategies.

The project **NEM-EMERGE** (An integrated set of novel approaches to counter the emergence and proliferation of invasive and virulent soil-borne nematodes) runs from January 2024 to December 2027. Both root-knot and potato cyst nematodes are increasing. Climate change is an important cause because winters are becoming milder and hence . Root knot nematodes are moving northwards. Climate change also influences soil temperature. At temperatures of 28 degrees Celsius or higher several important resistance genes don't function anymore. In addition, genetic selection also plays an important role. Because of the use of a limited number of resistant varieties, nematodes are selected with a lower sensitivity for these resistance genes. The molecular mechanisms behind the functioning of the resistance genes requires better understanding. Another challenge is to understand which populations of nematodes are controllable and which ones not anymore.

Because the use of pesticides is being increasingly limited in the EU, growers need other control methods. The EU emphasises integrated pest crop protection, but how does that look like? How can you increase the disease suppressing capacity of the soil? These are questions that the project addresses. Researchers also want to know what farmers need to be able to provide solutions that can be used in practice.

The number of partners in the project totals 19 and includes the Dutch research organisations Wageningen University, Stichting Wageningen Research, Hilbrands Laboratorium and the breeding company Enza Zaden,

Horizon 2020 projects without Dutch participation

The project **PhotoBoost** is titled A holistic approach to improve the photosynthetic performance and productivity of C3 crops under diverse environmental conditions. The project started April 2020 and ends October 2025 with a budget of almost 5 Million Euro. As market demand for food continues to

grow, agriculture is required to produce more food to feed a growing population. The EU-funded PhotoBoost project will tackle closing the widening gap between agricultural productivity and the global market demand for food/feed and bioenergy crops in an environmentally friendly manner. Specifically, the project will increase photosynthetic efficiency to develop enhanced C3 crops (potato and rice). It will do this by combining multiple approaches: optimisation of light reactions, integration of an algal CO₂ concentrating mechanism, introduction of an engineered photorespiratory bypass mechanism, and optimisation of source-sink capacity. While consortium members have increased photosynthetic efficiency up to 15 % by using one of the above approaches, combining two or more of these in the same plant has never been attempted. Partners in the project are two German research institutes, two UK based universities, one Spanish and one Portuguese university, the international rice research institute in the Philippines, and a German breeding company.

3.3.6 Large research projects with a focus on organic potato

The main aim of the research project Bioimpuls is to stimulate the development of non-gmo Phytophthora potato varieties suited for organic agriculture. In 2009 a consortium was built consisting of 6 potato breeding companies, 12 farmer breeders, Wageningen University which already had a breeding program with the aim of introducing resistances from wild relatives into cultivated potato and the Louis Bolk Institute that acted as the coordinator of the project. Most of the farmer breeders worked together with one of the breeding companies. The farmers get new seeds from Wageningen University to be tested on their field for Phytophthora resistance and other traits important for organic cultivation (like Nitrogen Use Efficiency). With molecular markers Wageningen University could provide information whether the Phytophthora resistance is based on multiple genes. Part of the project was also the establishment of a breeding course for farmers and an instruction book which is translated into English and Chinese.

The initial funding of Bioimpuls was achieved via an amendment of the Dutch parliament. Then it formed the basis of the Green Breeding program that aims to support research for sustainable breeding approaches applicable for both conventional and organic. The second and third funding phase were organised through this Green Breeding program. The third phase runs from 2020 till the end of 2025.

The third phase of Bioimpuls will focus more on varieties for processing (French fries and chips) as the last years a sufficient number of table varieties have been developed. The new varieties developed in the scope of this project can also be considered useful for conventional farmers who want to use fewer inputs (pesticides and fertilisers).

In the first five years of the project the following breeding companies were involved: Agrico/Bioselect, C. Meijer BV, Den Hartigh, Fobek, HZPC/Bonna Terra and KWS-Potato. In the second phase (from 2015 to 2019) four of the original partners continued and two other breeding companies were involved: C. Meijer BV, Den Hartigh, Fobek, HZPC, Plantera and TPC. In the third phase 10 companies are involved: Den Hartigh BV, Fobek, Plantera, TPC, Bejo Zaden B.V., Danespo Holland B.V., Geersing Potato Specialist B.V., Royal ZAP B.V. / Semagri B.V., Schaap Holland B.V., Mts. Heren en Dames Vos. The latter being originally one of the first farmer breeders involved.

The breeding companies involved in Bioimpuls are currently not involved in the HIP consortium and vice versa. The companies HZPC and Meijer were involved in the first two project phases of Bioimpuls, but

today are part of the HIP consortium. After the outbreak of Phytophthora, HZPC decided to not make their Phytophthora resistant varieties available for organic.

Although Bioimpuls does not specifically focus on climate change, the results can be expected to contribute to dealing better with climate change. The varieties developed in the context of Bioimpuls are expected to grow well with lower nitrogen inputs and without pesticide use. Hence, these varieties are not important to organic farmers, but can also be of interest to conventional farmers who want to use fewer inputs. Over the years, a few new varieties have been bred that can do well with much lower levels of nitrogen than what farmers are used to apply.

Linked to Bioimpuls was a research that ran from 2020 to 2023 to develop markers for Phytophthora resistance in potato that allows the stacking of multiple resistance genes in order to develop varieties that can withstand a Phytophthora breakthrough (Groeneveredeling, 2025). The researchers work with twelve sources of resistance. For four resistance genes markers have been developed and for another four genes markers are under development. During the research it was found that other genes are needed to make the resistance function. The markers will become publicly available.

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