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Systemic analysis of the mildew issue in the Belgian potato system

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Summary

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Potato late blight caused by the oomycete *Phtyophthora infestans* (Mont.) de Bary may be the best known, longest studied and still amongst the most destructive of all plant diseases. Today, late blight is mostly controlled by the preventive use of fungicides, which has serious ecological consequences. As resistance against these fungicides increases in *P. infestans* populations, the number of necessary applications to fight the plague grows over time, reinforcing these ecological effects. At the same time, public opinion and societal pressure creates an additional pressure on the production system and the European agricultural policies tend to reduce the use of fungicides and pesticides.

Our objective is to explore a series of alternatives that meet the requirement of rendering the management of potato late blight more sustainable in a near future. The study relies on a systemic and qualitative approach, based on twenty-two semi-directed interviews with various types of actors of the system. The emphasis is on the point of view of the actors with respect to current and future management of potato late blight in the Belgian potato system. The collected data provide a clear view of the different ways of struggle that the actors know and/or use against late blight and offer a critical comparison of their different visions regarding the solutions to the issue and the barriers that prevent their implementation.

The study reveals the complexity of the issue and confirms the existence of a lock-in. It suggests that three main strategies for the introduction of a positive change are available, namely the adoption and/or creation of resistant varieties, a more reasoned and better regulated use of fungicides, and the capitalization on IPM methods. The majority of the actors identified the consumers and their preferences as the main obstacle for change. The fact that this so-called 'external' reason is given for the lock-in has direct consequences on the willingness of the actors 'inside' the system to modify the current situation. This means that consumers have to be included in the system, so as to weigh on the decision process and change the current posture of the actors inside the system. Turning to fungicides, the lock-in is maintained due to the efficiency and dependency of the current system on their use. A change at this level will be likely to take place if authorities more decisively enter the picture and change the regulations or if sensitized consumers succeed in changing the actors' habit of actors concerning the broad adoption of the fungicide-dependent Bintje and 'Bintje-alike' varieties. Regarding the scaling-up of IPM methods, the organic sector can play a major role in the knowledge transfer process towards the conventional sector. This would however come along with a source of inoculum. For each of these various solutions, the feasibility and temporality differ and has to be taken into account so as to ensure a transition towards a more sustainable management of potato late blight.

In conclusion, this study shows that alternatives exist concerning the use of fungicides in order to manage potato late blight but, that in order to exit the existing lock-in currently characterizing the Belgian potato system, various actions need to be undertaken in order to modify the way the actors currently see their relations with the other actors and the options available to them.

Key words: potato, mildew, systemic analysis, sustainability, semi-directed interviews, lock-in

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ABS	Algemeen BoerenSyndicaat	General Farmer Syndicate
AFSCA/FAVV	Agence Fédérale pour la Sécurité de la Chaîne Alimentaire / Federaal Agentschap voor de Veiligheid van de Voedselketen	Federal Agency for the Safety of the Food Chain
AM	Matière Active	Active ingredient
APAQ-W	Agence Wallonne pour la promotion d'une agriculture de qualité	Walloon Agency for the promotion of quality agriculture
CARAH	Centre Agronomique de Recherches Appliquées de la Province de Hainaut	Agronomic Center of Applied Research of the Hainaut Province
CPP	Centre Pilote Pomme de terre	Potato Pilot Center
CRA-w	Centre wallon de Recherches Agronomiques	Walloon Center of Agronomic Research
CRIOC	Centre de Recherche et d'Information des Organisations de Consommateur	Research and Information Center of the Consumer Organizations
DGARNE	Direction Générale Agriculture, Ressources naturelles et Environnement	General Directorate of Agriculture, Natural Ressources and Environment
CWFPDT	Conseil Wallon de la Filière de la Pomme De Terre	Walloon Council of the Potato Sector
FIWAP	Filière Wallonne de la Pomme de terre	Walloon potato sector
FUGEA	Fédération Unie de Groupements d'Eleveurs et d'Agriculteurs	United Federation of Groups of Breeders and Farmers
FWA	Fédération Wallonne des Agriculteurs	Walloon Farmer Federation
GWPPPDT	Groupement Wallon des Producteurs de Plants de Pomme De Terre	Walloon Group of Seed Potato Producers
ILVO	Instituut voor Landbouw- en Visserijonderzoek	Institute for Agricultural and Fisheries Research
INRA	Institut National de Recherche Agronomique (FR)	National Institute of Agricultural Research (FR)
KUL	Katholieke Universiteit Leuven	Catholic University of Leuven
MAP	Mouvement d'Action Paysanne	Peasant Action Movement
MLV	Ministerie van Landbouw en Visserij	Ministry of Agriculture and Fisheries

NAPAN	Nationaal Actie Plan/ Plan d'Action National	National Action Plan
NEPG	Groupe des Producteurs de Pomme de terre du Nord-Ouest Européen	North Western European Potato Growers Group
NPO	Association Sans But Lucratif	Non Profit Organisation
PAMESEB	Promotion de l'Agrométéorologie en Wallonie	Promotion of Agrometeorology in Wallonia
PCA	ProefCentrum voor de Aardappelteelt	Research Centre for Potato cropping
PIO	Organisation d'intérêt Public	Public Interest Organization
POMMAK	Pomme de terre Marché/Markt AKkerbouw	Potato Market/ Agricultural Market
RW	Région Wallonne	Walloon Region
SPW	Service Publique Wallonie	Walloon Public Service
TMCE	Techniques Minérales Culture et Elevage	Mineral Techniques for Cropping and Breeding
UAA	Surface Agricole Utilisée	Utilized Agricultural Area
UCL	Université Catholique de Louvain	Catholic University of Louvain
UGent	Université de Gand	University of Ghent
UNamur	Université de Namur	University of Namur
VIB	Vlaams Instituut Biotechnologie	Flemish Institute of Biotechnology
VVP	Vlaams Verbond van Pootgoedtelers	Flemish Union for seedling potato growers

INTRODUCTION

Introduction

Potato late blight caused by the oomycete *Phtyophthora infestans* (Mont.) de Bary may be the best known, longest studied and still amongst the most destructive of all plant diseases (Mizubuti and Fry, 2006). Today, late blight is mostly controlled by the preventive use of fungicides (Cooke et al., 2011). This use of fungicides in the potato cropping system has serious ecological consequences. As resistance against these fungicides increases in *P. infestans* populations, the number of necessary applications to fight the plague grows over time, reinforcing these ecological effects. At the same time, societal pressure and public opinion create an additional pressure on the production system and the European agricultural policies tend to reduce the use of fungicides and pesticides. It is in the context of this need for more sustainable management methods of mildew that the present study is being conducted.

Our objective is to explore a series of alternatives that meet the requirement of rendering the management of potato late blight more sustainable in a near future. The study relies on a systemic and qualitative approach, based on twenty-two semi-directed interviews with various types of actors of the system. The emphasis is on the point of view of the actors with respect to current and future management of potato late blight in the Belgian potato system. The collected data will provide a clear view of the different ways of struggle that the actors know and/or use against late blight. They provide a critical comparison of their different visions regarding the solutions to the issue and the barriers that prevent their implementation.

The presentation of this study is divided into four parts. The first part relies on the review of the literature and sets the general context regarding the subject of the study. It describes the relationship between the potato and *P. infestans* and gives an objective view on the Belgian potato system. It also relates the current and alternative manners of managing late blight, to finally introduce the theoretic frame of this study, which is based on the lock-in theory. The second part clarifies the objectives of the thesis, as well as the used materials and methods that have been chosen so as to tackle the issue. In the third part, the mildew issue as it seen by the actors is detailed. Various topics are covered such as the current situation with respect to the Belgian potato system and the ways of managing late blight in Belgium. More precisely, the interviews concerned the perceived relationships between the different actors of the potato system, the daily struggle of farmers against mildew, and the future alternatives that the actors see to exist when it comes to controlling late blight. Finally, the barriers impeding a change towards a more sustainable system are also examined in this part. In the fourth and last part, the discussion first tackles the coherence of the used methodology, showing its strengths, weaknesses, and limits. Furthermore, it confronts the literature with the interview data so as to provide an analysis of the factors that create the lock-in inside the Belgian potato system. Finally, it brings to light the main paths that can be taken if one wishes to see change occur. Three main alternatives are discussed, along with their temporality and feasibility. This will lead to the final conclusion.

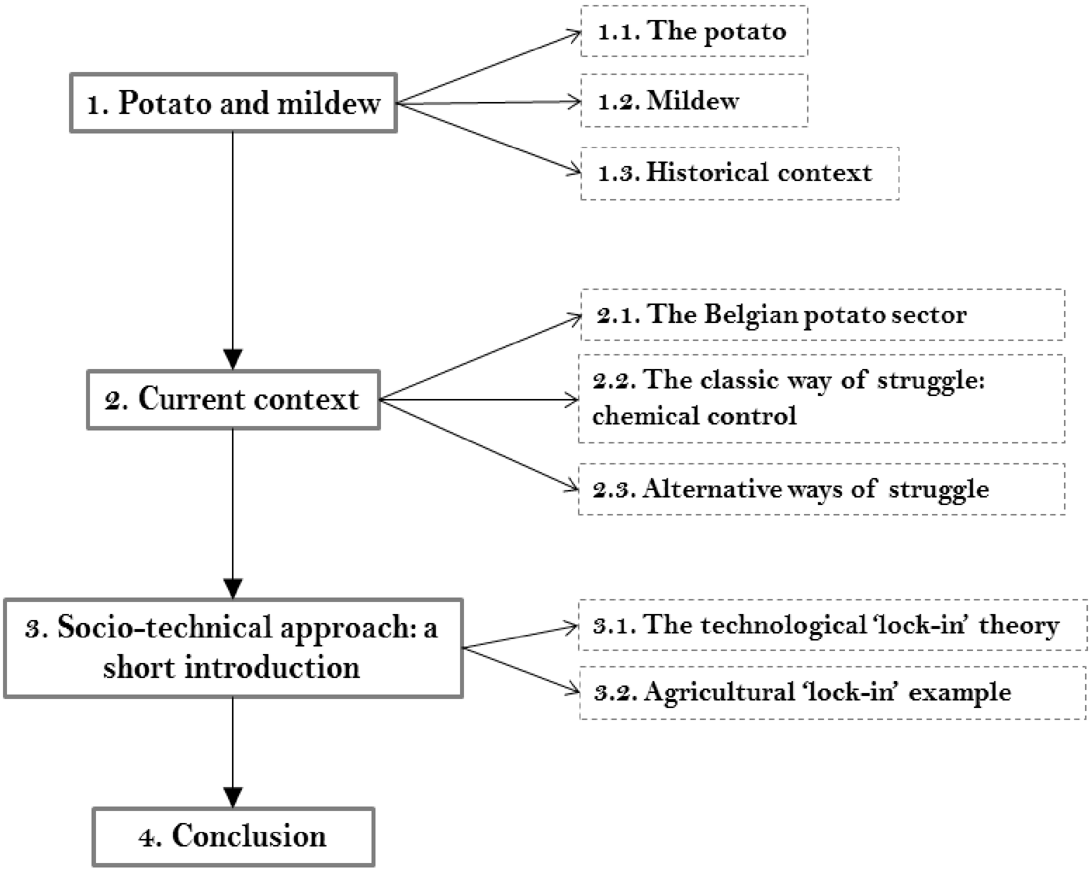
PART ONE: REVIEW OF THE LITERATURE

Part one: Review of the literature

In this first part, a review of the literature is given. In first instance, the general characteristics of the potato and *P. infestans* are described, leading to the biological relationship uniting these two organisms. The historical context of late blight clarifies how the potato-mildew system has evolved to the present situation.

Secondly, the current situation is explained broadly through an objective vision of the Belgian potato system and a description of how late blight is managed today.

Finally, the concept of lock-in will be introduced theoretically and explained by the use of an agricultural example.



1. Potato and mildew

1.1. The potato

1.1.1. Botanical description[1]

The potato, also called *Solanum tuberosum* is an herbaceous, tuberous and perennial plant. It is cultivated as an annual plant for its tubers, which are an important source for human and animal alimentation. The potato grows best in slightly acid soils. In more humid and basic soils, it is more subject to diseases.

The root system is fascicled and strongly ramified. It can stretch out up to 0.8m in the soil. The growth of the root system is very rapid until the apparition of the first tubers.

The leaves are deciduous, alternate and are about 10 to 20 cm long. They are composite and imparipinnate and count from seven to nine lanceolate leaflets of heterogeneous sizes. The epidermis shows trichomes on its surface.

The potato has two types of stems: areal stems, with an angular or circular section on which are disposed the leaves, and the underground stems (stolons), on which appear the tubers. The areal stems appear from buds that are on the tubers used as seed. They are herbaceous and can be as long as 0.6 to 1m in length. These stems are erected or decumbent[2]. The stolons form from lateral buds that grow at the base of the areal stems. They grow alternatively from the sub nodes situated on the areal stems and they grow horizontally under the soil surface (diageotropic growth). The growth of the distal extremity of each rhizome engenders a tuber.

The tuber (also called potato) has a nutrient stock function. It mostly stocks starch and has a variable form and size. Four types exist: kidney shaped, oblong (e.g. the 'Bintje' variety), rounded or elongated and cylindrical. The color of the skin is mostly yellow but can as well be red, black or rose. The flesh is generally white, yellow, rose or violet depending on the variety. On the surface of the tuber, 'eyes' are observable. These contain the vegetative buds. In commercial strands, the surface 'eyes', that are easier to remove, have been selected. Germs develop after a period of dormancy and the first to develop are situated at the apex.

Formation of the tubers always starts in the sub apical meristem zone at the extremity of the stolons. A radial growth is caused by the elongation of the parenchyma cells and their loss of polarity. At the end of the tuber formation, the tuber surrounds itself with an exodermis that is thicker than the initial one and starts dormancy. This 'real dormancy' can last between 17 and 40 weeks (depending on the variety) and impedes the tuber to start growing. The abscisic acid (ABA) seems to be an important factor concerning the dormancy.

The dry matter content of a tuber can vary between 18 and 26%. The tuber is thus mostly composed of water (almost 80%) but also a strong content of amylated matter, sugars, albuminoids, mineral elements and vitamins.

[1] This part used as a source the course of Pr. Pierre Bertin and Pr. Draye (Bertin, Draye, 2010) and the book 'La Pomme de Terre: Production, Amélioration, Ennemis et Maladies, Utilisations. Mieux Comprendre' (Rousselle, Robert, and Crosnier, 1996).

[2] 'lying or trailing on the ground with the extremity tending to ascend' (Dictionary.com, n.d.)

Reproduction

The inflorescence is a cyme that grows at the end of the stem. It counts from one to thirty flowers. The number of inflorescences and flowers varies depending on the cultivar. The flowers have a diameter of three to four cm and have pentamer symmetry[3]. The flower consists of five green, welded sepals, five welded petals and five stamens with a short inserted on the corolla and the two-celled anther. The pistil has a superior ovary with two boxes.

The potato is autogamous but also manifests an endogamous depression and thus also reproduces by outcrossing means. The self-pollination is most frequent. The fruit of the potato is a little green bay that looks like a tomato. This fruit isn't edible. Its diameter varies from one to three cm. The seeds are albuminous and the embryo is enrolled. There are 1000 to 1500 seeds per gram. Reproduction by pollination is quite uncommon in modern agricultural systems, because of the heterogeneity of the obtained plants. It is more usual to use the vegetative reproduction, starting from certified tubers, as to obtain a more homogeneous harvest and higher sanitary quality (FIWAP, 2012).

1.1.2. Growth and cultivation

Potatoes are generally grown from certified seed potatoes. Their growth is characterized by five essential steps. First, the sprouts emerge and root growth begins. Secondly, leaves allow the beginning of photosynthesis. Thirdly, stolons develop starting from the lower leaf axils on the stem. At the extremities of these stolons, new tubers develop. This phase is often associated with flowering. During the fourth phase, there is tuber bulking. The fifth final phase is maturation during which the leaves die, the tubers' skin hardens and their sugars convert to starches. When this phase is over, the time has come to harvest the potato (Bertin, Draye, 2010). After the harvest period, potatoes are usually stored so as to keep the potatoes alive and to slow the natural process of breakdown of starch. The storage area should be dark, well ventilated and maintained at temperatures near 4 °C. Under optimal conditions, potatoes can be stored for ten to twelve months (Pawaneh, 2009).

1.1.3. Taxonomy and varieties

The *Solanum* family counts more than 1000 different species of which more than 200 are tuberous species(Bertin, Draye, 2010; Rousselle, Robert, and Crosnier, 1996). There exist over 5000 different cultivated varieties of potatoes today (and 200 wild species and subspecies), belonging to eight or nine species (depending on the taxonomy school) (Rousselle, Robert, and Crosnier, 1996).

The wild potatoes are more often diploid (with 24 chromosomes), allogamous, highly variable and incompatible, whereas the cultivated potatoes are more often tetraploid (with 48 chromosomes) and mostly represented by the *S. tuberosum indigena* kind and the "European" potato *S. tuberosum tuberosum*. The subspecies *S. tuberosum indigena* is a subspecies that gave birth to the *S. subsp. Tuberosum* (Bertin, Draye, 2010). Concerning the ploidy, the taxa vary from diploid (2n = 24) to hexaploid (6n = 72) (Bertin, Draye, 2010; Rousselle, Robert, and Crosnier, 1996).

The prevailing diversity of the potato is represented by the many varieties that exist today. Each variety has its own characteristics concerning resistance to climate conditions, to pathogens, etc. Many have been identified and used in breeding programs as to transfer desired characteristics to more commercial varieties. An example is the use of *S. demissum*, a wild species from Mexico, which was one of the first varieties used in breeding programs as to insert resistances to mildew in commercialized varieties (Gebhardt and Valkonen, 2001).

[3] The pentamer symmetry is a characteristic of the *Solanaceae*

1.1.4. Distribution

The home of the potato is located in South America in two distinct areas. The subspecies *andigenum* are located in the Northern Andes region in Peru, Bolivia and Ecuador, while the subspecies *tuberosum* are originally from zones situated near Santiago in Chili (Salaman, 1985). Nowadays, the potato is cultivated all around the globe between the latitudes of 47° South and 65° North. More than half of the cultivated area devoted to the potato is situated in Europe and one third in Asia (Hijmans, 2002).

Compared to other countries, Belgium is a country where the potato production is quite important. As a matter of fact, the average annual Belgian production over the last five years is of almost 3.5 MT (Eurostat, 2014a). The relative importance of the potato crop is high because about 6% of the UAA[4] in Belgium has been devoted to potato cropping in 2010 (the European average is of 1.2%) (Eurostat, 2014).

1.2. Mildew

1.2.1. Phytophthora infestans

Mildew is a disease that affects the potato and other *Solanaceae.* It is caused by the pathogen *Phytophthora infestans* (Mont.) de Bary. This pathogen is an oomycete (which is a filamentous protist) that has its center of origin in Mexico (Haverkort et al., 2009). It was formally classified as a fungi but due to recent research on the DNA strands, the species is now classified as an oomycete, considered closer to algae then fungi (Perez and Forbes, 2010). This success of this pathogen's is not only due to its elevated virulence but also to its capacity to rapidly adapt to resistant plants by being very flexible genetically (Haverkort et al., 2009).

Life cycle (Henfling, 1987)

P. infestans can reproduce in two different ways: sexual and asexual (see Figure 1).

Asexual reproduction can be seen as a normal cloning process. Hyphae are produced, and then follow the sporulation and the germination process. This can happen either by formation of zoospores (when the temperature is less than 18°C) or by immediate germination (at an optimum temperature of 18 to 24°C) (Axel et al., 2012).

During **sexual reproduction**[5], two different mating types (A1 and A2) have to enter in contact. When these two mating types meet, they first have hormonal communication and the oogonium and antheridium are formed. These two cells merge to form an oospore that will develop in a sporangium. Afterwards, the normal life cycle continues. This type of reproduction creates genetic variability in the population.

The spores are disseminated by wind or water and can travel long distances. The zoospores and sporangia have a short life expectancy (several hours depending on the weather conditions) whereas the oospores can survive during numerous years in the soil (Schumann and D'Arcy, 2000).

The ideal weather conditions for the development and sporulation of *P. infestans* are temperatures between 16 and 26 °C and high air humidity (near 75 - 80%) (Axel et al., 2012).

[4] 'Utilized Agricultural Area'

[5] Until 1984, sexual reproduction had only been observed in Mexico (home of *P. infestans*) (Henfling, 1987)

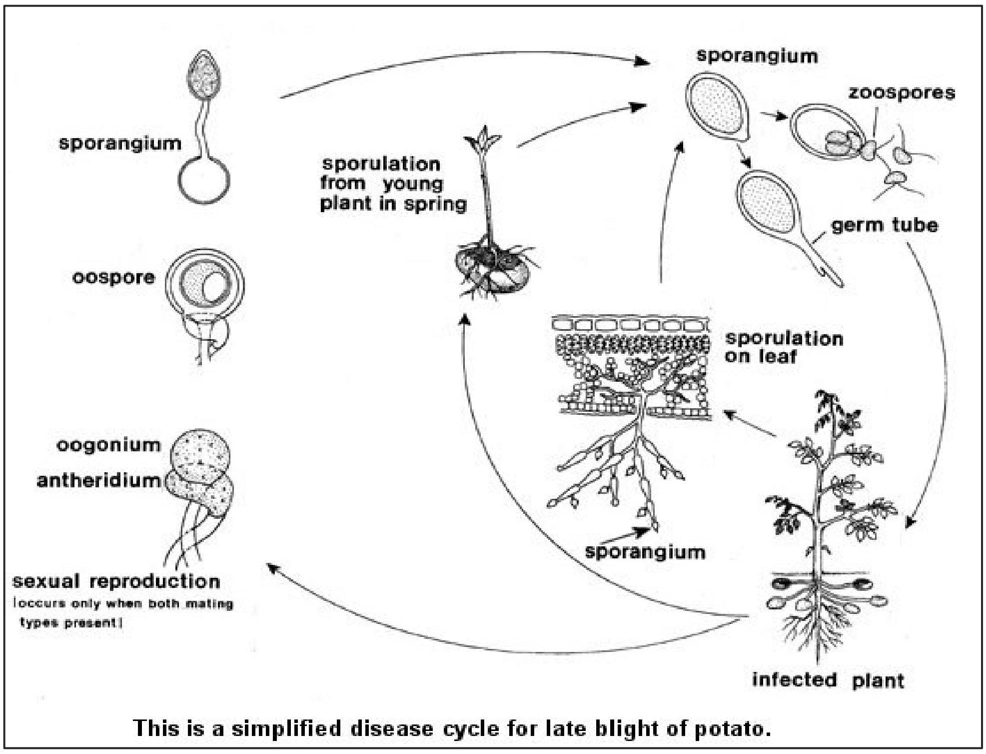


Figure 1 : Simplified disease cycle for late blight of potato with sexual (left side) and asexual reproduction (right side) (Henfling, 1987)

Genetics

The *P. infestans* genome shows an unusual discontinuous distribution of gene density in which disease effector genes and other virulence factors are localized in repeat-rich and gene-dense regions (Haverkort et al., 2009). In contrast, housekeeping genes occupy repeat-poor and gene-dense regions. This characteristic promotes evolutionary plasticity and enhances genetic variation of the subset of genes that determine pathogenicity and host specificity (Raffaele et al., 2010). This is the reason why *P. infestans* is classified as a "*high evolutionary potential*" pathogen (McDonald and Linde, 2002) and an "*R-gene destroyer*" (Haverkort et al., 2009).

1.2.2. Late blight or mildew

Late blight is the most devastating disease of the potato and results in global yield losses of 16% (Haverkort et al., 2009). It can eradicate a potato field in less than a week if the weather conditions are favorable. It is a polycyclic disease because the causal agent is able to reproduce and re-infect other plans in the same crop season (Mizubuti and Fry, 2006; Perez and Forbes, 2010).

The symptoms (Henfling J.W., 1987)

Late blight attacks all parts of the plant: stems, leaves and tubers. It is visible and recognizable due to its characteristic grey-brown lesions.

Concerning the **leaves**, lesions are more visible on the leaves located close to the ground. Dark green dots that become brown or black depending on the humidity level are visible. Lesions mostly show first on the borders or at the end of the leave. A yellow border, a several millimeters thick, separates the dead tissue from the living one. These lesions grow as conditions are more favorable. They are very contagious and can cause the fall of the leaves.

The same lesions can appear on the **stems** after a direct infection or an extension coming from the leaves. The affected stems are weakened and this can cause the death of all the superior parts of the plant. Infected **tubers** show irregular superficial discolorations. The necrotic lesions can enter inside the tuber and thus give access to all kinds of other pathogens (bacteria, fungi…) that are as harmful to the plant.

The infection spreads through the form of oospores or zoosporangia through air or water. The origin either comes from infected tubers that give birth to infected individuals, or from other infected individuals (Figure 2).

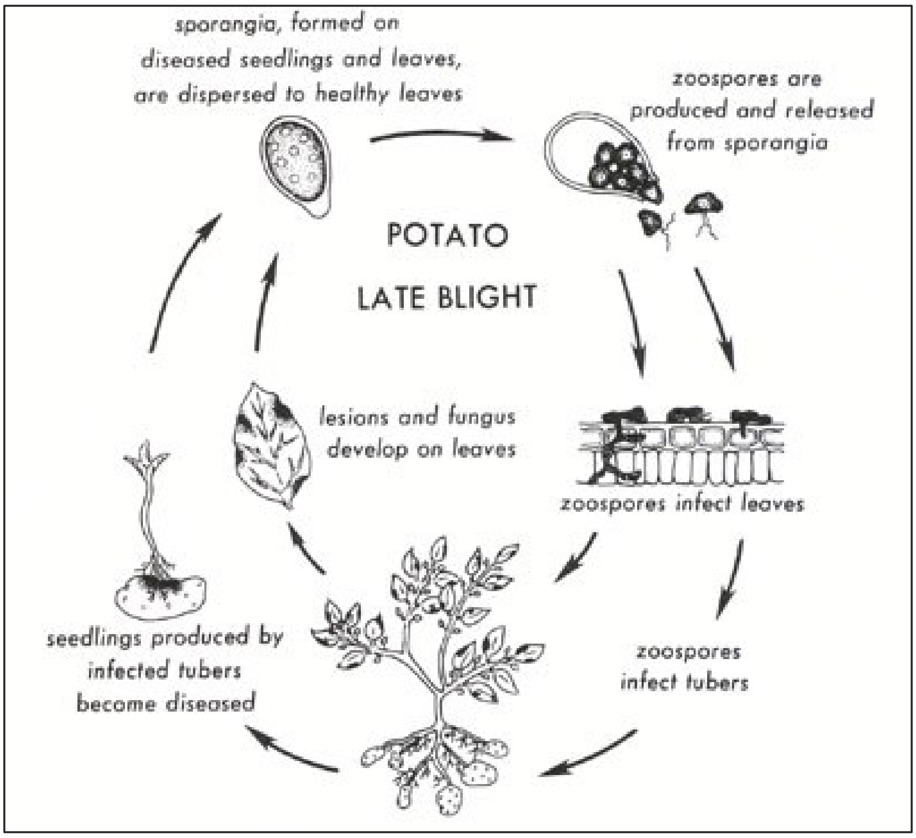


Figure 2 : Disease cycle of late blight on the potato (Apple and Fry, 1983)

1.3. Historical context[6]

The potato was domesticated in the Andes region 7000 years ago (CIP, 2008). When the Spanish arrived in America, the potato was the basic aliment of the Incas (Hawkes and Francisco-Ortega, 1993). It was imported in the 16th century by the Spanish and quickly became a staple crop in Europe and Asia. During more than 200 years, the potato was never subject to the late blight disease in Europe (Semal, 1995).

1.3.1. From the European crisis (mid-19th century) until today

Mildew first broke out on the East coast of the USA in 1843 (Semal, 1995). By 1845, it was imported to Europe where the disease spread. This spread started from Belgium to reach out to England, central Europe, the Pyrenees, Ireland and East Germany (Semal, 1995). The production losses where enormous (-87% in Belgium, -71% in the Netherlands) (Vanhaute, Paping, and Ó Gráda, 2006).

[6] A list of chronological events is presented at Annex 4

In 1846, mildew caused the loss of approximately 88% of the whole potato production of Ireland (Vanhaute, Paping, and Ó Gráda, 2006). At that time, Ireland had its economy based almost only on this monoculture crop, meaning the results of this epidemic where catastrophic. The Great Famine that followed killed more than a million people and caused the migration of more than two million Irish (Vanhaute, Paping, and Ó Gráda, 2006). Since the Great Famine, many scientific research programs have studied late blight and the pathogen was finally accepted as being a fungi, renamed by the German botanist de Bary as *P. infestans* (Mont.) de Bary in 1860 (Semal, 1995).

To fight mildew, it first seems that resistant varieties of potato were cropped. This was due to the high selection pressure caused by *P. infestans* and the lack of other strategies (Forbes and Simon, 2007). About forty years after the Great Famine, Pierre Millardet invented the 'Bordeaux Mix' (Roudié, 1994). This ushered in the new era of chemical protection of plant disease, which eventually had a very negative effect on the potato resistance to late blight. It is during that period that susceptible varieties such as the Bintje became popular, what could not have happened without any chemical protection (Forbes and Simon, 2007).

With the years, the importance of copper-based fungicides like copper oxychloride (which is still used today to control late blight) kept on growing. In the 1940's, 'organic' [7] fungicides like zineb, maneb, matiran, mancozeb and propineb were created. These represent the group of fungicides that are still in use today to fight late blight (Forbes and Simon, 2007).

In the 1970's, new systemic fungicides were invented. These are phenylamides such as metalaxyl, ofurace, oxadyxil and benalaxyl. The strength of these systemic fungicides is that they can contain or kill the pathogen even after it is in the plant. Their weakness is that the pathogen populations easily develop resistances against them (Forbes and Simon, 2007).

The use of systemic fungicides seemed to be efficient until the 1980's. But, in 1980, new resistance appeared against systemic fungicides (like metalaxl) as well as observations of severe symptoms early in the season in the Netherlands. This suggested that new parameters influenced the existing populations of *P. infestans* (Semal, 1995).

In 1981, the A2 mating type of the fungus, which had not been observed outside Mexico since 1845, was found in England. The late blight that had been fought during more than 135 years appeared to just be a clone. This explains the efficiency of the systemic fungicides that were used, because genetic variety was inexistent and resistances in pathogen populations could hardly develop (Semal, 1995).

The introduction of this new A2 mating type in the 1980's allowed sexual reproduction, giving the pathogen increased genetic diversity and thus a greater probability of acquiring a resistance against the various fungicides in use. As a matter of fact, the use of fungicides causes a natural selection in the populations of *P. infestans*. If these fungicides are used as the only way to fight late blight, mutants that derive from sexual reproduction may survive the spraying and replace the original population, creating a fitter population with generalized resistance against the initially used fungicide (Axel et al., 2012).

Not only has a new mating type A2 settled, but this type also caused the replacement of the initial A1 mating type by a new, genetically different A1 type, that seemed more aggressive. These new strains thus become more difficult to combat: spraying has to be augmented and the emergence period keeps on coming earlier year after year (Forbes and Simon, 2007). The arrival of this new mating required it be handled with new fungicides (Semal, 1995).

[7] Organic fungicides are chemical compounds with a carbon basis (Forbes and Simon, 2007)

2. The current context

Today, the potato is the third most cultivated crop on earth after rice (718 Mt/year) and wheat (675 Mt/year) . More than 368 Mt of potatoes were produced worldwide in 2012. Two thirds of this production is for human consumption, while the other third is destined for animal consumption (FAOSTAT, n.d.). Mildew remains the most important threat for the potato as it causes global yield losses of about 16% (Haverkort et al., 2008). The most common way to fight late blight in industrialized countries is still by applying fungicides (Forbes and Simon, 2007).

2.1. The Belgian potato sector

2.1.1. An important economic expansion

The Belgian potato sector is characterized by an important economic growth during the last fifteen years (see Figure 4) (De Blauwer and Florins, n.d.; Lebrun, 2011). From 1996 to 2010, the cropped area has risen on average by 1000 ha a year (Lebrun, 2011). The mean annual potato production of the last five years is of 3.5 Mt a year (Eurostat 2014a), with yields around 43 tons per hectare (FAOSTAT, n.d.). In 2013, the surface devoted to the crop was of about 76000 ha (Eurostat, 2014b; De Blauwer and Florins, n.d.).

This economic expansion is mostly driven by the important growth of the transformation sector, that has made important investments so as to augment its transformation capacity (Lebrun, 2011). The transformation of potatoes into fries, chips, and other potato-based products has thus known a linear growth and the export of transformed products has tripled between 1999 and 2010 (see Annex 1, Figures 12 to 14). Farmers have adapted to this growing demand and have also invested in conservation hangars and machinery so as to augment their production capacity (Lebrun, 2011). The number of farmers in the sector has been reduced throughout the years, meaning farms are bigger (see Annex 1, Figure 15). As a matter of fact, Lebrun (2011) indicates that the mean surface has grown from 4.3 to 7.3 hectares per producers from 2000 to 2010. The proportions of farmers according to the cropped potato area is also exposed at Annex 1, Table 13)

2.1.2. A well-organized market

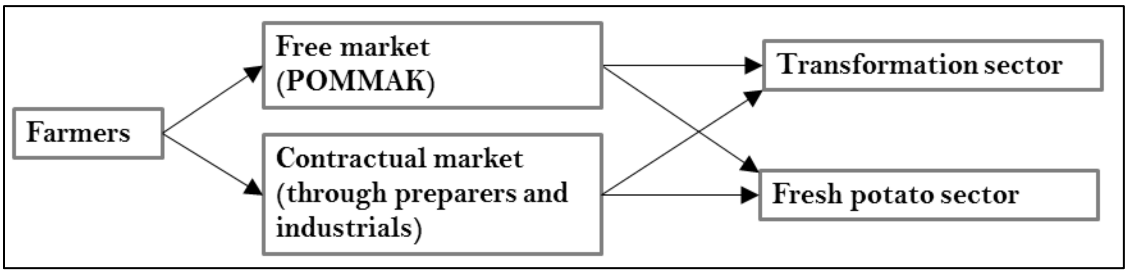


Figure 3 : Scheme explaining the functioning of the potato market and outcome

In Belgium, the potato market functions in two dimensions. Farmers can either produce potatoes that are destined for the transformation sector or the fresh potato sector (see Figure 3). Next to this, farmers can decide to work by using contracts or by selling their production on the free market. By using contracts, farmers sell the production of specific plots at a fixed price at the beginning of the season. Farmers working on the free market will sell their potatoes to buyers at the market price after the harvest (Belgapom, 2014a). For both markets, it is important to have a notion of the evolution of potato prices. This is why trading prices are given weekly by organisms like Belgapom, FIWAP & PCA (as one entity). This information is centralized for the free market by the POMMAK (POMMAK, n.d.).

The recent evolution shows that more and more actors are willing to work by contracts so as to ensure their production. Prices on the free market are much more volatile than contractual prices because they are much more affected by meteorological circumstances that determine the growth, the grubbing and conservation of the potatoes (Belgapom, 2014a).

Next to this, the production is either destined for the fresh sector or the transformation sector. The fresh potato sector represents but a small proportion of the total production in Belgium. It appears that about 10% of the total production comes from the fresh sector (Ryckmans, 2014).

2.1.3. Bintje is the most cropped variety

From 1996 to 2010, around 50% of the total potato production in Belgium was represented by the Bintje variety (De Blauwer and Florins, n.d.; Lebrun, 2011). Lebrun (2011) indicates that the area destined for Bintje did not really change between 1996 and 2010 (see Figure 4), whereas the area destined for other varieties (like Fontane, Innovator, Challenger, Asterix, Ramos, Lady Claire…) and hasty varieties rose respectively from 850 ha/year and 100 to 150 ha/year. Bintje is a free variety, meaning it is not subject to royalties, whereas Fontane, Innovator, Challenger, Asterix… are subject to royalties (Breeders Trust, n.d.). The cropped area (in 2013) destined for each one of these varieties is exposed in Annex 1, Table 14.

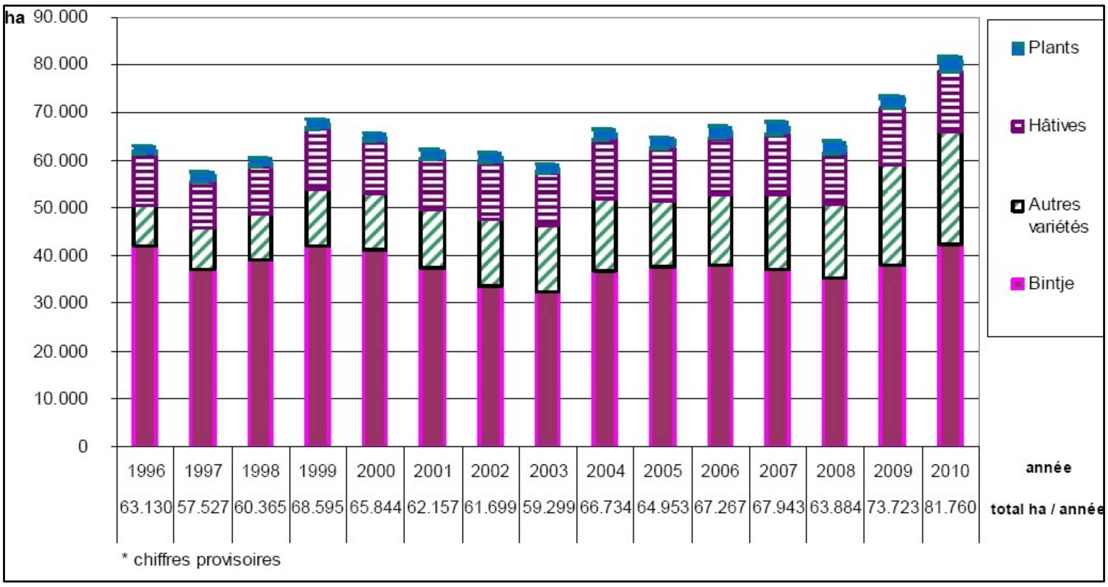


Figure 4 : Evolution of the area destined for the potato crop in Belgium from 1996 to 2010 ((Lebrun, 2011) ('Plants'=seedlings,'Hâtives'=hasty ,'Autres variétés'=other varieties))

Concerning the cropped varieties, it seems that they hardly known by the consumers. It seems that Bintje, Nicolas and Charlotte are the most notorious varieties, whereas other varieties are not known (CRIOC, 2011).

2.1.4. A growing organic sector

The Belgian organic sector is noticing a steady growth since 2005, even though the organic potato sector remains marginal (BioWallonie, 2014). Globally, the growth of the organic sector in Belgium is important in both regions. For instance, in Belgium the area destined for organic cropping has risen by 208% from 2000 to 2013 (rising from 20.265 to 62.492 hectares) (see Annex 2 , Figure 16), the number of producers has risen by 127% (from 666 to 1514 producers) (see Annex 2, Figure 17) (BioWallonie, 2014) and the total turnover of the sector was of 3% in 2012 (Bioforum Wallonie, 2013). Finally, from 2008 to 2013, the consumer's spending for the organic sector has risen by 58% (see Annex 2, Figure 18) (BioWallonie, 2014).

Concerning the organic potato sector, the (restricted) available information shows the observed tendencies for the cultivated area are quite similar. As a matter of fact, from 2000 to 2012, the area destined for the organic potato crop has more than doubled (a rise of 113%) in Belgium, growing from 162 to 341 hectares. This represents a growth of almost 10% a year. The majority of this area is located in Wallonia, where the growth was also more important (from 100 to 265 hectares) with a mean growth of almost 14%. In Flanders, the organic potato area is less important and underwent a lesser growth (from 61 to 80 hectares) of about 3% a year from 2000 to 2012. The total production of fresh organic potatoes in Belgium in 2010 was of 2778 tons thus representing 0.7% of the total market share of the Belgian fresh potato market (Ryckmans, 2014). In 2013, the potato represented 3.1% of the market share of the Belgian organic sector (BioWallonie, 2014). Politically speaking, the regions of Flanders (Hope, 2014) and Wallonia stimulate the organic sector (Di Antonio, 2012).

2.1.5. Mildew control in Belgium

The commercialized varieties of potatoes are very sensitive to late blight (Poulet et al., n.d.). Since resistances against fungicides have appeared in *P. infestans* populations, the use of fungicides remains the condition *sine qua non* in order to maintain the use of these commercialized varieties (Forbes and Simon, 2007).

2.2. The classic way of struggle: chemical control

In order to control late blight, in general, various kinds of fungicides are applied on the potato leaves during the season (Perez and Forbes, 2010). The fungicides currently in use are represented by a broad variety of families. These families of molecules are quite diverse, especially in order to attack the pathogen by various means. Fungicides are classified depending on various criteria. Knowing how the pathogen - fungicide relationship works allows a more efficient use of these chemical products (Rolot, 2012).

2.2.1. Types of fungicides

Fungicides can be classified according to two distinct aspects that are the interaction with their host and their mode of action (see Table 1). Various examples of fungicides and their characteristics are given (see Table 2).

Table 1: Main characteristics of fungicides used to control mildew (Rolot, 2012; Perez and Forbes, 2010)

	Host interaction and need of application
Contact fungicides	- Do not enter the plant but form a layer of active substance on the surface of the plant - Have to be sprayed more often when the plant grows fast otherwise the youngest parts will not be protected
Translaminar fungicides	- Enter the plant by crossing the leaf thickness but do not circulate in the plant (for example from leaf to leaf) - Leaves formed after the spraying will not be protected
Systemic fungicides	- Enter and circulate inside the plant and generally move to the new formed parts of the plant, which means they can protect leaves formed after the application. In this case, the concentration inside the plant is of importance
	Mode of action
Preventive	- Must be present on the plant before a possible infection process
Curative	- Are active against *P. infestans* immediately after a post infection period, but before the symptoms of infection become visible - Are able to stop the infection immediately after its initiation
Anti-sporulant	- The *P. infestans* lesions are affected by the fungicide by decreasing sporangiophore formation and/or decreasing the viability of spores and sporangia formed

Table 2 : Review of the different types of fungicides and their characteristics (Rolot, 2012; Perez and Forbes, 2010)

Type of fungicide	**Contact fungicides**		**Translaminar fungicides**	**Systemic fungicides**
Example	*Copper, Dithiocarbamates (e.g. mancozeb)*	*Cyazofamid, Fluazinam, Zoxamide*	*Cymoxanil, Mandipropamid, Benthiavalicarb, Dimetomorph, Fenamidone*	*Benalaxyl, Metalaxyl, Propamocarb, Famoxadone*
Washable by rain	Yes (> 20 mm)	No (>50 mm) (cyazofamid)	No	No
Curative effects	None	None	Yes (Cymoxanil)	Yes
Comments	- Generally used in case of low infection pressure - Cheap	- More expensive	- More expensive	- Can favor the selection of late blight resistant strains - Best used when plant growth is maximum

2.2.2. Resistance to fungicides

The constant use of certain products has caused the appearance of pathogen strains that prove resistant to this specific kind of fungicides (Perez and Forbes, 2010). As a matter of fact, two types of risk of resistance to fungicides have been observed: fungicide inherent risk and pathogen inherent risk. The mode of action and chemical features of a fungicide determine the fungicide inherent risk. Fungicides can thus also be classified depending on the risk for the development of resistance. The pathogen inherent risk depends on the characteristics of pathogen life cycle, its reproductive rate, mode of dispersal and its mutation potential. Selection pressure of resistant isolates of a pathogen to a particular fungicide in large crop areas is also an important factor. By combining these two risks, the appearance of resistance to fungicides can be measured (Perez and Forbes, 2010).

In this case, phenylamid fungicides (like metalaxyl) were very efficient in the 70's until new resistant strains emerged. New mildew crisis were noted in various regions around the globe during the 80' and 90's (Forbes and Simon, 2007; Fry and Goodwin, 1997) . Because of this resistance, *P. infestans* was classified by the FRAC[8] as a high risk pathogen for phenylamide-type fungicides, while remaining a medium-risk pathogen for fungicides with other modes of action (Perez and Forbes, 2010). Today, the genetic variety of *P. infestans* continues to grow and new strains, resistant to fungicides such as propamocarb, zoxamide and cyazofamid have appeared (Axel et al., 2012).

It is by attacking *P. infestans* in various ways that fungicides are used most efficiently (see Table 3) (Forbes and Simon, 2007). As a matter of fact, by attacking the pathogen by various means, and avoiding the constant use of the same 'silver bullet', one gives it less chance to adapt to a specific kind of attack (Perez and Forbes, 2010). That is for instance why most of the used products on field are blends of various types of fungicides (see Table 4). Today, the most common type of application is preventive, in order to impede *P. infestans* infections from appearing in the first place (Lebrun, 2013; Perez and Forbes, 2010).

Table 3 : Commonly used fungicides for the treatment and their action against late blight (Axel et al., 2012)

Fungicide	Action on *P. infestans*
Metalaxyl	Inhibit protein synthesis, growth and reproduction in fungi
Cyazofamid	Diminish the formation of sporangia
Fluazinam	Uncouples oxidative phosphorylation
Fluopicolide	Lysis of the zoospores and hyphae
Mancozeb	Inactivate the sulfhydryl (SH) groups of amino acids in enzymes of fungi

In order to reduce the risk of appearance of resistance to fungicides in pathogen populations, Perez and Forbes (2010) propose other various solutions:

- Restrict the number of high-risk fungicide applications
- Mix high and low risk fungicides as to be sure the spores do not survive
- Alternate the use of high-risk and low-risk fungicides by assuring a different mode of action
- Add other integrated management practices (non-chemical ones) as to avoid disease development

[8] 'Fungicide Resistance Action Committee (FRAC)'

2.2.3. Economic impact

In the EU, more than 2 Mha are destined to potato cropping (Haverkort et al., 2008). In 2013, the surface devoted to the potato crop in Belgium was of 75400 ha (Eurostat, 2014b). The total Belgian production was of about 3.428 Mt (Eurostat, 2014a). The price that is obtained by the farmers for their potato harvest varies a lot from year to year (see Figure 5).

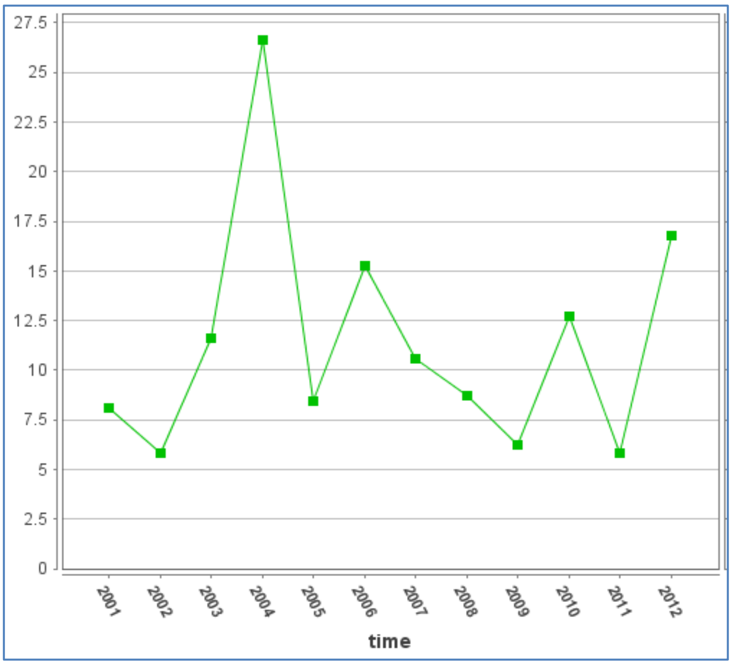


Figure 5 : Obtained price (in €10) by the producer per ton of potato in Belgium from 2001 to 2012 (Eurostat, 2014c)

Next to potato prices, the use of fungicides depends on the type on agriculture, but also on the conditions in which they are applied (type of soil, type of climate, time of year…) (Haverkort et al., 2008). As explained, different combinations of fungicides are generally used (Table 4). The costs of these fungicides vary and their application is alternated so as to reduce the possibility of appearance of resistances in late blight populations (Haverkort et al., 2008; Perez and Forbes, 2010).

Table 4 : Most common mixes of chemical agents used to control mildew and their price per unit (De Wolf and Van der Klooster, 2006)

Active agent	Trademark	Price in €
Cymoxanil + mancozeb	Curzate	10.80 /kg
Cymoxanil + famoxadone	Tanos	43.20 /kg
Fluazinam	Shirlan	67.10 /l

In Belgium, more than 1000 tons of fungicides are applied every year in order to control *P. infestans* (VIB, n.d.). This costs roughly € 55 million per year (Belgapom, n.d.; VIB, n.d.). The total cost per hectare (in the Netherlands) is €330 if there are 15 applications [9] (Haverkort et al., 2008). At a European level, *'yearly fungicide usage for late blight control in Europe is estimated to be about $150 million'* (Forbes and Simon, 2007).

[9] The type of potato cropping in the Netherlands is comparable to the Belgian methods

Added to these losses, potato late blight also leads to lateral costs due to losses caused for example by premature harvest and immediate delivery to the market or bad storability conditions. At a global level, Haverkort and colleagues (2008) indicate that potato late blight causes 16% of yield losses.

2.2.4. Regulatory frame

Inside the EU, pesticides are regulated at a national level based on their persistence that is related to climate conditions and the chemical's properties (Axel et al. 2012). The actual regulations concerning pesticides in the EU are based on four major texts (Phytofar, 2010).

- The regulation 1107/2009 that replaces the directive 91/414/CE concerning the placing on the market of plant protection products. The list of authorized active substances is to be found in the execution regulation 540/2011 of the 25th of May 2011. The list of prohibited or potentially dangerous substances is to be found in the regulation 1272/2008.
- The framework directive 2009/128/CE that concerns the national plans of the sustainable use of pesticides
- The regulation 1185/2009 organizes the statistical system and the regulation and directive 2009/127/CE controls the machines destined for the application of pesticides
- The regulation 396/2005 defines the maximum limits of residues of the allowed active matters.

The framework directive 2009/128/CE has led to the adoption, since January 1st 2014, of the 'IPM directive', which demands of Member States to apply IPM methods in professional sectors using pesticides (Anonymous, 2010). This means the use of pesticides has to be reduced as much as possible by the users. In order to meet these requirements, in Belgium, the Walloon Region has set up a 'Walloon Plan for Pesticide Reduction'[10] (DGO3, n.d.), whereas Flanders has put up a symmetric 'Action Plan for Sustainable Pesticide Use' (Vlaamse regering, 2013). These two plans will be evaluated in a common national action plan (NAPAN), and new goals will be set starting from 2017.

Moreover, in Belgium, the regional authorities are in charge of the certification of seedlings (Di Antonio, 2012), and are also responsible for the financing of the alert systems and various research programs. The certification of chemical products is ensured by the legislations established by the Federal Ministry of agriculture. A Certification committee (established in the 'Public Federal Service') will always use as its legal basis the royal decree of the 28 February 1994 concerning the conservation, usage, and introduction on the market of pesticides for agricultural use (BeSWIC, n.d.).

2.2.5. Energetic, ecological, and sanitary impacts

To grow one hectare of potatoes, the necessary energy is about 25 GJ (Haverkort et al., 2008). The application of fungicides also requires energy. It is estimated that the application of one kg of fungicides per ha costs roughly 40 MJ (in energy content) and two liters of diesel (x 55MJ per l). The total cost per application is thus of 150 MJ. If fungicides are to be applied 15 times, the total energy needed is 2,25 GJ (which represents 9% of the total energy costs needed) (Haverkort et al., 2008)[11]. Reducing the number of necessary fungicide applications could thus be an important way to reduce the energetic needs for the potato crop.

Next to this energetic demand, fungicides have nocuous effects on human health and the environment. For every type of fungicide, a record card has to be made by the producers. This record card illustrates all the characteristics (chemical, toxicity, physical, half-life…) of the fungicides. By

[10] 'Plan Wallon de Réduction des Pesticides' (PWRP)

[11] The production of the applied fungicides is also a source of energy use that hasn't been taken into account in this equation (Haverkort et al. 2008).

the use of this record card, the hazard of using this type of fungicide is determined and allowed (or not) by the politics (Phytofar, 2010).

However, even if allowed, fungicides still have an impact on the environment. For example, mancozeb can affect groundwater quality due to its spontaneous degradation to ethylenethiourea (ETU) that is more persistent (five to ten weeks) and is carcinogenic (Xu, 2000; EPA (Environmental Protection Agency), 1999). Fungicides also clearly impact soil life (this will be discussed later).

Concerning the effects of fungicides on human health, they are less important than those of herbicides (according to European directives). The LD_{50}[12] values of fungicides range between 2000 & 5000 mg/kg while pesticides have values of LD_{50} under 1000 mg/kg (Haverkort et al., 2008). Any exposure to highly concentrated doses of fungicides can cause important health problems. Farmers are always very well informed by the plant protection firms as to how they need to handle these products.

2.2.6. Mildew alert models

Nowadays, forecasting models of the late blight spread have been created[13] in order to maximize the efficiency of the fungicide application. Because *P. infestans* is a very climate-related pathogen, these models can predict, based on weather conditions and other variables, when and where the pathogen will spread. Farmers can thus determine when it is the best moment to spray and as a consequence spray less (Mizubuti and Fry, 2006). These models exist at various levels: in Belgium they work at a regional scale (Flanders and Wallonia).

The use of these models has helped a lot during recent years and they are becoming more and more accurate, as the relationships between different variables are more and more precise. Still, it is important to keep in mind that some variables (like climate and pathogen genetics) can vary strongly at a local level, impeding the use of such models at a large scale. The assumptions made during the creation of the model must never be forgotten when these models are used for a very local and specific case. Furthermore, it is important to keep in mind that these models do not provide a method to eradicate late blight but they are of crucial importance in order to allow a reasoned use of fungicides until better control methods have been found (Mizubuti and Fry, 2006).

[12] LD_{50} : 'Lethal Dose for 50% of the subjects'
[13] for example the 'late blight model of Bruhn'

2.3. Alternative ways of struggle

A variety of other methods exist in order to partially fight *P. infestans* and to control its ravaging impact besides the use of fungicides. Here, we examine methods associated with genetic control, with the organic sector and finally with IPM [14]methods.

2.3.1. Genetic control

Mildew can be fought by the use of genetic control. *'Genetic control refers to the use of varieties or species of the host that have resistance to the pathogen which acts to stop or slow down disease development'* (Perez and Forbes, 2010). Two types of resistances exist concerning the manner in which the resistance to *P. infestans* is expressed in the potato plant (Perez and Forbes, 2010; Forbes and Simon, 2007).

The first one is the '**qualitative**' or '**vertical**' resistance that is race-specific (Colton et al., 2006). This resistance is characterized by triggering a hypersensitivity response (HR) such as small necrotic lesions (Perez and Forbes, 2010). At first, qualitative resistance was considered a silver bullet for late blight control because it was extremely efficient against avirulent races of the pathogen (Forbes and Simon, 2007). However, virulent races reach a state of predominance so fast that it never takes long before the pathogen overcomes the resistance (Forbes and Simon, 2007; Perez and Forbes, 2010; VIB, n.d.).

The second type of resistance is the '**quantitative**' or '**horizontal**' resistance. It is governed by minor genes of additive effect (Colton et al., 2006; Perez and Forbes, 2010). It is more sustainable and more effective against all pathogen races (Colton et al. 2006; Forbes and Simon 2007; Perez and Forbes 2010).

Resistant varieties and R genes

The potato is a species that is represented by many different varieties. In conventional agriculture, the potatoes found on the market are represented by varieties that are very susceptible to late blight (Mizubuti and Fry, 2006). Breeding techniques have not yet been able to create resistant, commercially viable potatoes (Haverkort et al. 2008).

- **Conventional breeding techniques**

Intentional breeding for resistance to late blight began more than a hundred years ago with the introgression of resistance from *S. demissum*[15] (Gebhardt and Valkonen, 2001; Haverkort et al., 2009). Different varietal programs trying to insert resistances in commercial varieties have been conducted throughout the century. Traditional breeding has proven to be difficult because of the various ploidy groups that exist between potato cultivars. This variety in ploidy creates barriers to crossing (Smith, 1983). Nevertheless, after more than forty years of intentional breeding, both Dutch and Hungarian researchers obtained convincing results (Haverkort et al., 2009; VIB, n.d.). On one hand, the Dutch achieved to insert a single resistance gene *Rpi–blb-2* from *Solanum bulbocastanum*, into two distinct varieties called 'Bionica' and 'Toluca'. On the other hand, Hungarian researchers created the 'Sarpo Mira' variety, which is an accumulation of numerous existing resistances. This variety is thus characterized by a more sustainable resistance to late blight (VIB, n.d.).

These three varieties might be resistant, but have difficulties entering the market. Added to this, the durability of Bionica and Toluca is disputable, since they contain but one resistance gene (VIB, n.d.).

[14] 'Integrated Pest Management'
[15] a wild potato species indigenous to Mexico

It seems thus that scientist have not yet succeeded in inserting durable varietal resistances in commercially cropped varieties through traditional breeding techniques (Gebhardt and Valkonen, 2001; Haverkort et al., 2009) .

- **R-genes**

In the context of the introduction of more resistant varieties in breeding programs, R-genes can be used to confer resistance properties to commercial varieties of the potato (Vleeshouwers et al., 2011; Forbes and Simon, 2007; Mizubuti and Fry, 2006). Resistance to *P. infestans* is characterized by a cell death-associated defense reaction known as the 'hypersensitive response' (HR) (Kamoun, Huitema, and Vleeshouwers, 1999; Vleeshouwers et al., 2000). First, the pathogen enters the plant and translocates effectors[16] inside host cells. These effectors promote pathogen virulence, for example, by suppressing the plant immunity. Specific effectors can activate corresponding R genes by acting as avirulence (Avr) factors. When the effector is recognized by an R protein, effector-triggered immunity is activated, often resulting in the HR. By using these effectors, we can analyze and isolate R genes that will become candidates for introgression for the making of a resistant variety. A catalog of R and Avr gene pairs has recently become available for the potato – *P. infestans* pathosystem (Vleeshouwers et al., 2011). For instance, eleven *S. demissum* resistance *(R)* genes, designated *R1-R11*, were distinguished (Colton et al., 2006; Vleeshouwers et al., 2000). Some of these genes (R1, *R2, R3 and R10)* have already widely been used in breeding programs. Alas, the resistance of these genes was not durable because *P. infestans* quickly overcame it by the use of its Avr[17] genes (Vleeshouwers et al., 2011).

However, more and more R-genes are being discovered from other wild *Solanum* species (VIB, n.d.; Vleeshouwers et al., 2011). It seems if these resistance genes are to be used in a sustainable manner, it would be best to insert many different R-genes at one time as to create a quantitative resistance and reduce the chances of *P. infestans* to adapt to every single type of gene at a time (Forbes and Simon, 2007; Perez and Forbes, 2010; VIB, n.d.). At this stage, the insertion of many R-genes at once is still difficult but research is now one step beyond traditional 'pathogen-blind' approach, thanks to the use of effectors (Vleeshouwers et al. 2011).To date, 21 *R* genes that confer differential resistance specificities have been cloned, offering a wide range of future possibilities (Jacobsen, 2011; Vleeshouwers et al., 2011) .

GMOs

The creation of new resistant varieties against mildew via the artificial insertion of R-genes coming from other organisms constitutes an innovative way of fighting the disease (Mizubuti and Fry, 2006). These new varieties could be both resistant and commercially competitive (Haverkort et al., 2009). The positive ecological impacts would also be very important because if resistant varieties can be made as a result of genetic engineering, the use of fungicides should, according to Haverkort and colleagues (2009), be strongly diminished.

Societal approval will have a major impact in the success of this type of struggle. According to Haverkort and colleagues (2009) the created GMO plants will have to respect the rule of the triple P:

- First of all, the new potatoes that are resistant to mildew would largely contribute in **profits** by reducing the costs of struggle and by increasing the yields in less industrialized countries.
- The impacts on the environment can only be benefic (**planet**) because the use of chemical inputs will be reduced dramatically.

[16] Effectors are '*pathogen molecules that alter host cell structure and function, thereby facilitating infection and/or triggering defense responses'* (Vleeshouwers et al., 2011)
[17] 'Avirulence genes'

- Finally, the image of the potato crop would be improved as well as the food security in poor countries (**people**).

Today, many research programs are conducted in order to find 'the resistant potato'. This can be achieved by adding resistance genes from another potato with which a natural crossing could be possible ('intra-specific transgenesis' or 'cisgenesis').

- **Cisgenesis (or intra-specific transgenesis)**

A cisgenic organism is an '*organism that has been genetically modified by the use of one or multiple genes (containing introns and adjacent regions like the original promotor and terminator) isolated from another organism with whom genetic crossings would be possible in nature'* (Schouten, Krens, and Jacobsen, 2006). Thus, for their creators, these cisgenic organisms have a different status than transgenic plants because they do not contain genes that would be impossible to insert naturally in the genome (Haverkort, et al. 2009; Schouten, Krens, and Jacobsen, 2006; VIB, n.d.).

For scientists who support this method, it simply accelerates the natural process of selection conducted by man by choosing and inserting in a much faster way the desirable characteristics in the final plant. In fact, the final plant could equally well be obtained by the use of natural crossings of selected varieties of plants (Haverkort et al., 2009; Schouten, Krens, and Jacobsen, 2006; VIB, n.d.). Cisgenesis does not add any new traits to the species, because these traits already exist in one of the varieties of the global existing species (in this case *Solanum* species). It affects the fitness of the organism, but in a way that could have been obtained naturally. These traits can be transferred to wild organisms but the impact is comparable to the dispersion of and already existing natural trait (Haverkort et al., 2009; Schouten, Krens, and Jacobsen, 2006; VIB, n.d.).

- **Transgenesis**

Next to this, organisms created by inter-specific transgenesis are '*organisms that have been genetically modified that contain genes that come from organisms with whom natural genetic crossings are impossible (for example genes coming from a bacteria that are transferred to a plant), synthetic genes or artificial combinations from a gene coding with regulatory sequences like a promoter, coming from another gene'* (Schouten, Krens, and Jacobsen, 2006).

New inexistent phenotypic traits can appear and this can have a considerable impact on the fitness of the organism. This trait could be released in nature and thus create new, weaker or invasive organisms (Schouten, Krens, and Jacobsen, 2006).

An example of transgenic potato that exists today is the 'Fortuna' potato (that contains two resistant genes, being *Rpi-blb1* and *Rpi-blb2)* created by BASF in 2011. This genetically modified potato is, for now, not allowed on the European market (VIB, n.d.).

- **A future distinction between transgenic and cisgenic organisms?**

The discrimination at a regulatory level between the two types of GMOs (transgenic and cisgenic) has not yet been operated (Haverkort et al., 2008; Schouten, Krens, and Jacobsen, 2006; VIB, n.d.). In fact, the European directive 2001/18/EC still regulates all types of GMOs (Haverkort et al., 2008).

2.3.2. Organic struggle

In the organic sector, synthetic fungicides are not allowed, with the exception of copper based fungicides in limited quantities (Gianessi and Williams, 2011; Speiser et al., 2006). The use of anti-germ products is also prohibited (Di Antonio, 2012). In general, yields of organic potatoes in Europe are 50% lower than from conventional fields because of various pathogens, mildew being the most important cause (Gianessi and Williams, 2011).

Effective methods for the control of late blight are extremely limited in organic agriculture (Speiser et al., 2006). Copper treatments reduce foliar blight by a relative constant degree, on average by 27% (Speiser et al., 2006). They also increase yields by 20%, but have no significant effect on tuber blight (Gianessi and Williams, 2011; Speiser et al., 2006). In the EU, the use of copper fungicides on organic crops was limited to eight kg ha $^{-1}$ of pure copper in 2001 and reduced to six kg ha^{-1} by the year 2006 (Gianessi and Williams, 2011; Tamm et al., 2004). Today, this is still the case in Belgium. In some countries however, the use of copper fungicides is prohibited by national legislation (particularly in Scandinavia and the Netherlands[18]) (Axel et al., 2012; Gianessi and Williams, 2011; Lammers et al., 2008). In the Netherlands, organic potatoes are cropped by using IPM methods and hasty or resistant varieties. When 7% of the plot is struck by mildew, the potatoes have to be harvested (van Bueren, Tiemens-Hulscher, & Struik, 2008). The ultimate goal of the E.U. is to prohibit the use of copper in potato production. This perspective still seems unrealistic for European organic farmers who very well know that late blight epidemics are looming (Gianessi and Williams, 2011).

Because of this restriction in use of (copper based) fungicides, the organic sector would even more benefit from the making of resistant varieties. These new varieties would thus have to meet some required characteristics (Speiser et al., 2006):

- Better resistance to late blight
- Similar or higher yields than commercial potato varieties
- Similar or lower tube blight incidence
- Similar tuber characteristics with respect to market demands

According to Speiser and colleagues (2006), the use of more resistant varieties could have a major impact on the use of copper fungicides and could lead to a reduction of 16.5 to 50%. To minimize the risk of resistance breakdown and its adverse consequences, they also recommend diversifying within a season, by using several varieties with genetic differences.

Next to this varietal aspect, organic plant protection strategies are usually characterized by a combination of as many components as possible to reduce the likelihood of infection, to limit the impact of the pest or disease, and finally to achieve functional control over the disease (Tamm et al., 2004). More than in conventional farming, a systemic approach is needed, which combines as many control measures as possible. Even measures which are insufficient on their own may be useful, if they have a synergistic effect when used in combination (Tamm et al., 2004; Speiser et al., 2006). This method can also be called Integrated Pest Management.

[18] As a response, the Louis Bolk Institute (Netherlands) has decided to augment research levels as to conduct a breeding program named 'Bio-impuls' (van Bueren, Tiemens-Hulscher, & Struik, 2008)

2.3.3. Integrated Pest Management applications (IPM)

Integrated pest management (IPM) is a type of struggle that relies on two major types of control: cultural and biological control (Cowan and Gunby, 1996; Perez and Forbes, 2010). These types of control depend on knowledge intensive applications. This means that IPM methods require a lot of familiarity in various techniques such as rotation, mixed cropping, early sowing and soil protection that are some of the many existing aspects of this method (Cowan and Gunby, 1996). IPM methods are more often used in organic farming due to the limitations applied on the use of copper fungicides but can be applied in the conventional systems too (Speiser, 2006). IPM techniques are used for potato cropping and can be applied to control mildew (Perez and Forbes, 2010).

Cultural control[19]

Cultural control involves all the activities carried out during agronomic management that can help avoid or reduce pathogen activity. These activities will have an effect on the microclimate, host condition and pathogen behavior. Factors that can be targeted in the potato agricultural system are for example:

- **Planting time** : so as to avoid the period of higher incidence of the disease
- **Selection of crop fields**: soils must have good drainage en adequate aeration, in order to avoid moisture on foliage and ground
- **Destruction of volunteer plants and weeds**
- **Avoiding monocropping:** (does not apply for potatoes)
- **Selection of the variety:** selection of resistant varieties as to slow the infection
- **Selection of planting material** : selection of healthy seed tubers
- **Distance between plants and between rows** : as to reduce moisture on the foliage
- **Hilling**: make high, well-formed hills to avoid or reduce contact of tubers with sporangia or zoospores coming from infected foliage.
- **Plant nutrition:** high doses of phosphorus and potassium reduce late blight whereas high doses of nitrogen increase its incidence. Nitrogen slows down tuber maturity, favoring late blight appearance, whereas phosphorus does the exact opposite
- **Foliage cutting:** fifteen days before harvesting, foliage should be cut and removed from the field. Instead of using desiccants or herbicides that are dangerous, it seems more profitable to operate a 'green lifting' or 'green harvest' which consists in harvesting the tubers and putting them back in the soil, without any stem or roots
- **Adequate irrigation**
- **Sanitation:** eliminating the infected plants on field as soon as possible
- **Timely harvest**
- **Destruction of discarded tubers**
- **Appropriate storage conditions…**
- **Adequate rotation duration**

[19] (Perez and Forbes, 2010)

Biological control

Instead of using chemical inputs (that have serious consequences on the environment and human health) to combat mildew, this method intends to use interactions between one or more living organisms to control the pest management (Perez and Forbes, 2010). Biological control, also called biocontrol, is classically defined *"as the use of living organisms to suppress the population density or impact of a specific pest organism, making it less abundant or less damaging than it would otherwise be"'* (Eilenberg, Hajek, and Lomer, 2001).

The use of natural predators to combat pathogens is common and has been used in past agricultural systems (Axel et al., 2012; Cowan and Gunby, 1996; Perez and Forbes, 2010). As a case in point, various research shows that several microorganisms have an antagonistic effect against *P. infestans* (for example *Serratia spp*., *Streptomyces spp*., *Pseudomonas spp*., *Bacillus spp*., *Trichoderma spp*., *Fusarium spp*., *Aspergillus spp*., *Penicillium spp*., etc…) (Axel et al., 2012; Vossen et al., 2005). These organisms could, by various modes of action (i.e. antagonistic effects or induction of plant defense mechanisms) be used as bio-fungicides (Axel et al. 2012).

Axel and colleagues (2012) also add that '*This definition can be expanded to include microbial metabolites and other naturally derived compounds'*. This means that non-living products, such as elicitors, can be used to stimulate plant immunity mechanisms. These elicitors have the property to induce various defense mechanisms in the plant, thus reducing the risk of resistance of the pathogen. Elicitors are most effective when used preventively. They have a complementary effect when used with fungicides. This means that doses of fungicides can be reduced, while maintaining the same level of protection (FREDON (Fédération Régionale de Défense contre les organismes nuisibles) 2008).

For now, the commercialization of such products is still difficult given the lack of reproducibility in combatting mildew, the effectiveness of the existing products should be improved. Nevertheless, the screening of potential antagonist microbes and their metabolites, and other elicitor products should be explored (Axel et al. 2012).

3. Socio-technical approach: A short presentation

3.1. The technological 'Lock-in' theory

In order to understand the current situation of the mildew-potato system in Belgium, it is important to underline the importance of the socio-technical 'lock-in' that exists in this system today. A clear definition of a lock-in, given by Cowan and Gunby (1996) is that *'the existence of dynamic increasing returns implies that a path once chosen has a tendency to become entrenched. One concern that follows is the possibility of ex post inefficiency – that self-reinforcing mechanisms might drive the economy to an inefficient outcome. While these issues are well-understood at an abstract, theoretical level, they have been difficult to elaborate empirically*[20]*'*. This means that the actual way of functioning is not the optimal one anymore, but remains in place because of various factors and choices. This existing lock-in is a result of a past technological competition where the consequences of positive feedback, self-reinforcing mechanisms and minor events eventually pushed the system into a particular direction, maintaining just one of the many initial technologies (Cowan and Gunby, 1996). In theory, the competition between various young technologies will depend on the 'degree of adoption' of these technologies (Cowan and Gunby, 1996). This degree of adoption can be modulated by three different factors.

First, Farrell and Saloner (1985, 1986) argue that the degree of adoption will depend on **coordination problems**. This means that no agent will be ready to adopt a technology if she or he knows that many others will not adopt it. The agent is not ready to give up the large existing network to which she or he belongs in order to join a small or non-existent one. Secondly, Arthur (1989) underlines the issue of **improving technologies**. Learning by using or learning by doing can increase the experience with a technology and increase the benefits of adopting it. This is reinforced by a snow-balling effect that locks-in the market. Finally, Cowan (1991) addresses the learning about **payoffs**. When experience with more than one technology accumulates, it is easier to decide which one is the best, and thus to disregard the less interesting one, assuring an uncertainty reduction.

Technological externalities, learning, and uncertainty reduction operate as positive feedbacks. This means that the more users there are, the more the value of a technology rises. If there is positive feedback, it results in path dependence, inflexibility, and potential regret of the chosen technology (Cowan and Gunby, 1996).

3.2. Agricultural 'Lock-in' example

Building on a series of very clear examples, Cowan and Gunby (1996) show that the choice of a given technology depends on various (historical) factors. The technology in use today comes from a path dependent strategy and can vary a lot from region to region. In agriculture, an example of lock-in is the actual dominating stance of an intensive, chemical, and fuel input-based agriculture. This situation seems to be more and more inefficient, if not today, in the near future, because of the resistances that arise within predator populations and the ecological impact of such system (Cowan and Gunby, 1996). In contrast to this system, the holistic, systemic (or 'IPM') approach does not rely on any inputs and is self-sufficient. On example of this approach is agroecology (Altieri 1995). The main difference between chemical control and IPM is that IPM is a knowledge intensive technology

[20] The main reason why these issues are difficult to elaborate on empirically is because of a problem of availability of the data. As a matter of fact, the data of comparison with a 'possible evolution' are very hard to obtain (Cowan and Gunby, 1996).

based on an economic damage study that tries to enhance natural interactions. In contrast, chemical control relies more on the extensive use of inputs and on constant yield measurements. It is based on a physical damage focus (Cowan and Gunby 1996).

Historically, at the beginning of the 20th century, pest control comprised chemical, cultural and biological techniques. After the Second World War though, synthetic organic insecticides such as DDT were introduced on the market. The farm community quickly accepted the use of these chemical products because they were effective, very cheap, and allowed to secure more important yield increases. Information indicating that pesticides represented a new, even more efficient technology caused this rapid adoption. Other types of control were almost totally replaced. The development of new pesticides was in vogue and huge profits were made by the chemical industry. A positive feedback undoubtedly gave the chemical sector a great lead during the following decades (Cowan and Gunby, 1996). Nowadays, pesticide resistance is threatening various kinds of crops in many areas around the globe (for example cotton in the southern US). As a result, a shift to IPM is increasingly being made in those places. In other locations, the use of chemical pesticide use remains the dominant strategy (Cowan and Gunby, 1996).

IPM is a technology that is subject to increasing returns: the starting costs are fixed (machinery…), learning by doing makes the cost of production decrease over time and, finally, network externalities make the sources of localized information inexpensive. IPM may thus be dominant in parts of the globe where the switch was really necessary and where support was given at different levels (by means of programs, alleviation of transition, coordination, R&D, etc…). Having said this, the switch to IPM remains difficult because of the different barriers that continue to exist today (uncertainty, lack of support, payoffs…). This is clear indication that there remains a lock-in concerning the use of inputs and chemicals in our modern agriculture (Cowan and Gunby, 1996).

4. Conclusion of part one

This first part was devoted to a review of the literature detailing the link between the potato and late blight, the current status of the Belgian potato sector, and the various strategies implemented in order to manage the pathogen. The part ends with an overview of theory of 'lock-in'.

Potato late blight, caused by the oomycete *Phtyophthora infestans* (Mont.) de Bary has devastating consequences on the potato crop (Mizubuti and Fry, 2006). The damages caused have been estimated to results in global yield losses of 16% (Haverkort et al., 2009).

Today, the Belgian potato sector is in economic expansion and transforms around 3.5Mt of potatoes a year (Eurostat, 2014a). Various potato varieties are cultivated, but Bintje represents about half of the potato cropped area (De Blauwer and Florins, n.d.; Lebrun, 2011). In fact, all current commercialized varieties are highly susceptible to mildew (Poulet et al., n.d.).

This implies the use of fungicides so as to control the pathogen. Not surprisingly, the use of these fungicides has important economic and ecological impacts. In Belgium alone, the costs of late blight control are estimated at € 55 million per year (Belgapom, n.d.; VIB, n.d.). Moreover, resistance to fungicides appears in mildew populations, meaning that new, more performing fungicides have to be created. Alert models, based on meteorological data, allow a more efficient use of these fungicides (Mizubuti and Fry, 2006).

Alternatives to fungicides exist in order to control mildew. The three main options are genetic control, organic struggle, and IPM methods. Genetic control relies essentially on resistance genes in the host plant. These resistance genes come from resistant potato varieties and can be inserted into commercialized varieties through traditional breeding techniques or genetic manipulation (Haverkort, 2008). Regarding the organic struggle, the sector relies on copper fungicides. Because the organic sector is limited by a maximum dose of 6kg/ha a year, it is more and more inclined to rely on IPM methods. These consist in the implementation of various cropping techniques and the use of resistance cultivars in order to keep pest pressure as low as possible (Speiser et al., 2006; Perez and Forbes, 2010).

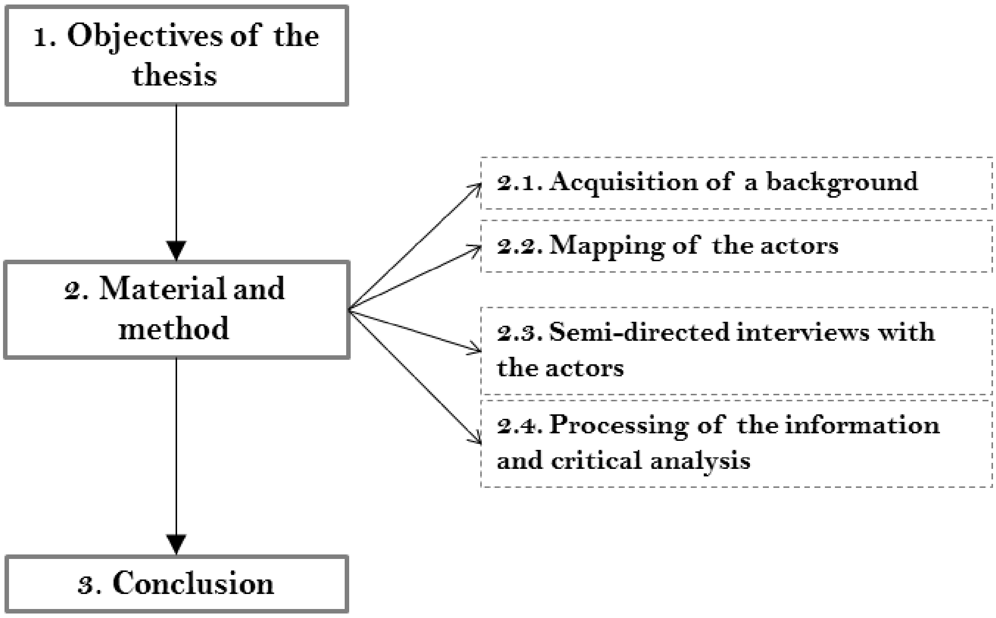
The part ends with an examination of the theory of 'lock-in'. This socio-technical approach holds that positive feedback for a technology can result in path dependence, inflexibility, and potential regret of the chosen technology (Cowan and Gunby, 1996). This approach will be called upon in our discussion to suggest that the Belgian potato system is indeed in a situation of 'lock-in'.

PART TWO: OBJECTIVES, MATERIALS, AND METHOD

Part two: Objectives, materials, and method

In this second part of the thesis, the objectives, the materials, and method are addressed.

First, the objectives of the thesis are exposed. Secondly, the 'materials and method' section explains how the study was conducted. The section presents the several steps that were implemented during the study and gives more information on the methodology applied for the collection of data.



1. Objectives of the thesis

As was indicated in the first part, the EU wants to reduce the use of fungicides, pesticides, and herbicides in its agricultural systems (Pimentel and Peshin, 2014). In order to meet this challenge, a sustainable way of managing late blight has to be found for the potato crop. Fungicides offer a means to control the pathogen but come at a high economic and ecological cost. Several possible alternatives to fungicides exist, but none of them can actually claim controlling the late blight pathogen entirely. On top of this, and this is a key aspect of the present thesis, it would seem that the various actors of the potato system entertain their own specific view of the late blight issue in general and of the ways the pathogen must be dealt with in particular.

The objective of this thesis is to explore and analyze a series of alternatives that meet the requirement of rendering the management of potato late blight more sustainable in a near future. To do so, this study details the point of view of different actors of the system with respect to the current and future management of potato late blight. It brings together a rich set of information regarding the different ways of struggle that they know and/or use against late blight and offers a critical comparison of the different opinions and visions of the encountered actors. The present thesis also intends to explain why these ways of struggle do not seem to enter the system, why there is a 'lock-in' that maintains the system as it exists today even if great societal and agronomical benefits could be obtained by a change in habits (Vanloqueren and Baret, 2008).

2. Materials and method

The global approach of this thesis is a soft-system approach. As Vanloqueren and Baret (2008) explain, *"Soft-system approaches are useful to understand and integrate agronomical socio-economic and organizational dimensions of complex problems"*. The method adopted in the present thesis is based on four major steps.

2.1. Acquisition of a background

The first step consisted in acquiring a solid background on potato blight, based on scientific reviews and literature. This background literature covered the various fields that are addressed during this thesis. It was essential to understand in a richer way the information the interviewee shared with us and was also of great importance at the end of the thesis to compile all the necessary information and verify the relevance of the obtained answers.

2.2. Mapping of the actors

The second step of this thesis consisted in the identification of various actors who represent different sectors within the Belgian potato-mildew system. These sectors vary from R&D to the organic sector, the mainstream production chain, the existing niches, and many others. It is important that they represent the whole system and, in particular, all existing production methods and niches. The map of actors was obtained through personal research but also through a series of first interviews with key actors who had a holistic vision of the system.

2.3. Semi-directed interviews with the actors

The third step started once the first actors of interest were met. In total, twenty-two in-depth semi-directed interviews were conducted with the actors of prime importance who represented as many types of actors as possible. These actors were chosen by using a 'prospective sampling' method, based on the initial mapping. After a series of interviews, we also relied on a 'snowball sampling' [21] to find new, interesting subjects. The semi-directed interviews always comprised a series of elementary questions common to all interviews (Annex 3), but allowed for secondary, in-depth questions that followed the answers given by the interviewee (Vanloqueren and Baret, 2008). These interviews were organized in two different phases.

2.3.1. First phase of interviews

The objective of the first phase of interviews was to meet people who are confronted with mildew on a regular basis. Their vision and experience helped understanding the difficulties that farmers and researchers are facing today but also gave a more specific vision of the Belgian potato system in its whole. Possible solutions to the problem and the barriers that prevent these solutions from becoming a reality were also discussed.

During this first phase of the study, fourteen different actors from three main categories have been interviewed using an interview guide (see Annex 3, section 1 and 2). These three categories were:

- The R&D sector
- Conventional farmers who use fungicides
- Organic farmers who use copper as sole fungicide

Even if the organic sector represents a small portion of the total potato production in Belgium, it seemed of great importance to include it in the research. As has been shown in part one, this niche sector is expanding and might bring about future alternative solutions to the mildew issue. The R&D sector is closely related to the farmers and provided a more scientific vision of the problem.

During the present study, no distinction was made between the two regions of Flanders and Wallonia since according to the first met actors, both regions have very similar potato systems. The actors are thus dispersed throughout the entire country.

Concerning the plantations of the met farmers, the area devoted to potato cropping varied from 5 to 25 ha with one exception of 250 ha of industrial potato (Table 5). Some farmers had more than just a role of potato grower: two farmers had mixed farms with cattle, one conventional farmer was also a potato seedling grower and another conventional farmer was also a preparer. Three farmers had both conventional and organic potato fields[22]. They allowed building rich comparisons of both agricultural systems.

The market and outlet type were more secondary topics. Nevertheless, these influenced greatly the mentality of the farmer.

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[21] '*A snowball sample is a non-probability sampling technique that is appropriate to use in research when the members of a population are difficult to locate. A snowball sample is one in which the researcher collects data on the few members of the target population he or she can locate, then asks those individuals to provide information needed to locate other members of that population whom they know.'* (Babbie, 2001)

[22] The type of agriculture (organic or conventional) the farmers were associated to for the study was selected depending on the outcome of the interview

Table 5 : Information concerning the different visited farmers during phase one (CF = 'Conventional farmer', OF = 'Organic farmer')

Farmer	Code[23]	Type of agriculture	Potato Area (ha)	Market type	Outlet type
1	CF_1	Conventional	25	Contract	Industrial
2	CF_2	Conventional	25	Contract	Industrial
3	CF_3	Conventional/ Seedling	50	Free	Fresh
4	CF_4	Conventional/ Preparer	250	Contract	Fresh
5	OF_1	Organic	25	Contract	Industrial
6	OF_2	Organic	5	Free	Fresh
7	OF_3	Organic	6	Contract	Fresh
8	OF_4	Organic	5	Free	Fresh

Concerning the R&D sector, as many research groups as possible were represented: two in Flanders four in Wallonia (Table 6).

Table 6 : Information concerning the visited researchers during phase one (R = 'Researcher')

Researcher	Code	Research center	Region
1	R_1	FIWAP	Wallonia
2	R_2	UCL	Wallonia
3	R_3	PCA	Flanders
4	R_4	CRA-W	Wallonia
5	R_5	UGent	Flanders
6	R_6	CARAH	Wallonia

The obtained interviews were transcribed and analyzed using the 'R' program with 'RQDA' ('R Qualitative Data Analysis') plug-in. A comparative, qualitative analysis between different categories and actors was then made.

2.3.2. Second phase of interviews

During the second phase, two main objectives were pursued. First, a verification and confirmation procedure regarding the first phase was secured. Is the explained system in phase one the same as in phase two? Secondly, a more precise opinion concerning all the presented solutions and barriers encountered during phase one was obtained. A total of eight more interviews were prepared, with a more specific, new interview guide (Annex 3, section 3). In order to remain consistent with the conclusions of the first phase of interviews, actors from seven different sectors were chosen for the second phase (Table 7).

After having finished the interviews, both phases were merged into one global analysis. As a matter of fact, the verification phase proved satisfactory and it did not seem necessary to separate both parts of the collected information. All of the obtained information concerning the actual mildew context with its existing alternatives could now be processed and analyzed.

[23] During the analysis, any direct report from interviewees will be followed by the corresponding code of the actor

Table 7 : Information concerning the actors met during the second phase of interviews

Interviewee	Code	Sector	Organization
1	S	Snatcher	KUL
2	RE	Retail	Belgapom
3	I	Transformation industry	Lutosa
4	PP_1	Plant protection	TMCE
5	PP_2	Plant protection	Belchim
6	D	Distribution	Colruyt
7	C	Consumers	CRIOC
8	PR	Preparers	Pomuni

2.4. Processing of the information and systemic analysis

Finally, in the fourth phase, the information obtained from the twenty-two interviewees was analyzed, processed, and revised. Thanks to the transcriptions and encoding with the '*RQDA*[24]*-program'*, information concerning certain themes could easily be clustered for an easier analysis. After a theme-by-theme examination of the various actors' point of views, a systemic analysis[25] was made.

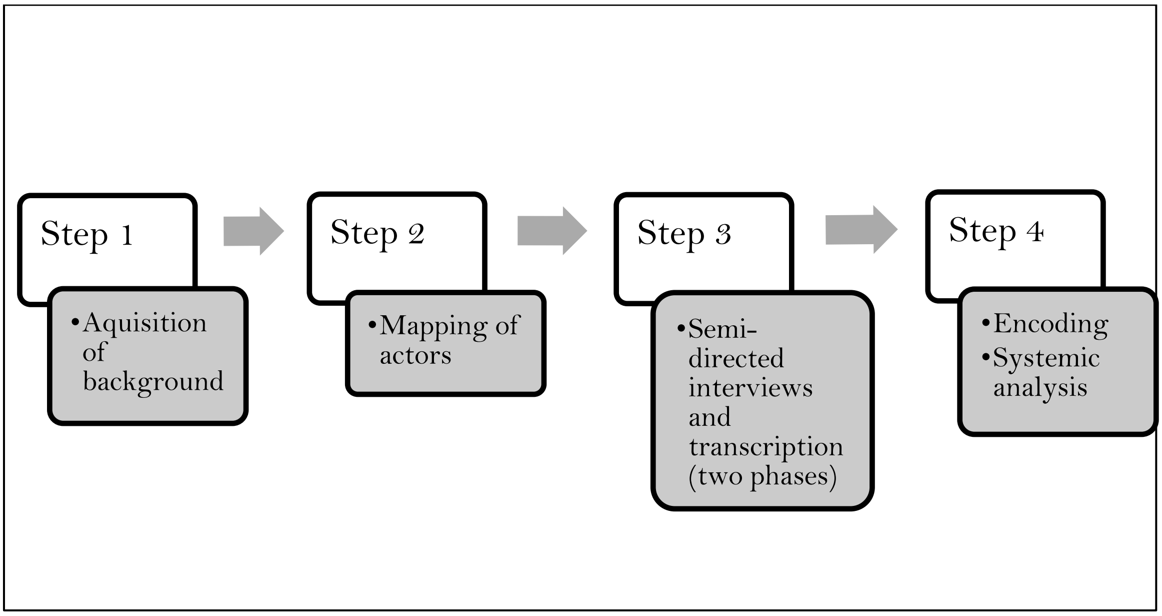


Figure 6 : Scheme representing the steps of the used methodology during this thesis

[24] 'R Qualitative Data Analysis'

[25] A systemic analysis has been used to apprehend the Belgian potato system. It is defined as *'a general methodology (not a fixed set of techniques) that applies a 'systems' or 'holistic' perspective by taking all aspects of the situation into account, and by concentrating on the interactions between its different elements. It provides a framework in which judgments of the experts in different fields can be combined to determine what must be done, and what is the best way to accomplish it in light of current and future needs.'* (BusinessDictionary.com, n.d.)

3. Conclusion of part two

This second part allowed stating the objectives of the thesis in an explicit manner. The various materials and methods were also described. The third part of this thesis will now turn to a detailed analysis of the views of the various actors who were interviewed. This will set the stage for the final discussion.

PART THREE: RESULTS

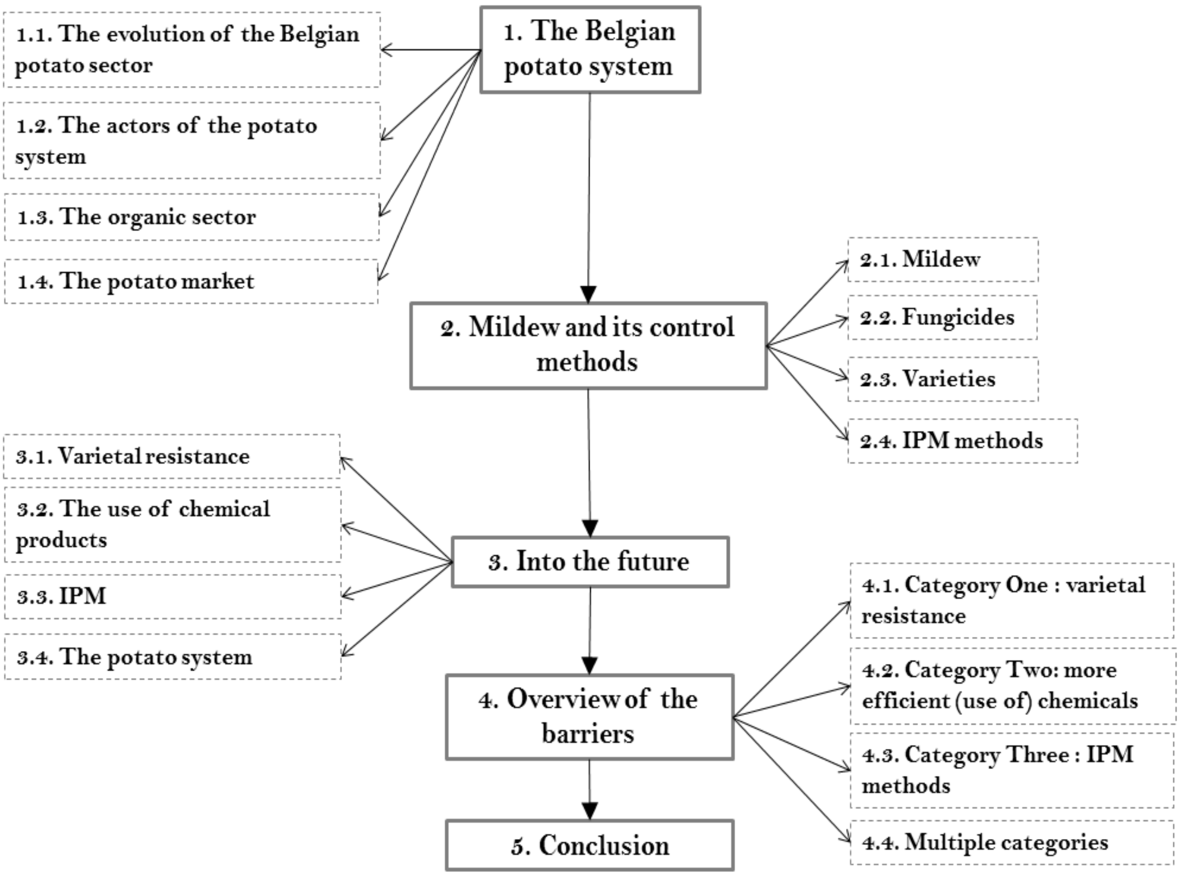
Part three: Results

The third part of the thesis focuses on the information that has been collected during the interviews. The goal is to bring to light the opinions and visions of the encountered actors on the various issues raised during the interviews.

In first instance, the opinions of the actors concerning the historical and current context are exposed. They were invited to clarify how, according to them, the Belgian potato sector mutated during the last decades. Building upon the input of the interviews, a systemic analysis was conducted regarding the various actors and sectors that comprise the potato system in Belgium. Also presented is the current organic sector as it is seen by the various actors of the system.

Secondly, the vision of the actors on the evolution of the various factors concerning mildew and mildew control is elaborated upon. This leads to the question of the possible future situations as they are seen by the actors. Three main options are being discussed: varietal resistance, the use of chemical products, and the implementation of IPM methods. The actors were also questioned about their perception of the system as a whole.

Thirdly, for each of the above options, the interviewees were asked about the various barriers that they believe would impede a change towards a more sustainable management of late blight.



1. The Belgian potato system

1.1. The evolution of the Belgian potato sector

In order to better understand the current situation, the first topic covered in the interview concerned the historical context. Various questions were asked: How did the farmer start growing potatoes? How did the mildew-fungicide relationship evolve until to today? What are the main events that explain the current situation? All the actors who were interviewed indicated that the potato system continuously evolved over the last decades.

As a matter of fact, according to various actors, in the beginning of the 20th century, the potato was a substantial crop that was mostly grown in the Western part of Belgium (West-Flanders and Hainaut)[26]. They explained that plots were in general of small sizes (smaller than 10ha) and were managed in a non-industrial way. Potato crops in the Hesbaye and Namur region[27] were non-existent. The seedling production was organized geographically according to climate conditions. Seedling producers were either close to windy see regions like the Netherlands, Bretagne, Scotland… or on plateau's (e.g. the Ardennes) so as to avoid aphid and mildew pressure[28]. One farmer noted that after the Second World War, thanks to the use of chemical plant protection products that allowed the control of plagues, and the mechanization of agriculture, the potato and seedlings could be grown in new regions and on bigger plots.

Two farmers explained that due to low market prices in classical crops and vegetables in the late 90's because of globalization, farmers tended to diversify in various crops. This led to the adoption of the potato crop for many farmers because the potato sector was interesting economically and was supported by a growing international demand. One researcher added that, on the one hand, because the largest portion of fresh potatoes was imported from France, Belgian farmers started competing on the fresh market while on the other hand, familial transformation industries kept increasing their demand for industrial potato. The success present and the expansion kept on growing until today (Lebrun, 2011). An organic farmer illustrates this growth with the importance of the crop expansion: '*Potato crops in the region (Namur) have doubled or even quadrupled in 25 years…' (OF$_2$).*

Today, the actors indicated, potatoes are even being cropped in the Hesbaye region (Di Antonio, 2012) and the Eastern part of Belgium (Liège), two regions, where potatoes were never cropped before. These regions are characterized by bigger plots with grounds of good quality. The potential of these regions is thus of great importance for the sector (Di Antonio, 2012). Due to the economic potential of the potato on the export market (of frozen transformed potato products), the growth in converted lands, industrial transformation capacities, and stock capacities, this growth is likely to continue (Lebrun, 2011).

[26] These two regions are indeed the historic center of the potato crop in Belgium
[27] A region that lies in the center of Belgium
[28] Researchers have explained that the situation today is quite different in the Netherlands concerning mildew management. They have much more problems with nematodes and have replaced the more susceptible varieties concerning the struggle against mildew (R$_4$, R$_5$)

1.2. The actors of the Belgian potato system

The potato system is represented by a whole range of actors who each have their role in the system. By retrieving information from the many interviewees, a systemic vision of the actors of the potato system could be made (Figure 7). The function and characteristics of type of actor will now briefly be exposed.

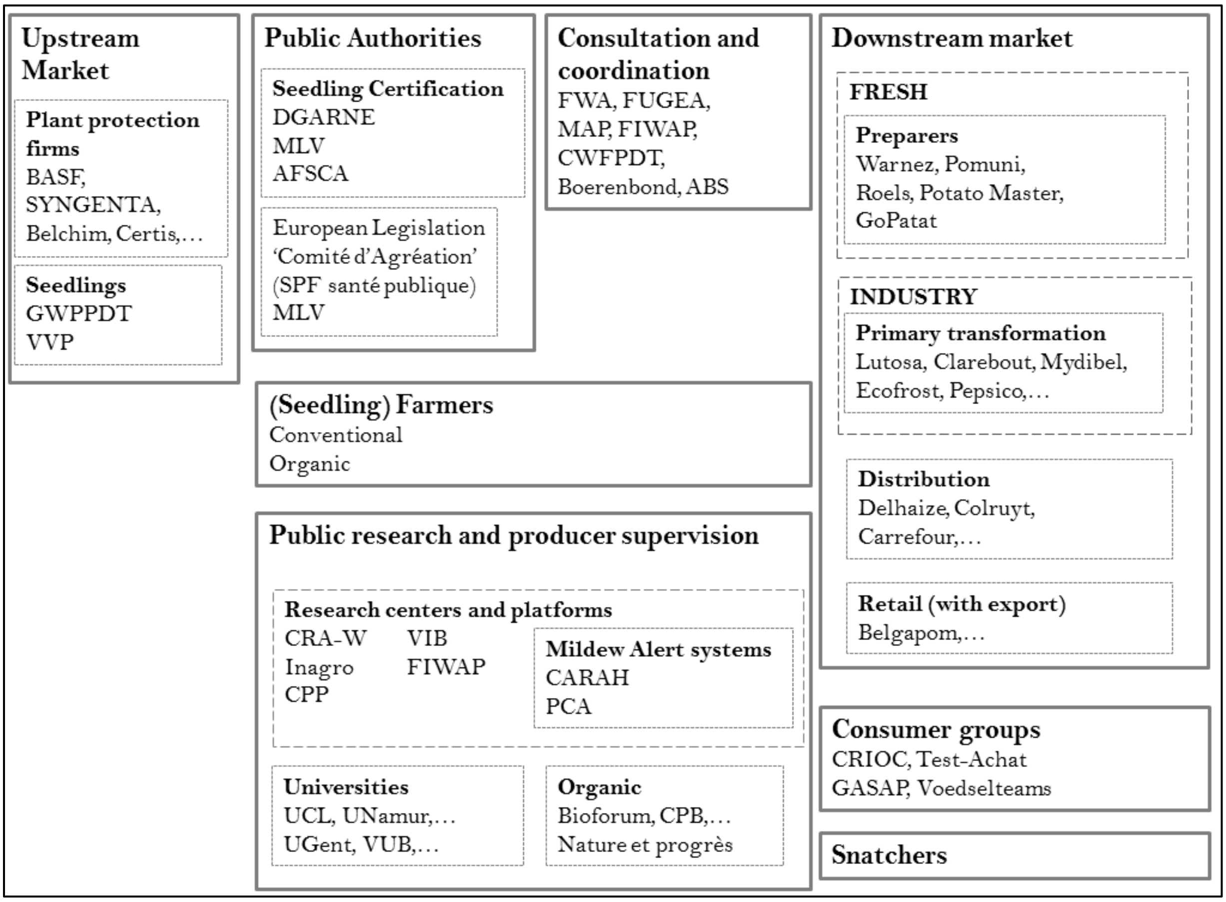


Figure 7 : Schematic representation of the different groups of actors of the potato system

a) Potato seedling growers

Potato seedling growers plant potatoes that will be used as planting material by the farmers. According to potato seedling grower, these cultures are much denser and shorter in time, so as to have adequate calibers (28 to 50 mm). Seedlings are controlled for viruses, pathogens, and other infections and thus have to be certified by regional authorities (that will be discussed later) (Schollaert and Gossiaux, 2005). In Belgium, there is more import then export of seedlings (FIWAP 2012a) (see Annex 1, Figure 11). The seedling growers are represented by groups like the GWPPPT in Wallonia and the VVP in Flanders (FIWAP, 2012b ; VVP, 2014).

b) Farmers

Potato farmers are characterized by the agricultural paradigm they are in (organic or conventional), by the outlet type of their production (fresh or industrial), by their production size, and by the kind of market they are on (contract or free). According to the actors, even though the potato is a financially interesting crop for farmers, the number of farmers cropping potatoes is diminishing throughout the years (Annex 1, Figure 15) , while the average surface per farm is rising.

Both potato seedling growers and potato farmers are represented and defended by various syndicate federations like the FWA, FUGEA, MAP in Wallonia (FWA, 2012; FUGEA, 2013; MAP, n.d.). and by the Boerenbond and ABS in Flanders (ABS, 2012; Boerenbond, 2013). They are also helped and represented by counsel groups like for instance the FIWAP (FIWAP, 2012b).

c) R&D

A researcher explained that historically, the potato crop was more prevalent in Flanders: the main research centers were the PCA, Inagro and the CRA in Libramont. Nowadays, both regions have a mildew alert system (PCA in Flanders and CARAH in Wallonia) and various research centers. According to the visited actors of these research centers, all of these groups try to work together on several research programs and have regular contacts. They also confirmed that the federal authorities encourage cooperation between all research centers.

Research is divided into two categories: private and public research. Next to the public sector, universities and private firms also conduct research with private funds.

- **Public research**

Different research centers exist in Belgium. Each one of them has a particular role. According to actors of this sector, together, all of these centers try to be as complementary as possible. A quick review of the various actors of the R&D sector is given in the following paragraphs.

The **CRA-W** is a research center and a PIO ('Public Interest Organism'). It is financed by the ministry of agriculture and has a broad fundamental research mission in different agricultural sectors. Initially, the CRA was responsible, along with CARAH, for the mildew alert systems. Actors from both research centers explained that four years ago, these roles were separated. The CRA is based in two different stations, namely Gembloux and Libramont. Today, the research of the CRA-W is more development driven (CRA-W, 2014). As far as our present topic is concerned, a researcher of CRA-W distinguished four main programs:

1) **Mildew strains characterization**: Strains are collected on field each year (for more than ten years now) and analyzed on a phenotypic basis and their resistance to metalaxyl. They can be used in research programs, to test varietal resistance or fungicide resistance.
2) **Varietal selection:** Analysis of the sensitivity of about 20 to 25 varieties on a yearly basis.
3) **In vitro conservation of genetic material of potato plants**
4) **ELYSA lab**: This lab ensures the quality control of seedlings. Seedlings are checked for viruses and other pathogens.

The CRA-W is also conducting, since 2013, an organic research program upon instruction of the minister of agriculture (actually, Carlo Di Antonio) (CRA-W, n.d.). A more specific program on mildew named 'GEREPHYTI' [29]is also conducted and focuses specifically on mildew. This project intends to intensify the breeding program (started in 2005 by CRA-W) so as to obtain clones and fitter varieties for a durable resistance against *P. infestans.* (CRA-W, 2014).

The **CARAH** is a provincial research center that conducts fundamental research and is responsible for the mildew alert system in Wallonia. A researcher explained that this NPO's infrastructures and research programs are financed by the province, whereas the alert system is financed by the Walloon Region and the subscribers of the program. Besides the alert system, they offer continuous help to

[29] 'Gérer P. infestans' meaning 'Coping with P. infestans'

farmers with questions and also conduct independent research. They test for example varietal resistances and fungicides on request of private firms or farmers (CARAH, n.d.).

ILVO is a Flemish research center based in Merelbeke, in West Flanders. This center belongs to the Flemish region and can be seen as the counterpart of CRA-W, even though ILVO does not conduct any research on mildew at this day. They do currently conduct a research program concerning bacteria involved in the rotting of potato seedlings. Besides this program, all the research concerning potato mildew has been handed over to the PCA. (Van Vaerenbergh, 2014)

The **PCA** is the Flemish equivalent of the CARAH. The PCA has two working sieges in two provinces of Flanders (the provincial testing center in Kruishoutem, East-Flanders and Inagro in Beitem-Rumbeke in West-Flanders). It has as goal to support the potato sector in all of its aspects (PCA, 2009a). … According to an actor of this research center, the PCA has more than a thousand affiliated potato farmers, representing about 35% of the total potato area in Flanders. The research of the PCA concentrates on varietal tests, fertilizing tests, conservation methods, etc… This research is either carried out for private firms or based on public funding (PCA, 2009a). Concerning the mildew alert systems, the interviewee assured that the PCA and CARAH work very closely together, trying to coordinate their alert systems in order to make them work at a national level.

FIWAP is an interprofessional association founded twenty years ago that is active exclusively in the potato sector in Wallonia. The FIWAP brings together actors from the whole sector, who occupy the seats at the board of directors and decide which activities will be proposed for financing at the RW[30] (FIWAP, 2012c). According to an actor of the FIWAP, it is funded at a regional level for two thirds of their needs and relies on its own funds for the remaining third. The researchers conduct their own research programs and ensure the coordination between the various research centers(FIWAP, 2012c) . The FIWAP (in partnership with the PCA) announces the weekly market value of the potato and are also busy with market monitoring, yield monitoring, quality, stocks, statistics, import, export (POMMAK, n.d.)… Finally, they also develop collaboration project with the industry and retail sectors (FIWAP, 2012c).

The **CPP** is a platform between actors of the research center that was created in 2003. Its objective is to create a synergy between all the various existing research groups in Wallonia. The CPP is actually in partnership with FIWAP, CARAH, CRA-W, CORDER (that will be introduced later), the GWPPPT, and the 'Comité Régional Phyto' (based at the UCL) (CARAH, n.d.; FIWAP, 2012d).

Belgapom, a main actor in the retail sector, is conducting research in partnership with the **ILVO**, **VIB**, **Boerenbond,** and **UGent.** Their research program, which should start in 2015, aims at creating a mildew-resistant Bintje (Bintje+1 or Bintje +2) through cisgenesis. The production and commercialization of this new variety would entirely belong to producers and buyers, thus avoiding any type of privatization. They hope to obtain this variety by the year 2021-2022 (Belgapom 2014b).

Various universities have research programs that concern mildew at a larger scale. As it turns out, both UCL and UGent work with the research centers of their region, but a formal partnership between these different universities does not exist.

Concerning the **UCL,** different research programs exist. Firsts of all, there is the plant pathology lab that is attached to the 'Life and Earth Institute'. This lab is actually conducting a screening of potentially interesting antagonistic bacteria so as to combat mildew. A second research program explores the efficiency of an elicitor (more specifically the elicitor 'COS-OGA') for the potato crop (UCL, n.d.).

[30] Walloon Region

Secondly, in this same lab, the NPO CORDER ('Coordination, Research and Rural Development') consists in a 'plant clinic' and a 'regional plant protection committee'. On one hand, the plant clinic , that makes part of the CPP, consists mainly of counseling and plant illness diagnosis for various crops (CORDER, n.d.; R_2). On the other hand, the regional plant protection committee is '*a multidisciplinary interface that has as goal to create an active relay between the various actors of the plant protection sector'* (Comité Régional PHYTO, n.d.).

According to a researcher from UGent, **UGent** and **Hogeschool Gent** are two institutions that are working more and more together. He explained that in the late nineties, Hogeschool Gent was working on a genetic study of the mildew strain evolution. This research aimed to propose an efficient chemical product to fight these new strains. A few years later, realizing that the use of chemical products had to be reduced, the research programs concentrated on genetic manipulation programs of the potato.

- **Private research**

Next to public research, various private firms like plant protection firms conduct their own research. According to actors of the research sector and plant protection sector, it is more concentrated on the elaboration of efficient fungicides and is slowly orienting itself towards a varietal research.

d) Plant protection firms

The plant protection sector is of capital importance for the potato system today. Actors explained that without chemical products, it would be impossible to crop industrial potatoes in Belgium.

An actor from the plant protection sector explained that through time, public opinion and the authorities have become more and more demanding, obliging this sector to adapt their products. He added that this sector thus keeps on searching for the best active ingredient possible in order both to fight mildew and, at the same time, respect the various health and environment policies. According to actors, because of this growing pressure, many of these firms[31] have started breeding programs in order to be ready for the near future. At this hour, their goal is to make sure that mildew does not overcome their products and to secure their sales (PP_2, R_5, and R6).

- **Soil life stimulating products**

Actors noticed that firms selling mineral, soil life stimulating products have also entered the market during these last decades. According to a salesman of such firm, their posture is somewhat different because they do not promote a chemical plant protection but rather a natural plant protection through a soil life booster. The majority of farmers agreed to say that these products seemed very useful for the soil so as to boost biodiversity and soil structure. Still, after one trial, real effects on these two factors were said to be disputable. The global feeling was skepticism even though the importance of these firms grows from day to day. A salesman explains: '*Twenty years ago we were seen as a kind of sect, and today we are being approached by research centers, by firms… '*(PP_1).

For instance, an actor explained that TMCE is a firm that sells mineral products that boost and regulate micro-organic activity in the soil. According to this actor, TMCE is now conducting various research programs in partnership with 'Génosols' (INRA) and the CRA-W. This research is oriented on the consequences of good soil health and soil structure on crops. Results on the impact of micro-organisms are starting to show but no results concerning mildew have been demonstrated yet. A salesman explains: *'With 'Génosols' we haven't been able to show anything yet concerning mildew, but we are*

[31] Firms like for instance BAYER, BASF, SYNGENTA,…

only on a two-year research. We can't go faster than nature. But everything they discover confirms what we already observed on field.' (PP$_1$).

e) Preparers/ Packagers

Actors explained that preparers are the link between producers and the distribution in the fresh potato market. A preparer explained that they either grow potatoes themselves or buy potatoes from farmers, so as to package them and finally sell them to the distribution. They also decide with the farmers which varieties will be produced and propose new varieties to the distribution.

f) Retail

An actor of the retail sector explained that the role of the retail sector is to connect producers and industrials so as to secure supplying, but also to ensure the export of the final products. The main actor of the retail sector in Belgium is Belgapom[32]. The retail sector is one of the main characteristics of the Belgian potato system. As a matter of fact, it is quite developed in Belgium compared to other countries. A researcher explained the retail sector is of prime importance: '*To ensure the supply you need people who are on the roads, who are on the fields, who are in the sheds, in farms… Belgian industrials have always relied on this link to increase progressively their supply.*' (R$_1$).

g) Industry

The industrial sector is represented by firms of the transformation[33] sector. A researcher explained that geographically, all of these firms are mostly located in the Western part of Belgium due to the historical context. It has been shown that this sector has known an important expansion during the last two decades and today it transforms around 3.5 Mt of potatoes in puree, chips, frozen fries, etc..., per year. Today, the transformation sector has made Belgium the biggest exporter of frozen fries in the world (Belgapom, 2014b).

h) Authorities

The authorities that are concerned are numerous and work at different scales. First of all, one finds the European authorities. They impose, through a series of directives, how the agriculture in Europe has to function and what the allowed doses of chemical products are (Anonymous, 2010). In Wallonia, one has in first instance the SPW ('Service public Wallonie') with more precisely the DGARNE that is responsible for the certification of potato seedlings (FIWAP, 2012e). The Flemish counterpart is the MLV (MLV, 2013). At a Belgian scale, the AFSCA (FAVV) operates to guarantee the use of healthy potato seedlings (that do not contain any viruses or pathogens) (Comité Régional PHYTO, n.d.).

i) Distribution

The distribution sector is represented by the supermarket groups like Delhaize, Carrefour, Colruyt, Aldi, and many others. The actors assure the main goal of these actors is to ensure the sale of their products. As explained before by interviewees, for the fresh market, these firms will either trust the preparers regarding the choice of variety or impose the choice of the variety themselves through

[32] Belgapom is the recognized professional association of Belgian trade and processing of potatoes (Belgapom, 2014)
[33] The main firms representing this sector are Lutosa (Mc Cain), Clarebout, Mydibel, Ecofrost, Pepsico… Most of these firms in Belgium are family-run (Belgapom, 2014b)

contracts. As a matter of fact, The distribution sector has an important role in the consumers' perception of the product and their habits (C).

As a matter of fact, the actors explained that the distribution sector is also the closest one to the consumer. They added that the educative role is clearly undermined by the sector. An interviewee explains: *'Distribution does not assume this role but it's also very hard to for the authorities to make her endorse that role because the benefit margins between the different firms are really small and making them assume non-rentable activities to educate the consumers would be just too pushy. They're here to have a lucrative business, not to educate their clients.'* (C).

j) Consumers

The consumers are at the end of the whole chain. They are followed by various groups like Test-Achat and CRIOC that analyze preferences of the consumer and also compare different products. These groups publish the collected information in a monthly leaflet and try to educate the affiliated consumers about the studied products (CRIOC, n.d.). According to an actor of CRIOC, the research subjects are often mandated by a specific sector. An interviewee explains: *'Our role here is to explain to the consumer how things go, to popularize… We're not purchase subscribers'* (C).

k) Snatchers

'Snatchers' or 'pullers' represent a group of people that are against GMO's and are for a more drastic and global change of the agricultural system. In 2009, this group of actors led an action against the open field trials of the GM potatoes. Indeed, a research program put up by Hoogeschool Gent /UGent, ILVO, BASF and VIB in Wetteren, had as goal tests GM potatoes on-field so as to test their in-bred characteristics. Since that action, the activists have become quite notorious in Flanders, mostly due to an important mediatization (Het Laatste Nieuws 2011 ; Van Dyck 2012).

The farmers and researchers that were interviewed had quite negative visions of this group of people. A farmer explains: '*Here we're talking about research. It was authorized and done in a very strict frame. We live in a democracy. When democracy says, 'we can do this', it's not 50 people that have the right to demolish everything…'* (CF_3).

A researcher adds: '*Even if you say to these people 'Look, if this system works, we'll spare more than 80% of the fungicides and help the environment, better the health of people…'.But still, it's a difficult story to get accepted by this people… It's a quite unique European problem.'* (R_5).

Nevertheless, this event shows that the acceptance for GMO-potatoes and GMOs in general has not yet been made in the Belgian society.

l) Breeding houses

In Belgium, no private breeding houses exist (Di Antonio, 2012). A researcher explained that newly created varieties often come from the Netherlands or France were breeding houses[34] are very specialized. The interviewee added that these breeding houses create new varieties that mostly respond to criteria demanded in these respective countries and not in Belgium. As a response to this situation, various research groups like the CRA-W and a collaboration between VIB, ILVO, UGent have started breeding programs to respond to the specific Belgian needs (CRA-W, 2014; Di Antonio, 2012; VIB, n.d.).

[34] HZPC and AGRICO are for example breeding houses from the Netherlands

1.3. The organic sector

The organic sector is a parallel paradigm to the mainstream sector and regroups actors that are part of all the previously mentioned groups. Even though their roles are exactly the same, they can be considered as another type of actor, since they represent another agricultural paradigm. Today, the organic sector is supported by the authorities in Wallonia (Di Antonio, 2012) and in Flanders (Bioforum Vlaanderen, 2014). Even though the demand is growing at a steady rate, the organic sector is still at a very early stage (Di Antonio, 2012). Various organic platforms exist like for example 'Bioforum'[35], 'Nature et progrès', CPB …These platforms regroup the various actors of the organic sector. According to organic farmers and researchers, they do not seem to create a unanimous corpse that takes clear and justified decisions. A researcher tells us: '*We see that the organic sector is growing in the potato sector, just like for other crops… It's a diffuse sector that isn't organized enough, not structured enough, and not proactive enough.*' (R_1).

Next to this factor, several elements distinguish the organic and conventional sector. First, it seems clear for both groups of actors that the organic sector is much **more hazardous** and that mildew has much greater impacts. An organic farmer that also has conventional potatoes explains: '*I don't know when I'm going to plant. I don't know when I will harvest, depending on mildew. With conventional products I know that I'll be able to conduct them much further through time. For weeding, in conventional we spray and it works very well, in organic agriculture it's much more difficult*'. (CF_1). A conventional farmer assures: '*If everybody changes to the organic sector from one day to another, we'll have a famine.*' (CF_3). Even a researcher affirms: '*Imagine 100% of the areal is organic, like some would like it, you would inevitably have catastrophic years*'. *(R_5).*

Secondly, the actors believed that the organic sector has lower **yields** than the conventional sector. According to the actors, the conventional sector has yields varying between 40 and 50 tons per hectare while the organic sector varies from 25 to 40 tons per hectare. This does not seem to be a big issue for organic farmers. They explained that for them the selling price for organic potatoes is higher, which means the final revenue is quite similar. Economically, farmers say the main reason for the switch to organic agriculture is economic. As a matter of fact, they explained that by receiving subsidies, the farmers can gain more by working (and producing) less.

Furthermore, an organic farmer explained that compared to the conventional sector, retail in the organic sector is much less developed. A conventional farmer with organic crops argues: '*In the organic sector, retail gravitates around two-three people. Since we don't impose a system where the Belgian production must be consumed in Belgium, they get their supplies in the Netherlands, Germany… They already have contracts and then the Belgian farmers come last.*' (CF_1).

Because the organic sector is still small, an important raise in production can have important impacts on the selling price. This can mean the outlet is not always guaranteed. An organic farmer explains: '*I would have liked to raise my production but as long as I don't have an outlet… Today there is a raise in organic surfaces in big crops, they (buyers) are served a bit too much and this means the prices of the contracts tend to lower.*' (OF_4).

Nevertheless, organic farmers say that they obtain more and more interest from the distribution sector. This is confirmed by an actor from the distribution sector: *'Five years ago, the organic potato sector represented 2.5% of the market shares of the fresh potato 'shelf''. If you look now, five years later, we're almost at 6%, so it has more than doubled! This means you really have an interest coming from the consumers' (D).*

[35] This platform exists in Flanders and Wallonia.

Added to this, organic farmers explained that the mentality of the distribution groups has changed over the last years, giving more opportunities to local producers to sell their harvest. A conventional farmer having also some organic crops explains: '*Now there's a system that's starting and that I appreciate a lot: in some supermarkets they make a small spot available for organic, local products.*' (CF_1). This makes organic farmers believe that these distribution firms may become an important factor for the expansion of the organic potato sector in Belgium.

A researcher explains confirms: '*The organic sector is growing in reaction to a demand of the distribution sector and the industry. The industry gets its organic potatoes mostly abroad, for historical reasons… Who can change things? The distribution sector, because the organic sector has affirmed convictions. If it's the case, industrials, so as to respond to Delhaize will have to develop the local production here… I believe there's a quite positive future for organic products.*' (R_1).

Finally, differences between these both sectors can also be positive. A researcher explains: '*If you ask me what's the necessity of organic agriculture… One of the most positive things the organic sector has done is putting pressure on the mainstream sector ... They can also transfer techniques to the conventional sector.*' (R_5).

1.4. The potato market

The actors explain that farmers can crop potatoes that are destined for the fresh market or the transformation industry. They can also either rely on contracts that are made with industrials or packagers, or either sell their production on the 'free' market. The latter means that the farmers do not have any contract and try to sell their production themselves at a convenient price. Interviewees explained that this is quite common in the sector. To them, it also means that there's a higher uncertainty on the selling price and the fact of selling the production. Next to this factor, according to the actors, the farmers mostly rely on 'free' varieties that do not have a patent anymore. As a matter of fact, when a new variety comes on the market, there is a patent that producers have to pay in order to be able to grow this variety. This patent can last from 25 to 30 years (Breeders Trust, n.d.).

A conventional farmer explains why he works with contracts: '*The advantage of being on contract is the security. The bigger your farm, the more you'll need a contract. In the conventional agriculture we see that on the last ten years there's no real difference in prices.*' (CF_1).

Notwithstanding, another farmer explained that there are some disadvantages: '*I know some farmers who have contracts. They also have warehouses that are never empty. The defaults of the production are exacerbated by the buyer when there's an abundant year. When there's shortage they'll buy everything... You're never sure of selling your production when you're a potato grower.*' (CF_3). The first farmer continues: '*Even with contracts, there are so many elements they can refuse your production for: They're too green, they're sick, there are knocks… so many elements*'. (CF_1).

So it seems that even having a contract does not ensure the sale of the whole production. Next to this, the free potato market is very volatile and prices vary strongly during the season and from year to year (Lebrun, 2011). Free potato growers can thus earn a lot of money certain years, but also lose a lot if the prices are low (R_1, I). This is why actors from the industrial sector, retail sector and preparers explained that they prefer working with contracts.

For the retail sector, it seems clear that contracts are increasingly popular: '*In Belgium we've witnessed an enormous growth of the contractual policy. Before we had about 50% of free and 50% of contracts. Today we almost have 70% of contracts and 30% of free market.*' (RE).

The interviewee of the industrial sector confirms this tendency. According to him, it's much more interesting to ensure the procurement by using contracts than by relying on the free market, because prices are known. He also adds that this tendency affects the whole sector: *'If we want contracts, we also need the farmers to want to use contracts and the potato crop has intensified and specialized so much in recent years that people have invested a lot. To invest they needed money from the banks, and these would only give them the required amounts if they used contracts to ensure their income… So everything is a bit linked you see.'* (I).

Concerning the organic sector, the market functions in the same way, but seems far more impacted by mildew. A farmer explains: *'The problem of the organic production is that it's (mildew) the worst enemy but it's also mildew that decides how the market goes… If you didn't have mildew, you would have to regulate the market in another way'.* (OF_4)

2. Mildew and its control methods

The actors were invited to convey their appraisal of the evolution of mildew and of the factors that can be used to control and fight the pathogen. Figure 11 presents an overview of the subsections that will be discussed.

2.1. Mildew

All the interviewees agree to say that mildew strains are more aggressive and are more difficult to control than before. At first, the appearance of genetic variety in mildew populations astonished the farmers. *'During the 80's appeared the first attacks of mildew in June, something which had never happened before…'* (OF$_2$) an organic farmer explained. Now, dramatically, mildew appears much earlier in the season. A conventional farmer clarified: *'Now we start the treatments when the plants just start growing above the soil. Back in the days it was when the plants touched one another. We start a lot earlier now.'* (CF$_3$).

An actor described the evolution of mildew using the Figure 8: *'Before, we used to say that the fungi could develop starting from ten degrees. Nowadays it has moved to the limit of six degrees. This means this fungus can develop at colder temperatures and cause earlier infections. Everything starts earlier and the global pressure at the end of the season is far worse. The same holds for the incubation time … So the time between the infection and a new stain… Before it needed 6 days, now it needs just 3 days and a half. The same for the density of the fungi on a stain: it has doubled so this stain can produce twice as many spores.'* (R$_3$).

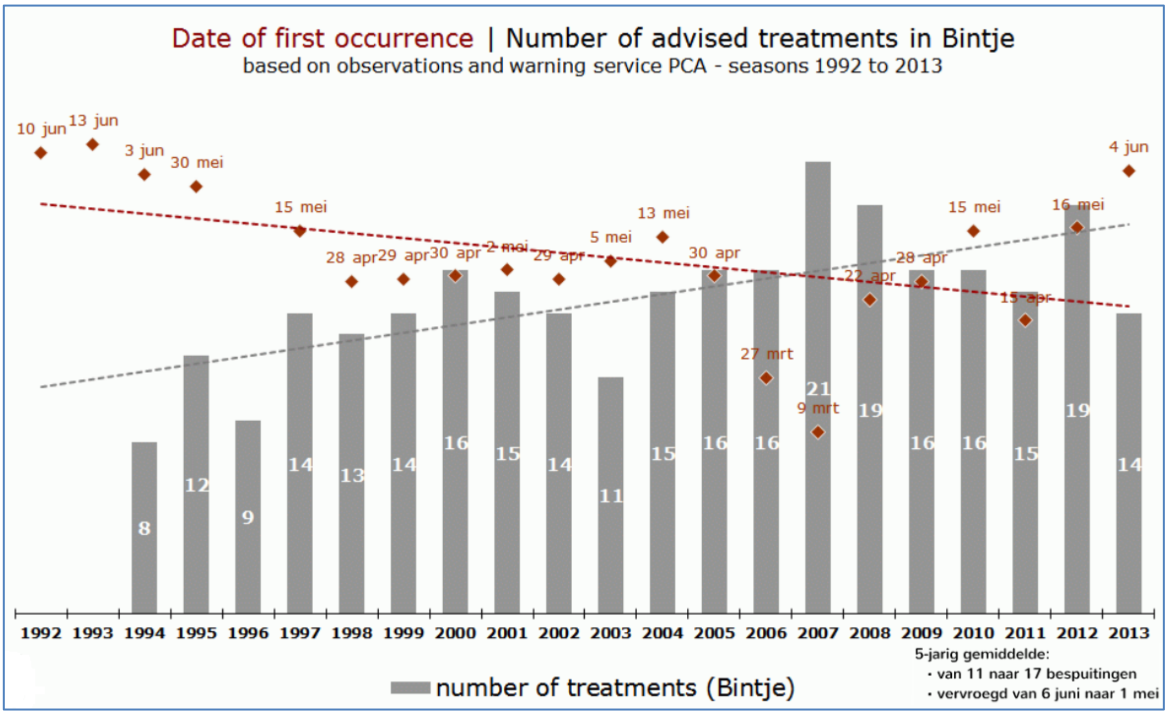


Figure 8 : Graph showing the evolution of date of appearance of the first mildew infection and the number of sprayings during the season (Vanhaverbeke, 2013)

According to the actors, the year to year climatic variability makes it very difficult to control the pathogen and the sustainability of the actual potato system remains very hypothetical. An organic farmer says: *'Modern agriculture is heading into a wall. We are creating resistances (in mildew) and this evolution is faster than the production of new attack methods or products. I think we're losing ground on the pathogen…'* (OF$_3$).

As a response to this new adaptability of the pathogen, the organic farmers explained that the organic sector still relies mostly on copper as chemical matter to fight mildew. In the conventional sector, actors said the evolution of mildew has been countered by the creation of more and more efficient fungicides. This has led to an unstoppable race for complete varietal resistance and total effectiveness of the used fungicides.

2.2. Varieties

According to the actors, whereas the varieties used in the industrial sector did not really change after the evolution of the mildew strains, they underwent a change in the organic sector. An organic farmer explained that in organic farms, resistant varieties were already used to counter mildew attacks before the 80's. These varieties (like Condea, Bionica…) had leaves that were more resistant to mildew attacks which means that they could stay longer on the field, thereby producing bigger tubers. After the evolution of mildew populations, early, rapidly-growing varieties were used in organic farming because they would be more suitable for sale before being struck by mildew (OF_2).

2.2.1. The Bintje

As has been shown in part one, today, the Bintje variety is the reference for the potato crop in Belgium. Bintje is very susceptible to mildew, and according to organic farmers, this is why it is quasi never cropped in the context of organic agriculture. Nevertheless, on all other aspects, actors have shown that it is by far the most competitive variety on the market. This is due to several points presented in Table 8.

Table 8 : Characteristics of the Bintje variety (Interviews with the actors)

Characteristic	Consequence
Free variety	For seedling growers and farmers, the costs of buying the prime resource is much lower than for a non-free race This factor also suits the industrial sector, the retail sector and preparers
High yields	Interesting for producers and the industrial sector that requires important quantities
Good conservation	Assurance towards the farmer's investment and easy to cope with for preparers, the retail sector, and the industrial sector
Producer's knowledge	Reassures the producers in their choice
Adequate for transformation and broad outcome	All parts of Bintje can be used and transformed in French fries, chips, puree, flakes or other final products, making it an excellent prime resource for the industrial sector and a sure outcome for farmers. It is also adequate for the standardization of products
More secured sale	Even if a producer does not have a contract, he can sell his production easily because there is an existing demand
Benefits of a cultural attachment	Consumers will often choose Bintje instead of another variety
Susceptible to mildew	Needs important spraying that guarantees the sales of the plant protection firms

For farmers, various criteria converge towards the adoption of Bintje. First of all, many actors indicated that Bintje is a **free variety**. They explained that this characteristic lowered the final costs of production for the farmers. A farmer explained: '*All the farmers who are on the free market, they have to buy potato seedlings. And compared to a 'protected' variety, the Bintje costs nothing*' (CF_3). For an industrial, it was also an important factor for the same reason: '*We still work a lot with Bintje today because it's a free variety, meaning the potato seedlings can be bought for a far lower price.*' (I). Actors from the retail sector and a preparer explained that they also benefit from this characteristic because it ensures lower prices and greater flexibility.

Next to the fact that Bintje is a free variety, many actors argued that Bintje entails **high yields**. This seems to benefit both farmers (because they are paid on the basis of the quantity that they produce) and industrials, (who need important quantities of prime resource).

Thirdly, a farmer explained that Bintje was very **apt for conservation**. This factor was really important for farmers because the longer they could conserve their potatoes, the more time they had available in order to sell their production. He explained: '*No other variety conserves as well as Bintje. That's her most extraordinary quality, it conserves well.*' (CF_3). The industry, retail, and prepares also benefit from this characteristic because they can better plan how they will manage the stocks.
Finally, conventional farmers in general explained that Bintje was easy to crop for them because they **know the characteristics of this cultivar**. They showed that it was more comfortable for them to work with a cultivar that they knew.

Next to farmers, industrials consider that the Bintje seems difficult to replace because it is **adequate for the transformation process** and has a **broad outcome**: '*The Bintje is really passe-partout. We can make fries, croquettes, puree, anything you want. Even for the fresh market it functions well. You can do anything with this variety. On the other hand, for instance, Fontane is perfect for making long, clear fries. But we can't make any croquettes with it, and that is what is blocking for the moment. We don't have a variety that could replace Bintje, which would have all the qualities of Bintje, except that it would be more resistant to mildew.*' (I). It seems thus that even if other existing varieties have higher yields, because of their other characteristics, they are less readily chosen than Bintje. For farmers working on the free market, this broad range of outcome means a **more certain sale** of the production than for other varieties.

Another important factor seems to be the **cultural attachment** of the consumers. The demand for Bintje seems to be unstoppable. A researcher explains: *'Bintje is still the principal cropped variety in Belgium because it is the most demanded one by the consumer.'* (R_4). The actors even said that Bintje was seen as a Belgian cultural symbol by the exterior world.

Furthermore, a researcher added: '*What is the explanation for Bintje today? 1) It is a 'passe-partout', meaning you can still sell it on the fresh market, because there is an existing demand for it. 2) The industry wants it. The market is still very broad. 3) Yields are lower than for other cultivars but on the other hand, it is a free variety, meaning the potato seedlings are far cheaper.*' (R_5). However, whereas for some actors, Bintje symbolizes the success story of the Belgian potato sector, for others, Bintje can be seen as one of the main reasons of the mildew issue. A snatcher explains: *'What Bintje shows is that we start with the idea of 'We will surely find a technical solution to solve the problem that we are dealing with today (by adding resistance to Bintje, so that we can keep this variety)', while this problem is mostly created by the Bintje.' (S).*

Ultimately, according to the actors, Bintje is also very sensitive to mildew. This means that fungicides are vital for the cropping of this variety. A researcher explains: '*Bintje will assure its own ban in the end. If we become more and more stringent concerning pesticide use, then you can't crop it anymore. Imagine we decide we can spray only ten times a year, then Bintje is automatically out of the market!*' (R_5).

According to the actors, this factor is particularly convenient for one actor of the system, namely the plant protection firms that produce adequate plant protection products. Figure 9 offers a schematic representation of the use of Bintje. All of the actors and the characteristics that motivate these actors to select the Bintje variety are included.

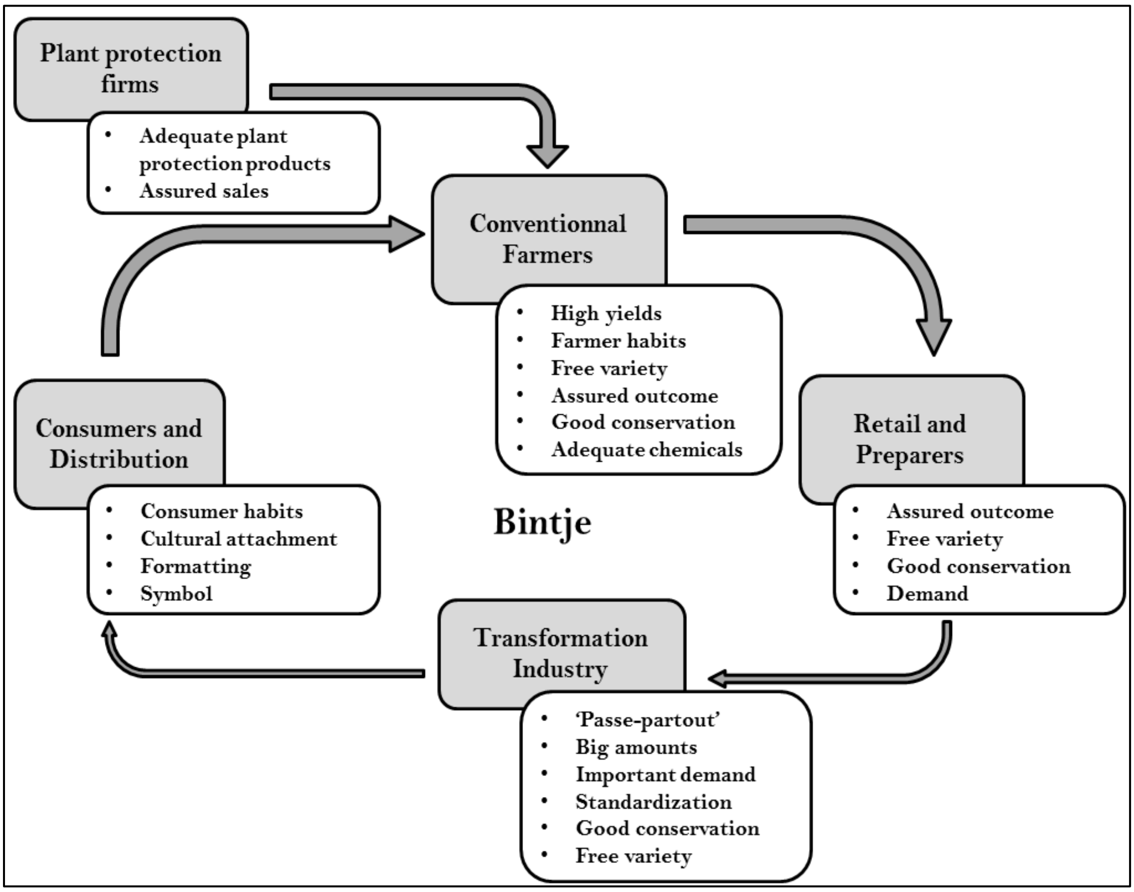


Figure 9 : Schematic representation of the use of Bintje involving the various actors of the system. The organic sector is not present in this figure because organic farmers indicated that they never cropped Bintje because of its low resistance to late blight. This figure is complementary to Table 8, which summarizes all the characteristics of Bintje.

2.2.2. Criteria for the choice of variety

During the interviews, it appeared that the choice of the variety relies on many criteria that vary depending on the objectives and needs of the actor of the sector. The following paragraphs expose the criteria mentioned by the actors during the interviews.

Table 9 : List of the criteria required in the variety choice exposed by the actors

Actor	Criteria
Farmers	- Ability to sell - Seedling costs and availability - Final revenue (depending on contracts or not) - Past experience of the farmer - Resistance to mildew (mostly for organic farmers)
Transformation sector	- Yields, quality, and homogeneity - Transformation ability - Type of outcome
Fresh sector	- Yields, quality, and homogeneity - Esthetic of the potato - Washing ability - Type of potato (floury or firm-flesh)
Distribution sector	- Secured sales
Consumer	- Fresh sector: esthetical aspect, type, taste, variety - Frozen sector: taste, homogeneity in taste and size

According to farmers, their first criterion on the choice of variety is the **ability to sell** their production. If a variety cannot be sold, it will not be cropped. An organic farmer argues: '*The first key to a sustainable solution for the fight against mildew is the market. It's the first key. A farmer, he's ready to do whatever variety, as long as he can sell it.*' (OF_2). According to farmers, this means that farmers will eventually crop the varieties that fulfill the demand of the consumer and the transformation industry or the fresh potato market. If cropped varieties do not respond to these demands, sales are difficult and other varieties will be chosen for the next season.

A second criterion is the **seedling cost and availability**. The farmers noticed that they will more easily choose free varieties because they are cheaper. Contractual varieties, that are more expensive, will be chosen if the budget and outcome are secured. Next to this, farmers can either work by using contracts or by selling on the free markets. If they sell on free markets, farmers explained that they select any variety they want. On the other hand, if farmers work with contracts, they already have a reduced/imposed choice of variety. The choice of variety then appears to depend either on the knowledge and past experience of the farmer with this variety and on the final revenue that is offered.

For **organic farmers**, **mildew resistance** is a more important factor. That is why cultivars that are more resistant to mildew like Sarpo Mira, Bionica, Gazorée and various others are selected (Bruyère et al., 2007; VIB, n.d.). It seems the organic sector will be the first to use new resistant varieties, even if a problem persists today. A researcher explains: '*The organic market is still too small and not interesting for breeders.*' (R_1).

The **transformation sector** will be far more concerned by factors such as **yield, quality, homogeneity, transformation ability, and outcome** of the variety. An industrial explained that yields were very important to the sector because this is what ensures an adequate supply of the entire production chain. A conventional farmer explains: '*What an industrial wants is a lot of tons with big potatoes. What they need is a primary resource that is healthy and in sufficient quantities.'* (CF_1). As a matter of fact, farmers explained that the required yields are stated in the contracts established with the industrials.

Secondly, the quality of the potatoes is of great importance. The industrial and various farmers explained that the quality of the final product was a must. This means that the presence of pathogens (like mildew), illnesses, but also physical damage to potato tubers could justify a refusal of the harvest. An industrial explained: *'You have to know that concerning mildew and rotten potatoes, we are truly inflexible. This means zero contaminated potatoes. If there are potatoes with mildew symptoms, we use refusal clauses.'* (I).

Thirdly, the homogeneity of tuber size and quality is most important. The fact is the industrial sector wants to standardize the final product. A clear example is the production of French fries in fast foods: these fries all need to be of the same length, color, taste…. Like a researcher says: '*Once the industry has its process, it will be difficult to change, even more when it functions well and that there's profitability'*.

Finally, actors pointed out that the transformation ability and **possible outcome** of a variety is also a main criterion for variety selection. On one hand, varieties that have a broad culinary outcome (like Bintje) are selected. On the other hand, some varieties have a more specific outcome because of particular traits they possess. A famer gave a clear example: '*Why do other varieties than Bintje come on the markets? It's because they have higher yields and bigger potatoes… And most of all, now, we try to have long potatoes. Mc Cain wants long potatoes to be able to make long fries, so now we grow more and more elongated potato varieties'* (CF_3). Many other criteria for the variety selection were metioned by the various interviewees.

Next to criteria like yield, quality and homogeneity that are common to the industrial sector, the actors explained that the **fresh potato sector** will mainly focus on the **esthetic aspect** and the ability of the variety to be **washed**. Skin color, tuber caliber and the absence of germs are criteria that are also taken into account. Finally, the variety will often be classified as '**floury'** or '**firm-flesh'**. Concerning this aspect, actors explained that on the one hand, commonly known varieties were promoted such as Nicolas and Charlotte, and that on the other hand, the culinary type of potato was promoted.

The actor of the **distribution sector** explained that a variety is considered interesting if the sale**s are secured**. This means that for the fresh sector, varieties like Nicolas, Charlotte and other best-selling varieties are always in demand. This also means implicitly that the required standards are very high. For instance, the farmers explained that the competition between shops creates a very demanding context for the quality of the potatoes. In this case, the same farmer tells us: '*You won't believe me but the demand of supermarkets towards organic products…. 40% (of the production) is to be sold (whereas the rest is simply thrown away because it does not comply the required quality standards), that's how far we've come!'* (CF_1).

Many actors indicated that the **consumer's** choice of variety depends on different factors. As a matter of fact, the actors explained that the consumers are formatted by the industrial sector as well as the distribution sector and that their habits strongly influence their choice of variety. Finally, consumers do not have any knowledge of the mildew problematic because of the distance currently existing between farmers and consumers.

As mentioned various actors, the consumers are formatted by the industrialization and the distribution. Interestingly, in the fresh sector, all actors tend to say that 'the consumers buy with their eyes', meaning that for a variety to be good for sale, it has to have a good taste, a particular skin and flesh color and no germs.

For the transformation sector, an example of this 'standardization' in appearance is the quasi identical size and color of fries in fast foods. According to organic farmers, this standardization has also started to permeate the organic sector, which is a recent phenomenon. A farmer tells us: '*At first, it was best to have very misshapen potatoes with illnesses…. Now it has to be more calibrated, it has to be this, it has to be that, and that's how it starts… The organic sector is being eaten up by industrialization and I fear the worst. We're starting to grow and sell organic products like conventional ones…'* (CF_1).

The actors confirmed that the same problem arises with the germs. Potatoes with germs are currently considered as uneatable even though they are totally apt for consumption. This creates a huge pressure on the organic producers because they cannot use any anti-germ products. A conventional farmer tells us: '*And that's exactly the dilemma. Potatoes with germs are better for consumption because it means they don't have any product on them anymore, but people don't understand that.'* (OF_3).

2.2.3. Introducing a new variety

Choice imposition

The selected varieties are, as has been shown above, selected on various criteria depending on the actor. Nevertheless, there are some actors that have a greater say with respect to the final choice of the variety.

The actors explained that the **industrial sector** plays an important part in the varietal selection. As a matter of fact, an industrial and a farmer explained that by relying on contracts with a great number of farmers, the industrial sector could guide the choice of the farmer, making contracts for certain varieties more attractive than for others.

Various actors noted that the **transformation sector** could have a major role in the varietal selection: '*The only real possibility for resistant varieties is the industry. They transform the potatoes in fries, puree, chips… The consumer buys fries, he doesn't buy a variety. So it's possible. Some transformers in the organic sector buy more resistant varieties, but they're the only ones…'* (OF_2) an organic farmer shared. The actors explained that the same phenomenon happens concerning the fresh sector. When the culinary type is a more important marketing factor than the variety, new varieties can be proposed to the distribution sector.

Preparers and packagers also have an impact on the choice of variety. A researcher explained: '*The preparer somewhere takes all the financial risks: he seeks for varieties out of more than ten new varieties that come out each year. He proposes them to his farmers and gets them produced with a contract or another type of warranty.'* (R_1). The researcher explained that the distribution then decides if this variety will be sold the next season or not. He added that if the sales are bad, the packagers have to endorse the losses.

As to the **organic sector**, the farmers appear to have a larger flexibility concerning the choice of their varieties (if they are not contracted). According to farmers of the fresh market, very often the variety is chosen by the buyer/preparer or is discussed between buyer and farmer.

Finally, the interviewees explained that the **distribution sector** also has an important role in the promotion of new varieties. An actor of the distribution sector explained that they can, by the use of marketing and advertising, change the consumer's habits and orient him towards a more ecologically responsible choice.

The criteria of varietal selection

As explained in the first part, for decades now, varietal selection has been operated so as to obtain the desired characteristics in the cropped potato variety. A researcher explains: '*Concerning varietal selection, the traditional varietal selection has not found many solutions to fight mildew for some time. It takes a lot of time to select the adequate genes with the desired resistances.*' (R_1)

Nevertheless, varietal selection can be used to import varietal resistances into a plant, but until now the focus has been on other characteristics. A researcher explains: '*Varietal selection still essentially concerns yield and specific characteristics for the industry like a nice fry color, a big caliber and for the fresh market a good skin and a high yield for soft flesh varieties. Mildew just comes after this.*' (R_4).

Resistant varieties do exist today but again, selection has been imperfect. A farmer explains: '*New varieties are being developed and these are almost fully resistant to Phytophthora. The only thing that's a pity is that they totally undermined the culinary aspect. A perfect example is Bionica.*' (CF_4). To conclude, and organic farmer explains: '*Varietal selection has focused on yields and nothing else. It's the first thing to do if we want to improve the production of agriculture while reducing the use of fungicides, the selection must change.*' (OF_3).

A new debate, GMOs

The events concerning the field trials in Wetteren in 2009 showed the polarization concerning GMO's in the Belgian (and mostly Flemish) society. Whereas various research groups (like UGent, the VIB, ILVO) with the support of Belgapom and the Boerenbond have a positive stance towards GMOs, groups of snatchers are clearly opposed to them. In general, the opinions of the encountered actors concerning the capacity of GMOs to bring about an adequate solution were positive: '*I believe that in a near future, GMOs will be used, with all of their guarantees*' (CF_1).

Nevertheless, the meaning of other actors was more diverse. For instance, one research group was more skeptical concerning the use of GMOs: '*Mildew has a very short cycle. It can take seven and a half days and if the right conditions are put together it can even take just four days to complete. An illness with a four day cycle… I'm sorry but I don't think we'll find GMOs that will resist 'ad vitam aeternam' to this…*' (R_6).

Snatchers are against GMO's and do not believe that these could bring the solution: *'GMO's are for me the symbol of privatization of life in the agro-industry. GMO's would not even exist if they could not be privatized. That's the only reason I believe they exist… The number of genes is also limited which means you can't combine endlessly so it's a dead end...'* (S).

It appeared that those interviewees who saw any benefit to or had a positive stance towards GMO's explained that they agreed with calling it cisgenesis and not with transgenesis. Some actors even called the process 'plant to plant' so as to 'hide' the fact it actually is a GMO.

One farmer did warn for privatization and patents on the genetic material. He was not ready to accept GMOs offered by big firms '*If we can obtain resistances to pathogens through GMOs, why not? But commercial firms do not have to take part of this, because with privatization, it won't work.*' (CF_2).

The cited research program concerning Belgapom, the Boerenbond, VIB, ILVO and UGent tries in fact to address this problem (Belgapom 2014b). For instance, an actor from the retail sector explained: '*We are looking if it is possible, with the primary sector (Boerenbond or FWA and ABS) and Belgapom, to be owner of this new variety… This means the variety could stay in the hands of the producers and users. And if we're talking about a GM Bintje +1 or +2 (resistance genes), it would be very specific to the Belgian case… So if we respond to the privatization and environmental question, I believe there's a motivation to work in that direction, even if it will take ten years.*' (RE)

The same actor argues: '*We can make adapted varieties by introducing genes from other potato varieties. Then we talk about 'plant to plant' or cisgenesis*'. (RE)

Finally, the characteristics of the GMO are of great importance for the actors and could have an important effect on the nature of the future debate. A researcher tells us: '*Transforming a plant as to be able to use more fungicides… that's not my idea. On the other hand, transforming a plant to make it more resistant to a pathogen… there we can diminish the number of treatments which means it's better. We'll need time to explain to the public because there are messages that have been completely transformed that give a wrong image of GMO's.*' (R_2).

At the moment, no GMO potatoes have been introduced in Belgium and as an organic farmer said '*They haven't solved anything yet*' (OF_2).

2.3. Fungicides

2.3.1. History

Farmers assured that before the introduction of European regulations, mildew variability and mildew alert systems, farmers tended to spray common fungicides on a weekly basis, with the dose they considered suitable at the moment. They also explained that there was no real legislation on the type and amount of products allowed, which meant that the environmental impact was of great importance and that the sustainability of the used products was compromised.

In response to this situation, European measures were taken in 1991 so as to reduce the spectrum and doses of used products in agriculture (BeSWIC n.d.). The actors explained that this directive ensured the use of less ecotoxic products and a more specific research for eco-friendly plant protection products.

2.3.2. Quantity and noxiousness

Conventional sector

More than twenty years after the installation of the European directive of 1991, a great majority of the actors tend to say that, as a matter of fact, conventional products have been improving throughout the years both on environmental aspects and on plant protection aspects. All the conventional farmers that comprised our sample were convinced that they now use reduced quantities of fungicides that also have a shorter afterglow and a more specific attack on mildew. A conventional famer confirms: '*Before, we sprayed three, four, five kilos but now it's 0.3l (per hectare) so… we put a lot smaller quantities of products on the soil*'. (CF_3).

Still, for one interviewee, although the quantities were reduced, the products were far more harmful than before: '*Before we worked with the machine gun, now we work with the atomic bomb!*' (PP_1). This actor explained that the impact of newly allowed products had a disastrous impact on soil life. Except for this one actor, it seems the interviewees agree to say that the general frame regarding fungicide use, efficiency and afterglow has evolved in a positive manner.

Organic sector

In the organic sector, copper is the only allowed fungicide (Speiser et al., 2006). It is quite a paradox that a 'green sector' like this one uses heavy metals to control plagues. A researcher affirms: '*Well, copper is toxic, ecotoxic and persistent. It has everything we don't want in a pesticide.*' (R_5).

This seems to bother organic farmers and enrage conventional farmers. An organic farmer having also conventional crops explained: '*It's true that using copper isn't very logical. It's a heavy metal and has long term effects that we don't know… But in conventional agriculture, the products that are used are often organic molecules that degrade pretty quickly in the soil. In my organic fields I can only find traces, and when I say traces I mean 0.10 mg of active molecule. On the other hand, I'm sure that we could still find copper in 15 years.*' (OF_3).

Some conventional farmers did not understand how copper could still be used today. A conventional farmer said: '*You don't have to forget that one hectare of organic potato… The impact for the environment is 200 times bigger than for one hectare of conventional potatoes… It's being kept secret by the sector but in fact the organic sector is worse for the environment than the conventional sector*' (CF_3). A conventional farmer adds: '*There's nothing more polluting than that. It's a heavy metal, it pollutes the groundwater. It's worse! Organic isn't ecologic, it has nothing to do with it…*' (CF_4).

Next to its noxiousness as a fungicide, copper is also clearly seen as less effective than conventional products by both groups of farmers.

Concerning the authorized used copper quantities, as was explained in part one of this thesis, the legislation on the use of copper has changed over time in Europe. Today, in Belgium, a maximum amount of six kg/ha is allowed per cropping season (Gianessi and Williams, 2011). This limitation appears to have an effect on the used varieties and the number of sprayings (see later). According to two organic farmers, the potato crop is one of the crops where this limit is reached very rapidly, since mildew is difficult to control and that copper is used in a preventive way.

2.3.3. Number of fungicide applications

During the interviews, it appeared that the number of sprayings of fungicides depends on numerous factors. The farmers explained that the number of fungicide applications operated by the farmers has an impact on the total quantity of fungicides used and on the time devoted by the farmers to the protection of their potato crops.

Weather conditions

The use and application of products varies a lot from year to year since mildew propagation depends greatly on weather conditions (Speiser et al. 2006). Both conventional and organic farmers agree to say that they spray between five and twenty times per season, depending on meteorological conditions. The actors explained that most products used in both types of agriculture are washable by rain, which means that ideally, a new layer of products must be applied after every rainfall. This factor appeared really crucial to farmers. A conventional farmer tells us: '*If we have wind, heat and* *humidity, we have to spray and spray again, we don't have a choice… We have to spray if we want to keep our harvest.'* (CF_2).

The potato market and price of fungicides

Interviewees brought up the fact that the potato market has an impact on the number of sprayings. A researcher tells us: *'Everything depends of course of the market price. If the revenue price is high, the producers tell themselves 'I may do it, a treatment more won't cost me too much and it will make me earn a lot of money'. In contrast, when the price is low, producers will think twice before spraying.'* (R_2).

Next to this factor, even though fungicides are now used in reduced doses, farmers and researchers explained that the specificity of the new products has rendered them a lot more expensive. According to them, the new products are only effective for specific pathogens, whereas the older generation of products had a broader pathogen spectrum. This makes every type of fungicide more expensive in the end.

In general though, the cost of an application is relatively low compared to the obtained gain. For farmers, it is clear that they will not risk losing their harvest. A conventional farmer tells us: *'I will rather spray once more than once less, that's clear. Even more so given that the cost of one anti-mildew treatment is low, compared to the risk of losing the crop. So we won't take the risk to lose our crop for a treatment…'* (CF_3).

Mildew alert system

As mentioned earlier, two regional mildew alert systems exist in Belgium: one in Flanders (PCA) and one in Wallonia (CARAH) (CARAH, n.d.; PCA, 2009). These research centers have the mission to alert all their affiliated farmers of eventual favorable climate conditions for mildew propagation. The goal is to make the use of fungicides as efficient as possible, by minimizing the application of fungicides on field (CARAH, n.d.; PCA, 2009). This is made possible by the use of a model that integrates meteorological data. In Wallonia, this data is collected by Pameseb (Pameseb, 2009).

According to researchers belonging to these centers, data concerning mildew appearance is often given by farmers themselves in the first place. When an alert is given, these centers try to give the date of application and also the type of product that must be used. Researchers from these centers commented that this service is a counseling service, which means the final decision is made by the farmers themselves. Next to this system, some actors prefer relying on their own program. For instance, the preparer interviewed for the present study and who also possesses land explained: *'We have invested in software so as to follow the conditions favoring mildew on a much smaller and more detailed scale. The problem of the most generalized service is that it uses a mean value and that there's the umbrella effect.'* (RE).

Various actors talked about the functioning of this 'umbrella effect'. They explained that if mildew alert systems want to remain trustworthy over time, they have to ensure a positive outcome for the affiliated members. The net result of this situation is that in case of doubt, the centers will always recommend spraying.

Used varieties

According to the farmers, the variety that is used has an impact on the number of sprayings needed to control mildew. As a matter of fact, the interviewed farmers who use more resistant varieties make use of fewer fungicides, and this for a variety of reasons. For instance, farmers explained that hasty varieties will develop much faster, thus avoiding high mildew pressure and needing less fungicide applications. Secondly, tolerance of a variety will slow down the pathogen's development (Bruyère et al., 2007; Speiser et al., 2006).

Type of agriculture

All the interviewed organic farmers tend to spray in smaller doses but more often. They also tend to wait longer before their first application. This is easily explainable: an organic farmer indicates: '*It is better to apply 100g ten times instead of 1kg at once. If we apply 1kg one time, it is only efficient during a small period of time. But because we are limited in applicable (copper) quantity, it's better to apply every week, or even every three days if necessary with 100 g then applying a big dose at once… It is better to divide the risk.*' (OF_4).

For conventional agriculture, for which there is no limit in applicable chemical quantities, a conventional farmer said: '*Concerning the reduction of applied doses, for me it's the worst thing we can do with fungicides. Because there's no better way for creating resistances, so it's better to always use the recommended doses, no more, no less.*' (CF_3).

2.3.4. Reducing the use of fungicides

Next to the mildew alert systems, a number of solutions already exist in order to reduce the use of fungicides. The various actors shared their visions on this issue.

Better spraying and effectiveness of the fungicides

Many of the contacted farmers already used techniques in order to reduce the use and costs of chemical products. For example, a conventional farmer explained: '*We use an aquaphyto system. Dissolving a fungicide in water is in fact a chemical process. So what do we do? Most of the people just pump water out of natural sources and add the product in the recommended dose that is on the package and spray this mixture. We work differently. We are going to demineralize and neutralize our water. We'll then change the pH to a desired value. We will adapt the pH as closely as possible in order to make the product as effective as possible. That's how we reduce our use in fungicides by more than 50%.*' (CF_4).

Another farmer assures that it is possible to reduce the quantities by half if the application is made when the conditions are optimal: '*When for example we pulverize at two in the afternoon or at eight in the morning… Well, at two in the afternoon if it's 25 °C, a part of the product already evaporated before it arrives on the target and it ends up in the environment. If you apply your product at eight in the morning, you diminish your fungicide use by 30% and you have the same efficiency than at two in the afternoon. The thing is, the firms tell to apply the doses that are adequate for applications that are made at two in the afternoon because they need to ensure the efficiency of their product…*' (CF_2).

However, a plant protection firm specialist warned: '*When we accredit a new product, we indicate the dose that ensures the efficiency of the product. Now if it says to work at 0.4 l/ha and you start working at 0.1, in some cases it might work but we're almost sure at 100% that a resistance will appear at some moment… Some firms give dangerous advice as to reduce the used doses and use non accredited products…*' (PP_2).

Better application methods of fungicides could thus be a first step to a significant reduction of the used doses, but should be implemented with a lot of caution in order to avoid the emergence of new resistance in mildew populations.

Alternatives to copper

As already explained in part one, research is conducted in order to find new alternatives to chemical fungicides (Axel et al., 2012). According to various actors, biocides and biological control in general could offer interesting alternatives to copper for the sector. A researcher tells us: '*We have for example orange-bark based products, like for example PREVAL. We have MYCOSIN, that are sulfated clays or horsetail extracts. There's CHITOSAN, or products based on chitins that are oligosaccharides that could eventually be alternatives to copper too. Antagonist bacteria could also be used. It's the combination of these various strategies that could give positive results to fight mildew. I don't think that actually any of these products used alone be as efficient as copper*' (R_2).

Nevertheless, it seems that the acceptance of these products by the farmers has yet to be achieved. As an organic farmer explains: *'It's very complicated… There are a lot of products that we don't know and for which we don't have any experience… We wonder if it's really useful or not. And when we see the costs, it's pretty scary…'* (OF_4). Still, organic farmers explained that if new, more convincing and more efficient alternative products were proposed on the market in the near future, they would gladly try it.

Reduction of fertilizers

An organic farmer (OF_2) and a researcher also mentioned abusive fertilization of the fields as a factor that should be worked on. It appears that too much fertilization causes an exuberant growth of the plant, creating huge foliage that is very slow to dry (Perez and Forbes, 2010). The fact that foliage is too large and that the leaves touch one another on different layers creates very humid conditions that promote mildew proliferation (Perez and Forbes, 2010). The same farmer ensures: '*Ideally, the plants must touch one another, but they must not interweave. If there's a mass and it's three in the afternoon when the dew is gone and if the day in June is not too sunny, it remains humid.'* (OF_2).

2.4. IPM methods

2.4.1. Soil management

All four organic farmers, one conventional farmer and various researchers mentioned the importance of a rich soil with organic matter and rich micro biodiversity. None of them was ready to say that this could directly help to fight mildew, but all agreed that soils are getting worn-out, poorer with time and that this was clearly visible on plants. An organic farmer said: '*Working the soil and the pedological aspect in its whole is capital not only before planting but from A to Z. Micro fauna can also help to obtain a culture that develops correctly, but I'm not sure if it's very useful against mildew…'* (OF_2).

Another one adds: '*What I see is that if the plant is sick, it's not just because of mildew in the atmosphere, it's also because it's fragile. It's fragile because it's growing in a soil that's not at its best.'* (OF_3).

According to these actors, the soil quality can be improved through the implementation of various practices. As a result, farmers believe they will obtain fitter plants that will resist better to mildew.

Cultural practices

During the interviews, various cultural practices have been evoked (mostly by farmers) and, in particular, how these could help to fight against mildew. In general, farmers explained that practices could indeed have a positive impact on mildew control.

- **Tillage or no-tillage**

Farmers who have tried tillage and no-tillage methods explained that there were no real noticeable differences between the two methods.

- **Rotation duration**

All of the interviewed farmers, both conventional and organic, noted the importance of a long rotation for proper soil quality and the control of pathogen populations. Long rotations seem even of greater importance for organic farmers. Farmers rely on a mean rotation of five years. A researcher tells us: *'The West of Belgium is historically a greater producer of potatoes with a shorter rotation than in the East where the potato is more recent and the rotations longer… A three year-rotation is too intense. The average should be around four. I think we are between three and four in the Hainaut and West-Flanders and more five in the Hesbaye region'* (R_1).

Finally, a conventional farmer explains: *'We have to have long rotations. Here we work on a six year basis, but some work on a three year basis. You can sanitize your soil in a better way if you expand your rotation. It's a first way of struggle too.'* (CF_3).

- **Green fertilizers**

Four farmers (mostly organic) out of eight spoke about green fertilizers being of great importance for a good soil. Three of them said they commonly planted alfalfa and the fourth one grew phacelia. According to them, green fertilizers were important so as to sanitize the soil and to avoid having weeds when the potatoes would be planted. An organic farmer explains: *'I leave the alfalfa during two years… At least I have a rich soil, I have nitrogen in my soil and I put all the conditions in my soil as to succeed my culture as well as possible'*. (CF_1).

- **Irrigation**

According to the farmers, irrigation is needed for the production of high quality fresh potatoes with an adequate skin. Only three out of eight interviewed farmers irrigate their potato crops. Most of the time, it were famers who also cropped vegetables who used irrigation on their farm because of the existing installations.

Farmers explained that if irrigation is operated at a bad period, it can provide adequate conditions for mildew and raise the risk of a mildew epidemic. A conventional farmer says: *'Irrigation is a way to obtain perfect skin. Of course, irrigating increases the risk for mildew, but when it's very dry… the period when the plant is wet is too short for multiplication… We will not stop irrigating because of mildew in any case. If needed we'll adapt our fungicide doses.'* (CF_3).

An organic farmer also adds: *'It's better to irrigate for quality, but better sometimes makes it worse… You don't have to start irrigating when it's mid-august and you know very well there's mildew everywhere.'* (OF_4).

Irrigation should thus be regulated in an efficient manner so as to impede any new inoculums or infected areas.

- **Biological health of soils**

According to various actors encountered, a healthy soil is not just a soil with a good structure and enough nutrients; it also has a biological aspect that needs to be respected. A researcher explains: 'We *see that in the organic sector, the fields have fewer problems with Phytophthora compared with conventional fields, even though they grow the same variety. You can't explain it with non-soil-linked factors… We start seeing that in fact this biological diversity in the soil can be a source of induced resistance. Of course it's not absolute but it can delay the first infection.'* (R_5).

One organic farmer nicely captures the general mentality of farmers: *'We have to feed our soils so that the soil can feed the plant. I think the plant cells then develop slower and are more resistant.'* (OF_3).

In general though, farmers seek a balance of various elements in their soil. Another organic farmer explains: *'The soil mustn't be full of organic matter. You need to have a good equilibrium. Excess is always bad.'* (OF_2).

Those farmers practicing both types of agriculture were certain that organic agriculture was far better than conventional agriculture for all aspects concerning soil health. For them, it seemed that even though copper based fungicides take longer to eliminate, they would have a smaller impact on soil life. An organic farmer explains: *'It's been my fifth year in the organic sector and I see that for example my cereals are far less fragile than before. I see that, even though I use copper, the life in my organic soils is much more intense. I'm sure I have a lot more bacteria, worms and fungi and there's a better balance in the soil with a higher level of competition between these life forms.'* (OF_3).

A series of practices concerning the biological health of soils were also discussed. A conventional farmer explained for instance that it was more and more common, due to the rising prices of agricultural lands, to rent lands for a year. According to him, farmers renting fields would use very strong pesticides, killing all the life in the soil, so as to avoid pathogens: *'They use the strongest fungicides that exist. So all the fungi in the soil die. In fact we sanitize the soil. This works just during the cropping season and afterwards it's very hard to obtain a rich soil again…'* (CF_2).

Finally, research on soil life seemed to generate of a lot of interest. One researcher explained a research program, oriented towards soil life and the impact of bacteria on this soil life*: 'We are working on a way to promote the microfauna and microflora that we can use in Walloon soils. We are thus trying to look for Walloon bacterial populations that could have an effect either directly against pathogens of the potato or indirectly via stimulation of the natural defenses of plants… We've already been able to show interesting strains in this case…The thing is, we now know which bacteria might be interesting. The whole question is: How will we apply them? Do we need to pulverize? Do we need to enrobe the tuber? Does it have side effects on the environment? This whole process can take more than eight years!'*(R_2).

Additional mildew control methods

- **Inoculum**

According to various actors, farmer habits have changed through time. For them, parcels are now bigger, meaning that potatoes are harvested mechanically. These changes in habits seem to create numerous new inoculums of mildew.

First of all, actors explained that differential sorting containing inadequate tubers for the market may contain infected tubers. These heaps are placed next to the crop fields and may become a potential inoculum. The rotting vegetation in the heap induces higher temperatures, allowing the growth of early infected potato plants (R_3). A researcher tells us: *'This can be the start of an epidemic. There are some factors like this where the plague starts and you can have an impact by reducing them. You're not going to stop the epidemic, but you'll slow it down en that's important and quite easy to do.'* (R_3).

Another researcher was more moderate*: 'You have to be cautious. The first stains of mildew don't mean first treatment. It depends on the situation. If you have a differential sorting that has had the time to warm up, the general weather conditions are not always the same. They're not conditions on field, but just on that specific spot… We try, as much as possible to localize these heaps for our survey so that farmers can have the information. Sometimes it's just a very good farmer that has had a problem with his wheat and is worrying about his wheat, forgetting to turn over his heap…'* (R_6).

A second factor noticed by the actors is that infected potato tubers might stay on field after the harvest. These tubers give birth to plants on field during the next year, becoming a source of inoculum of mildew. An organic farmer said:*' After the potato, we usually grow maze. This maze is always sown quite late, end of April, beginning of May. Potatoes develop in this starting from tubers that are still on field…'* (CF_3) Interviewees assured that the best way to eliminate these tubers is by making sure that the left over tubers die because of the frost. The actors explained that if winters are not cold enough, it is best to grow crops that allow an elimination of these potato plants by tillage or by the use of specific herbicides.

Actors pointed out that kitchen gardens might be yet another important source of early mildew. According to them, people with few potato plants may not use the adequate amount of fungicides, not know which fungicides apply or decide not to use any fungicides at all. These plants may thus become sources of early mildew, spreading to big crop fields next door. A conventional farmer explains: *'The only thing people should do is tear out these plants, put them on a heap and try to burn them. That's the best thing they can do… People don't want to believe that they are the cause…'* (CF_4).

To conclude this point, an organic farmer summarizes the global situation quite well: *'All these elements put together make the mildew explosion phenomenal. And this didn't exist 30 years ago. Differential sorting didn't exist. Small potatoes were collected and given to the cattle. Surfaces were much smaller, so the farmers could check their fields. We used to tear out the plants by hand, I did it myself back in the days!'* (OF_2).

- **Reducing mildew-favorable conditions**

Most farmers showed that various applicable practices may efficiently reduce the appearance of mildew-favorable conditions, even though these greatly depend on meteorological conditions.

A first practice that can be worked on is the **space between the potato rows**. Two major schemes exist: the space between the lines is either of 75cm or 90 cm. The quantity of plants is the same per hectare, which means that this space only impacts the density of the plants in the line. According to the farmers, the choice of this space has an important impact because if the farmer decides to plant at an interval of 75 cm, the foliage of the plants of different lines will be in contact much sooner, thus covering the soil faster and reducing the growth of weeds. On the other hand, humid conditions are likely to prevail and this means that mildew can emerge more easily. If the farmer plants at 90 cm, it's the opposite. The foliage takes more time to cover the whole surface, giving more space for weeds to appear. Mildew favorable conditions are on the other hand strongly reduced. The space between the rows is the choice of the farmer and depends on the machinery and variety he uses, and his ability to take in charge weeds. An organic farmer said: *'I plant at 90… Let's say it's more difficult because the cover of the interline takes more time to be made, meaning I'll have more weeds… I plant Agrea that produces a lot of foliage, so it compensates a bit. If I have space in between my rows, I can also weed mechanically a lot longer.'* (OF_3). This factor was discussed more with organic farmers because they appear to have more problems to manage weeds.

Finally, the farmers assured that by playing on the **planting period,** they can also partially avoid mildew. By planting earlier, the tubers have more time to grow before mildew appears on the fields. Another method explained by the farmers so as to obtain suitable tubers at an earlier stage is by using pregermed seedlings. When these are planted, they start growing more rapidly and obtain bigger tubers than non pregermed potatoes planted at the same time. Actors said these are already very common practices in organic cropping because of the restriction on the use of copper.

3. Into the future

All actors conveyed their vision of the (near) future potato system. Because there are as many scenarios as there are actors, only the main tendencies are presented in the following paragraphs.

In general, the opinions of the actors on the future of the various topics presented above varied markedly. Some actors were persuaded that mildew can be eradicated within twenty years, whereas others think that it will be impossible to totally control mildew. Three farmers even explained that if no solution was found in a near future, mildew pressure would become too important and the Belgian potato system would collapse and disappear

3.1. Varietal resistance

The majority of the actors mentioned the fact that more resistant varieties will be used in the future, whether they are obtained through classical selection or genetic manipulation. For some actors, this alternative seemed utopic. A researcher tells us: '*I would want us to find resistant varieties... but these are resistant during one year and the year after they're not anymore. We'll never develop varieties fast enough to compete with the mutation of mildew strains…'* (R_6).

Concerning GMOs, most actors agree to say that in a near future, GMOs will impose themselves in Europe despite the current public opinion. These actors also believe that GMOs could provide an adequate (but not final) solution to the problem. As a matter of fact, a number of farmers (conventional and organic) said they were willing to crop GMOs if these brought a real change to the mildew problematic.

To conclude, varietal selection was the most-often cited solution by the actors. To them, this seemed to be the most promising option for the future fight against late blight.

3.2. The use of chemical products

A large number of these same actors argued that even if more resistant varieties are going to be used, chemical control products will still be necessary. They consider that these products will be more efficient and used only in extreme cases. A researcher tells us: '*I believe that either way we'll go to a reduced use of products, that's for sure. The main alternatives will be varietal.'* (R_4).

Another researcher adds: '*We'll still have to combine the use of these varieties with a limited use of fungicides in case the resistance genes fail us. That's how we can make sure that the pressure on these genes does not get too strong.'* (R_5).

Anyhow, the use of chemicals alone does not seem to be an option. An organic farmer explains: '*It's not by applying more products that we'll make it because if we invent new products, we'll invent new mildew strains to fight against that new product. It's written.'* (OF_4).

Next to the currently used fungicides, new, more biological products also have been brought up by various actors being mostly organic farmers. This 'green chemistry' could, according to them, be more ecofriendly and protect the plants as well as conventional chemical products in the future. A salesman warns however that the misuse of these products may happen quickly: '*We won't solve anything with this because they'll be in the hands of big firms… If this kind of struggle is in the hands of big firms, we're starting over with the problem. We'll use far too large quantities of products and we'll bombard the fields but it will be worse since we'll completely perturb the soil biology… Biological substances can be as dangerous as chemical ones.'* (PP_1).

Globally, all the actors explained that in a near future, the use of chemical products will not be excluded even though they were certain that authorities and public opinion will continue augmenting the pressure against the use of fungicides.

3.3. IPM

Various actors (farmers and researchers) explained that there will be an evolution in the practices that are applied to control mildew. For instance, inoculums will be controlled in a more efficient way, and certain practices will also become obligatory. A farmer argues: '*I believe that they will make plant disease licenses obligatory. They are going to impose obligatory courses to the farmers so they can spray in a more efficient way. I believe that slowly we'll get there.'* (CF_2).

Concerning soil conditions, two farmers and various researchers thought that the way the whole soil system functions will be much better understood and that this factor will be far more exploited in modern agriculture than today.

3.4. The potato system

Next to internal factors, the actors also mentioned that different external evolutions that impact the system in its whole will undoubtedly have an impact on the struggle against mildew. Below are the various points brought up by the interviewees.

First of all, farms are and will continue to get bigger. The actors say that the main reason is because there are no young farmers to take over the farms, and that becoming a farmer is very difficult because it needs a lot of funds.

The actors showed that a second fact is that arable land is getting rare in Belgium. Urban expansion is slowly but surely taking possession of agronomic lands. The actors say that this will make the price of the land increase, making it even more difficult for young farmers and small enterprises to kick off/expand. The renting price of lands will also rise because of the growing demand.

Thirdly, the potato market is a quite speculative market, meaning that the obtained prices are quite variable. The potato sector has known an important growth during the last fifteen years and the actors warned us that many farmers invested big amounts of money in stocking facilities and machinery so as to crop larger amounts of potato. This means that these farmers are due to pay back the money they received from the banks. The actors explained that only a few bad years are needed to expel all these new farmers that do not have any contracts. The instability on the market will be an important regulator of the potato production.

To conclude, the various solutions aimed at controlling mildew in the near future can be represented in three main categories, being the use of varietal resistance, the more reasoned use of chemicals, and the installation of IPM methods. These categories each have their own barriers, affect different actors, and require specifics implementations. These aspects are discussed in the following section.

4. Overview of the barriers

Given the interviewees' visions of the historical and current situation of the various factors linked to the mildew issue, and the future possible scenarios mentioned by these actors, a number of factors and actors seem likely to block changes towards a more sustainable control of mildew. As a matter of fact, just as the mildew problem is believed to be caused by multiple sources, the possible obstacles are seen as at least as numerous. The fact is that a new manner of managing mildew has to respond to the many demands of the various actors and that each of them has their own goals, visions, and habits. In order to explain this in a systematic and clear manner, all possible blockings will be explained category by category and actor by actor. A schematic representation of the present section is given at Figure 10, p69.

4.1. Category one : Varietal resistance

Varietal resistance was the most-often cited future alternative to fight mildew and also seemed the most realistic one for the actors. Still, it also seems to be facing the most barriers according to the interviewees (Table 10).

Table 10 : Main barriers for each type of actor concerning the installment of a new variety

Actor	Barrier to the installment/obtainment of a new variety
a) Research	- Funding (for breeding and testing) - Difficulty of inserting resistances in commercialized varieties - Time needed for results
b) Authorities	- Certification of new races
c) Plant protection Firms	- Economic losses
d) Farmers and seedling growers	- Habits - Adaptability to machinery and field conditions - Economic constraint (through yield or quality)
e) Industrial sector	- Need of a critical mass for tryout - Low adaptability to the transformation process - Need of large output (type) possibility
f) Consumer	- Habits, standardization and formatting - Poor knowledge of the problematic - GMO acceptance
g) Distribution and retail	- Low interest in new varieties - Rationalization of the sold varieties (some varieties are sold all year long) - Difficulty to start new varieties (need of a critical mass and direct sale results)

a) Research sector

The actors explained that the **research sector** can act on two different types of promotion concerning resistant varieties. On one hand the sector can promote existing resistant varieties, and on the other, it can create new resistant varieties obtained through classical breeding or genetic manipulation. Whereas existing resistant varieties have already been tested by various research centers (Bruyère et al., 2007; Poulet et al,. n.d.) , actors have shown that the **research sector** encounters a number of barriers concerning the varietal selection for the potato crop that make it very difficult to create a new, resistant variety.

A first problem, mentioned by a researcher, is that with classical selection, there is no 'adding up' of characteristics, because it is impossible to introduce the wanted properties without affecting the initial variety (R_5). This researcher explained: '*When you cross between varieties… For example: Solanum bulbocastanum and Solanum tuberosum… They can't cross in a natural way, so you have to use bridge crossings and all sorts of techniques. For example, Bintje, that Belgians love so much… If you start crossing with this variety, you won't get Bintje back, but with GMOs this could be possible*' (R_5).

Another factor brought up by the actors is the cost of a breeding program. As a matter of fact, growing funds are needed to start varietal selection programs. A researcher illuminates: '*Today there are many obstacles. First, the costs of R&D keep on getting more important over time, because the chance that something gets better becomes smaller and smaller. Second, the demands on ecotoxicologic aspect for fungicides are gigantic. So they start to realize that investing becomes difficult. And third… research in that sector is often confronted to a situation where 'We have been putting our efforts in a ten year long research to add resistance genes in a variety, we come on the market and it's not valued. We don't get a penny for our work'…*' (R_5). This creates a huge obstacle for actual breeding programs in the potato crop.

Furthermore, the actors say that obtaining new varieties via a classical selection process can take more than fifteen years. Because of the time needed to obtain results, investments are not secured to be profitable and often represent losses. The change in circumstances between the initiation of the breeding program and the finding of the variety may mean that the research, and thus the investment, eventually comes to a dead end, because the new variety does not fit at all in the new situation. To prevent this problem, GMOs may constitute a solution, because they speed up the breeding process.

To conclude, a researcher explains that the current situation is indeed quite complex for the research sector. Creating a new variety (by means of a classic or a genetic breeding program) costs a lot of money and the obtained variety must respond to a great many criteria.

b) Authorities

Not only has a new variety to be created, but it also has to be certified by the relevant authorities. The researchers explained that this process also represents an important barrier for the research sector. If a new variety is obtained after many years of research, and is eventually to be refused by the authorities, all the investments will be wasted.

c) Plant protection firms

The actors explained that the sector that will benefit the least of a varietal solution is the plant protection sector. Interviewees explained that this sector makes profits by selling fungicides and wants to continue doing so (R_5). The actors confirmed that research in this sector is slowly orienting itself towards varietal selection even though for now, they will still continue to sell as much fungicides as they can (R_1, R_5).

d) Farmers and seedling growers

In order to be accepted by the **farmers and seedling growers**, a new variety will have to replace the potatoes that farmers are used to grow today. Actors explained that farmers have habits that are also hard to replace. A researcher explicated: '*There are the farmers' habits. You can't forget that farmers have 36 things to do at the same time and thus having a variety that they know is easy.*' (R_6).

In addition to this factor, the solution also has to be commercially viable. Farmers say that this will depend on the value of the potato and on the fact that they will be able to sell their production or not.

The same researcher continues: '*There's also the demand of the industry. Because a farmer who wants to start and thinks 'I produce this variety because I like it but I don't have any contract'… He needs to be sure to be able to sell his stock.'* (R_6).

Yet another factor that emerged through the interviews is that there is no real consensus between farmers. In other words, the interests of farmers are diverse: some will favor the adoption of a new variety, whereas others will keep holding on to the actual system. Farmers explained that the coexistence between the actual system and the new one could also represent a barrier. If Bintje (and other less resistant varieties) cannot be replaced totally, will the new variety be strong enough to persist on the market, and not just disappear after a few years?

e) The industrial sector

According to several actors, the **industrial sector** is also an obstacle for various reasons. First, if a new resistant variety is found, it has to be tested. To test a new variety, a researcher said that at least 100 tons of potato are needed, which is an obstacle in and of itself. An industrial actor confirmed this statement: '*Mildew resistant varieties will have to be tested at a larger scale and tested in plants to see if they're adequate or not.'* (I). Who would want to produce 100 tons of potato that might go to waste?

Next to this problem, it is also important that the new potato can replace and exceed the Bintje in all the transformation processes and outlet possibilities. For example, the new variety will have to be available all year round. A farmer assumed: '*the whole system has to function. The industry… The plants won't stop producing during 4 months a year. They already find it hard to stop during the three weeks of holidays in June. There's need for merchandise.'* (CF_2).

This is confirmed by the actor of the industrial sector: '*If we can find a variety with which we could do as many things as the Bintje, it would function. The final product also has to please the costumer.'*(I).

f) The consumers

The obstacle that was mentioned the most by the interviewees was the acceptance of the **consumers**. According to various actors, the consumption habits of the consumers are one of the main reasons why Bintje is still so important on the Belgian market. The consequences of these habits are quite important for the introduction of a new variety. A researcher explains: '*We always have problems with the consumers if we want to install new varieties. A new variety… you, young person, you'll jump on it, but an old person… I think that people that are more than 50 years old have their little routine… They won't change. They're going to say 'I want firm flesh potatoes, not too floury…'* (R_6).

A farmer adds: '*I think young couples might be interested in organic potato, but old people, they don't give a s*** of organic… For old people, big potatoes… Even if we have an important marketing action: 'This variety has not been sprayed, needs no fertilizers, you have the perfect potato and it's not more expensive than the other ones. The only thing is, it has a bit less taste'… I think it won't even work'* (OF_3).

The price also has a big impact. The same farmer says: '*A big portion of the consumers just looks at the price. In the plate, it's clearly not the potato that will cost the most. People need to consume in a different manner.'* (OF_3).

Next to this, farmers explained that because of the many intervening people and firms between production and consumption, consumers have no knowledge about the farmers' problems and struggles. An organic farmer tells us: '*There are too many circuits. Between the producer and the consumer there are seven-eight-ten people that take some money. First of all, the price increases and second we get the consumer so far from the producer that there's no knowledge of one another.'* (OF_3).

The actors noted that consumers totally ignore the mildew criterion. Introducing new, mildew-resistant varieties seems difficult. An organic farmer explains: '*There's nothing more conservative than the consumer. The further the consumer is from the kitchen garden (which means 98% of the consumers nowadays), the more they are formatted… So because of this general formatting trying to introduce a new (ecologic) variety… it's impossible to sell… And once it's transformed into puree, chips or precooked fries, the consumer buys fries, he doesn't buy a variety.'* (OF_3).

Next to this, some actors explained that often the consumers' choice was directed. A farmer explained: *'We always say that the costumer is the 'king', but I see he's the king with what you offer him. My buyer that has a supermarket tells me 'this year I will give the client Nicolas and Agilla', and that's it. His choice is limited'.* (OF_4). A researcher added*: 'My personal meaning is that we make the consumer say whatever we want and there are many cases where he is imposed things. Afterwards we say he wanted it and that he liked it. For me, you can make the costumer say what you want.'* (R_1)

During the interviews, the examples of failed attempts to cultivate and sell more resistant varieties because of these requirements and standards were numerous. An organic farmer explains: '*I used to grow very resistant varieties like for example Sarpo Mira. I don't grow these anymore, because I can't sell them. It's a very interesting variety but with a red skin and a clear flesh. So the market is reduced.'* (OF_1). Another organic farmer adds: '*We tried to crop potatoes resistant to mildew, like Gazorée or Biogold, but you can't sell it'.* (OF_2). Yet another organic farmer: '*Last year I had Bionica. This variety is particularly white and it's not firm at all. Conclusion: commercialization is impossible. So this year I'm trying a new variety: Connect. This variety is also resistant but is yellow. It's not firm either but by desiccation, we could keep them firmer, making them apt for sale.'* (OF_3). It is interesting to notice that these experiences are only brought up by organic farmers, thus suggesting that this sector is far more explorative and diverse than the conventional farming system concerning resistant varieties.

The actors showed that the cultural attachment for the Bintje, the standardization of the product and a poor knowledge of the producers' situation are various factors that create a barrier that seems quite difficult to cross. According to the actors, this choice in habit has a direct effect on the entire production chain, freezing the decision power of farmers, industry, and distribution alike.

Concerning the European stance against GMOs, the resistance of the public with respect to new GMO varieties will have to be overcome, before these new variety can be cropped and commercialized at a larger scale. To an actor of the research sector, it seemed of great importance to explain the situation to the consumers: '*It will take time to explain to the public that GMOs can become the solution because many messages have been completely transformed because of their bad image'.*

g) The distribution and retail sector

Even though the **distribution sector** has a potential impact on consumer preferences, it will mainly sell potatoes that the consumers like. A farmer explains: '*If we have a new potato that doesn't need any treatment, that's cheaper…, the distribution won't sell it if it doesn't please the consumer and that there is a risk that the consumer is going to buy his potatoes elsewhere. It seems to me like it's the distribution sector that's going to block.'* (OF_3).

The actor of the distribution sector confirmed this statement: 'If *a variety is resistant but does not have all the required characteristics… I think you might have some success but I don't think it will really function… We can try to promote the variety, but if it does not sell, we can't change the costumer.' (D).*

The question in this case is: will the distribution sector bother doing any efforts to promote more ecological varieties? As explained by an actor from the retail sector for the 'Terra Nostra'[36] example, if the promotions do not function at an early stage, the distribution sector will not lose time, money and energy for the cause (RE).

Interactions between actors

It seems clear that the choices and actions of one type of actor will affect those of others. Everything now depends on which actor has the most weight in these interactions in order to bring about a significant change. If actors that weigh more heavily on the system decide to opt for new, resistant varieties, the change will be much easier. This will be discussed in the Discussion of the thesis.

4.2. Category two: more efficient (use of) chemicals

Searching for better chemicals and spraying them in a more efficient way is one of the solutions to a reasoned use of fungicides, according to actors. The three main sectors that could represent a barrier concerning these solutions are the authorities, the plant protection firms and the farmers and seedling growers (Table 11).

Table 11 : Main barriers for each type of actor concerning a reduced use of chemicals

Actor	Barrier to the more efficient spraying of chemicals
h) Authorities	- Certification process of new fungicides
i) Plant protection Firms	- Economic losses - Important research investments - Adaptability and efficiency of the new products
j) Farmers and seedling growers	- Habits - Adaptability to machinery and field conditions - Economic requirement (through yield or quality)

h) Authorities

According to the actors of the plant protection sector, the certification process of new products can represent a major obstacle for the introduction of new products on the markets. It has become a main obstacle for the investments made by plant protection firms: *'The economic aspect impedes the advance of technology. At this moment, even though we are now following a European system that in theory should shorten and facilitate approaches, we can only note that certification budgets for products are rising unreasonably. This means we'll have a very limited scope of action. We'll always ask ourselves 'Do we invest or not?' Many files will quickly be put aside because we won't even take the risk to evaluate the active matter or make it evolve on the market.'* (PP_2). This context thus seems to give little flexibility to smaller plant protection firms that have limited budgets devoted to research.

Furthermore, new regulations allow a fast withdrawal of products considered as harmful. The same actor argues: '*We're also scared that our AM might be taken off the market after just a few years. A new law will make it easier to forbid products on the market.*'(PP_2). This actor's point of view shows that it is indeed important to improve the current situation concerning the use of fungicides, but that an

[36] 'Terra Nostra agriculture of Wallonia is a label given to various varieties of potatoes produced in Wallonia. It is a distinctive sign of recognition and identification for potatoes produced on Walloon lands and produced following a specifications program… Since 1998, the Terra Nostra potatoes are cultivated through reasoned agriculture.'(APAQ-W n.d.)

overly strict frame for firms of this sector may also impede technological advances that are necessary for a more sustainable control of mildew.

i) Plant protection firms

According to actors of the plant protection firms, the main barrier for this sector is the obtainment of products responding to the regulatory frame (PP_2). The research that is required is very expensive and takes a lot of time because products have to become more efficient against *P. infestans*, while becoming less ecotoxic and less dangerous for human health. This same actor mentions that new products do not only have to follow strict ecological rules but also have to follow current trends of product application and form: *'Sometimes we have products that are entirely fit, but the dose is of 6l/ha. Nobody wants to apply 6l/ha… The same with the formulation: if farmers have to start mixing the products themselves like they did before, it won't sell very well…'* (PP_2).

Finally, the actors explained that a more efficient spraying operated by farmers also means a lesser use of products, which means that the sales of these firms will diminish, creating losses in the plant protection sector. The actors of this sector were convinced though that it is imperative for farmers to use the indicated doses if resistances in mildew populations are to be avoided.

j) Farmers and seedling growers

According to the farmers and seedling growers, the barrier mostly concerns the efficient spraying of these products: the machinery needs to be adapted and this is not financially accessible to all farmers. Added to this, the farmers pointed out that they will first want to secure their production. They also reported that it will be difficult for many of them to accept using fewer fungicides because it is perceived to be more risky and may generate harvest losses. It seemed that if plant protection firms give them new, more efficient products and advise them with respect to their application, the farmers will feel more confident.

4.3. Category three: IPM methods

The agronomic solutions that have been brought up concern the research sector, authorities, plant protection firms, as well as farmers and seedling producers.

Table 12 : Main barriers for each type of actor concerning the installment of new agronomic solutions

Actor	Barrier to the application of agronomic solutions
k) Research	- Need of effective research concerning agronomic practices - Dissemination of the new methods and knowledge
l) Authorities	- Political direction and priority accorded to the problem
m) Farmers and seedling growers	- Habits - Adaptability of machinery and field conditions - Economic requirement

k) Research

If agronomic practices are to be used at a larger scale, the effectiveness of these practices has to be secured. Researchers from various research centers explained that they tested several methods concerning for instance the use of a specific kind of green fertilizer, or the use of biological control methods. The actors were quite explicit regarding the fact that new, conclusive research had to be conducted along these lines in order to obtain more convincing results. According to farmers, an efficient manner of disseminating these techniques is by empowering the existing research centers and giving them a more important status in the whole system. The farmers say that these centers could, through their expertise and reputation, ensure a wider use of more adequate techniques. These centers could for instance organize training sessions for the farmers, so as to make them better aware of the impact of their methods on the fight against mildew and other pathogens in general.

l) Authorities

As explained by a researcher, the authorities will mainly impact this category of solutions through the importance that is being given to this issue. The authorities have to choose how they will use the funds that are made available for research and subsidies. This means they can have a really positive impact depending on the selected path.

m) Farmers and seedling growers

Farmers and seedling growers explained that the use of agronomic solutions vary strongly from farm to farm because of the many aspects that need to be taken into account (i.e., time allowed to every plot, size of the plot, machinery, financial capacities, geographical setting,…). The current agronomic practices that they apply on their plots derive from past decisions that were not always their own choice (for instance the use of their parent's machinery, their lack of time for any additional practice like tillage or others). For them, the scaling-up of such practices thus seemed difficult to achieve.

4.4. Multiple categories

Even though the solutions and barriers are illustrated by category, it stands to reason that several or even all of these categories could be considered simultaneously. A situation where all categories are being explored at the same time is even likely to be the most realistic one. We can make the hypothesis that if various categories are to be explored concomitantly, the various barriers that have been discussed would add up or, at the very least, combine.

5. Conclusion of part three

This third part details the data that were gathered during the two interview phases. These examined the visions of the actors regarding the current situation characterizing the Belgian potato system. The interviews also dwelled on the views of the actors concerning the various ways of managing late blight and their evolution. Last but not least, the actors also conveyed their opinions about the barriers that prevent the implementation of alternative ways of managing late blight.

The systemic analysis of the Belgian potato sector showed that the roles and interests of the actors vary strongly within the system. These roles and interests have an impact on the vision they have regarding the mildew issue. As a case in point, there is a marked contrast between organic and conventional farmers concerning the agronomic elements of mildew control. More will be said about this in the discussion. The interviews also revealed that some subjects of interest were specific to certain actors. As a clear illustration, the farmers and the researchers discussed the barriers preventing the adoption of agronomic solutions far more than the other actors. In sharp contrast, some topics like the varietal solution were evoked by almost all of the actors.

As can be seen, the problem is complex and involves a great many actors, all playing a distinct role in the system. Because of their limited role in the system and their partial ignorance of the views of the other actors, the different interviewees do not seem to be ready to act and change a situation that can be seen as a lock-in.

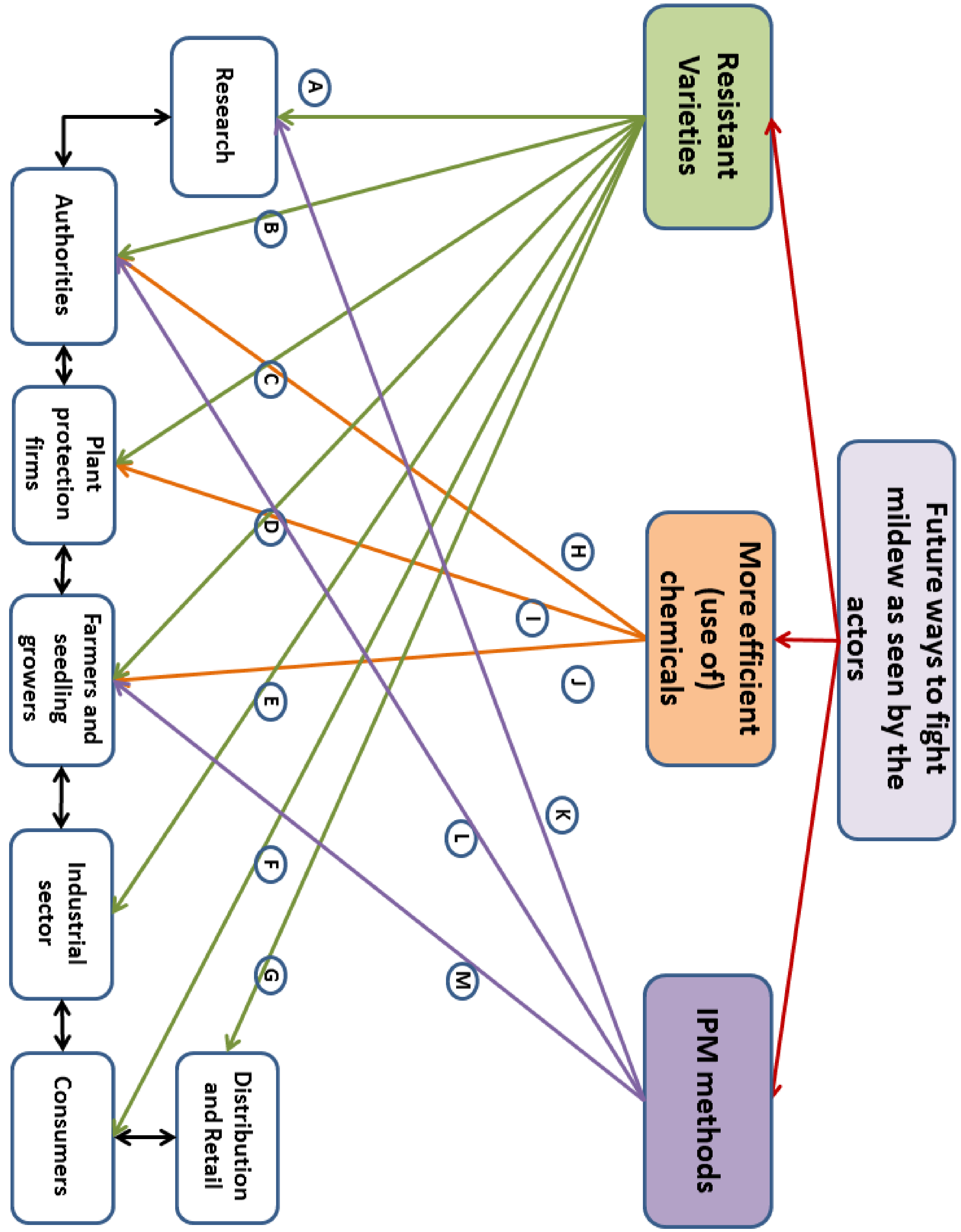


Figure 10 : Scheme representing the existing categories of solutions and the existing barriers depending on the actors

PART FOUR: DISCUSSION AND PERSPECTIVES

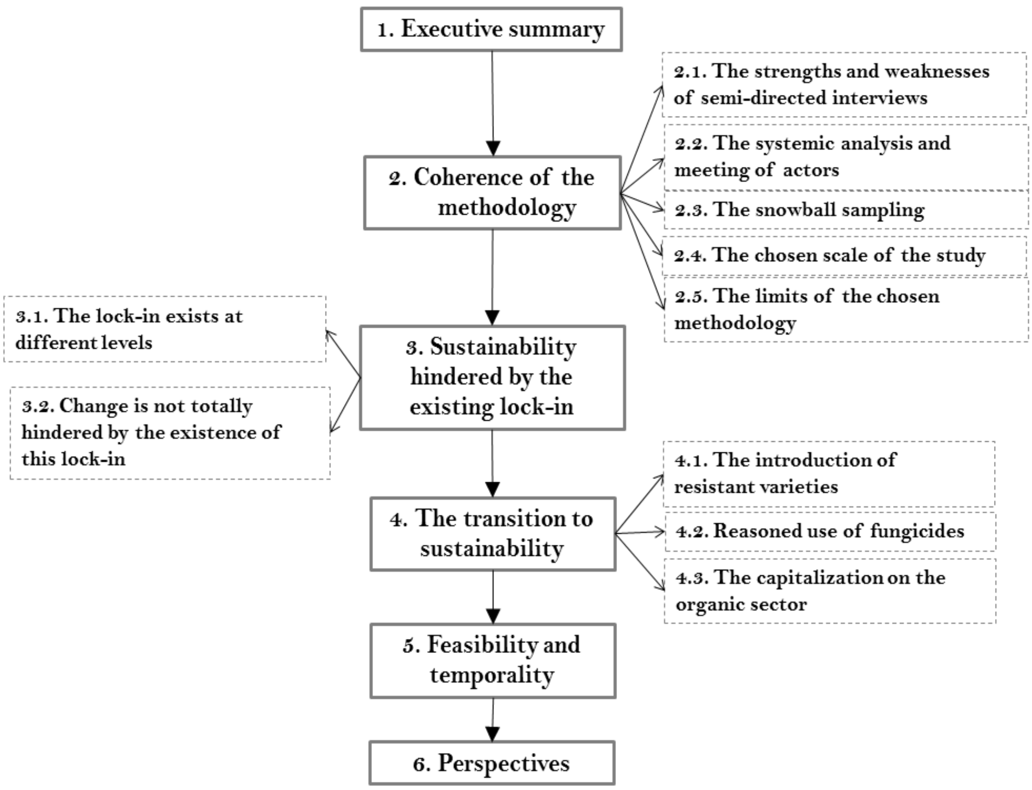
PART FOUR: DISCUSSION AND PERSPECTIVES

In this fourth part, a review of the different steps of the thesis and the main goals is given. Secondly, the coherence of the used methodology during the thesis is discussed. The strengths, weaknesses, and limits of this methodology are exposed so as to clarify the interpretation of the results.

In a third section, the confrontation of the existing literature to the current system confirms the existence of a lock-in. As a matter of fact, several actors indicate that they are aware of the limits and problems of the system as it works today yet consider that things cannot be changed easily because of the assumed interests of various other actors. The section gives a series of examples illustrating this mechanism.

This leads to a fourth section, which discusses various means to achieve a transition towards sustainability, in spite of this lock-in. As far as varietal resistance is concerned, the various options for the acceptance of existing resistant varieties and the development of new varieties are examined. Turning to fungicides, their tighter regulation will be discussed. Finally, the implementation of IPM methods at a larger scale will be evoked. The feasibility and temporality of the prospective paths will be addressed. As a matter of fact, not all options have equal chances to succeed and, even so, they do not play out on the same time span. Perspectives of the actions that could be implemented by the various actors will also be given.

The general conclusion of the present work will be provided in the final part.



1. Executive summary

The goal of this thesis is to explore alternatives for a more sustainable way of controlling potato late blight. In order to achieve this goal, a review of the current mildew issue and a systemic analysis of the Belgian potato system were made.

After having assimilated a grey background based on scientific literature, a mapping of actors was first elaborated. This mapping allowed collecting on-field information from various actors of the system. This information was obtained during two distinct phases through semi-directed interviews. The first phase concerned a total number of fourteen actors: six researchers, four conventional farmers and four organic farmers (see part two, Tables 5 and 6). During this phase, the goal was:

- to obtain information concerning the day to day struggle with mildew
- to understand the functioning of the agro-alimentary potato system
- and to examine all the existing possibilities and barriers for a more sustainable struggle against mildew

The second phase of interviews focused on actors representing the sectors that are (or could be) possible barriers towards the existing enounced solutions during phase one. These actors represented many sectors of the system (Table 7). The objectives of this second phase are (1) a validation to answer the following question: is the system described by these new actors the same as the one described by the actors of the first phase? A prospective discussion on all the possible barriers brought up during the first phase.

Possible future scenarios have been discussed with the interviewees. They show potential scenarios to fight mildew in a more sustainable manner. Nevertheless, the existing barriers pointed by the actors demonstrate the difficulty of the application of these solutions.

The scheme representing the used methodology during this thesis is available in part two, Figure 7.

2. Coherence of the used methodology

During this thesis, a systemic analysis was applied to tackle the mildew issue. The necessary material was collected through semi-directed interviews.

2.1. The strengths and weaknesses of semi-directed interviews

The use of semi-directed interviews implies that the following analysis is not quantity-based but quality-based (Blanchet, 2007; Kaufmann, 2011). As Blanchet (2007) explains: 'S*ole information given during an interview can have a weight equivalent to information repeated many times during the study'*. The number of needed interviews is thus a lot smaller than when working with a survey (Blanchet, 2007). Semi-directed interviews give access to very rich information that has to be processed by the student. Blanchet (2007) explains that the analysis of the collected material can be done following various methods. During this thesis, an analysis relying on the various themes was made. Finally, the collected material was scanned in a very subjective manner (Kaufmann, 2011)

The fact that the student is totally exterior to the studied system gives him two big advantages

First, the vision of the student is not influenced by a previous background. He can seize the system in its whole, which is not possible for an actor of the system itself. For instance, if a farmer were to make the same analysis, he would implicitly give more importance to factors that he knows and considers more interesting, while putting aside other aspects. The exterior vision of the student thus gives an important added value to the obtained analysis. Secondly, the student being exterior to the system, the interviewees trust him more during the dialogues. Indeed, the interviewees feel like the student is interested in their explanations, that they possess valuable information. They easily confess their fears, ambitions, needs… because they know the searcher is there to listen, and that he won't make any judgment. This situation gives the student great access to vital information (Kaufmann, 2011).

2.2. The systemic analysis and meeting of actors

The systemic analysis and meeting of actors of all sectors of the system are of crucial importance to understand the complexity of the system. The Belgian potato system is complex due to the important number of types of actors and relationships between these actors. A systemic analysis thus seems like a suitable method to apprehend the system (and its complexity) in its whole. It is by confronting answers of different actors to the asked questions that a valuable and really interesting analysis was made. This broad analysis allowed understanding the lock-in at different levels of the system. It was not only directed at more agricultural and technical questions but also took into account the social, economic and political aspects. Indeed, the objective of sustainable pest management in the case of the potato mildew does not rely just on the agronomic aspect of the issue, but on the sustainability of the system in its whole.

2.3. The snowball sampling

The application of a snowball sampling during the thesis was privileged compared to a randomized sampling. By using this method, the meeting of key actors (n=3) possessing a holistic vision of the system allowed obtaining a substantial list of farmers, researchers, industrials and other types of actors. This significant database allowed selecting the actors that seemed of greater interest because of the firm, research center, or agricultural paradigm they belong to or because of their location (in case of farmers) in the country. Finally, a total of twenty-two actors were selected.

The snowball sampling also allowed getting more easily in contact with actors, because there was an existing link between the student and an acquaintance of the actor. The number of met actors seemed adequate once the 'saturation point' was reached[37].

2.4. The chosen scale of the study

This study focuses on the Belgian potato system. This implies that the geographical scale of the study was restricted to the Belgian borders. Originally, it was suggested to expose eventual differences between the potato systems in Flanders and Wallonia, but, as explained in the methodology, actors explained that both these regions seemed quite symmetric and strongly interconnected.

The chosen scale of the study seems legit, most of all because the analyzed potato system functions at this exact same scale. For instance, in Belgium, the markets function at a national level with unique price quotes that concern both regions. The varietal situation in Belgium is also quite different from the neighboring countries. Added to this, actors explained that the importance of the late blight issue in Belgium is different than it is in the Netherlands for example. This is explained by various factors that completely change the issue (like for instance the cultivar choice (Bintje) or other potato-linked problematic like nematodes).

2.5. The limits of the used methodology

The used methodology faces limits concerning the interpretation of the obtained results. First, the number of interviewees is limited to a small group of actors. This is mostly due to the quantity of content that has to be processed but also due to the 'saturation point' concerning the obtained information. This also implies that various types of actors (like the industrial sector, distribution sector, retail…) are represented by a single interviewee. Unlike for organic and conventional farmers, the information coming from these actors could not be contrasted with similar actors. Secondly, the restricted number of interviews did not allow getting in touch with all types of actors of the system. For instance, actors of NGOs, organic platforms, syndicates… have not been met. Finally, the interviews were based on an interview guide (see Annex 3) that helped to structure the discussion. However, during the interviews, secondary, more in-depth questions were addressed and new elements, brought up by the actors, emerged. During the analysis of the interviews, it seemed that some of these elements that were addressed by a minority of actors were quite important but could not be contrasted with other point of views.

In conclusion, the use of a systemic analysis based on semi-directed interviews to evaluate the installation of possible alternatives to fight mildew in a more sustainable manner thus seems legit for this thesis. The application of a snowball sampling allowed the selection of actors that were of major interest for the study whereas the chosen scale of the study is also coherent with the scale of the potato system and the mildew issue. Nevertheless, limits concerning the collect of information exist because of the restricted number of actors and lack of contrasting information for several types of actors.

[37] As Kaufman (2011) and Blanchet (2007) indicate, the 'saturation point' is reached when meeting a new actor does not bring new information to the previously collected material.

3. Sustainability hindered by the existing lock-in

The examination of the literature and the actors alike revealed that even though Bintje and other commercialized varieties are subject to an extensive use in Belgium, they are also very susceptible concerning mildew. The existing barriers that explain the low level of adoption of late blight high-resistant cultivars and other non-chemical methods of controlling late blight in Belgium have been discussed with the actors.

It seems clear that the use of (multi-)resistant cultivars of the potato and a growing reliance on IPM methods would allow a significant reduction in the use of fungicides (Speiser et al., 2006). The benefits that could be obtained by the farmer (economic benefit due to reduced costs of fungicides and fuel due to a reduced need of application and benefit in service because less time being devoted to spraying and control) are very important, not to mention the benefits to society (Vanloqueren and Baret, 2008), yet a change is not taking place. It seems that there is an existing lock-in concerning the use of fungicides, given the current variety demands emanating from the market.

3.1. The lock-in exists at different levels

In part one, the existence of path dependence and lock-in processes has been shown to exist in the realm of agriculture by Cowan and Gunby (1996). Cowan and Gunby have shown the impediments to a switch from the historical use of chemical pesticides towards integrated pest management (IPM) strategies: uncertainty, coordination problems, technology immaturity, inflexibility, technology inertia and path-dependence. If the presence of a few negative factors is not a barrier in itself, the build-up of numerous negative factors creates a lock-in situation. In this specific case, chemical pest management has made possible the installation of the mildew-sensitive commercialized cultivars, which currently represent a lock-in within the Belgian potato system. This lock-in exists at different levels.

First, the actors and the literature both indicate that the **market forces** are an important barrier for the installation of resistant cultivars. As a matter of fact, the actors have pointed out that essential commercial traits are not satisfied by more resistant varieties, which thus have a great difficulty to impose themselves in the system. According to the actors, this is the case for example for the Sarpo Mira and Bionica varieties.

Furthermore, the **currently used fungicides to control mildew are rather efficient**. This means that the commercialized varieties can continue being cropped and that there is no crucial need for alternative pest management methods. In their example, Cowan and Gunby (1996) have shown that the installation of IPM methods often took place when the switch proved really necessary. This is the case for instance when fungicides do not suffice to control the pathogen, because of the emergence of resistance in the pathogen population. The use of fungicides is also subject to a **positive feedback**. As a matter of fact, the actors and the literature alike reveal that fungicides benefit from important research efforts and have become more efficient through time, thus reinforcing their legitimacy in the system.

Next to this, **technology inertia** is one of the factors impeding a switch in the system. The scientific literature (Haverkort et al., 2008, 2009; VIB n.d.) as well as the interviewees pointed out that traditional breeding programs have been working for many years in order to create resistant cultivars. Unfortunately, this technology has not significantly improved over the same time period, rendering this research long and tedious. Moreover, according to the actors, the obtained varieties like Sarpo Mira, Bionica and Toluca may well be more resistant to mildew but they do not meet the required commercial aspects. This state of affairs questions the strategy whereby new varieties are created by traditional means to satisfy commercial needs that are left unchanged.

Technology immaturity has also been observed. This factor was noticed by the interviewees and demonstrated in the used literature in several ways. Element that are characterized by technology immaturity are for instance biological control and the use of biocides. The review of literature shows they are still at a very early stage of development and have yet to be fully explored (Axel et al., 2012).

Inflexibility has also been discussed with the various actors. For instance, farmers explained that they cannot allow themselves to attempt various techniques concerning the control of late blight because of two factors. First, they do not want to lose their harvest, so as to guarantee their financial income, and secondly, a failed attempt to control late blight means the farmer will infect the neighboring farms. This inflexibility is exacerbated by the fact that farmers are not ready to rely on various control methods because there remains a high level of **uncertainty** concerning their efficiency. Inflexibility has also been observed for the industrial sector, where there is a lock-in concerning the used transformation process. The distribution sector is also characterized by inflexibility that is mostly due to the (assumed) market demands.

These various factors, which have been observed in the context of this thesis, confirm that there is an existing lock-in concerning the use of fungicides and mildew-susceptible varieties.

3.2. Change is not totally hindered by the existence of this lock-in

Although a lock-in situation is by definition associated with a high level of inertia, lock-in situations are seldom completely locked. In other words, exogenous forces and various actions can operate so as to exit the existing lock-in (Cowan and Gunby 1996; Vanloqueren and Baret, 2008). As explained by Vanloqueren and Baret (2008), naming the lock-in is the first step necessary for change: '*Naming the lock-in helps us understand that specific actions must be undertaken to get out of this static or very slowly changing situation'*. The present thesis suggests that there is an existing lock-in concerning the current commercialized potato varieties and fungicide use in the Belgian potato system. In line with Vanloqueren and Baret, naming this lock-in constitutes a first step for a transition towards a more sustainable management of late blight. The following section highlights concrete factors that could be worked on in order to disrupt the lock-in and instigate change towards sustainability.

4. The transition to sustainability

4.1. The introduction of resistant varieties

The most-often discussed alternative towards a more sustainable control of mildew is the use of resistant potato cultivars. According to the actors, the low adoption of resistant cultivars was mostly due to a lack of important characteristics such as culinary aspects (quality, taste, dry matter content, esthetic, skin and flesh color,…), transformation aspects (homogeneity, specifically required traits,…) and economic aspects. This is confirmed by the literature (Speiser et al., 2006), that explains that minimum characteristics are needed for the installation of resistant varieties. The various criteria for the choice of variety have been exposed at Table 9 and the many barriers impeding the instalment of a more resistant variety have been illustrated at Table 10.

Both the scientific literature and the actors confirm that there are two main strategies on this front: the adoption of resistant cultivars and the creation of new resistant cultivars. In both cases, the consumers are seen as major barriers. The current standards of consumption are invoked in order to justify the fact that either existing or newly-bred resistant varieties would be difficult to adopt. Similarly, consumers are believed to be highly reluctant to any GMOs.

For GMOs, the literature indicates that, in Europe, all GM organisms are technically and legally considered as transgenic organisms. This means that no distinction is being made between intra-specific (cisgenesis) and inter-specific transgenesis by the authorities. As a result, GM resistant potatoes, created through cisgenesis, are technically and legally considered as transgenic organisms. This may partly account for the fact that, although this distinction is made in the scientific world, consumers also consider GM potatoes as 'transgenic organisms'.

To change this posture, both the literature and the actors show that pro-GMO actors (that are mostly Flemish research groups like the VIB, ILVO, UGent…) would first like to bring out the concept of cisgenic potato so as to bypass the opposition transgenic potatoes (and GMOs in general) encountered in Europe. These actors believe the concept of cisgenesis will facilitate the acceptance by consumers of these new varieties. In order to do so, one actor even called this a 'plant to plant' method (see part three, section 2.3.3). As a matter of fact, the literature confirmed that, for pro-GMO actors, a new legislation distinguishing cisgenic and transgenic organisms was strongly expected (Haverkort et al., 2008; 2009; Schouten, Krens, and Jacobsen, 2006). In order to secure support from the farmers, one strategy consists in getting away from any form of royalties associated with the adoption of GMOs. As has been mentioned earlier by one of the actors of the retail sector (see part three, section 2), a collaboration of Belgapom, ILVO, UGent, VIB, and the Boerenbond is wanting to conduct a research program that strives for the creation of a GM 'Bintje +1 and Bintje +2' that would free of any royalties.

Turning to the adoption of resistant (and newly-bred) varieties, the collected data designate the consumers as being a major barrier. This is a very important message because it suggests that the actors consider that they have little room for change due to a single major exogenous actor. A small portion of the actors also point to the distribution and transformation sectors as being the source of the problem. Added to this, the interviewees also showed that the transformation sector has the most decision power concerning the varietal choice (through contracts with the farmers) inside the system. When analyzing the vision of these two actors, they mention the current habits of consumers as their justification for their resistance to change. From our point of view, this indicates that the actors weighing the most in the system are not willing to make a trade-off between the economic factors and the sustainability of the production system.

4.1.1. Perspectives for the introduction of resistant varieties

Because of the fact that consumers are seen as inflexible actors, largely exterior to the system, it would seem appropriate to integrate them into the system in order to change this situation. As has been indicated by various interviewees and shown in the literature, the consumers do not know which varieties they buy and have hardly any idea of the existing mildew problematic. By informing, sensitizing, and empowering the consumers, a new pressure could be exerted on the production system, offering possibilities to valorize more resistant varieties and to promote more sustainable production methods in the market. Examples illustrating the effectiveness of such a strategy in other areas are the 'rainforest alliance' certifications that sensitize the consumers' importance of local producers in the food production chain, or the organization of short circuits that are initiated between farmers and consumers. It seems thus crucial to give a more important role to the consumers in order to achieve change.

4.2. Reasoned use of fungicides

During the interviews, the various actors have discussed methods so as to reduce their use of fungicides (see part three, section 2). Added to this, the actors of the plant protection sector have also indicated that the stringent frame to which they are confronted makes it difficult to conduct research for smaller firms (see part three, section 2). On top of a series of behaviors and techniques that can be encouraged to use fungicides in a more adequate and more limited way, the review of the literature reveals that a more reasoned use of fungicides is best promoted by mechanisms that are implemented at a regulatory level. As has been discussed in part one, the regulatory frame has become more and more stringent through time, ensuring a reduction in pesticide use. As it happens, the IPM directive is obligatory since 1 January 2014 and imposes professional fungicide users to apply IPM methods in order to reduce their use of fungicides.

Various actors explained that tighter pesticide regulations would have a strong impact on the current production chain. Indeed, these actors mentioned that the cultivation of current commercialized varieties like Bintje might become impossible without the use of fungicides (see part three, section 2), meaning the implementation of alternative mildew-control methods would become essential. Several examples of the implementation of strict environmental regulations exist. This has been the case for the reduction of carbon dioxide emissions through the Kyoto protocol or for the ban of DDT use in agriculture.

4.2.1. Perspectives concerning the reasoned use of fungicides

The implementation of tighter pesticide regulations will always be imposed by the authorities (at a European, national, or regional level). This means that, in this specific case, exogenous forces are used so as to unlock the current situation and ensure the transition towards a more sustainable system.

Just as for the promotion of resistant varieties, the consumer can have an impact on the actors of the system so as to make them change their habits concerning the use of fungicides. As has been explained before, the transformation sector is the actor with the most decision power concerning the choice of the cropped varieties. If consumers become more demanding concerning the environmental aspects of the potato production, this actor will have to adapt.

4.3. The capitalization on the organic sector

The analysis of the interviews reveals an interesting aspect concerning the organic sector. Indeed, the more actors were met, the more it appeared that the organic potato sector was poorly known. First, it has been shown throughout part three that the majority of actors knew very little of the aspects of organic farming. In fact, they reduce the organic sector to a conventional farming system that uses copper fungicides. Knowledge of late blight management techniques used in the organic sector is very limited if not entirely absent. As for the actors of the industrial sector, the distribution sector, and the retail sector, they have discussed the organic sector, but only in economic terms. Finally, the actors of the research sector explained that the organic system in its whole is growing, but not well organized (see part three, section 1.3).

4.3.1. A neglected sector that is in full expansion

Although the organic sector in Belgium remains small, the review of literature has shown that it grows rapidly (see part one, section 2.1.4.). Organic farmers knew that they were quite marginal. According to one organic farmer, this is because the outlet was not always secured and that prices fluctuate a lot from year to year (see part three, section 1.3). At the same time, the organic potato farmers also mentioned that the distribution sector gives more and more importance to organic products, offering market space in shops for local producers (see part three, section 1.3.).

4.3.2. The organic sector is more susceptible to mildew

Literature and actors have shown that controlling mildew in organic farming systems remains quite difficult because of the sole use of copper as fungicide (Speiser et al., 2006; Tamm et al., 2004). Since 2006, the use of copper-based fungicides within the EU is limited to 6 kg of the elemental copper per ha per year (Axel et al., 2012).

Consequences of mildew on organic potato crops are more important than on conventional plots. This is confirmed by conventional farmers but also by organic farmers (see part three, section 1.3.). Organic farmers said they clearly knew that they were more exposed to the effects of mildew and that controlling it was not always possible. An example was given through the regulations of markets during the results. An organic farmer explained that it was indeed mildew that regulated market prices of the organic sector (see part three, section 1.4.).

4.3.3. The organic sector is more inclined to the use of knowledge intensive control methods than the conventional sector

The literature shows that the fragility of the organic sector concerning mildew is exactly the reason why various types of management additional to copper are applied and have to be found in order to control mildew (Axel et al., 2012; Speiser et al., 2006). This means that the organic sector is much more open to IPM techniques (that are knowledge-intensive) and resistant varieties that have been presented (Perez and Forbes, 2010; Speiser et al., 2006). The interviews with organic farmers showed that this was a reality on the field. It has been shown throughout part three of the thesis that they were more accepting towards soil management techniques, towards the selection of more resistant cultivars, and finally towards the rotation that they used on their lands.

4.3.4. A double transfer from the conventional to organic sector

Because of the above aspects, a potential growth of the organic sector implies the control of a double flow from the organic to the conventional sector: a flow of knowledge and a flow of mildew inoculum.

On the one hand, a researcher explained (see part two, section 1.3) there is knowledge flow from the organic to the conventional sector. IPM methods can indeed be transferred from the organic sector in order to be adopted by conventional farmers so as to reduce the impact of mildew by the use of these techniques. This knowledge transfer is already happening today (for the least in Wallonia), as stated by Di Antonio (2012): 'G*iven the mandatory European IPM directive, agronomic warnings are the major information and framing tool… their evolution towards a farm-scaled, or even plot-scaled reasoning are essential. They have to be supported by the public authorities and the professional sector. Concrete propositions concerning rotation, obligatory subscription and legislation against mildew inoculums have been formulated at the Walloon Region… Innovation is essential so as to use fewer fungicides in order to manage pathogens. Various research programs on alternative methods are conducted in Wallonia, namely on ideas coming from the organic sector.*'

On the other hand, the susceptibility to mildew of the organic sector means the organic potato plots represent possible inoculums. The areal growth of the organic sector thus implies an increase of potential mildew inoculums that could become difficult to accept for the conventional sector.

4.3.5. Perspectives for the capitalization on the organic sector

In order to organize the knowledge flow from the organic sector to the conventional sector, it is crucial that the farmers of these two sectors, who still appear quite estranged, start collaborating. Added to this, the authorities and actors of the R&D sector can also play a major role in the creation and exchange of knowledge. As a matter of fact, during the interviews the farmers explained that the research groups such as FIWAP, CARAH, PCA, CRA-w… should be more driven towards the dissemination of techniques and knowledge. Concerning the authorities, as stated in the above sub-section, they are essential to the implementation of coordination programs and the funding of public research.

5. Feasibility and temporality

The feasibility and temporality of the three alternatives for a transition towards sustainability differ.

In first instance, the adoption of more resistant cultivars will depend on two major aspects. First, the adoption of GM potatoes is not yet accepted by public opinion. The efforts coming from the pro-GMO actors and the change in a political stance might bring about a turn that is crucial for the use of GM potatoes in the near future. Secondly, from our perspective, a meaningful installation of resistant varieties will only take place if the most important actors of the system are ready to make a trade-off between quality and resistance. This could be achieved by empowering and integrating the consumers inside the system, so as to create a new pressure group.

Secondly, the feasibility and temporality of the implementation of tighter pesticide regulations will mostly depend on the political will of the acting authorities. For now, it seems impossible to fully eradicate the use of fungicides in modern agriculture, but great efforts are already being done. The temporality of such implementation has to be studied at a certain time span because the system has to adapt to future demands. From our point of view, this process will be rather slow face substantial resistance from the whole system.

Finally, concerning the capitalization on the organic sector, the transfer of IPM methods coming from the organic sector to the conventional sector is already feasible today. The organic sector is not as dependent on breakthrough innovations (new resistant cultivar) as the conventional sector, since it relies more strongly on a set of various IPM techniques that exist. Next to this, the future success of the organic sector still has to be evaluated. If the growth rate continues as it has during the last decade (of 10% a year), the total area destined to the organic potato crop could represent about 1000 ha in 2025. If we consider that the actual potato system is at a saturation point[38] , this could mean the organic sector will represent a growing portion of the Belgian potato sector. From our point of view, this means the organic sector needs to be taken much more into consideration so as to fit as well as possible in the future potato system. Concerning the knowledge flow, Di Antonio (2012) shows it has already started.

In conclusion, the feasibility and temporality of the three proposed options appear to be quite different. In our opinion, this difference could be an interesting asset so as to ensure their implementation. For instance, the knowledge flow between sectors is something that could be implemented quite rapidly, whereas the empowerment of the consumers and the installation of tighter pesticide regulations have to be evaluated on a larger time span. This means that the system is not changed radically but evolves at an acceptable pace, allowing actor to adapt.

[38] It has been shown in part one that the cropped area has stabilized between 2010 and 2014

6. Perspectives

After having analyzed the possible transitions towards sustainability, it seems that many actors of the system each have a role in order to solve the issue. A quick review of the possible actions that could be operated by the various actors is now given.

Farmers and seedling growers *are at the beginning of the production chain. Collaboration between these actors (and especially between organic and conventional farmers) is essential in order to share their knowledge on mildew management methods with research groups and other farmers. They can also guarantee the creation of short circuits in order to sensitize the consumers to the mildew issue.*

The public ***R&D*** *sector has a major role in the research of new technologies but also in the dissemination of IPM methods. Research fields like the creation of GMOs, traditional varietal selection, the study of mildew strains, the impacts and applicability of IPM methods, etc. have to be fully explored by this sector.*

The ***distribution sector*** *is the closest one to the consumers. The role of this sector seems thus essential for the promotion of more resistant cultivars through marketing actions.*

The ***transformation sector*** *is a major actor in the selection of varieties through contracts with the farmers. This sector could improve its image by making the use of more resistant cultivars a marketing asset (even at an international scale).*

The ***retail sector*** *can have a crucial role in the expansion of the organic sector. As has been explained during the thesis, the Belgian organic sector is not valorized enough at a local scale by the retail sector. Imports have to be stopped, so as to favor a local production and consumption.*

The ***plant protection sector*** *can strongly impact the way mildew will be managed in the future. First, this sector has to ensure the obtainment of adequate fungicides until other methods are fully operational. These fungicides have to become even more efficient, and more eco-friendly. Next to this, research concerning biocides should be fully investigated. Finally, varietal selection has to be fully explored (as it seems these firms have already started doing). For firms like TMCE, it is important that they can verify and prove scientifically the benefits of their products on soil life and indirectly on plant fitness.*

The authorities *have a crucial role in the struggle against late blight. The actions that can be led by this actor are numerous. For instance, they can put up sensitization programs and educational campaigns so as to inform the consumers, who know nothing of the issue. This can also be done in the case of GMOs if the authorities decide to allow importance to this solution. Next to this, the authorities also have a clear role in the allowance of funding for public research, market development, and promotion of the organic sector. The actual stance towards the organic sector in Flanders and Wallonia should be persevered. Next to this, the authorities also decide on the regulatory frame concerning the use of fungicides.*

Finally, the consumers *have to be fully implicated in the problematic in order to assure a change. The creation of short circuits of consumption, the pressure on several actors such as the transformation sector and the creation of eco-labels are some examples of actions that could be pursued. The actions of the consumers will mostly be effective on the fresh market, which represents around 10% of the total market.*

Ideally, all of the actors of the Belgian potato sector should strive together to achieve this same goal of sustainability. This could be done for instance by creating a whole-chain label, assuring the sustainability of the production chain from the field to the plate. The reduced use of fungicides could in this case become a major marketing asset. It appears the different actors of the Belgian potato system are already much interconnected, which is already an interesting point for this idea.

CONCLUSION

Conclusion

The present study has as goal to explore a series of alternatives that meet the requirement of rendering the management of potato late blight more sustainable in a near future.

This study shows that alternatives exist concerning the use of fungicides in order to manage potato late blight but, that in order to exit the existing lock-in currently characterizing the Belgian potato system, various actions need to be undertaken so as to modify the way the actors currently see their relations with the other actors and the options available to them.

By focusing on the implementation of a series of alternatives that meet the requirement of rendering the management of potato late blight more sustainable in a near future, the study reveals the complexity of the issue and confirms the existence of a lock-in. It suggests that three main strategies for the introduction of a positive change are available, namely the adoption and/or creation of resistant varieties, a more reasoned and better regulated use of fungicides, and the capitalization on IPM methods.

The majority of the actors identified the consumers and their preferences as the main obstacle for change. The fact that this so-called 'external' reason is given for the lock-in has direct consequences on the willingness of the actors 'inside' the system to modify the current situation. This means that consumers have to be included in the system, so as to weigh on the decision process and change the current posture of the actors inside the system. Turning to fungicides, the lock-in is maintained due to the efficiency and dependency of the current system on their use. A change at this level will be likely to take place if authorities more decisively enter the picture and change the regulations or if sensitized consumers succeed in changing the actors' habit concerning the broad adoption of the fungicide-dependent Bintje and 'Bintje-alike' varieties. Regarding the scaling-up of IPM methods, the organic sector can play a major role in the knowledge transfer process towards the conventional sector. This would however come along with a source of inoculum. For each of these various solutions, the feasibility and temporality differ and has to be taken into account so as to ensure a transition towards a more sustainable management of potato late blight.

To conclude, the systemic analysis that has been conducted during this study reveals that further investigation is needed concerning the implementation, feasibility, and temporality of the addressed alternatives so as to guarantee the transition towards a more sustainable management of late blight in the Belgian potato system.

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Annexes

Annexes

Annex 1: Complementary information concerning the Belgian potato sector

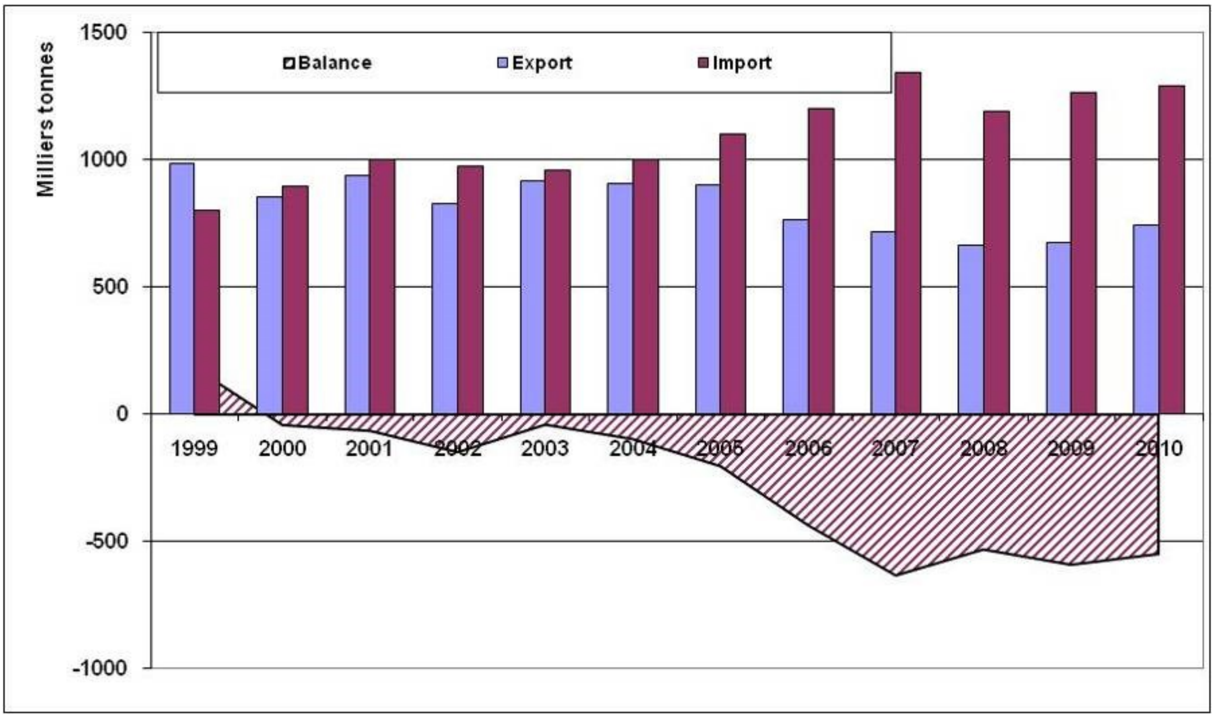

Figure 11 : Evolution of the balance between export and import of seedling potatoes in Belgium in thousands of tons (Lebrun, 2011)

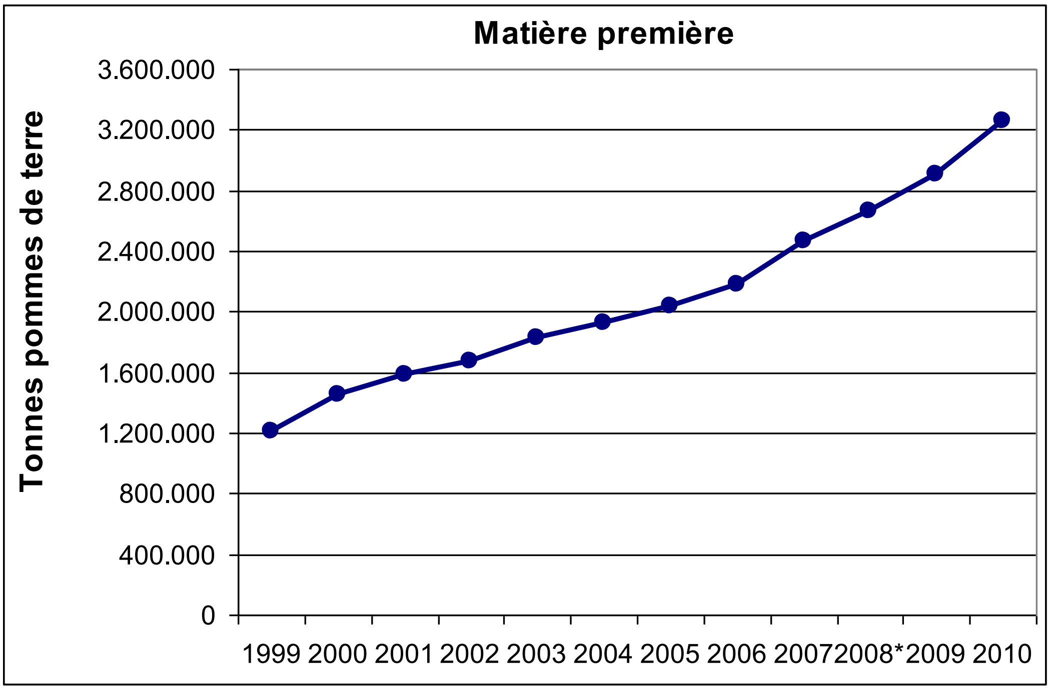

Figure 12 : Evolution of the production of prime resource potatoes for the transformation sector in Belgium from 1999 to 2010 (Y-axis : 'Tons of potato', Title: 'Prime resource')(Lebrun, 2011)

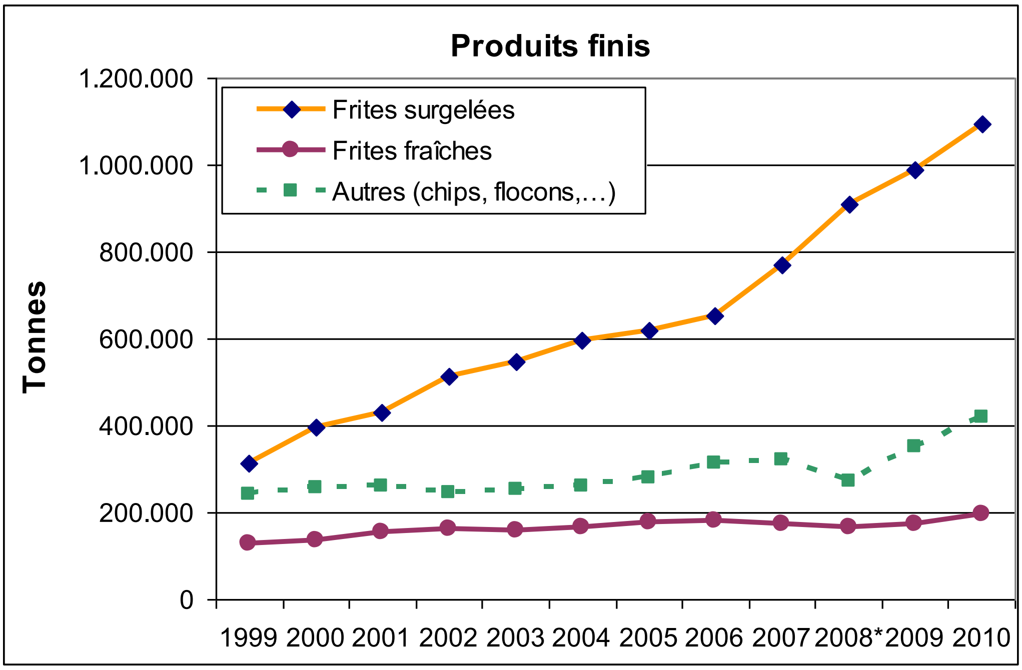

Figure 13 : Distribution of the outcome of the final products of the transformation sector from 1999 to 2010 in tons (Title: 'Finished product', Legend: 'Frozen fries', 'Fresh fries', 'Others (chips, flakes,…) (Lebrun, 2011)

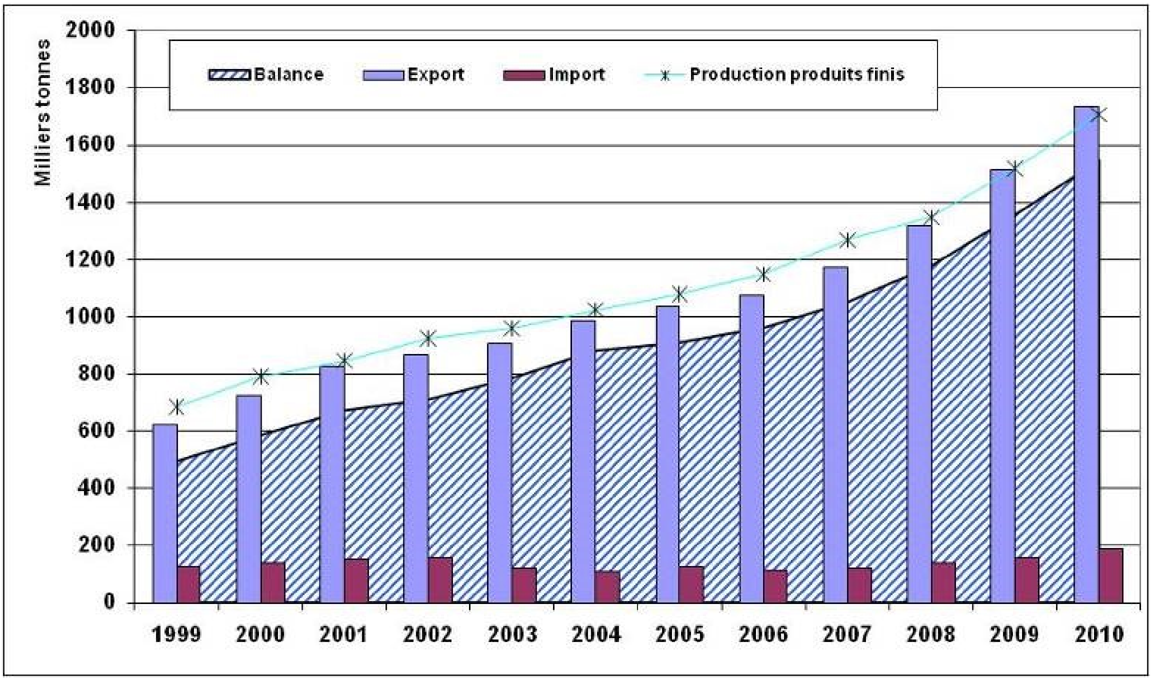

Figure 14 : Total exports of final transformed products in the Belgian potato sector from 1999 to 2010 in thousands of tons (Production produits finis = 'Production of finished products') (Lebrun, 2011)

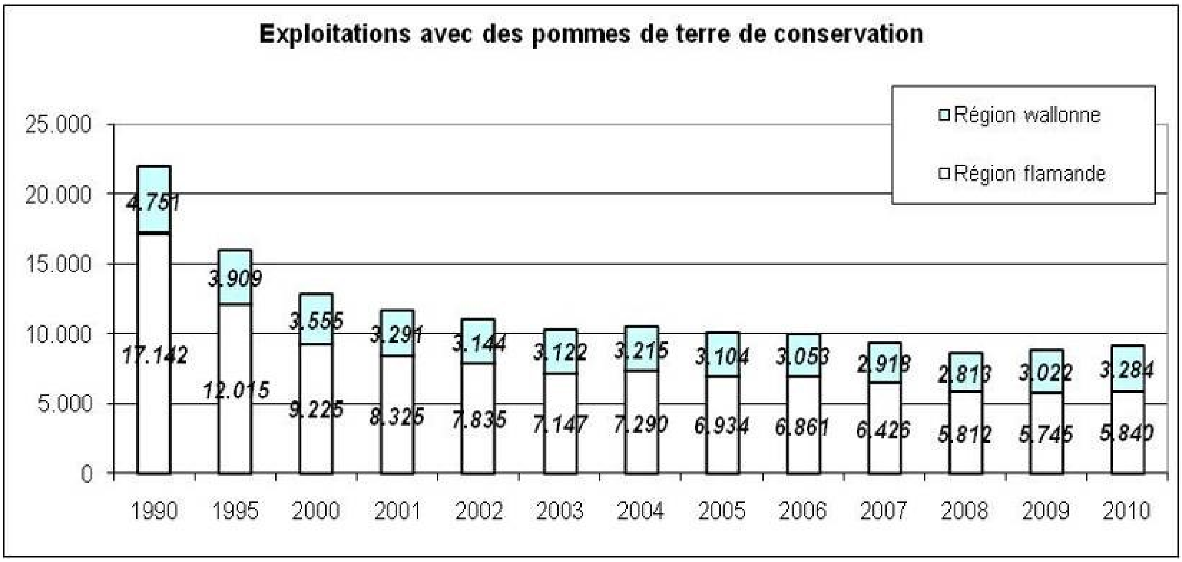

Figure 15 : 'Number of exploitations with conservation potatoes ('Walloon Region', 'Flemish region') (Lebrun, 2011). This graph shows there is a clear concentration of farms in the Belgian potato sector, meaning there are less and less farmers in the sector.

Table 13 : Proportion of producers according to the area destined for the potato crop and mean area per producer in 2010 (Lebrun, 2011).

	Surface (ha)	Nbre producteurs	Surface/prod (ha)
> 5 ha pdt	68.809 (85 %)	5.072 (45 %)	13,6
> 10 ha pdt	49.142 (60 %)	2.249 (20 %)	21,9
> 20 ha pdt	27.871 (34 %)	684 (6 %)	40,7

Table 14 : Representation of various varieties in the year 2013 based on telephone surveys made in april by the FIWAP, the PCA and Inagro on 170 farmers – Distribution of conservation varieties (De Blauwer and Florins n.d.)

Importance	Flandre	Wallonie
> 4,0%	Bintje (43%) Fontane (25%), Innovator (9%) Asterix (6%)	Bintje (50%) Innovator (15%), Challenger (7%), Fontane (6%)
1,0 - 4,0%	Felsina, VR808, Challenger, Agria, Markies	Lady Claire, Magnum, Hansa, Agria, Markies, Nicola, Victoria, Asterix
< 1,0%	Folva, Zorba, Ramos, Lady Olympia, Lady Rosetta, Artemis, Annabelle, Cilena, Santé, Victoria, Lady Claire, Nicola, Hansa, Charlotte, Miranda, Fribel, Daisy, Spirit	Artémis, Royal, Rumba, Lady Britta, VR 808, Trésor, Ramos, Felsina, Zorba, Crsip4all, Lady Rosetta, Saturna, Jaerla, Annabelle, Désirée, Léontine, Charlotte, Marabel, Ciléna, Exempla, Pépite

Annex 2: Complementary information concerning the Belgian organic potato sector

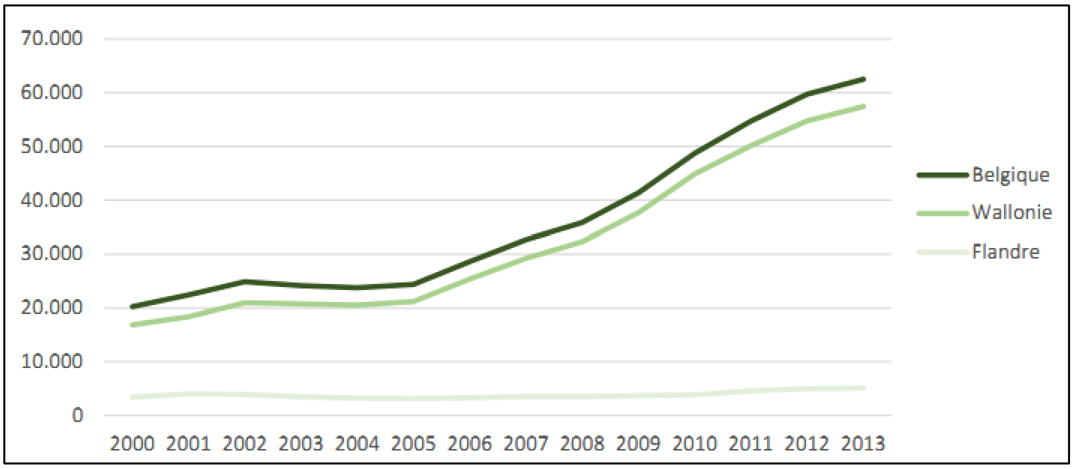

Figure 16 : Evolution of the area (in hectares) destined for organic farming in Belgium, Wallonia, and Flanders from 2000 to 2013 (BioWallonie, 2014)

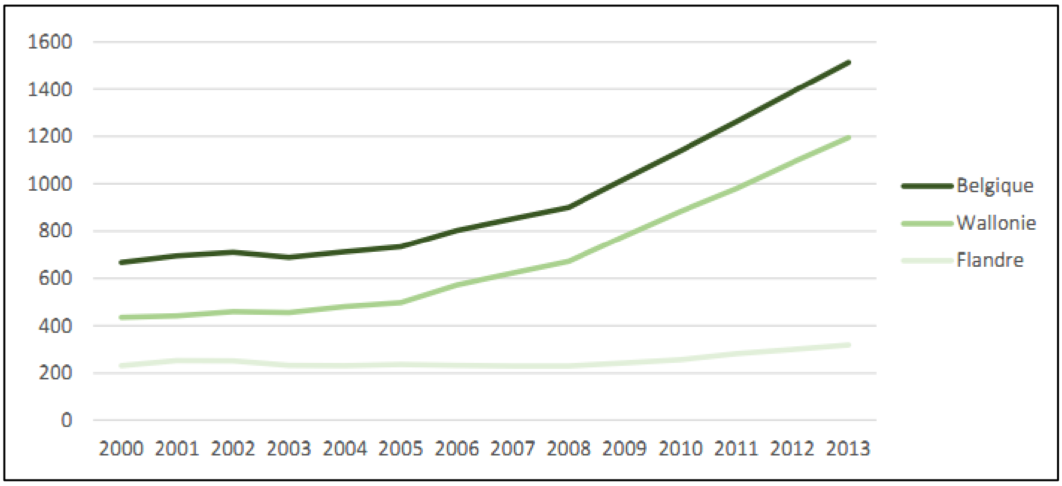

Figure 17 : Evolution of the number of producers of the organic sector in Belgium, Wallonia, an Flanders from 2000 to 2013 (BioWallonie, 2014)

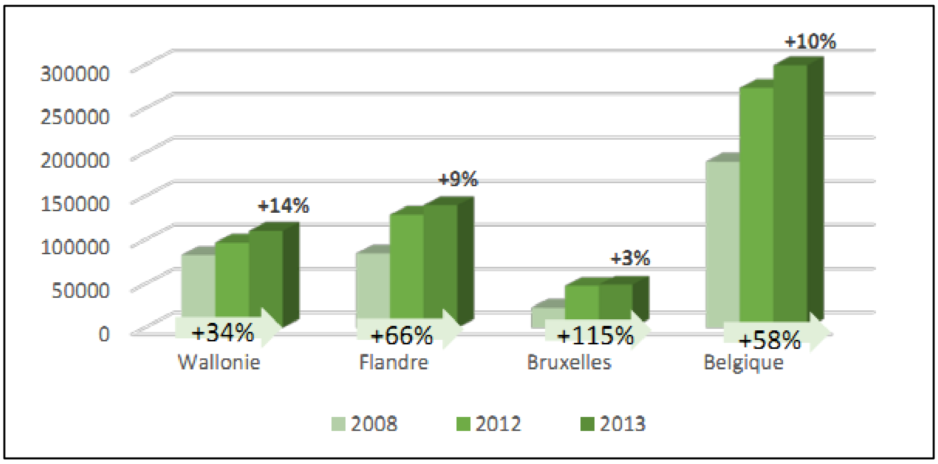

Figure 18 : Evolution of the household expenditure destined to organic products (fresh products and drinks) in thousands of € in Wallonia, Flanders, Brussels and Belgium from 2008 to 2013 (BioWallonie, 2014).

Annex 3: Interview guides

1. Interview guide phase one (farmer)

A) Why do I visit this actor?

The aim of this phase is to collect as much information as possible about the struggle against mildew and the day to day situation of the farmer concerning mildew. The alternatives to fungicides or applied techniques by the farmer should also be explored. This phase should also try to understand the actual situation by exploring the past evolution until today. Finally, the farmers should explain how they see the struggle against mildew in the near future. If alternatives for the use fungicides exist, the barriers impeding its installation should be discussed.

B) Questions

1) Explain the subject of my thesis and why I came to see him/her.

2) What is his/her position in the potato-mildew system? What does his/her organization do and what's its goal? (Learn more about the actor himself)
   - *For how long have you been cropping potato? Organic or not?*
   - *How many hectares of potato do you crop? What's your average production?*
   - *Do you sell on the fresh market or for the transformation sector? Why? Is there a difference?*
   - *Which varieties do you crop? Why? Did you choose to crop this variety?*
   - …

3) How does he struggle against mildew today and what are according to him the best manners to fight mildew in the near future? Try to understand which methods (s)he uses to control mildew.
   - *How many times a week do you apply fungicides? Did you apply less in the past?*
   - *What type of fungicides do you use? Are they the same as five years ago? Do you follow the mildew alert systems? How reliable are they?*
   - *Do you have any (mechanical) factor impacting your number of applications?*
   - *(If organic) How do you apply your copper doses? Did this change in the recent years? Do you rely more on resistant varieties?*

4) What are the various barriers that would impede a more sustainable way of struggle against mildew?
   - *Would you change your methods of struggle? Why (not)?*
   - *Who has the power to choose how the struggle is operated? How is this choice imposed? Does the farmer have anything to say, or a possibility to act against this (systemic) choice?*
   - *If a change has to come, which sectors will support it? Which won't?*

5) How does (s)he see the mildew-potato system in the near future ?

2. Interview guide phase one (researcher)

A) Why do I visit this actor?

The aim of this phase is to collect as much information as possible about the struggle against mildew and the day to day situation of the researcher concerning mildew. The alternatives to fungicides and various research programs by the research sector should also be explored. This phase should also try to understand the actual situation by exploring the past evolution until today in the research sector. Finally, the researchers should explain how they see the struggle against mildew in the near future. If alternatives for the use fungicides exist, the barriers impeding its installation should be discussed.

B) Questions

1) Explain the subject of my thesis and why I came to see him/her.

2) What is his/her position in the potato-mildew system? What does his/her organization do and what's its goal? (Learn more about the actor himself)
   - *How was your organization implied in the potato-mildew system and what is its role today ?*
   - *What is your specific research domain?*
   - *What is your link with the farmers and other sectors of the potato system?*

3) What is according to him/her the best way to fight mildew today and in the near future? Try to find out what (s)he knows about the struggle against mildew and how his/her research is implicated.
   - *How does your research help in the struggle against mildew? What is its potential in the coming years? Has this reseach branch already delivered concluding results?*
   - *Is mildew different than twenty years ago? How did your research adapt to this?*
   - *Do you see any change in the struggle against mildew and the whole potato system during the last few years?*

4) What are according to him/her the differnt barriers impeding the installation of a more sustainable struggle against mildew (that (s)he indicated?
   - *Would you change the actual manner of fighting mildew? Why (not)?*
   - *Who choses? How is this choice of struggle imposed? Does the farmer have any power to change things? If a change has to be operated, which sector would be of utter importance? How would the research sector adapt?*

5) How does (s)he see the potato-mildew system in the near future ?

3. Interview guide phase two

A) Why do I visit this actor?

The aim of this second phase is to apply a validation phase of what was said during phase one. It also needs to continue investigating why the encountered barriers exist. The answers must not be induced but should be passed in review as to have an opinion of every actor on this method. It is best to avoid a listing of solutions.

B) Questions

1) Explain the subject of the thesis and why I came to see him/her

2) What is his/her position in the potato-mildew system? What does his/her organization do and what's its goal? (Learn more about the actor himself)
    - *What do you do? For how long have you been doing this? Has there been a change?*
    - *With which sector do you have the most interactions?*

3) How does (s)he know about the struggle against mildew now, and what are the best options to fight mildew in the near future ? What are the most probable options ?
    - *Do you know how mildew is controlled today?*
    - *Does your organization/group care about this struggle?*
    - *How does/could your organization/sector contribute to this struggle?*

4) What are according to him/her the various barriers that impede the installation of more sustainable ways of struggle against mildew (that (s)he indicated earlier)?
    - *Who has the most to say? How is this choice of struggle imposed? Does the farmer have any power to change things? If a change is to be operated, which sector will enhance it?*
    - *If we would apply what you proposed, how would the change process happen?*

5) Run through the various options of struggle that (s)he hasn't talked about and try to understand why (s)he hasn't talked about it. Try to obtain a general meaning about all the known control methods and the relationship with the actor's organization/sector.
    - *Varieties (with GMOs)*
    - *IPM practices (rotation, irrigation, controlling mildew favorable conditions…)*
    - *Reduction of applied fungicide doses (better fungicides or application methods)*
    - *Stimulation of soil life*
    - *Etc…*

Annex 4: Chronological events

- **13000 B.C.** : Age of the first fossil potatoes found in Chili (Ugent, Dillehay, and Ramirez, 1987)
- **8000 B.C.** : Age of fossil potatoes found in Peru (Ugent and Peterson, 1988)
- **7000 B.C.**: Domestication of the potato in Bolivia (CIP, 2008)
- **1532 A.D.** : The Spanish conquistador discover the potato, that is part of the Inca staple diet (Hawkes and Francisco-Ortega, 1993)
- **Mid-16th century** : The potato is imported by the Spanish to Europe (Hawkes and Francisco-Ortega, 1993)
- **1650 A.D.** : The potato is a field crop in occidental Flanders (Morineau, 1970)
- **1753 A.D.** : Linné gives the name *Solanum tuberosum* to the potato in his '*Species plantarum*' (Rousselle, Robert, and Crosnier, 1996)
- **1843 A.D. :** On the East coast of the U.S.A, potato crops are strongly hit by the mildew illness (Semal, 1995)
- **1844 A.D.** : First signals of mildew in Belgium and England (Semal, 1995)
- **1845 A.D.** : Mildew hits Northern Europe and causes enormous production losses (-87% in Belgium, -71% in the Netherlands) (Vanhaute, Paping, and Ó Gráda, 2006)
- **1845 A.D.:** The Belgian mycologist Marie-Anne Libert is the first one to describe the pathogen of mildew and calls it *Botrytis vastatrix*. (Semal, 1995)
- **1846 – 1851 A.D.** : the Great Irish Famine (Semal, 1995)
- **1861 A.D.** : Anton de Bary, German microbiologist, describes the biological cycle of the mildew pathogen and calls it *Phytophthora infestans* (Semal, 1995)
- **1883 A.D.** : Alexis Millardet invents the 'bouillie bordelaise' to fight late blight (first used on the vine) (Roudié, 1994)
- **1904 A.D.** : Creation of the 'Bintje' variety (Stevenson, 1966)
- **1910 A.D.** : Discovery in Scotland of a resistant variety to mildew (*Solanum demissum)* (Frederick, 1995)
- **1981 A.D.**: A new strain of *P. infestans* coming from Mexico appears in England. It spreads through the whole of Europe and finally the whole globe (Semal, 1995)
- **1988 A.D.** : First genetic map of the potato (Bonierbale, Plaisted, and Tanksley, 1988)
- **1991 A.D.** : Introduction of the European Directive 91/414/EC that has a juridical impact on the quantity and type of fungicides allowed to control mildew (Phytofar, 2010)
- **1995 A.D.** : Commercialization of the GM-potato 'Newleaf', resistant to doryphore (created by Monsanto) in the USA (Duncan et al., 2002)
- **2013 A.D.** : Cancellation of the authorization demand of BASF crop science towards the EU for the insertion on the market of the mildew-resistant transgenic variety 'Fortuna' (Le Monde, 2013)

Systemic analysis of the mildew issue in the Belgian potato system
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Résumé Potato late blight caused by the oomycete *Phtyophthora infestans* (Mont.) de Bary may be the best known, longest studied and still amongst the most destructive of all plant diseases. Today, late blight is mostly controlled by the preventive use of fungicides, which has serious ecological consequences. As resistance against these fungicides increases in *P. infestans* populations, the number of necessary applications to fight the plague grows over time, reinforcing these ecological effects. At the same time, public opinion and societal pressure creates an additional pressure on the production system and the European agricultural policies tend to reduce the use of fungicides and pesticides.

Our objective is to explore a series of alternatives that meet the requirement of rendering the management of potato late blight more sustainable in a near future. The study relies on a systemic and qualitative approach, based on twenty-two semi-directed interviews with various types of actors of the system. The emphasis is on the point of view of the actors with respect to current and future management of potato late blight in the Belgian potato system. The collected data provide a clear view of the different ways of struggle that the actors know and/or use against late blight and offer a critical comparison of their different visions regarding the solutions to the issue and the barriers that prevent their implementation.

The study reveals the complexity of the issue and confirms the existence of a lock-in. It suggests that three main strategies for the introduction of a positive change are available, namely the adoption and/or creation of resistant varieties, a more reasoned and better regulated use of fungicides, and the capitalization on IPM methods. The majority of the actors identified the consumers and their preferences as the main obstacle for change. The fact that this so-called ‘external’ reason is given for the lock-in has direct consequences on the willingness of the actors ‘inside’ the system to modify the current situation. This means that consumers have to be included in the system, so as to weigh on the decision process and change the current posture of the actors inside the system. Turning to fungicides, the lock-in is maintained due to the efficiency and dependency of the current system on their use. A change at this level will be likely to take place if authorities more decisively enter the picture and change the regulations or if sensitized consumers succeed in changing the actors’ habit concerning the broad adoption of the fungicide-dependent Bintje and ‘Bintje-alike’ varieties. Regarding the scaling-up of IPM methods, the organic sector can play a major role in the knowledge transfer process towards the conventional sector. This would however come along with a source of inoculum. For each of these various solutions, the feasibility and temporality differ and has to be taken into account so as to ensure a transition towards a more sustainable management of potato late blight.

In conclusion, this study shows that alternatives exist concerning the use of fungicides in order to manage potato late blight but, that in order to exit the existing lock-in currently characterizing the Belgian potato system, various actions need to be undertaken in order to modify the way the actors currently see their relations with the other actors and the options available to them.

Key words: potato, mildew, systemic analysis, sustainability, semi-directed interviews, lock-in

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