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Best practice document for the coexistence of genetically modified potato with conventional and organic farming

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This best practice document is the result of work carried out by the European Coexistence Bureau – Technical Working Group for Potato, consisting of the following European Commission staff and experts nominated by EU Member States:

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Executive summary

The Technical Working Group (TWG) for Potato is the fourth one of the European Coexistence Bureau (ECoB) and is established for elaboration of the coexistence issues between genetically modified (GM) potato cultivation and non-GM potato and honey production in the EU.

The present technical report analysed the possible sources for potential cross-pollination with GM potato and adventitious admixture of GM potato material such as seeds and pollen and presents consensually agreed by TWG for Potato best practices for coexistence. The terms of reference for this review are presented in Section 1. The scope of the Best Practice Document is coexistence in potato production in the EU. It includes the coexistence between GM potato cultivation and honey production.

The ECoB TWG for Potato held two meetings in November 2015 and May 2016 and examined the state-of-the-art from scientific literature, research projects and empirical evidence provided by existing studies for segregation in potato production looking at the factors determining the cross-pollination rates in potato as well as other sources of admixture of GM material in conventional potato harvests and EU-produced honey. The review of this information (coming from a total of 155 references) is presented in a structured manner in Sections 4-6 of this document. Finally, the TWG for Potato reviewed the up to date approaches for the detection and identification of traces of GM potato material in non-GM potato harvests and honey (Section 7).

The TWG for Potato of the ECoB, based on the analysis of the evidence summarised in this document submitted proposals for best management practices, which form the ground for the agreed consensus recommendations presented in Section 8, complemented by an ex-ante view about their economic impact (Section 9).

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1. Introduction

1.1. Legal Background

The European legislative framework for coexistence in agriculture was created to ensure that the cultivation of genetically modified (GM) crops is carried out in a way that allows different agricultural systems to co-exist side by side in a sustainable manner, which in turn promotes freedom of choice throughout the food chain. The coexistence rules support market forces to operate freely in compliance with the Community legislation. The legislative basis in the EU for the coexistence of GM and non-GM crops is established by the relevant legislation for the release of genetically modified organisms (GMOs) into the environment, and food and feed legislation for the labelling requirements of GMO presence. Both pieces of legislation provide a harmonised approach for the assessment of all potential environmental and health risks which might potentially be connected to placing of GMOs on the market.

Directive 2001/18/EC[1] on the deliberate release of GMOs into the environment and Regulation No 1829/2003[2] on GM food and feed ensure strict control of placing on the market GMOs in the EU. All GMOs and food and feedstuffs derived from them have to be clearly labelled to ensure freedom of choice for the consumer. In addition to that, and as an exemption of the labelling requirements, the European legislation takes into consideration the presence of technically unavoidable or adventitious traces of GM material. Directive 2008/27/EC[3] which amended Directive 2001/18/EC established the threshold of 0.9% for commodities intended for direct processing, which comprises all crop harvests (excluding the case when they are intended for seed production) below which traces of market-approved GM products do not require labelling. Regulation (EC) No 1829/2003 establishes the same threshold for food and feed. With Directive 2014/63/EU[4] amending Council Directive 2001/110/EC relating to honey the threshold of 0.9% adventitious admixture of GM pollen over total honey was adopted. These labelling rules are also valid for organic products, including food and feed, according to Regulation (EC) No 834/2007[5].

The adopted threshold for labelling exclusion is applicable only for adventitious, technically unavoidable admixtures. For farm-scale activities which are performed in open-space environments, it has always been understood that some admixing will occur. To control adventitious GM presence, adequate technical and organisational measures during cultivation, on-farm storage and transportation are required. Therefore the potential admixing below the threshold for which particular coexistence measures are designed is possible and technically unavoidable and adventitious. Thus the effectiveness of the coexistence measures used to limit the

1 Directive 001/18/EC of the European Parliament and of the Council of 12 March 2001 on the deliberate release into the environment of genetically modified organisms and repealing Council Directive 90/220/EEC. OJ L 106, 17.4.2001, p. 1 Eur.

2 Directive 001/18/EC of the European Parliament and of the Council of 12 March 2001 on the deliberate release into the environment of genetically modified organisms and repealing Council Directive 90/220/EEC. OJ L 106, 17.4.2001, p. 1 Eu.

3 Directive 2008/27/EC of the European Parliament and of the Council of 11 March 2008 amending Directive 2001/18/EC on the deliberate release into the environment of genetically modified organisms, as regards the implementing powers conferred on the Commission, OJ L 81, 20.3.2008, p. 45-47.

4 Directive 2014/63/EU of the European Parliament and of the Council of 15 May 2014 amending Council Directive 2001/110/EC relating to honey. OJ L 164, 3.6.2014, p. 1–5.

5 Council Regulation (EC) No 834/2007 of 28 June 2007 on organic production and labelling of organic products and repealing Regulation (EEC) No 2092/91. OJ L 189, 20.7.2007, p. 1-3.

potential intermixing to below a certain threshold defines what is "adventitious or technically unavoidable" in terms of coexistence for open-space farm activities.

As local environmental conditions and farm structures may have a significant impact on the effectiveness and efficiency of coexistence measures, their development is under the remit of individual Member States (MS).

Recommendation 2010/C 200/01[6] of the EC provides guidelines for development of national coexistence measures to avoid the unintended presence of GMOs in conventional and organic crops, replacing Commission Recommendation 556/2003[7]. Recommendation 2010/C 200/01 recognises that the market demand for particular food crops may result in economic damage to operators who would wish to market them as not containing GMOs, even if GMO traces are present at a level below 0.9%. Therefore MS may establish different thresholds for adventitious and technically unavoidable admixture of GMOs in non-GM harvests, taking into account the demands of the consumers and their market. The Recommendation also takes into consideration the extreme diversity of European farming systems, natural and economic conditions and clarifies that under certain climatic and/or agronomic conditions MS may exclude GMO cultivation from large areas, if other measures are not sufficient to ensure coexistence.

Directive 2015/412[8] amended Directive 2001/18/EC regarding the possibility for MS to restrict or prohibit the cultivation of GMOs in their territory. This Directive reaffirms the existing approach for development of coexistence measures, established by the Commission Recommendation of 13 July 2010. Directive 2015/412 places on MS (in which GMOs are cultivated) the responsibility to take appropriate measures in border areas of their territory with the aim of avoiding possible cross-border contamination into neighbouring MS in which the cultivation of these GMOs is prohibited, unless such measures are unnecessary in light of particular geographical conditions.

6 OJ C 200, 22.7.2010, p. 1-5.

7 Commission Recommendation 556/2003 of 23 July 2003 on guidelines for the development of national strategies and best practices to ensure the co-existence of genetically modified crops with conventional and organic farming. OJ L 189, 29.7.2003, p. 36.

8 Directive 2015/412 of the European Parliament and of the Council of 11 March 2015, amending Directive 2001/18/EC as regards the possibility for the Member States to restrict or prohibit the cultivation of genetically modified organisms (GMOs) in their territory OJ L 68, 13.3.2015, p. 1–8.

1.2. The role of the European Coexistence Bureau

The diversity of agricultural practices and legal environments among the MS has led to adoption of the subsidiarity approach in the EU for the implementation of coexistence regulations. Although the development of coexistence measures is under the remit of individual EU MS, the European Commission retains several roles in this process. One important role is the technical advice offered to MS through the European Coexistence Bureau (ECoB).

The mission of the ECoB, created in 2008, is to organise the exchange of technical and scientific information on the best agricultural management practices for coexistence and, on the basis of this process, to develop consensually agreed crop-specific guidelines for technical coexistence measures. The ECoB is managed by and located on the premises of the Joint Research Centre (JRC) of the European Commission.

The work of ECoB is organised into crop-specific Technical Working Groups consisting of experts nominated by EU MS. Their main task is to develop Best Practice Documents (BPDs). The BPDs of ECoB comprise a methodological tool to assist development of national coexistence measures, based on scientific evidence and practical experience.

The ECoB has established TWG for maize, soybean, cotton and potato. The first TWG for maize crop production started its work in 2008. The TWG for maize has developed three BPDs for:

- Coexistence of GM maize crop production with conventional and organic farming (Czarnak-Kłos and Rodríguez-Cerezo, 2010);
- Monitoring efficiency of coexistence measures in maize crop production (Rizov and Rodríguez-Cerezo, 2014); and
- Coexistence of GM maize and honey production (Rizov and Rodríguez-Cerezo, 2013).

The second TWG, for soybean, was established in 2013 and developed a BPD for Coexistence of genetically modified soybean crops with conventional and organic farming (Rizov and Rodríguez-Cerezo, 2015).

The third TWG, for cotton, was established in 2014 and developed a BPD for Coexistence of genetically modified soybean crops with conventional and organic farming (Rizov and Rodríguez-Cerezo, 2016).

The TWG for potato started work on this BPD in 2015.

1.3. Scope of the Best Practice Document

This document focuses on the development, based on current scientific knowledge and agricultural practices, of a set of best agricultural management practices that will ensure coexistence of GM potato with conventional and organic potato while maintaining economic and agronomic efficiency of the farms. The TWG for potato was also asked to examine the issue of coexistence between GM potato cultivation and honey production in the EU. The scope of the BPD is coexistence in the cultivation of potato in the EU.

It is assumed that for the purpose of this document, the coexistence measures should be addressed to GM potato producers. All these measures should be proportionate, technically and economically consistent.

The document considers both the need for compliance with the regulated labelling threshold of 0.9% as well as with lower thresholds of adventitious presence of GM material (0.1%) which may be required by private operators in some markets.

The document exclusively considers GM potato with a single gene transformation event.

2. Potato cultivation in the EU: demand and crop production

2.1. Market and demand

Potato is the fourth most important crop in the world in terms of human consumption, following rice, wheat, and maize (corn) (Arvanitoyannis et al., 2008; Llorente et al., 2011; Zaheer and Akhtar, 2016) and the second most important arable crop in Europe, with 1.7 million hectares under potatoes in the EU-28 in 2016 grown at a value of 9.2 billion Euros in 2014 (Eurostat, 2016a,b). Potato is grown in over 100 countries, with world potato production being 385 million t (Mt) in 2014 (FAOSTAT, 2016). China, India, Russia, the Ukraine and the U.S. are the five largest potato producing countries (FAO, 2013; Zaheer and Akhtar, 2016). Since the early 1960s, the growth in potato production area has rapidly overtaken all other food crops in developing countries. It is a fundamental staple, ensuring food security for millions of people across South America, Africa and Asia, including Central Asia. Presently, more than half of the global potato production comes from developing countries. Potatoes for human consumption also belong to the most competitive sector of EU agriculture, despite the relative and absolute decline in production observed in recent years. Germany, Poland, France, the Netherlands and the United Kingdom are the main potato producing EU Member States (Eurostat, 2016).

The EU potato sector shows a competitive edge in international markets, especially in the sub-sectors of seed potatoes and processed products. Potatoes for human consumption are not covered by the Single Common Market Organisation, except for the standard rules on state aids. Since 2008, all the potato areas in the EU are potentially eligible to receive direct payments. Moreover, potato operators may benefit from the CAP promotion and quality schemes. The legal framework for these actions is laid down in Council Regulation (EC) No 3/2008 of 17 December 2007 on information provision and promotion measures for agricultural products on the internal market and in third countries.

The potato market is complex, and in addition to GM/non-GM/organic separation, consideration must be given to potatoes of specific designated origin. Examples of potatoes that are registered as Protected Designation of Origin (PDO) / Protected Geographical Indication (PGI)[9] comprise, among others, “Patata Kato Nevrokopiu” (PGI - Greece), “Pomme de terre de Merville” (PGI - France), “Pomme de terre de l’Île de Ré” (PDO - France), “Opperdoezer Ronde” (PDO - Netherlands), “Lapin Puikula” (PDO - Finland) and “Jersey Royal potatoes” (PDO - UK).

The potato market is also becoming increasingly segmented as new varieties are created to satisfy particular needs of the value chain. However, as a starting point, early potatoes, main crop potatoes, seed potatoes, and starch potatoes can be identified as some broad categories of potatoes.

Potatoes for human consumption, i.e. early and main crop potatoes (also referred to as ware potatoes), can be used

9 More on PDO/PGI and TSG at http://ec.europa.eu/agriculture/quality/schemes/index_en.htm.

fresh as table potatoes, or as raw material for the food processing industry. The food industry requires potatoes for different types of products:

- pre-cooked products (mostly French fries);
- dehydrated products (i.e. potato flours, potato flakes or potato granules);
- snacks;
- other products (gnocchi, salads, ready prepared meals, etc.).

The extent of potato production varies among different European countries. An overview of potato production for a number of selected countries is outlined in the following paragraphs.

2.1.1. Production in selected Member States

Austria

In Austria potatoes were grown on an area of 20,400 ha in 2015, an 8% reduction within the past 10 years. On 53% of the production area ware potatoes are produced, including 4% early potatoes, and on 7% of the area seed potatoes are propagated. About 40% of the production volume is used for industrial purposes.

Belgium

In Belgium, the potato acreage increased significantly from 60,000 to 81,500 hectares over the last ten years. In 2014 the total Belgian production of consumption potatoes was estimated at 4.58 Mt with yields up to 60 t per hectare. This record production (because of an increased area and higher yields) is almost 30% higher than the average production, which amounted to 3 Mt over the past years. Belgian production consists almost exclusively of consumption potatoes. There is no starch potato production and seed potato production is limited. After strong growth of its potato processing activities Belgium became a world-leader. In 1990, only 500,000 t of potato were processed, increasing to almost 3.5 Mt in 2013, of which 1.87 Mt were exported. Belgium also imports potatoes for processing.

Croatia

The annual production of potato in Croatia is around 160,000 t per year corresponding to a production area of about 10,000 ha. In the last ten years the production area has been reduced from approximately 18,000 ha to 10,000 ha. The production of potatoes takes place in all Croatian regions.

Denmark

In Denmark the potato production area of 46,000 ha represents 1.5% of total agricultural area and has increased in the previous 5 years slightly from 41,500 ha. 20% of this area is used for ware potato production and 57% for starch potato production. The main production region is the Western part of Denmark (middle and west Jutland on sandy soils). There has been an increase in the area of potatoes grown for starch production with an expected future trend towards a further increase, a decline in production of ware potatoes, and a slight increase in production of seed potatoes. Organic potato production represents approximately 3.6% of total potato area.

Estonia

In Estonia, production in 2015 was 117,200 t on an area of 5,800 ha. Although the area sown to potato has decreased by 59% over the past 10 years, the total annual potato yield increased by 34% in the same period.

Finland

Commercial potato production is focused on a narrow strip in the coastal areas of Finland and potato monoculture is very common. The cultivation of the highest seed potato grades is focused on the Northern Ostrobothnia region. Total potato production area in Finland is on average 22,000 ha with a total production volume of 0.65 Mt.

Germany

In Germany, the annual production area of potatoes steadily decreased during the last century and the early part of this century; this trend is likely to continue in the coming years. In 2016, potatoes were grown on an area of approximately

236,000 ha. Prior to 2000, the area used for potato production exceeded 300,000 ha. However, the total tuber yield only decreased slightly from 11.6 Mt in 1999 to 10.2 Mt in 2016 due to significant yield increases. The main production area within Germany is the Federal state of Lower Saxony, followed by the states of North Rhine-Westphalia and Bavaria. About 5% of the total production area is used for the cultivation of early potatoes.

In 2015, about 3.5 Mt of potatoes were processed into food. Whereas the per capita consumption of fresh potatoes is decreasing from year to year, the proportion of processed potato products (French fries, potato chips, mash, cooled and deep frozen potato products, etc.) is increasing. The per capita annual consumption of potatoes has decreased from 285 kg in 1900 to 58 kg in 2015. About 43% of the potato production is used for human nutrition while 20% enters the starch industry. Approximately 30% of this starch is used in non-food applications such as glues, lubricants, paper and corrugated cardboard production, as well as packaging and building material.

The use of potatoes as an animal feedstuff is at present of no significance. Mainly unmarketable potatoes enter this market in addition to being used for the production of energy in biogas plants.

Greece

Approximately 821,500 t of potato are produced annually in Greece with an average yield of 24.7 t /ha (2001-2011 average). Potatoes are produced in all parts of the country with approximately 60% being produced in the southern regions (Sterea Ellada, Peloponissos and Kriti) and 30% in the northern part (Makedonia, Thraki, Ipiros and Thessalia). Production is based on a large number of small production farms with an average area of 1.5 ha in the mainland and 0.1 ha on the islands.

Due to the typical Mediterranean climate, there are three production cycles for potato. There is spring cultivation (planting between December and early April), summer cultivation (planting between late April and early May), and autumn cultivation (planting in August and September). Summer and spring cultivation account for approximately 75% of annual potato production. All potato production is irrigated. Potatoes are produced mainly for direct consumption but also for frozen potato products and for chipping.

Lithuania

Approximately 399,200 t of potato were produced in Lithuania in 2015, with an average yield of 17 t/ha. The total area planted with potatoes in 2015 accounted for 23,500 ha which is a reduction of 13.9% compared to 2014 and 37.7% compared to 2011. Average yield of potatoes over the 2011 to 2015 period was 16.2 t/ha. Over the past five years, potato production in Lithuania has declined by 32.1%. Potatoes are integrated into predominantly cereal based rotation systems and are cultivated every 4-5 years.

The Netherlands

In 2014, 7.1 Mt of potatoes were harvested in the Netherlands on an area of 156,252 ha. Approximately 3.87 Mt of consumption potatoes were produced on an area of 74,068 ha and approximately 1.75 Mt of starch potatoes on 42,310 ha. An area of 39,874 ha was dedicated to seed potato production with a yield of approximately 1.48 Mt. Around 70% of the seed potatoes produced in the Netherlands are exported. In 2013, 1,479 ha were dedicated to organic potato production.

Potatoes for consumption are mainly produced on clay soil in the central part (IJsselmeerpolders) and in the southwest of the country, as well as on sandy soils in the south-eastern part (provinces of Noord-Brabant and Limburg). The main production regions for starch potatoes are the provinces of Groningen and Drenthe in the northeast of the Netherlands, which are characterised by sandy soils. Seed potatoes are produced on clay soils in the north (provinces of Groningen and Friesland) and in the northwestern province of Noord-Holland.

Spain

In Spain, 2.2 Mt of potatoes were produced on 73,000 ha in 2016. Seed potatoes account for 2,300 ha. The main production areas are Castile and León (40%), Galicia (20%), and Andalusia (12%). The area used for potato cultivation has decreased from 95,123 ha in 2005 but production area has not changed to any great extent over the last years.

Sweden

The yearly potato production in Sweden is about 25,000 ha of which 7,000 ha are starch potatoes and 900 ha seed potatoes. Potatoes are grown in the whole country but with a concentration in the southern part. The average yield for food potatoes is a little more than 30 t/ha and for starch potatoes close to 40 t/ha.

After a long period of slowly decreasing potato cultivation acreage, there was a slight increase in 2016, for both food and seed potatoes.

United Kingdom

The UK is the twelfth largest producer of potatoes globally, harvesting around 6 Mt of the crop each year. Whilst long-term trends show a considerable decrease in the UK planted area, from over 250,000 ha in the 1960s to just over 100,000 ha in 2015, increased yields (from around 23 t/ha in 1960 to around 48 t/ha in 2014) have compensated for this reduction. This yield increase has been driven largely by improved agronomy, crop protection, fertiliser regimes, change in varieties and better irrigation. In 2014 the number of registered growers in the UK stood at 2,160 (down from over 250,000 in 1960), with the average area per grower around 53 hectares. The number of smaller growers is in decline, whilst the number of larger, specialist, growers is increasing. The largest proportion of the area grown, at around 35%, is intended for use in the pre-pack market, with the processing sector, making up the second largest area, at 30% of the total. Seed potatoes are grown predominately in Scotland where the levels of virus-transmitted aphids are low, although there is some seed potato production in England (especially in Yorkshire) and Wales. In terms of ware potatoes, around 57% are produced in the East of England (in Norfolk, Yorkshire and the Humber regions) and around 12% are produced in Scotland, with the remainder spread across England and Wales.

2.2. Growth and cultivation

Potatoes are efficient in using water and therefore produce more food per unit of water than any other major crop (FAO, 2008). They can be grown at altitudes from sea level to up to 4,700 meters above sea level, from southern Chile to Greenland. Although special cultivars have been bred that are adapted to these diverse environmental conditions, extreme low or high temperatures, in particular during the night, can obstruct tuber formation. Tubers of varieties of *S. tuberosum* subsp. *tuberosum* cannot survive temperatures of -3°C or below and potato foliage dies at temperatures of -4°C (van Swaaij et al., 1987; Vayda, 1994). Dale (1992) reported that potato tubers lose viability following a 25 hour-period at -2°C or 5 hours at -10°C. Additionally, the exposure of tubers to low temperatures in the field or during storage can cause low temperature injury, while high soil temperatures and nutrient or water imbalances can cause tuber deformities.

S. tuberosum subsp. *tuberosum* is a daylight neutral crop, which means that tubers are set at a growth stage independent of the day length. But variation for daylight sensitivity can be found among *S. tuberosum* subsp. *tuberosum* cultivars. Short days with less than 14 hours and moderate ground temperatures of 15-18°C enhance tuber formation, while longer days of 14-16 hours and higher day temperatures of 20-25°C enhance flowering and seed formation (Beukema and van der Zaag, 1979; Burton, 1989). The potato is commonly considered a cool season crop, but it also grows at high temperatures if sufficient water is available (Haverkort, 1990).

Potatoes are very sensitive to soil water deficit (Vayda, 1994) and therefore can only be cultivated in areas with adequate rainfall or the ability to irrigate (Bohl and Johnson, 2010; Haverkort, 1990). A wide range of soil pH can be tolerated by potatoes, normally pH 5 and higher is optimal, but even at pH 3.7 good production has been observed, and potatoes can grow well on a wide range of different soil types (Vayda, 1994).

Potato is a perennial crop grown annually from vegetative tubers, known as seed tubers or seed potatoes, which can persist in the soil when the plant dies back each autumn. Under European conditions the tubers persist poorly in cold wet soils and tubers, as well as plants rapidly become infected with a range of fungal and viral diseases, hence the crop is grown as an annual.

Planting time varies considerably from region to region depending not only on local climatic conditions but also on intended market use. This means that potato production can be achieved in many different areas and, indeed, explains why potatoes are grown in all EU countries.

Potato cultivars adapted to different regions within the EU have been bred. Early cultivars mature in less than four months, medium within 4 - 5 months, and late cultivars in up to 7 months, depending on the prevailing weather conditions. Early potatoes are harvested before being fully mature, have easily removable skin, and are marketed as soon as possible after harvest. Harvest time depends on the climatic conditions and starts in the first semester of the year in the Mediterranean area including Spain, Cyprus, Greece, Malta and Portugal and in late May until August in the Continental and Northern part of Europe. The yields of early potatoes are lower, but as they attract a premium price and farmers usually make a larger profit than with main crop potatoes.

The harvest of main crop (medium and late) potatoes starts later, usually in September, and production costs are lower due to higher yields. The progress in storage techniques allows a prolongation of marketing main crop potatoes until May-June. As a consequence, there is an overlap of the season of main crop potatoes with that of early potatoes from the Mediterranean area.

The geographical distribution of potato production within the European Union is characterised by 5 main aspects:

- The Mediterranean part of the EU is mainly specialised in early potatoes that are commercialised in the first semester of the calendar year;
- Early potatoes cultivated in Northern, Eastern and Central European countries are brought on the market between late May and August. However, these countries focus on marketing main crop potatoes;
- There is a trend towards the concentration of potato production in five Member States: Germany, the Netherlands, France, UK, and Poland (so called EU-5). As a consequence, the potato production of Poland as the former first potato producer in the EU has considerably declined due to the strengthening of the EU-5 countries' position on the EU markets;
- The new Member States' potato production underwent a drastic process of structural change following the end of the former central planning economy;
- The path towards a modern system of market economic relationships is bringing about some developments but the re-organisation of the sector is still not completed.

Usually, seed potatoes normally weigh between 35 and 85 g and seeding rate typically ranges between 1 – 6 t/ha depending on the intended end use (Firman and Allen, 2007). Planting depth is between 10 and 18 cm. Depending on variety, the intended market, soil moisture, planting date, seed potato size and age, in-row spacing ranges from 15 to 46 cm, and rows are typically 75 to 97 cm apart. Potato tubers may be planted before the usual date of the last days with sub-zero temperatures. However, soil temperatures should be at least 8-10°C.

Potatoes draw a lot of nutrients from the soil, and sufficient applications of nitrogen, phosphorous and potassium are generally required to ensure adequate plant growth, tuber yield and quality, and to minimise susceptibility to diseases. Nitrogen is the most likely parameter to limit potato production, but excess nitrogen can have negative impacts as well. Soil and, in some cases, tissue testing is recommended in order to determine the most effective fertilization rates. In areas where the soil is naturally acidic agricultural limestone may be added to maintain pH within the desired range.

Potatoes typically require high levels of soil cultivation (Hopkins et al., 2004) for improved weed control, aeration and bed shaping as well as maintaining proper seed depth and establishing irrigation furrows (Bechinski et al., 2001; Sieczka, 2010). Potato production is generally not conducive to maintaining healthy soil conditions because of intensive tillage, minimal crop residues left on the field, heavy field traffic and long periods of soil being left bare (Hopkins, 2010). In the Northwest of the USA, potato fields are typically tilled both before and after the season (Hopkins et al., 2004).

Irrigation is often applied in potato production, since *S. tuberosum* is a drought-sensitive crop and has a shallow active root zone (Obidiegwu et al., 2015). Water demand is highest during the tuber bulking stage of growth, and an inadequate supply will reduce tuber yield and quality.

There are many serious diseases that may be inherent in seed potatoes, including late blight (*Phytophthora infestans* (Mont.) de Bary), early blight (*Alternaria solani* Sorauer), bacterial wilt (*Ralstonia solanacearum* (Smith) Yabuuchi et al.), bacterial ring rot (*Clavibacter michiganensis* subsp. *sepedonicus* (Spieckermann and Kotthoff; Davis et al.)), black leg (*Pectobacterium* spp. and Dickeya ssp.), and black scurf (*Rhizoctonia solani* Kühn), as well as several viral diseases. The best protection against some of these diseases is to use certified disease-free seed potatoes and the use of fungicide sprays. Crop rotations, the use of resistant cultivars, and proper sanitary practices are also important for reducing the incidence of disease (Bohl and Johnson, 2010).

Employing practices to prevent the entry of weeds, such as proper equipment cleaning are common best agricultural practices. Pre-plant incorporated, pre-emergence, and post-emergence herbicide applications as well as pre-emergence burn-off can be used to control weeds in addition to cultural practices such as harrowing and hilling. Integrated pest management is strongly recommended, with a combination of cultural and chemical approaches.

Tubers should ideally be harvested when their skin is ripe, the tubers are chemically mature, and temperatures range between 7 and 15°C to reduce shatter bruises and to avoid frost damage. Chemical maturity of tubers is important for long-term storage and processing and is reached when the amount of free sugars falls below a variety dependent standard minimum level (Western Potato Council, 2003).

3. Potato biology, evolution and breeding

3.1. Biology and taxonomy

Potato, *S. tuberosum* subsp. *tuberosum,* is an herbaceous perennial crop (OECD, 1997). The aerial parts of the plant range from 30 to 80 cm in length, with some cultivars reaching a height of two meters, and with a habit varying from erect to fully prostrate (Spooner and Knapp, 2013). Stems range from nearly hairless to densely hairy and may be green, purple, or mottled green and purple. Leaves are pinnate with a single terminal leaflet and three or four pairs of large, ovoid leaflets with smaller ones in between (Spooner and Knapp, 2013; Struik, 2007). The flowers are white, yellow, purple, blue or variegated, usually with a five-part corolla and exerted stamens with very short filaments. The fruits look like a small cherry tomato and are yellowish or green, globose, and have a diameter of less than 2.5 cm. Some lack seeds, but others may contain several hundred (Linsinka and Leszczynki, 1989). The nomenclature differentiates between potato seed (meaning seeds from fruits, and also known as 'true potato seed') and seed potatoes (meaning tubers for planting).

Cultivated potato (*Solanum tuberosum* L.) and its wild relatives are classified in order Solanales, family Solanaceae, genus *Solanum*. The genus *Solanum* is polymorphous and the largest genus comprising 1,500–2,000 species (PBI Solanum Project, 2014), predominantly found in tropical and sub-tropical regions (Fernald, 1970; Burton, 1989; Spooner and Knapp, 2013). The species *S. tuberosum* is divided into the two subspecies *tuberosum* and *andigena*. The subspecies *tuberosum* is the cultivated potato used worldwide, whereas the subspecies *andigena* is restricted to Central and South America (Hawkes, 1990; OECD, 1997). *S. tuberosum* subspecies *tuberosum* and *andigena* are fully cross-compatible (Plaisted, 1980). Hybrids can occur in nature, although the frequency of occurrence of such crosses is not well documented, as the morphological distinction between the two subspecies is very small. The greatest difference is the short day dependence of the subspecies *andigena* (OECD, 1997). As both subspecies only occur in southern North America and some parts of South America, natural crosses are likely to be found only there.

3.2. Evolution and breeding

A considerable number of highly diverse species exist in the genus *Solanum*, therefore cultivated potato has an extremely large secondary gene pool consisting of related wild species. The evolution of the cultivated potato is quite complex due to introgression, interspecific hybridisation, auto- or allopolyploidy, sexual compatibility among many species, a mixture of sexual and asexual reproduction, recent species divergence, and phenotypic plasticity resulting in a high morphological similarity among species (Spooner, 2009; Spooner and Bamberg, 1994). Wild potatoes are widely distributed in most parts of America, from southwest USA to Mexico and Central America. In South America, they occur in almost every country, mainly in the Andes of Venezuela, Colombia, Ecuador, Peru, Bolivia and Argentina (Hijmans et al., 2002). The adaptation to a wide range of habitats has made the wild species tolerant to different environmental stresses and resistant to a broad range of pests and diseases (Hawkes, 1994). Wild potato species, however, are not present in Europe.

The value of germplasm of primitive cultivars and wild species in potato breeding is determined by its genetic diversity, availability and utility. In this sense, potato stands out among all other crops (Bamberg and del Rio, 2005). Primitive forms of cultivated potato and their wild relatives provide a rich, unique, and diverse source of genetic variation, which is a source of various traits for potato breeding.

The potential for using these genetic resources in conventional breeding depends on their 'crossability' with the commonly cultivated potato (*S. tuberosum*). Cultivated potato is only sexually compatible with some of the other tuber bearing species in the section *Petota* and rarely with the non-tuber-bearing species in the section *Etuberosum*, and there are very strong barriers to hybridisation with other *Solanum* species (Jackson and Hanneman, 1999; Andersson and de Vicente, 2010), such as differences in the endosperm balance number (EBN) and ploidy level. The EBN concept was first published by Johnston et al. (1980) to explain the success or failure of intraspecific crosses. The EBN is a measure to express the "effective ploidy of a genome in the endosperm". To enable normal development of the endosperm after fertilization, the maternal EBN must be twice that of the paternal EBN (2:1), hence this system forms a strong isolating mechanism present in the section *Petota*. The EBN is independent of ploidy level and is determined based on cross compatibility using standard EBN test crosses. Crosses between species with different EBNs are very often unsuccessful, whereas crosses between species with the same EBN number are frequently successful, even if they have different ploidy levels (Johnston and Hanneman, 1980).

The basic chromosome number in the genus *Solanum* is twelve. *S. tuberosum* subsp. *tuberosum* can be diploids ($2n = 2x = 24$) or tetraploids ($2n = 4x = 48$). The diploid form is found primarily in South America, while the tetraploid form is cultivated all over the world. The tetraploidy of cultivated *S. tuberosum* subsp. *tuberosum* originated either from autotetraploid (doubling of the chromosomes of a diploid species) or from allotetraploid (doubling of the chromosomes of a diploid hybrid between two related species) (Hawkes, 1990; Andersson and de Vicente, 2010).

Due to complex chromosome segregation ratios, polyploid crops are inherently more difficult to breed (Hoopes and Plaisted, 1987). Furthermore, vegetatively propagated crops like potato are often poor seed producers due to partial or full sterility. Additionally, continued self-pollination of *S. tuberosum* can lead to large inbreeding depression due to the fact that many traits are determined by non-additive genetic effects (Gopal and Ortiz, 2006).

Potato breeders have developed methods for overcoming this hybridisation barrier, such as ploidy manipulations, bridge crosses, auxin treatments, mentor pollinations, and embryo rescue (Jansky, 2006). Using these effective tools, potato breeders can gain access to the promising traits present in wild potato species.

However, the inherent complexity of genetics makes potato breeding time-consuming. Polygenes are believed to underlie quantitative resistance, which is difficult to maintain intact during the breeding process. Thus, the selection cycle, from initial crosses to variety release, requires approximately 10 or sometimes even more than 30 years (Gebhardt, 2013, Haverkort et al., 2009). Consequently, to overcome these hurdles, marker-assisted selection is applied to reduce breeding time and molecular biology techniques to overcome inter-specific hybridisation barriers (Song et al., 2003; Van der Vossen et al., 2003), both of which significantly speed up the breeding process. By employing cisgenesis, in which genes obtained exclusively from cross-compatible species are used in their native state, efficient stacking of multiple resistance genes can result in potato varieties with a more durable resistance to late blight. Proof of concept has been attained in the DuRPh programme in the Netherlands (Haverkort et al., 2016) as well as in the UK and Belgium (Haesaert et al., 2015), and locally popular varieties are presently being addressed for late blight resistance using cisgenesis. Other novel breeding techniques, such as intragenesis and genome editing, are being used in potato to engineer novel traits such as lower content of asparagines (for lowering amounts of acrylamide produced during heating) and reducing sugars (Cardi, 2016).

The genome sequencing of potato was completed in 2011 based on the DNA from two different diploid genotypes (The Potato Genome Sequencing Consortium, 2011). The sequence information of the potato genome with a size of 844 Mb revealed 39,031 protein-coding genes, suggesting a paleohexaploid duplication event during genome evolution. This genome sequence information, as well as supporting phylogenetic research on the genus *Solanum*, is also helping to expedite the genetic improvement of potato.

3.3. Reproduction

Potatoes flower under long day conditions, moderate temperatures, high humidity and availability of sufficient soil nutrients (Kumar et al., 2006). The percentage and duration of flowering as well as the influence of environmental conditions on flowering is highly determined by cultivar (Burton, 1989). The flowers can be cross fertilised by insects, but are largely self-pollinated. Wind pollination is of minor importance (White, 1983). The extent of pollen dispersal in potato is related to the pollinating insect species, weather conditions and the fertility of the cultivar (Treu and Emberlin, 2000).

Flowering starts on branches located near to the base of the plant and proceeds upwards. Each flower will typically remain open for two to four days, with the stigma being receptive and pollen being produced for approximately two days (Plaisted, 1980). Fertilization occurs approximately 36 hours after pollination (Clarke, 1940). Viable seeds require a minimum of six weeks to develop.

Flower development does not ensure fruit set, and pollen sterility is frequently encountered under field conditions in parts of Europe (Anonymous, 1996). Very early varieties can complete their vegetation cycle before they start to flower. In some cases, flowers are set but abort early. Some cultivars may also exhibit male sterility, and/or inability to set fruit (Gopal, 1994). The berries are toxic due to the presence of glycoalkaloids (Bailey and Bailey, 1976).

Potato pollen is small and round with little or no ornamentation (Symon, 1981; Mali et al., 2014). Pollen sterility is the most important obstacle to sexual recombination of potato dihaploids (Gorea, 1970; Carroll and Low, 1976; Iwanaga, 1984; Ross, 1986). Pollen sterility and varying levels of pollen fertility can be caused by inbreeding depression as a result of dihaploidization (Carroll and Low, 1976) or by the interaction of nuclear genes and cytoplasm in dihaploids (Howard, 1970).

Many *S. tuberosum* cultivars exhibit reduced fertility, and this may limit their ability to hybridise. Male sterility, premature flower drop and the inability to set fruit are common (Gopal, 1994; Sleper and Poehlman, 2006). Male sterility may result from deformed flowers with anthers that do not dehisce or produce shrivelled microspores. Pollen may not form at all or the pollen may be of poor quality (Sleper and Poehlman, 2006). In a study of 676 tetraploid *S. tuberosum* accessions from 25 countries, it was found that in 20.4% of the accessions, flower buds dropped prematurely and 23% of the accessions were found to be completely male sterile (Gopal, 1994). Pollen sterility occurs frequently in *S. tuberosum* and ovule sterility occasionally; many varieties do not produce any seed.

The cultivated tetraploid *S. tuberosum* subsp. *tuberosum* is self-compatible, although most of the related diploid species are self-incompatible. The S alleles occur in this species, but somehow the incompatibility system is weakened. The mechanism behind this is not known. Plaisted (1980) has shown that under field conditions selfing is most likely for tetraploid *S. tuberosum*, with 80-100% of the seeds formed due to selfing.

Hanneman (1995) reported that the occurrence of unreduced gametes is a common phenomenon in *Solanum* species. In most *Solanum* species, additional to the normal haploid gametes (n), unreduced gametes (2n) can be found that greatly extend the possible number of natural crosses. Also Watanabe and Peloquin (1991) observed the production of 2n pollen in most of the 38 examined tuber-bearing *Solanum* species with a frequency varying from 2 up to 10%. The occurrence of unreduced gametes in *Solanum* spp. provides an exception to the general rule that crosses between species with differing EBN are not successful.

S. tuberosum plants produce rhizomes (often called stolons) that have rudimentary leaves and are typically hooked at the tip. They originate from the basal stem nodes, typically below ground, with up to three rhizomes per node (Struik, 2007). Tubers, spherical to ovoid in shape, are swellings of the rhizome at the end of underground stolons. They maintain the characteristics of the above ground stem, such as nodes, internodes, scale leaves, and lenticel pores. Tubers have two ends – the bud end and stem end, the latter of which is attached to the stolon.

Potatoes are very easily regenerated with the use of *in vitro* tissue culture techniques. This form of vegetative propagation normally leads to genetically identical individuals, but considerable heterogeneity is common after tissue culture in which a callus stage is included. This variation is called somaclonal variation. *S. tuberosum* subsp. *tuberosum* is, like all potatoes, quite prone to this kind of variation (Cutter, 1992; Hawkes, 1990).

Information on the dispersal of true potato seed is somewhat lacking. Birds are unlikely to distribute the seeds because the berries are green and inconspicuous, although Hawkes (1988) suggests that the distribution of berries by small (or perhaps large) mammals is possible due to their sweet and aromatic nature. However, there is no mention regarding the toxicity of the berries and whether this may impede browsing by animals. Love (1994) reports that true potato seeds can survive and germinate for periods of time in excess of seven years, whilst Lawson (1983) showed that in Scotland true potato seeds could be stored in the ground for up to ten years without losing viability. However, a long dormancy period of true potato seeds makes the resulting plants weak competitors with cultivated crops during a particular cropping year.

In practice, the seed is seldom used in commercial plantings and mostly utilised in breeding programmes. Most common is vegetative propagation using tubers. The major disadvantage of true potato seeds is that they segregate for numerous traits because of high potato heterozygosity, and plants arising from true potato seeds typically take longer to establish than seed tubers, resulting in lower yield than from seed potatoes (Pallais, 1987).

Potato is vegetatively propagated, meaning that a new plant can be grown from a potato tuber or piece of potato tuber. On the surface of the tuber are axillary buds with scars of scale leaves that are called eyes (Struik, 2007). When tubers are planted, the eyes develop into stems to form the next vegetative generation. Thus, tuber formation is a method of reproduction, as each plant produces a multitude of tubers, each of which can theoretically develop into a new plant. The eyes on the tubers are buds that can sprout and develop into new stems. During the growing season tubers are produced continuously leading to the first tubers being the biggest, with smaller fertile tuber as small as one centimetre in diameter. The tuber acts as a source of nutrients for the new plant, and plants grown from tubers tend to have more early vigour than those grown from true potato seeds (Hoopes and Plaisted, 1987). Vegetative propagation may transmit diseases into successive generations.

4. Review of available information on adventitious GM presence in potato crop production

4.1. Seed potato impurities

Potatoes are vegetatively propagated by planting tubers or tuber pieces, while true potato seeds are normally used in breeding programmes. Because of the clonal propagation of commercial potatoes, the risk of affecting seed potato supplies through cross-pollination is negligible. Commercial seed potatoes are certified for purity before distribution to potato producers and contamination with a different cultivar by tubers from volunteer potatoes as well as mixing during sorting and grading can lead to small amounts of admixture. Although this is not critical in the fresh or processing market, it may lead to the rejection of the harvest for seed production (Steiner et al., 2005).

The two important parts of EU legislation covering the purity requirements of seed potatoes are the Council Directive 2014/20/EU determining Union grades of basic and certified seed potatoes and Directive 2001/18/EC on the deliberate release into the environment of GMOs. In annex I and II of the Council Directive 2014/20/EU the conditions which must be satisfied by seed potatoes are laid down. For basic seed potatoes the number of plants not breeding true to the variety and the number of plants of a different variety shall, together, not exceed 0.1%. For certified seed potatoes, the number of plants not breeding true to the variety and the number of plants of a different variety shall, together, not exceed 0.2%.

In terms of adventitious GM presence, there are no tolerance thresholds (for authorised or unauthorised GM events) laid down for the marketing of conventional seed potatoes in the EU. In order to avoid potential admixture of GM seed potato, official controls of conventional seed potatoes are regularly applied by Member States of the EU. However, these controls differ between the countries. In the following paragraphs information is presented for different Member States.

4.1.1. Approach to adventitious GM presence control in selected Member States

Many countries like Denmark, Estonia, Greece and Spain do not apply any controls for the adventitious GM presence in potatoes.

Belgium

In Belgium, about 2,200 ha of seed potatoes were grown. Clear guidelines, taking into account e.g. soil quality, diseases, isolation distances etc., describe how seed potatoes have to be grown. Before, during and after production the whole process is controlled by the regional inspection services, i.e. the Product Quality Management Division of the Department of Agriculture and Fisheries for the Flemish Government and Direction de la Qualité for the Walloon region. If all quality criteria are met, these authorities provide certification for the seed potatoes. Only certified seed potatoes can be traded. The top varieties of which seed potatoes were produced in Belgium in 2016 were Bintje (487 ha), Spunta (230 ha), Fontane (226 ha), Agria (153 ha) and Royal (81 ha). In particular cases, farmers also have the opportunity to use their own, farm-saved seed potatoes ('hoevepootgoed').

Czech Republic

In the Czech Republic, the GM potato variety "Amflora" was tested on an area of approximately 50 ha and was commercially cultivated by Czech farmers in 2010. After the cultivation of Amflora was stopped, fields on which Amflora potatoes had been cultivated were monitored for several years by the Czech Environmental Inspection together with the company BASF. Volunteers were recorded. In addition, the Czech Food and Feed Inspectorate tested for two years the possible occurrence of GM potato starch in commercial starch, using validated methods of DNA extraction and Amflora potato detection. No GM potato starch was detected.

Finland

GM potatoes were grown in Finland only for research purposes during 2009-2010 by the Potato Research Institute; GM potatoes are not cultivated for commercial use. No coexistence legislation for GM potatoes has been established in Finland, but still farmers have the obligation to notify the cultivation of GM varieties.

Germany

Germany established GM control inspection guidelines for standardised sampling, sample preparation, analysis, and assessment of results in 2006 and subsequently adjusted them in 2010 and again in 2014. Although the focus is on maize and rape seeds, other species including potato are also considered. The results of seed monitoring for GM percentage are available before seeding to avoid post-sowing enforcement activities. In the case of potatoes, fewer samples are taken, but on a regularly basis. The official GM monitoring programme for seed potatoes is only applied to seed potatoes produced within Germany.

The control programme consists of two steps and is based on existing routines and processes of official seed certification and phytosanitary controls. Step 1 is the official field inspection for varietal identity and purity while step 2 is the official investigation of seed potatoes for GM admixture in the laboratory. Samples for GM-analysis are taken from 10% of the seed crops (fields) where admixture has been observed through field inspection. A sample of 200 tubers is taken for every 3 ha either from the field or during storage. The laboratory used for the analysis is accredited for the purposes of PCR analysis for the detection of GM potatoes.

The first year of analyses for the presence of GM was 2011 where 15 samples were taken from the Federal State of Mecklenburg-Vorpommern. No admixture was detected in 2011 or in the years since. Sampling has been continued in 2012 (52 samples), 2013 (51 samples), 2014 (61 samples) and 2015 (19 samples).

Greece

In Greece, basic and certified seed potatoes are imported from other Member States (the Netherlands and Cyprus lead the market) for planting as the domestic seed production is limited with the main production area on the island of Naxos (Kyklades) but also in Tripoli (Peloponissos), Ioannina (Ipiros) and in Thessaloniki (Makedonia). In these regions, private companies and local agricultural co-operatives are responsible for the production of certified seed under the control of the local Departments of the Decentralised Agricultural Development (T.A.A.) of the Ministry of Rural Development and Food.

In the last ten years, potato growers tended to plant basic and certified seed potatoes of high productivity and resistant to pathogens. The main prospective for potato production in Greece is to increase the limited seed potato production in order to reduce the dependence of Greek potato growers on imported seed potatoes.

Lithuania

In Lithuania, nine samples from potato crops were tested for GM admixture in 2015 and showed no presence of GM. No samples were taken from seed potato crops in 2015.

United Kingdom

No GM potatoes are grown commercially in the UK at present, although a number of experimental trials of GM potatoes have been carried out. The Genetic Modification Inspectorate (GMI) for England, based at the Animal and Plant Health Agency, has designated responsibility for ensuring compliance with legislation pertaining to the deliberate release to the environment of genetically modified organisms in England. This includes (where appropriate) carrying out audits of companies that market seed of conventional crops, to assess whether they have appropriate controls in place to minimise the risk of adventitious GM presence (AGMP) in the material they handle. The GMI has assessed the risk of AGMP in potatoes for planting and has concluded that this risk is very low compared to other crops. Consequently the GMI does not currently conduct audits of seed potato producers and/or retailers in England. UK seed potatoes are subject to statutory inspections in terms of varietal purity and freedom from disease.

4.1.2. Registered potato varieties in selected Member States

In the following paragraphs information is presented about the number of registered varieties and their ability to flower for selected EU Member States. Segregation requirements for seed potato production are added if available.

Austria

The Austrian national catalogue contains 48 potato varieties. On about 1,600 ha seed potatoes are produced. The estimated rate of using farm saved seed potatoes in Austria is about 40 – 50%.

Croatia

In the national catalogue of Croatia, 50 potato varieties are registered. In the season 2014/2015, 514,621 kg of seed potatoes were certified for the Croatian market.

Denmark

In Denmark approximately 113 varieties are in the national catalogue. Information on the proportion of male sterile and fertile varieties is difficult to obtain. In 2015, pre basic seed were produced on 239 ha and basic seed on 4,310 ha. In the Danish propagation of seed potatoes the segregation requirements regulate a distance of 50 m for pre-basic seed, of 25m for basic seed, and of 15 m certified seed to potato production fields.

Estonia

In Estonia, 10 varieties are registered in the national catalogue. Certified seed potatoes are produced on an area of about 200 ha. As segregation requirements, a separation distance of 50 m has to be met for pre-basic seed potatoes, whereas for basic seed potatoes 25 m and for certified seed potatoes 10 m are sufficient.

Germany

210 potato varieties are listed in the German national catalogue. However, only a limited number of these are grown in the field. Information in respect to fertility of these varieties is not given in the catalogue. According to the German potato breeders about 30% of the actual potato varieties are sterile. The proportion of sterile varieties is particularly high in starch potatoes.

In 2014, the demand for seed potatoes represented about 0.55 million ha. Around 70 – 75% of these are produced in Germany. For seed potato production, contracts between breeders and farmers are closed. Breeders clearly describe the obligatory production management in annual newsletters. In addition, legal regulation from the German seed marketing act, plant certification, and plant breeders' rights have to be taken into account. It is important to note that only about 50% of seed potatoes in commercial production are certified seed, the other 50% being farm saved seed.

Greece

The current National Catalogue of Greece contains 18 potato varieties which are all fertile. The National production of certified seed potatoes (4-year average, 2012-2015) is approximately 1.191 t.

According to Greek Legislation (Ministerial Decision 276357/29-07-2002, National Gazette 1020/05-08-2002: "Technical Regulation for the certification and control of potato propagating material for cultivation"), the field requirements for seed potato are:

for basic seed potato production:

- 10m distance for potato cultivation for consumption
- 5m distance from seed potato crop of lower class
- 3m distance from seed potato crop of another variety of the same class
- one skip row to seed potato crop of the same variety and class.

for certified seed potato production:

- 10m distance for potato cultivation for consumption
- 2m distance from seed potato crop of another variety of the same class
- one skip row to seed potato crop of the same variety and class.

In Greece, commercial potato production relies 100% on certified seeds. However, there are also growers who cultivate potatoes for their own use and possibly save seed potatoes for next cultivation. Since these growers are not registered, the kind and quantity of seed potatoes cannot be controlled.

Hungary

There are 60 potato varieties on the Hungarian National Catalogue. While ware potatoes were produced on 18.000 ha in 2015 with a total yield of 412.000 t, 32 varieties are grown for seed multiplication purposes on 181 ha. Approximately only 15% of the ware potato production relies on certified seed potatoes.

There is a 200 m isolation applied between seed potato and ware potato production on the field to protect crops from aphids transmitted virus infections. Each field is inspected at least 4 times a year, and each potato field is tested for quarantine pests.

Lithuania

In 2016, 22 potato varieties were included in the Lithuanian list of plant varieties. The quantity of certified seed potatoes grown in Lithuania during the last five years ranged between about 2,800 t in 2015 and 3,200 t in 2011. In 2015, approximately 2,800 t of seed potatoes were produced. Segregation requirements for propagation of seed potatoes were established in the Order of the Minister for Agriculture ("Concerning Mandatory Requirements on Seed Potatoes Intended for Placing on the Market", 2015 December 18, No. 3D-938).

The Netherlands

In the Netherlands, there were 511 consumption and 77 starch varieties on the national list in 2016. No information is available about the fertility of the registered varieties. Some information is presented in cultivation manuals pointing out profuse berry production e.g. by the varieties Désirée, Hansa, Morene, Saturna, and Van Gogh, whereas poor berry formation is described in, for example, the variety Bintje. In 2014, 1,475,000 t of seed potatoes were produced in the Netherlands (~70% for export) on an area of 39,874 ha. 38,626 ha were inspected and 1,083,000 t certified by the inspection service NAK (The Dutch General Inspection Service). As segregation requirement for propagation of seed potatoes, a separation distance of 3 m to other potato cultivations has to be met. About 10% of the starch potatoes are grown from farm-saved seeds (one round of multiplication).

Spain

Most of the potato varieties grown in Spain are registered in the European Common Catalogue, but not in the Spanish Catalogue. Around 40,000 t of seed potatoes are produced on an area of 2,300 ha. Around 75% of seed potatoes are certified seed and 25% farm saved seed.

United Kingdom

In 2015 there were 183 varieties on the UK National List. The most popular variety in terms of production is Maris Piper (a main crop multipurpose variety), accounting for around 15% of planted area in 2015. This is followed by Markies (a popular variety for chipping) at around 6%.

4.2. Potential admixing during cultivation

4.2.1. Outcrossing to wild relatives

Numerous biological and geographical obstacles make gene flow from cultivated potato varieties to the two wild relatives in Europe, *S. nigrum* and *S. dulcamara,* a highly unlikely occurrence, and there have been no reports that such crosses have ever occurred naturally (Love, 1994; Spooner et al., 2004). In most parts of the world, no *Solanum* species from the section *Petota* with a ploidy level and an endosperm balance number (EBN) of 2 or 4 will occur next to cultivated tetraploid *S. tuberosum* subsp. *tuberosum*. Crosses are therefore not likely, due to geographical isolation. Only in the southern United States and South America do potential crossing partners with a suitable EBN occur next to cultivated tetraploid *S. tuberosum* subsp. *tuberosum*. (OECD, 1997; Celis et al., 2004; Scurrah et al., 2008; Capurro et al., 2013).

Within the family *Solanaceae*, potatoes have a number of crop species as relatives, the closest being tomato (*Solanum lycopersicum*), as well as tobacco (*Nicotiana tabacum*), sweet pepper (*Capsicum annuum*) and petunia (*Petunia hybrida*). However *S. tuberosum* is not able to hybridise with any of the non-tuber bearing *Solanum* species outside of the section *Petota* (Conner, 1994; Love, 1994). There is also no evidence to suggest that intergeneric hybridisation can occur between potato and its related crop species (Treu and Emberlin, 2000). Other than potato, there are around 13 species within the genus *Solanum* found in various parts of Europe. Most of these species are introduced casuals, although some, including *S. dulcamara* (bittersweet nightshade) and *S. nigrum* (black nightshade) are native and common. Eijlander and Stiekema (1994) and McPartlan and Dale (1994) found that the cross of tetraploid *S. tuberosum* subsp. *tuberosum* with *S. dulcamara* did not result in any viable seeds and plants. For the cross of *S. nigrum* with *S. tuberosum* the same is valid. Therefore, the natural gene flow from potato to its wild relatives *S. nigrum* and *S. dulcamara* is highly unlikely. Eastham and Sweet (2002) concluded that naturally occurring cross-pollination and subsequent gene flow between potato and its related wild species in Europe is unlikely. Without the help of sophisticated embryo rescue techniques no viable hybrids between cultivated potato and its related wild species in Europe have been obtained. Also, it is likely, given the breeding barriers known within the genus that even if cross-pollination was successful, strong post-zygotic barriers would prevent the formation of a viable hybrid (DoE, 1994).

4.2.2. Outcrossing between GM and non-GM potato

Cross-pollination between fields of potatoes may be less significant than in some other crops since the potato tuber as a harvest product is not affected by the fertilisation of the plant with foreign pollen. Furthermore, the crop is almost exclusively sown with seed tubers rather than true seeds (Treu and Emberlin, 2000).

Outcrossing has primarily been observed to occur between adjacent plants and the rate of outcrossing decreases rapidly thereafter, with only small rates observed beyond 4.5 m (Conner, 1993; Dale et al., 1992; McPartlan and Dale, 1994; Tynan et al., 1990).

Tynan et al. (1990) measured outcrossing using a gene encoding a chlorsulfuron-insensitive form of acetolactate synthase as a selectable marker. They found that within the plot with marked potatoes, 1.14% of seedlings were resistant to chlorsulfuron, while between 0-1.5 m from the trial, only 0.03% of seedlings were resistant. At a distance of 1.5-3 m and 3-4.5 m, 0.05% of seedlings were resistant. No resistance was detected beyond 4.5 m.

McPartlan and Dale (1994) carried out a similar field experiment using the variety 'Désirée' transformed for herbicide tolerance. A central 20 m x 20 m plot of the transgenic potato plants was established, with non-transgenic sub-plots planted in four directions from the central plot at distances of 0 to 20 m. The frequencies of herbicide tolerant seedlings obtained from the non-transgenic potato plants were 2% in a distance of 3 m, 0.017% in case of 10 m distance, and 0% in a distance of 20 m.

In a study by Skogsmyr (1994) much higher rates of outcrossing using the variety Désirée transformed with the *npt*II and GUS marker genes as the pollen donor and Stina as the pollen receptor were observed. Rates were 72% at a distance of 0-1 m and 31% at 1,000 m. The authors attributed the high rates of outcrossing observed in this study to the behaviour of the predominant pollinator species found in the plots, the pollen beetle *Meligethes aeneus*, which tends to move together in large numbers and fly over large distances (Skogsmyr, 1994). This research was scrutinised by Conner and Dale (1996) who concluded that there had been a large number of false positives during the PCR analysis of the *nptII* marker gene, giving the impression of high levels of gene dispersal. They collected outcrossing data from several field experiments with genetically modified potatoes, performed in New Zealand, the United Kingdom, and Sweden. In none of these studies was outcrossing detected when the pollen-receiving plants were separated by more than 20 metres from the genetically modified plants.

Another study from seven field-test sites over six seasons screened a total of over 1.3 million progenies from non-transgenic pollen-trap buffer rows (Erasmuson et al., 2005; Conner, 2006). The accuracy of this phenotypic screening was verified by PCR. In the buffer row immediately adjacent to the donor plot, the frequency of transgenic progeny ranged from 0.007 to 0.059% and declined to between 0 and 0.005% at the third buffer row from the field trial, representing a distance of 2.25 m.

Petti et al. (2007) also found higher rates of outcrossing between the varieties Désirée and British Queen, due to the latter's male sterility. Using a microsatellite marker system, they found evidence of out-crossing at the maximum distance studied of 21 m, but with very low frequency (23 germinating seeds from 140 berries).

Capurro et al. (2013) examined pollen mediated gene flow from a commercial potato cultivar to the compatible cloned genotype of the related wild potato *S. chacoense* Bitter in a field experiment in Argentina. Berry formation with hybrid seeds occurred at 30 m from the pollen source (1 out of 69 harvested berries contained 3 hybrid seeds). In another study outcrossing was investigated using a male fertile commercial potato cultivar as pollen donor and a male sterile cultivar as pollen recipient (Capurro et al., 2014). Three berries with seeds were collected from plants at a distance of 40 m from the pollen source; these contained 21, 22 and 70 seeds/berry, respectively. However, again a quantification of the results is difficult.

The extent of pollen dispersal undoubtedly varies with cultivar, climatic conditions during flowering and presence and frequency of pollination vectors. The majority of field studies have detected potato pollen at a maximum distance of about 20 m from the source (Eastham and Sweet, 2002).

Because potato is planted with seed tubers rather than true seed, any GM contaminant would not be transmitted to progeny crops (Eastham and Sweet, 2002).

4.2.3. Insect impact on cross-pollination

Cross-breeding and selfing is enhanced by some insects. In particular bumblebees (e.g. *Bombus funebris* Smith and *B. impatiens* Cresson) are good pollinators for potatoes (White, 1983). Potatoes possess apically dehiscent anthers that only disperse pollen to bees that vibrate the anthers to collect it (Roulston et al., 2000). This specific plant-bee mechanism is called "buzz pollination" (Buchmann and Hurley, 1978; Buchmann, 1983), meaning bees use their thoracic muscles to produce very high frequency vibrations that expels pollen from the anthers. Moreover, bumblebees preferentially visit the flowers of potato cultivars that produce viable pollen grains instead of cultivars that produce primarily unviable, shrunken pollen grains (Batra, 1993). Since potato flowers do not produce nectar, honeybees (*Apis mellifera* L.) and *Bombus fervidus* Fabricius are not pollinators of potato (Sanford and Hanneman, 1981). Moreover, honeybees do not practice buzz pollination and it is likely for this reason that they are uninterested in *S. tuberosum* flowers (Sanford and Hanneman, 1981).

It was observed that bumblebees are more likely to visit plants at the edges of plots as opposed to their centres, allowing them to stay closer to their nests (Batra, 1993; Free and Butler, 1959; McPartlan and Dale, 1994). Highest levels of berry formation were also recorded at the edges of plots, compared with the centre, suggesting that bumblebee activity was a contributing factor to pollination. Bumblebees will selectively visit different potato cultivars, preferring those with fertile pollen (Arndt et al., 1990; Batra, 1993; Sanford and Hanneman, 1981).

Besides Hymenoptera, the pollen beetle species *Meligethes aeneus* Fabricius has also been observed to transfer potato pollen in Europe (Petti et al., 2007; Skogsmyr, 1994).

4.2.4. Volunteers

The presence of volunteer potatoes and the resultant problems in crop rotations have been recognised for almost 80 years (Bonde, 1942; Fernow, 1959) and are the subject of continual research efforts. Volunteer potatoes appear to occur in virtually all crops to a greater or lesser extent on all farms where potatoes have been grown in the rotation (Askew, 1993).

S. tuberosum volunteers may develop either from true potato seed or from tubers that are left behind following harvest

(Andersson and de Vicente, 2010). While many potato cultivars are partially or fully sterile and rarely produce fruits, some cultivars are capable of prolific fruit and seed production. The amount of true potato seed produced in a given crop will depend on the cultivar as well as environmental conditions, particularly photoperiod, temperature, plant density, and nitrogen supply (Askew, 1993; Struik, 2007). However, the early growth of seedlings from true potato seed is slow compared to that of plants growing from tubers, and daughter tubers are generally smaller as well (Pérombelon, 1975; Rowell et al., 1986). Therefore, the majority of volunteer potato plants originate from tubers (Bond et al., 2007).

Most potato volunteers are the result of harvesting methods of commercial potato production, and the fact that potatoes keep on producing a magnitude of small tubers which are not picked up by commercial harvesters or are lost in the process of loading and transport of the harvest. The number of potato tubers left on top of the soil or up to 20 cm underground following harvest varies greatly and ranges approximately between 20,000 and 460,000 tubers/ha (Lutman, 1977; Kempen et al., 2005, Pérombelon, 1975; Steiner et al., 2005), with most of these tubers being small in size. Due to this great variability, the exact effect of this phenomenon on different following crops is unpredictable. Moreover, the small size of some of the viable tubers results in an underestimation of tuber volunteers as they may not have been identified (Askew and Struik, 2007). Rahman (1980) reported 367,000 tubers per hectare; this corresponds to 10% of the potential yield or 1 – 4 t/ha and represents a total potential population of 2 to 30 volunteer potato plants per m^2 (20,000 to 300,000 plants per ha). Phelan et al. (2015) reported an average post-harvest tuber loss of 141,758±911 tubers per ha, with a maximum of 210,513±973 and a minimum of 39,082±669. As a consequence, volunteer establishment in the following crop ranged from 400±59 plants per ha to 55,698±47 plants per ha. These data correlate quite well with previously reported values by Andersson and de Vicente (2010) of up to 20% of tubers left in the soil being able to sprout in the next season. The persistence of viable daughter tubers as small as one centimetre in diameter is an exacerbating factor in volunteer management.

In areas with mild winters, it is estimated that it may take up to 4 – 5 years to get rid of *S. tuberosum* volunteers grown from daughter tubers in most arable crops (Makepeace and Holroyd, 1978).

Tubers on top of the soil and up to 10 cm below the surface are often exposed to low temperatures during winter and are killed by temperatures below -2°C, but the deeper tubers may be insulated from the cold by the soil. These findings are further influenced by snowfall, stubble and soil cover crops which all serve as insulation. Under Finnish conditions all potato tubers planted at soil depths of 10 and 20 cm were killed by frost during two out of three winters. However, in one winter when the field was covered with 30-40 cm of snow and the soil temperature ranged between -0.4 and -0.9°C up to 3.5% of tubers survived (Mustonen et al., 2009).

Under Canadian conditions potato plants will not proliferate and become established as weeds; volunteers were detected just periodically near animal feed lots, waste disposal sites or in the vicinity of production sites (Anonymous, 1996). The restriction to such habitats in Europe would seem consistent with the findings of Evenhuis and Zadoks (1991), who assert that this is caused by the limited competitiveness of *S. tuberosum*. *S. tuberosum* is not a primary coloniser in unmanaged ecosystems, and seedlings do not tend to compete successfully with plants of a similar type for space (Anonymous, 1996). However, research on the subject should continue to ensure new varieties do not lead to an increase in feralisation (Treu and Emberlin, 2000). Therefore, although *S. tuberosum* can be cultivated throughout Europe, it is unlikely to grow outside of cultivation areas (Holm et al, 1979; Muenscher, 1980; Love, 1994; OECD, 1997). Potatoes are not known to escape from fields (become feral) or show weedy potential.

4.2.5. Volunteer management

Volunteer potatoes affect crop production in four ways (Petti et al., 2007; Kim et al., 2010):

- competition with the following crop;
- transmission of pests and diseases to the next crop;
- the contamination of the succeeding crop during crop rotation; and
- possible spread of transgenic material to other potato plants through pollen or seed.

The potato tuber is a living organism and can thus protect spores or eggs of pathogens and their vectors until the next season. Even if disease is not a problem for the follow-on crop, the persistence with which volunteer potato tubers can reproduce year after year in the soil can lead to the next potato crop and in some cases also neighbouring potato crops to be seriously infected with a pest or disease (e.g. *Phytophtora*). These pests and diseases can not only have a direct effect on yield, but cause problems during storage after harvest as well. Like volunteer potato tubers, volunteer potato plants can also act as hosts for insect vectors, especially aphids that commonly carry plant pathogenic viruses (Thomas and Smith, 1983). For these reasons, farmers usually grow potatoes only every third or fourth year within a crop rotation.

Although this practice may prevent the carryover of potato diseases to healthy plants in the following season, there is still the competition of volunteer potatoes with the following crop for water, nutrients and light leading to lower yields. The more volunteers appear, the larger is the effect on the yield of the successive crop. Therefore, it is imperative that volunteers are controlled as quickly as possible within a crop rotation. Additionally, if volunteer potato plants are not controlled, they can regenerate within the rotation crops so that they ultimately carry over to contaminate the following potato crop. Therefore, controlling these plants is very important, but also difficult, and can only be achieved successfully using integrated management methods.

Potato tubers have a fairly low frost tolerance; shallow tubers and those exposed to the surface are often destroyed by frost. In regions with subzero temperatures during winter, delayed or no ploughing during the preparation for the next crop contributes to volunteer reduction. By ploughing deeper, buried tubers can be lifted up and be exposed to lethal frost temperatures (Thomas and Smith, 1983). Soil cultivation like ploughing can also transfer tubers deeper into the soil, and thereby protecting them against freezing (Boydston et al., 2006). In temperate climates up to 20% of tubers left in the soil show no dormancy and will sprout in the next season (Andersson and de Vicente, 2010). Soil temperatures below -2.8°C have been shown to result in significant tuber mortality (Boydston et al., 2006). Thus, in areas where *S. tuberosum* is grown commercially, the measures required to control *S. tuberosum* volunteers do not differ from the cultural and pest management practices that are usually applied in a crop rotation.

However, several methods of volunteer management have been developed and it has to be decided on a regional scale which ones are most appropriate. In general, it is better to follow a holistic, multi-pronged, management approach to face this problem.

There are basically five approaches that can be used to manage volunteer potato plants: preventative, cultural, mechanical, biological, and chemical. Preventative management is used to avoid the introduction of volunteer tubers to a field, so focussing on the cause of the problem. Cultural management relies on the use of cropping practices to either reduce the occurrence of the problem, or to create an environment that is less suitable for the survival of the volunteer potato plants. For example, plants that are very competitive with potatoes can be used in the rotation system, planning the rotation system in such a way that suitable herbicides can be applied without damage to subsequent crops. Mechanical management relies on the use of farming equipment to either remove or destroy the tubers or volunteer potato plants mechanically before they can create a major problem. An example of such a mechanical management is shallow tillage following harvest. Biological management relies on living organisms, such as natural enemies in order to suppress volunteer potato plants. Most commonly, chemical management methods are used to control weeds of any type. In order to control volunteer potatoes, this might include the use of suitable herbicides and soil fumigants within the rotation crops to kill the potato plants, as well as sprout inhibitors to prevent tubers from sprouting.

All of these methods should be considered in a collaborative approach in order to be able to successfully address the problem of managing volunteer potatoes (Steiner et al., 2005). It should be kept in mind that agronomic practices and pest control measures have to be site specific and adapted to potato cultivation and crop rotation.

Some varieties of potato are capable of producing large numbers of true seed as well as tubers if not controlled, and although the main volunteer problems are caused by the tubers, germinating seeds can also cause problems if plants are allowed to form seed. Since no single method is fully effective for controlling *S. tuberosum* volunteers, an integrated weed management approach is recommended.

4.2.5.1. *Preventative management*

Preventative management is one of the most cost effective measures for controlling volunteer potatoes. These strategies consist of any measure that reduces the number of tubers that remain behind in the field following harvest, and can easily be incorporated into a holistic approach to volunteer potato management. According to Steiner et al. (2005) the management procedures that are applicable to prevent volunteer potato plants emergence are harvester management, proper harvest time (e.g. plants have to be completely dead rather than still green), and the use of a sprout inhibitor. In some cases these procedures need to be coupled with the agronomic management of the crop.

During mechanical harvest smaller tubers stay in the soil or on the surface, medium tubers are mainly lost during the harvesting process and even large tubers can fall from the harvester and transport vehicles. Hand weeding during or after harvesting is an effective, although time-consuming, method for controlling *S. tuberosum* volunteers, and grazing has also been applied in some countries (Rahman, 1980; Steiner et al., 2005).

Phelan et al. (2015) pointed out that reducing tuber loss at harvest plays a central role for the reduction of volunteer quantity. They further stipulated that reducing the level of harvest loss would require either a re-engineering of the harvester to include an additional mechanism to collect tuber pieces/unsalable tubers or a reversal of current practises towards the removal of all harvested material from the field for processing and grading. As both options have cost implications for the grower, any motivation to pursue either option will only occur in the presence of a financial benefit and/or due to a regulatory decree.

4.2.5.2. *Mechanical control*

During soil preparation for the succeeding crop the soil is disturbed and tubers and tuber pieces will start to germinate and be well established by the time the following crop is planted. Favourable weather conditions in terms of rain and temperature will enhance potato growth (Steiner et al., 2005).

Improving the efficiency of the harvesters at separating tubers from soil would reduce the number of tubers left behind as potential volunteers. Some harvesters have been developed for *S. tuberosum* that retain or crush tubers that would normally be lost during harvest (Rahman, 1980; Steiner et al., 2005). Crushers can be used to destroy tubers, although their efficiency varies with soil type and environmental conditions, and they are not effective for small tubers with a size of 1 cm or less (Rahman, 1980).

Ploughing tends to bury tubers deeper, which will protect them from frost, allowing them to survive longer in times with unfavourable conditions (Lumkes and Beukema, 1973; Rahman, 1980). Tubers at the surface may also be more prone to rotting and their earlier germination allows them to be controlled with pre-planting herbicides. Non-turning soil cultivation or shallow harrowing is therefore recommended (Lumkes and Beukema, 1973; Phelan et al., 2015).

Proper management of the harvesting process reduces the number of lost tubers, which not only results in a reduction of volunteer potatoes in the following season, but also increases yields. According to Steiner et al. (2005) the following steps help to minimise the number of tubers that are lost during harvest:

- The blade depth should be managed in a way to ensure that all tubers are removed from the soil. If the blade is too shallow not all the tubers will be lifted and some will be sliced, so leaving a portion of these tubers behind in the soil. This should be coupled with the agronomic practices to ensure that the earthing up is sufficiently high so that all tubers will develop within the ridge;
- Tubers should be removed from the haulms by the harvester so that they are not carried off of the harvester;
- The trucks that receive the tubers from the harvester should be positioned in a way to prevent spillage;
- Harvesters should be operated in a way to avoid pushing tubers out around the throat of the harvester;
- Soil separation and tuber transport should be maximised by using the optimal ratio of forward speed to chain speed;
- The gaps between the links in the primary chain should be set in a way to reduce the number of tubers that fall through the chain, but this must be compatible with the intended market.

The condition of the potato vines at harvest has been found to play an important role as both premature senescence of vines and green versus dead plants affect the number of tubers that are left in the soil after harvest as well as the depth at which tubers are formed in the soil (Steiner et al., 2005). Agronomic factors such as soil fertility and soil moisture management as well as pest and disease control can contribute to premature vine senescence. Plants that senesce early produce a greater percentage of small tubers than those plants that mature later, and therefore more tubers will remain behind on the field at harvest. Additionally, plants that are still green at harvest and must be defoliated prior to harvest, produce more large tubers than dead plants at harvest. Steiner et al. (2005) state that in the Washington state area of the USA the numbers and sizes of tubers from green plants are double that harvested from dead plants.

In a study carried out in Washington it was found that 75% of the tubers were within 10 cm of the soil surface if plants were still green at harvest in contrast to only 34.2% if plants were already dead (Steiner et al., 2005).

As sprouts from tubers buried as deeply as 20 cm below the soil surface still can emerge, it is crucial that the harvester is able to reach this depth to catch all those tubers. This should be combined with ridge planting.

In the northern climatic conditions mid-winter and early spring ploughing can bring buried tubers to the surface and expose them to low temperatures. This may be combined with fumigation and sprout inhibiting hormone treatment. In some cases animals were released into the fields to graze, but this has to be handled with care (Thomas and Smith, 1983).

Mechanical control has proven to be far more effective when it followed the application of herbicides (Allemann and Allemann, 2013). The efficiency of all herbicide treatments can be improved by combining them with a tillage operation (Boydston and Seymore, 2002).

4.2.5.3. *Chemical control*

A seed potato usually provides enough nutrients for 30 days of growth. The smaller the tuber and the deeper it is buried in the soil, the smaller the chance that the stem will emerge. It normally takes between 10 and 20 days for the above-ground parts to produce enough photosynthates to become independent of the tuber. At this stage the plant is most sensitive to herbicides as few if any daughter tubers will have already been formed (Colquhoun, 2006).

Volunteer potato plants are very difficult to eradicate using herbicides, with most products tested proving to be either ineffective or only partially effective at best (Rahman, 1980). The greatest problem is caused by the biology of the potato tuber, as large food reserves available in the parent tuber, coupled with a number of adventitious buds that can sprout after the death of the apical sprout, enable recovery from damage that would be lethal to most other plants. The problem is further compounded by the variation in the time of emergence of volunteer potato plants. Potato volunteer emergence usually takes place long after many crops have been planted, which makes application of many post-emergence (foliage-applied or contact) products very difficult to time correctly to obtain good control (Lutman, 1977). As contact herbicides will only affect the plant parts they come into contact with, the parent and/or daughter tuber is able to produce new sprouts which then emerge long after the primary plants have been killed (Rahman, 1980).

The only way to prevent tuber production is through complete shoot removal prior to the shoots initiating tubers.

Use of single conventional herbicides has proven to be unsuccessful in the control of volunteer potatoes. Due to the devastating effect these plants have on succeeding crops such as carrots and onions as well as grains such as maize, various regimes of herbicide combinations have been investigated and limited and varied success has been achieved (Koepke-Hill et al., 2010).

Soil application of herbicide treatment allows tubers to be exposed to the herbicide for a longer period of time, and soil-applied herbicides are readily available for absorption by the roots of developing potato sprouts, so making this an attractive option for control of volunteer potatoes.

One of the biggest advantages of foliage herbicide application (post-emergence) is that the extent of the weed problem is already evident, and spot treatments can be used rather than applying herbicide over the entire field. Generally, post-emergence applications should be considered when the potato plants are starting to initiate tubers on the stolons.

Volunteer potato control of between 80 and 90% was demonstrated in research trials conducted at Michigan State University using 92 g/ha tembotrione or 5 g/ha topramezone (Everman et al., 2010). Tembotrione belongs to the same family as mesotrione but is not persistent in the environment except when present in loamy sands. It has a high mobility in the soil and the potential to leach into ground water, but the relatively rapid rate of biodegradation may alleviate this process (EPA, 2007).

Since 1974, evidence about the efficacy of glyphosate as a post-emergence herbicide on potato has been amassed (Rahman, 1980). This product can be applied prior to planting or after harvest (Steiner et al, 2005). The greatest advantage of this herbicide is that it does not only kill the aerial parts of the plant, but is also translocated to the underground parts, including the early-formed tubers. Field trials demonstrated excellent control of potatoes with application rates in excess of 1 kg/ha, if applied sprouts had fully emerged at the time of treatment.

Boydston (2001) reported that applications of 2, 4-dichlorophenoxyacetic acid (2, 4-D or fluroxypr) can significantly reduce volunteer numbers in follow-on maize crops. However, the study of Phelan et al. (2015) revealed that multiple factors (e.g. machinery performance, timing of application relative to volunteer growth stage, appropriate chemical mix preparation, environmental conditions at time of application) influence herbicide efficacy. In one of their field surveys, fluroxypr applications were found to significantly reduce the number of volunteers in follow-on crops by up to 96%. In another survey the observed reduction of more than 65% in tuber weight in the second year was not found to be related to herbicide usage across the fields.

Considering the information provided on single herbicide applications in conjunction with the biology of volunteer potato plants, it is not surprising that a great deal of research has been conducted on the use of more than one herbicide to control these plants.

Sprout inhibitors are applied mainly to prevent sprouting of tubers during storage of harvested potatoes, but can also be applied to plants at the end of the growing season. This prevents the formation of small unusable tubers, which are often the source of volunteer potato plants. These chemicals inhibit cell division, and should therefore not be applied to seed potato fields or where spray drift can contaminate seed potato fields (Anonymous, 2011). According to Rahman (1980), three chemicals are available that effectively inhibit sprouting in potato tubers: maleic hydrazide (MH), chlorpropham (CIPC [isopropyl N-(3-chlorophenyl) carbamate]) and TCNB (tetrachloro-nitrobenzene). Newberry & Thornton (2007) studied the suppression of volunteer potato emergence with MH and concluded that success is cultivar and tuber-size dependent. Suppression was least in the smallest tuber category. MH treatment reduced emergence of treated tubers in all size categories and all cultivars tested and should be considered for use in integrated weed management plans Phelan et al. (2015) also reported that the application of a sprout suppressant prior to harvesting of potato crops proved a very effective method of volunteer control, with the suppressant eliminating volunteer emergence through two succeeding rotational crops.

Soil fumigation consists of the introduction of a volatile compound into the soil, primarily to suppress nematodes and other soil pathogens in crop rotations (Thomas and Smith, 1983; Boydston and Williams, 2003). A number of products have been tested in potato producing countries for their efficacy against volunteer potatoes, with varying degrees of success. One of the biggest problems is finding a suitable product that fits into the rotation programme used by producers, as many products are capable of controlling volunteer potato plants, but can be phytotoxic to other plants in the rotation system.

It is very important to bear the next crop in the rotation system in mind when choosing a chemical for the control of volunteer potatoes. The reason is that certain products that control volunteer potatoes can have fairly long periods of residual activity in the soil, and have a negative impact on sensitive crops if these are planted while the residual activity of the herbicide is still sufficiently high to cause damage.

4.2.5.4. *Crop rotation*

Crop rotation is mainly used to reduce the pest load from diseases, nematodes and insects (Wright and Bishop, 1981; Thomas, 1983; Steiner et al., 2005) by planting crops not susceptible to those affecting the previous crop. Crop rotation has to be implemented together with cultivation and an integrated weed control programme (Rahman, 1980).

S. tuberosum volunteers do not compete well in cereals and perennial ryegrass, but are a greater problem in vegetable crops, silage maize, sugar beet and subsequent potato crops (Lumkes and Beukema, 1973). A proper rotation can therefore also contribute to minimizing the number of *S. tuberosum* volunteers in subsequent crops. Frequent rotation of other crops with potatoes is recommended in order to increase potato yield and reduce insect and disease pressure, as well as to reduce the population density of weeds (Hopkins, 2010; Seaman, 2013). Farmers are also advised to avoid planting potatoes near fields where potatoes were planted the previous year.

4.3. Extent of mechanical admixture during planting, harvesting, transportation and storage

Management and phytosanitary practices must be in place to minimise the spread of diseases by contact with machinery, tools or with surfaces encountered during planting, harvesting, transport and storage. In addition to the problem of volunteer plants, the risk of accidental admixture exists, which is mainly related to the cleanliness of equipment (counter-rotating planter, calibrator, lorries, etc.) and may be cumulative across production steps.

4.3.1. Planting

Given the size of potatoes, the risk of significant numbers of potatoes remaining in the planter or passing out unnoticed, is very low. Usually, farmers empty planters, leaving the last rows more or less bare. Manual cleaning of the planter can remove the tubers that have been stuck in the machine; this can be done simply and quickly, the planters are relatively small and all parts are accessible.

4.3.2. Harvesting

The risk of admixture during harvesting is higher than at planting due to immediate and delayed consequences. First, the tubers from the previous plot can stay in the harvester; therefore it is necessary to always ensure the cleanliness of the harvester at the end of harvesting a field. The circuit is generally visible and somewhat streamlined, allowing the control and maintenance of the chain. Second, the harvester is equipped with a main grid with mesh sizes of 30-32 mm for potato crops and optionally with grids with a variable mesh dimension according to the particular production requirements (but typically greater). Therefore, tubers with a diameter less than 30 mm are not collected and thus remain in the field. These small tubers and those left in the soil by the harvester are the main source of regrowth. The choice of a suitable calibre mesh can limit these losses.

The collecting, cleaning and initial sorting of the harvested potato is done either simultaneously on the plot or cleaning and/or sorting is carried out on the farm. The chosen practice has different consequences on the risks of admixtures and volunteer appearance.

With a combined harvester (equipped with a hopper), the potato crop is collected, cleaned and sorted simultaneously. Debris and defective tubers in this case are immediately returned to the field.

With a simplified harvester, the collected potatoes are directly discharged into the trailer and sorting takes place on the farm. This second scenario is the one encountered in seed potato production because it minimises health risks and varietal contamination. The total waste (non-marketable tare; composed of earth, stones, vines, stem scraps, defective or damaged tubers and foreign varieties of tubers) is mixed and usually stored as a heap on the edge of land. To promote the destruction of the included tubers, the piles are covered with a tarpaulin, preventing the sprouting of potatoes in the spring. Piles usually end up being spread on land.

Harvested potatoes are continuously sorted at farm, warehouse and processors. The harvesters are commonly equipped with a receiving hopper in which a moving carpet backs up the tubers for the subsequent unearthing and sorting. The sorted tubers are then calibrated by a large table equipped with a series of square mesh grids decreasing in diameter. At each gate, tubers with a diameter greater than the mesh are retained and crated or packed in bins.

4.3.3. Storage, packaging and transportation

Harvested potatoes are first dried for about 15 days. After this intermediate stage, the dried tubers are packaged in bags or boxes and then stored in two different ways:

- The storage can take place in a fridge. After verifying that the lot has not changed and has not degraded during the conservation, tubers are packaged for delivery to the final consumer.
- The storage for shorter time takes place in ventilated stores before bagging, certification and distribution.

The type of packaging depends on the considered market: Jute bag 25 or 50 kg; big bag sealed (from 500 to 1,200 kg) or crate (wooden bins) when the goods are sold from one producer to another. In all cases, the packaging carries a certificate, required for the declaration of goods to control.

Up to 85% of potato crop storage is on farm. Afterwards, storage is undertaken by the industrial site processor, wholesaler or, rarely, by a cooperative.

Required storage conditions depend on the market designation:

- For the fresh market potatoes are put in refrigerated pallet boxes of one to two t.
- For processing and starch production potatoes are stored

in bulk in ventilated stores equipped with partition walls for managing multiple lots.

A final sorting is done before stocking and transport to the place of use (processing, packaging). During storage, which can last up to 6-8 months, the tubers are regularly visited and eventually sorted to remove tubers that have turned green or are rotting. Defective tubers are placed on the waste pile already established at harvest.

In processing plants, waste is mainly controlled after the initial preparation stage, for example sorting is done after washing or peeling. Co-products and waste are especially valued in animal feed and bio-energy production. Preservation comprises a drying or cooling phase and usually is combined with application of a sprout inhibitor (maleic hydrazide); such treatment can be avoided by maintaining a sufficiently low temperature.

Calibration of potatoes can be done at different stages. For the fresh market, a pre-calibration is conducted on the farm. For processing, calibration is less common due to the use of specific varieties for a particular purpose and the associated difficulty to change the intended use.

Unlike storage and bulk transport, the use of boxes (bins), which are small packaging units, can effectively ensure the traceability of production identification with variety-by-variety, plot-by-plot and even intra-plot segmentation. This facilitates maintenance of the local storage and transport trailers and avoids admixture between batches. In some production plants and consumer production manifolds (conservation treated batches), labelling of boxes includes a conspicuous colour code to minimise orientation errors in the handling steps.

Transportation of potatoes encompasses risks of admixtures between products from different fields or different farms, unless the cleanliness of the trailers is ensured. Precaution should be taken by the farmer for transportation from the field to the farm and by the wholesaler for transport outside the farm. The management of potato transportation to the place of use/processing is 95% provided by the wholesaler.

Finally, potato producers are diversifying their markets and therefore the number of varieties simultaneously grown on the farm. However, the tuber size (compared to that of most seeds) and the fact that farmers have their own equipment are likely to facilitate the cleaning of equipment and premises.

In general, it can be concluded that the potato chain is well organised in order to ensure qualitative and pure end-products and also to ensure traceability in case of food safety problems.

5. Existing systems for segregation and identity preservation in potato production in selected EU Member States

The following information was provided by the representatives of the EU Member States in the Technical Working Group (TWG) on potato, and is presented in alphabetical order.

Belgium

Belgium adopted legislation on co-existence of genetically modified crops with conventional and organic farming in 2009. In Belgium, the competence lies at the regional level. The Flemish government issued a general coexistence decree, next to crop-specific regulations for maize (2010), potato (2011) and sugar beet (2011). Besides some administrative regulations, the following crop-specific technical regulations were defined:

- 5 m minimum isolation distance from the border of the GM plot
- A mandatory volunteer control in the three years following the GM potato crop. No tilling allowed for the installation of a crop the same year or the year after
- Separate storage of GM seed potatoes. Unused GM seed potatoes can only be sold or given to registered professional growers. Leftovers of GM seed potatoes that will not be used have to be destroyed, avoiding germination of the seed potatoes
- Traders of GM seed potatoes have to make a register containing data about buyer, amount and selling date of GM seed potatoes
- Mandatory cleaning of machinery after GM potato sowing and harvesting on the plot where GM potatoes were planted and harvested
- Transport and storage of GM potatoes physically separated from non-GM potatoes, with a clear labelling of the GM variety at any time
- Specific regulations for the production of GM seed potatoes can be put in place
- Material derived during cleaning of harvested GM potatoes can only be brought back to a field where during the same production season GM potatoes were grown

In Belgium, no commercial GM potato cultivation took place. In 2011-2012 a single field trial with GM potatoes was carried out to evaluate the resistance of the susceptible potato variety Désirée transformed with single or multiple late blight (R) resistance genes (*Rpi-sto1*, *Rpi-vnt1.1* and a stack of *Rpi-sto1:Rpi-vnt1.1:Rpi-blb3*).

Czech Republic

Based on extensive research and field trials with various GM potato cultivars, coexistence rules were established before GM potato cultivation in the Czech Republic was launched. The Czech Republic coexistence rules are defined by Act on Agriculture no. 252/1997 amended by Act no. 441/2005 and Act 291/2009. Specific rules for the coexistence of GM crops are regulated by Decree no. 89/2006 Coll. on detailed conditions for the cultivation of genetically modified crops amended by Decree no. 58/2010 Coll. An amendment is foreseen to come into force in 2017. All farmers cultivating GM potatoes have to take measures against the mixing of potato tubers. The isolation distance between GM and conventional potatoes is 3 m and 10 m between and along the rows, respectively, considering the width of the planting machine. A minimum of 20 m isolation distance is necessary in case of organic potato production. The Decree imposes an obligation to notify the owner of a neighbouring field if the GM potato field is located at a distance of less than 20 m (conventional potato production) and 40 m (organic potato production).

Additionally, general requirements include:

- a special GM course/education and a license/approval (includes also contractors working on the field and in transport until 1. stage)
- distance to non GM field can be reduced/neglected in agreement with the non-GM neighbour
- information of neighbours about GM cultivation
- information in case of sale or rent of an area where GM crops have been grown
- new owner or leaseholder of an area where GM crops have been grown takes the responsibilities for volunteer control and crop rotation regulations
- cultivation of GM must be reported and a fee (100 kr/ha) has to be paid

Denmark

No GM seed potatoes are grown in Denmark. In the Danish regulation "Bekendtgørelse 1559 of 11/12/2015 the following measures are included for potatoes:

- isolation distance of 20 m to seed potato (15 m if not flowering or male sterile)
- isolation distance of 10 m to commercial potato production (2 m if not flowering or male sterile)
- a minimum of 4 years without potato production after GM potato production (seed potatoes)
- a minimum of 3 years without potato production after GM potato production (commercial potatoes)
- requirements for control of volunteers and cleaning of machinery

Estonia

In Estonia, no GM potatoes are grown or have been grown. However, a coexistence provision is available (legislation, scientific reports etc.; https://www.riigiteataja.ee/en/eli/ee/PÕM/reg/522122014013/consolide).

Germany

In Germany, 72 field trials with transgenic potatoes were carried out in the period 1992 – 2008. In 2010 and 2011, the GM potato variety Amflora was commercially cultivated for seed potato production on an area of 15 and 2 ha, respectively.

Until now, only general coexistence regulations and crop-specific regulations for maize have been adopted but no special coexistence regulations for potato. However, in 2007 an expert hearing was held at the Federal Ministry of Food and Agriculture and recommendations for good farming practice of GM potato cultivation were given based on the available literature and the knowledge about potato biology. These recommendations included:

- an isolation distance of 2 m,

- a reasonable crop rotation for optimal volunteer control (e.g. tillage, herbicide application, but no recommendation for a single specific measure) with at least 2 years potato cultivation break after GM potato production,
- the thorough cleaning of all machines, storage places, and containers and
- the obligation to inform neighbours (not a scientific but a political decision).

Lithuania

In Lithuania, no field trials or commercial cultivation of GM potatoes have been carried out. According to the Order of Minister for Agriculture of the Republic of Lithuania and Minister for the Environment of the Republic of Lithuania of 16 November 2007 (No. 3D-504/D1-608 concerning the Approval of the Rules on Co-existence of Genetically Modified Crops with Conventional and Organic Crops), key elements for potatoes coexistence are:

- 50 m minimum isolation distance between GM potatoes and other Solanaceae family crops
- a 2 years minimum period for conventional or organic potato in crop rotation after GM potatoes
- a mandatory 3 m wide buffer zone around GM potato crops
- a mandatory 2 years volunteer control in crop rotation
- the use of separate machinery or a mandatory cleaning of machinery after GM potato sowing, harvesting and transportation
- the storage of the harvest of GM potatoes separately from conventional and organic potatoes
- a minimum distance of 5 km from GM plants to apiaries

The Netherlands

In the Netherlands, no commercial GM potato production took place and no data review on field trials with relevance to coexistence is available. A cultivation regulation (WJZ/14148909) exists and includes (1) the announcement of plans for GM cultivation by the GM grower to neighbours before February 1st, (2) a minimum isolation distance of 3 m from conventional and 10 m from GM-free potato fields, and (3) all growers to take measures for separating GM at all stages of cultivation, in particular including control of volunteers. These measures are based on the proposal of the Dutch Coexistence Committee in 2004, based on a literature review and summarised in Van de Wiel and Lotz (2006). Recently a proposal for monitoring coexistence in GM potato cultivation was published (Van de Wiel et al., 2015, in Dutch).

Sweden

The production of seed potatoes is regulated according to the EU regulation. Coexistence measures for potato are regulated in the Swedish ordinance 2007:273 and regulation 2008:34. There are several general rules applicable for all GM crops including administrative measures, care during transport and cleaning of equipment. Specific measures for cultivation of GM potato are:

- isolation distance of 3 m to non-GMO potato
- a grower who has cultivated a GM potato variety in a field has, during the two following growing seasons, to inform another grower of the same field about the GM cultivation in the field.

6. Occurrence of potato pollen in honey

van Droogenbroeck et al. (2013) carried out a two-year field trial with late blight-resistant GM potatoes and conducted PCR analysis of honey samples produced within a distance of 5 km from these experimental fields. In all four of the samples no potato pollen was detected. After this initial finding, an additional experiment was set up with five beehives which were placed in different locations of a conventional potato field (in the middle of the field, at the border and at different distances from the potato field), forcing honeybees to overfly the potatoes. The experiment was carried out when the potato variety was in full bloom. As part of the experimental design, visual checks on honeybee visits to potato flowers were carried out as well as mellissopalynological observation by microscopy and PCR analysis of pollen collected by honeybees. Honeybees were not observed on potato flowers at any of the observational inspections. The observed insects on potato flowers were mainly hoverflies and to a lesser extent butterflies, beetles, bugs and bumblebees. The mellissopalynological analysis of the pollen collected by honeybees placed inside potato fields revealed that it was from the families *Asteraceae*, *Fabaceae*, *Castaneae*, *Geranicaceae*, *Malvaceae*, *Brassicaceae*, *Poaceae* and a limited number of other plant families, but not from potatoes. The potato-specific DNA analysis led to the same conclusion as the visual observations and microscopic pollen analysis. No evidence could be found that honeybees visit potato flowers and collect the pollen.

Jørgensen et al. (2012) studied the pollen availability for honeybees in an agricultural landscape. Denmark has the world's most intensive agricultural landscape. More than 60% of Denmark is arable land of which 92% is under crop rotation. This agricultural landscape, for some periods of the season, provides an abundant nectar and pollen source, but at other periods the landscape is a virtual desert for honeybees and other beneficial insects. The nectar flow stops normally mid-July as the main crops are winter wheat, maize, sugar beets and potatoes. In these conditions it has been shown that potatoes are an important pollen source in some areas with intensive production of potatoes for industry, and that potato pollen could comprise up to 29% of the pollen collected by honey bees.

The differences in findings of these two studies (Van Droogenbroeck et al., 2013, Jørgensen et al., 2012) are in fact in line with pre-existing knowledge about the interaction between honeybees and potatoes. Under natural conditions with different pollen sources available, honeybees are not interested in collecting potato pollen (Van Droogenbroeck et al., 2013). However, as a starvation response, in conditions lacking a pollen supply, honeybees can collect potato pollen as a source for colony survival (Jørgensen et al., 2012). Logically, this stimulus is very powerful and has long-lasting effects (Sanford and Hanneman, 1981). However, in such extreme conditions it is likely that honeybee colonies produce honey that contains potato pollen.

7. Detection of GM events in potato harvest and honey

The European Union Reference Laboratory for GM food and feed (EU-RL GMFF) validated a quantitative PCR method for the detection of potato event EH92-527-1 (starch potato Amflora). For potato event AM04-1020 (starch potato Amadea) a method was validated but not published due to withdrawal of application, and for the potato events PH048 and AV 43-6-G7 the validation was ongoing but not completed due to the withdrawal of the applications.

More PCR methods for identification and quantification of several other GM potato events can be found in the EU Database of Reference Methods[10] maintained by the Joint Research Centre in collaboration with the European Network of GMO Laboratories (ENGL).

When the results are primarily expressed as GM-DNA copy numbers, in most cases they need to be converted into mass fraction or vice versa. This ratio may depend on the number of copies of the transgene that were inserted in the GM crop's genome during transformation, and on the relative amounts of embryo, endosperm and maternal tissue in the case of true seeds (Holst-Jensen et al., 2003; Miraglia et al., 2004; Van De Wiel and Lotz, 2006 and Le Ny et al., 2011). The endosperm in most cases is derived from a fusion of two maternal nuclei and one sperm nucleus, and therefore contains two maternal genomes for each paternal genome. Using the real-time PCR method with the tetraploid potato, outcrossing results will be multiplied by a conversion factor of 0.25 from a number of tubers or plants with a quantity of DNA, since a single chromosome of quadruplet chromosome counterparts will cause the sequence established in the case of a simple transformation event. This factor needs to be adapted on a case-by-case basis, depending on the number of copies or the number of the transgenes inserted in the case of transgenes of stacked genes (Le Ny et al., 2011).

At the current state of the art of the technology, a practical and robust PCR protocol able to quantify GM pollen relative to total pollen in honey is not available. The reason is that in all honeys, even if classified as unifloral, the pollen fraction consists of pollen from several species (for details please refer to Rizov and Rodríguez-Cerezo, 2013).

10 http://gmo-crl.jrc.ec.europa.eu/gmomethods/.

8. Best practices for coexistence in potato crop production

8.1. Scientific background

The adventitious admixture of GM potato in non-GM harvests can only be efficiently managed if the whole production chain is covered. Also, because in some EU Member States fields are often rented by different farmers, the practice of 'coexistence within a given field' (meaning the cultivation of non-GM potatoes after growing GM potatoes in a given field) must be taken into account. Summarizing the aforementioned information in the preceding chapters, the following aspects are most important for coexistence considerations and the proposal of coexistence regulations.

(1) The use of good quality seed potatoes is important to successfully grow potatoes. Therefore the presence of GM seed potatoes in conventional seed potato lots is a critical factor and must be appropriately managed to achieve coexistence. The best approach to manage this is the use of certified seed potatoes that comply with EU regulations. Seed production, whilst being a very important factor, is not included in this work as it is already covered by EU requirements to ensure varietal purity.

(2) Due to the clonal propagation and low pollen transmission distances in potato, the potential for pollen-mediated gene flow from potato production systems to challenge the coexistence threshold in adjacent potato fields is regarded as negligible (Petti et al., 2007).

Isolation distances (buffer zones) are not only required to limit cross-pollination, but also to avoid the spread of potato volunteers caused by field work, machinery utilization, and probably animal and bird activities. The efficiency of the isolation distances (buffer zones) in potatoes is mainly determined by existing agricultural practices and differences in flower abundance among the cultivars. The available information from literature and current practices (e.g. in potato breeding) shows that, in order to limit adventitious GM presence caused by spatial dispersal of GM reproductive material (including pollen, tubers, and true potato seed) to 0.9%, 5 m between the fields is enough; in order to limit adventitious GM presence to 0.1%, 10 m isolation is sufficient.

(3) The rare occurrence of feral potatoes in the EU, the infrequency of potato seed production and high percentage of self-pollination probably mean that feral plants present little or no risk of acting either as a GM pollen source or as recipient.

(4) The field-to-field coexistence, where GM and non-GM potatoes are grown in adjacent fields at the same time has, no direct impact on the harvested crop during one cultivation cycle, since cross- pollination does not affect the harvested parts (tubers) of the potato plant. How-

ever, where the consecutive cultivation of GM and non-GM potatoes is carried out in the same field, an effective volunteer control strategy is important for coexistence (Phelan et al., 2015; Turley, 2001). For quantification of this recommendation, the authors used the Irish potato production figures from 2007 to 2010, which indicated a mean number of 339,533 (±30,721) tubers harvested per hectare. Imposing the labelling coexistence threshold of 0.9% would imply that the number of volunteer-derived tubers should not exceed 3,058 per hectare. While the study of Phelan et al. (2015) did not go beyond examining the fecundity of second generation volunteer-derived tubers, they refer to a previous report of McGill et al. (2005) recommending a minimum of three different crops in rotation before a conventional potato cultivar could be sown on a field that was previously used for GM potato cultivation. Due to short growing seasons and hard winters, the number of required rotations might be lower in northernmost EU Member States.

(5) The replacement of isolation distances by temporal isolation, meaning planting GM and non-GM potato varieties of different maturity classes, may be an effective measure in the case of appropriate climatic conditions; although scientific data proving this assumption could not be found. However, farmers in some Member States, as well as certain regions within a given Member State, are often specialised in cultivation of early or late potatoes, hence this within-year type of temporal isolation may not always be feasible.

(6) Since seed potatoes are bigger than seeds of other crops, cleaning of machines and transport bins as well as storage places is usually easier. Harvesting is the most critical step in potato cultivation, since harvesters are in general a primary source of on-farm comingling. Additionally, lost tubers and tuber pieces may act as volunteers in following years mainly within a given field.

(7) The current practices in honey production and marketing in Europe are sufficient to ensure that adventitious presence of GM potato pollen in honey is far below the legal labelling thresholds and even below 0.1%, as was concluded in the Best Practice Document for coexistence of GM maize and honey production (Rizov and Rodríguez-Cerezo, 2013). Therefore, there is no need for additional spatial segregation between GM potato fields and beehives.

Based on this scientific information, the TWG on potato analysed the possible sources for potential GM admixture in potato crop production and agreed on the following best practices for the coexistence of GM and non-GM potato cultivation as well as honey production. The thresholds for coexistence which were considered are the legal labelling threshold (of 0.9%) and the limit of quantification (generally accepted to be about 0.1% for routine analysis using PCR-based testing), which is required by operators in some markets. These two different coexistence thresholds are in line with the Commission Recommendation of 13 July 2010 on guidelines for the development of national coexistence measures.

It is suggested that the current practice of potato production allows respecting the 0.9% labelling threshold for adventitious GM admixture (Le Ny et al., 2011). Conversely, it is suggested that maintenance of an adventitious presence of GM below 0.1% instead requires the implementation of specific coexistence measures for potato production and distribution, even if low varietal purity thresholds are obeyed.

8.2. Best practices for ensuring seed potato purity

The use of certified seed potatoes that comply with EU legislation is considered best practice since according to EU legislation any seed lot containing traces of GM material needs to be labelled and therefore can be easily identified.

In the case of cultivation of both GM and non-GM varieties on the same farm, the seed potatoes of GM varieties should be transported to the farm and stored upon arrival in their original packaging, and separately from non-GM varieties. Label information should be retained with the seed potatoes.

8.3. Best practices for coexistence

8.3.1. Isolation distances

Isolation distances are feasible and effective coexistence measures to reduce adventitious presence of GM potato in conventionally and organically produced potato even if they are the only measure applied. All available information from the literature and pre-existing segregation systems shows that to limit adventitious GM presence caused by cross-pollination to 0.9%, a 5 m isolation distance is required. To achieve a threshold of 0.1%, a 10 m isolation distance is sufficient.

8.3.2. Sowing, harvesting, drying and storage on farm

To achieve the 0.9% GM threshold, separate treatment and storage of GM potatoes (including seed potatoes) are required; planting and harvesting machines should be properly cleaned before and after use, preferably on the plot where GM potatoes are handled. The storage space must be thoroughly cleaned and inspected after emptying of GM tubers and prior to storing of non-GM tubers. Ancillary plant material collected during cleaning of harvested GM potatoes should be properly destroyed. For achieving a GM threshold of 0.1%, in addition to the requirements for 0.9%, machinery should be dedicated to planting and harvesting either GM or non-GM potatoes.

The definition of specific recommendations for cleanout depends on type of the equipment and its construction. Additionally, choosing the appropriate technique for equipment cleaning should be based on the desired level of purity. In general, the use of dedicated equipment for different production systems (GM or non-GM) or its use for non-GM crops prior to GM crops is recommended.

8.3.3. Volunteer control

For a GM threshold of 0.9%, a cultivation break of three years in rotation is recommended, followed by monitoring of GM potato presence during the third year. If the amount of volunteers does not fall below the expected threshold, this period should be prolonged by another year of cultivation break followed by a further inspection of GM potato presence. This step may be substituted or complemented by a sprout inhibitor application followed by monitoring of its efficacy. This field inspection should be repeated until the required volunteer level is achieved to meet the threshold of 0.9%.

For a threshold of 0.1%, a cultivation break of four years in rotation is recommended, followed by a control check of GM potato presence during the fourth year. The optimization of the crop rotation shall follow the same systematics as for achieving a threshold of 0.9%, again with the option of the complementary use of a sprout inhibitor. This approach for crop rotation optimization has been chosen since the required cultivation break between GM and non-GM potato is highly dependent on the climatic conditions, and which can vary significantly between Member States.

8.3.4. Coexistence with honey production

There is no available empirical data to establish a statistical relationship between potato pollen content in honey and distance of beehives to potato crops. Potato pollen is not a major fraction of total pollen in polyfloral honey. In any case, considering the maximum pollen content (number of grains) in commercial honey and the average weight of potato pollen grains, the weight fraction of potato pollen in honey will definitely be below 0.1%.

In conclusion, the current practices in honey production and marketing in Europe in line with quality legislation are sufficient to ensure that the adventitious presence of GM potato pollen in honey is far below the legal labelling threshold and even below 0.1%.

8.3.5. GM detection and quantification

For detection and quantification of GM potato presence including GM potato pollen in honey, only quantitative PCR-based approaches such as EU-RL GMFF validated methods should be used.

9. Cost analysis of the management practices

In contrast to the crop species covered in the preceding Best Practice Documents of genetically modified maize, soybean, and cotton with conventional and organic farming (Czarnak-Kłos and Rodríguez-Cerezo, 2010; Rizov and Rodríguez-Cerezo, 2015), GM potato has not been grown commercially worldwide since 2001. Until that time, Monsanto sold insect resistant GM potato varieties, but consumer rejection has kept GM potatoes off the global market since then. Nowadays, the focus lies on late blight resistance, resistance to bruising and reduction of asparagine, an amino acid in potato that reacts with some sugars to oxidise into acrylamide, a possible carcinogen, especially during high-temperature frying (CBAN, 2016). However, with the exception of 160 ha in the US in 2015 these new GM potatoes called the "Innate" potato from the company Simplot were not planted anywhere in the world (ISAAA, 2016). For this reason, information about economic consequences of coexistence in potatoes along the whole value chain is extremely scarce.

Additional costs may result from minimizing unintended mixing during planting, harvest, on-farm storage, transportation, storage, processing and other activities beyond the farm gate such as shipment testing and labelling costs (Greene et al., 2016). However, USDA has not collected data on the cost of separation practices, but the environmental non-profit and organic grain cooperative Food and Water Watch estimated these costs by a survey of 1,500 U.S. organic grain producers representing about 19% of the farmers mainly from the Midwest (Food & Water Watch and OFARM, 2014). For grain production, the total median annual cost of practices to avoid GM material in their crops was $6,532 to $8,500 per farm, including the cost of buffer strips ($2,500), delayed planting ($3,312 to $5,280), testing ($200), and other measures ($520). However, only additional costs per farm are indicated and not the costs for a special field, field size or crop species. Since GM potatoes are only recently being grown commercially in the US on a small scale, the transferability to potato is not given. Tolstrup et al. (2003) evaluated the extra costs of complying with a given threshold value for adventitious presence of GM material in conventional or organic potatoes under Danish production conditions. Calculated extra costs amounted to 1-2% of average growing costs per ha for both conventional and organic production and arose from volunteer control as well as cleaning of soil treatment, sowing and harvest machinery and cleaning of storage facilities.

No empirical data is available to estimate the costs of implementing the above-mentioned best practices for coexistence by EU farmers intending to grow GM potatoes. However, the necessary isolation distances between GM and non-GM fields to limit outcrossing to GM contents below the regulated labelling threshold are small due to the low cross-pollination potential of potatoes in combination with the fact that potatoes are planted and harvested as tubers. Therefore, resulting additional costs for implementing distances should also be low. This is supported by the suggestions of Schenkelaars and Wesseler (2016) mentioning that the minimum distance requirements are lower for potatoes, followed by sugar beet, maize and oilseed rape. In general, isolation distance cost can be defined as the lost profit on the area bordering a crop plot on which farmers are not able to raise a crop (Gustafson, 2002). The total value of the lost area can be divided by the amount of crop yield sold to determine the value on a per unit basis. At a regional level, depending on the position of the farm and whether the potato variety grown by neighbours is GM or non-GM, the economic effect will depend on the physical landscape of the affected area (Messean, 2006). Moreover, increasing the cultivation of different crops than potato in crop rotation forces the farmers to cultivate potatoes in fields further away from farmhouses, which increases transportation costs. Potato production is characterised by the transportation of more bulky harvests than the cultivation of other crops, and by several pesticide sprayings during the growth season. This is one of the reasons contributing to the concentration of potato cultivation in the proximity of farmhouses (Tuomisto and Huiti, 2006).

Bullock and Desquilbet (2002) estimated the on-farm costs for non-GM soybean segregation and Identity Preservation to be 1 and 0.5 working hours per t, respectively. In contrast to soybean (and maize) seed, potato tubers are considerably bigger and therefore cleaning of machines for planting and harvesting (physical removal of soil, remaining seed potatoes and debris) should be easier to manage. Consequently, additional costs for cleaning potato equipment should be lower than the costs for cleaning of planters and combines in soybean. Furthermore, to minimise spread or recurrence of a pest, a good sanitation programme for equipment and storage facilities is necessary anyway for potatoes (Olsen and Nolte, 2011). Therefore, any additional costs for thorough cleaning of agricultural machines for GM segregation purposes should be low.

A thorough cleaning is also always important for potato storage facilities on-farm and transportation containers from the field to farm and from farm to processing, again from a phytosanitary point of view. As even small infected tuber pieces left behind can transfer diseases effectively to the next storage bulk, a further effort in cleaning for coexistence reasons is not considered necessary, even for complying with a threshold of 0.1%.

A cost calculation must also take the GM trait into account. As far as for example insect tolerance or late-blight resistance reduce costs for pesticides and, therefore, stabilise yields, costs for coexistence measures may thus be compensated or even overcompensated. In case of reduced asparagine or resistance to bruising, a price premium might be necessary. However, due to the absence of GM potato cultivation, a precise calculation is not possible.

With regard to within-field coexistence, there may be additional costs associated with the regulation of crop rotation where the land is rented to different growers on a yearly basis.

Additionally, the GM testing of a given potato harvest lot needs a considerable amount of tubers, and therefore of weight, to accurately estimate the GM content.

In conclusion, more research is needed to examine the cost and effectiveness of various coexistence strategies in potatoes.

10. References

Allemann, J. and Allemann, A. 2013. Control and management of volunteer potato plants. Report, Potatoes South Africa. http://www.potatoes.co.za/SiteResources/documents/Literature%20review%20Volunteer%20potato%20plants%20ALLEMANN%202013.pdf (verified 6 February 2018).

Andersson, M.S. and de Vicente, M.C. 2010. Gene flow between crops and their wild relatives. The Johns Hopkins University Press, Baltimore, MD.

Anonymous. 1996. The Regulatory Directive T-109–96: The biology of *Solanum tuberosum* L. (potato). Plant Biotechnology Office, Plant Health and Production Division, Canadian Food Inspection Agency. http://www.inspection.gc.ca/plants/plants-with-novel-traits/applicants/directive-94-08/biology-documents/solanum-tuberosum-l-/eng/1330982063974/1330982145930 (verified 6 February 2018).

Anonymous. 2011. Potato sprout inhibitors. https://extension.umaine.edu/potatoes/wp-content/uploads/sites/97/2010/03/Sprout-Inhibitors-section.pdf (verified 6 February 2018).

Arndt, G.C., Rueda, J.L., Kidane-Mariam, H.M., Peloquin, S.J. 1990. Pollen fertility in relation to open pollinated true seed production in potatoes. American Potato Journal 67(8):499-505.

Arvanitoyannis, I., Vaitsi, O., Mavromatis, A. 2008. Potato: a Comparative Study of the Effect of Cultivars and Cultivation Conditions and Genetic Modification on the Physico-Chemical Properties of Potato Tubers in Conjunction with Multivariate Analysis toward Authenticity. Critical Reviews in Food Science and Nutrition. 48(9):799-823.

Askew, M.F. 1993. Volunteer potatoes from tubers and true potato seed. Aspects of Applied Biology 35:9–15.

Askew, M.F. and Struik, P.C. 2007. The canon of potato science: 20. Volunteer potatoes. Potato Research 50(3-4):283-287.

Bailey, L.H. and Bailey, E.Z. 1976. Hortus Third: A concise dictionary of plants cultivated in the United States and Canada. Macmillan, New York.

Bamberg, J.B. and del Rio, A. 2005. Conservation of Potato Genetic Resources. In: M.K. Razdan and A.K. Mattoo (eds.). Genetic Improvement of Solanaceous Crops. Volume I: Potato. Science Publishers, Inc. Plymouth. 1-38.

Batra, S.W.T. 1993. Male-fertile potato flowers are selectively buzz-pollinated only by *Bombus terricola* Kirby in upstate New York. Journal of the Kansas Entomological Society 66(2):252-254.

Beukema, H.P. and van der Zaag, D.E. 1979. Potato improvement: some factors and facts. International Agricultural Center, Wageningen.

Bond, W.H. and Johnson, S.B. (eds.) 2010. Commercial potato production in North America. The Potato Association of America Handbook. 2 ed. The Potato Association of America. http://vric.ucdavis.edu/pdf/POTATOES/Commercial%20Potato%20Production%20in%20North%20America%202010.pdf (verified 6 February 2018).

Bond, W., Davies, G., Turner, R. 2007. The biology and non-chemical control of volunteer potato (*Solanum tuberosum*). HDRA, Ryton Organic Gardens, Coventry, CV8, 3LG, UK.

https://www.gardenorganic.org.uk/sites/www.gardenorganic.org.uk/files/organic-weeds/volunteer-potato.pdf. (verified 6 February 2018.)

Bonde, R. 1942. Ring rot in volunteer plants. American Potato Journal 19:131-133.

Boydston, R.A. 2001. Volunteer Potato (*Solanum tuberosum*) control with herbicides and cultivation in field corn (*Zea mays*). Weed Technology 15:461–466.

Boydston, R.A. and Williams, M. 2003. Effect of fumigation on volunteer potato (*Solanum tuberosum*) tuber viability. Weed Technology 17:352-357.

Boydston, R.A. and Seymore, M.D. 2002. Volunteer potato (*Solanum tuberosum*) control with herbicides and cultivation in onion (*Allium cepa*). Weed Technology 16:620–626.

Boydston, R.A., Seymore, M.D., Brown, C.R., Alva, A.K. 2006. Freezing behaviour of potato (*Solanum tuberosum*) cultivar 'Russet Burbank' tubers in soil. American Potato Journal 83:305–315.

Buchmann, S.L. 1983. Buzz pollination in angiosperms. In C. E. Jones and R. J. Little (eds.). Handbook of Experimental Pollination Biology. Van Nostrand Reinhold, New York, New York, USA. 73-113.

Buchmann, S.L. and Hurley, J.P. 1978. A biophysical model for buzz pollination in angiosperms. Journal of Theoretical Biology 72(4):639-657.

Bullock, D.S. and Desquilbet M. 2002. The economics of non-GMO segregation and identity preservation. Food Policy 27:81–99.

Burton, W.G. 1989. The potato. 3rd ed. Longman Scientific & Technical, Harlow, Essex, UK.

Capurro, M.A., Camadro, E.L., Masuelli, R.W. 2013. Pollen-mediated gene flow from a commercial potato cultivar to the wild relative S. chacoense Bitter under experimental field conditions in Argentina. Hereditas 150:60–65.

Capurro, M.A., Camadro, E.L., Masuelli, R.W. 2014. Gene flow between potato cultivars under experimental field conditions in Argentina. Potato Research 57:111–122.

Cardi, T. 2016. Cisgenesis and genome editing: combining concepts and efforts for a smarter use of genetic resources in crop breeding. Plant Breeding 135(2):139-147.

Carroll, C.P. and Low, R.J. 1976. Aspects of male fertility in group *Tuberosum* dihaploids. Potato Research 19:109-121.

CBAN, 2016. Canadian Biotechnology Action Network. https://cban.ca/gmos/products/not-on-the-market/ (verified 6 February 2018).

Celis, C., Scurrah, M., Cowgill, S., Chumbiauca, S., Green, J., Franco, J., Main, G., Kiezebrink, D., Visser, R.G.F., Atkinson, H.J. 2004. Environmental biosafety and transgenic potato in a centre of diversity for this crop. Nature 432:222-225.

Clarke, A.E. 1940. Fertilization and early embryo development in the potato. American Potato Journal 17(1):20-25.

Colquhoun, J. 2006. Herbicide persistene and carryover. University of Wisconsin-System Board of Regents and University of Wixconson-Extension, Cooperative Extension (A3819).

Conner, A.J. 1993. Monitoring "escapes" from field trials of transgenic potatoes: A basis for assessing environmental risks. Report on the Seminar on scientific approaches for the assessment of research trials with genetically modified plants. Organisation for Economic Co-operation and Development, Paris, France. 33-39.

Conner, A.J. 1994. Analysis of containment and food safety issues associated with the release of transgenic potatoes. In W. R. Belknap, M. E. Vayda, W. D. Park (eds.). The molecular and cellular biology of the potato. CAB International, Oxon, UK. 245-264.

Conner, A.J. 2006. Biosafety Evaluation of transgenic potatoes: Gene flow from transgenic potatoes. International Symposium (2006). Ecological and Environmental Biosafety of Transgenic Plants: 127-140.

Connor, A.J. and Dale, P.J. 1996. Reconsideration of pollen dispersal data from field trials of transgenic potatoes. Theoretical and Applied Genetics 92:505–508.

Cutter, E.G. 1992. Structure and development of the potato plant. In P.M. Harris (ed.). The potato crop: scientific basis for improvement. Chapman and Hall, London, UK.

Czarnak-Kłos, M. and Rodríguez-Cerezo, E 2010. Best Practice Documents for coexistence of genetically modified crops with conventional and organic farming. 1. Maize crop production. EUR 24509 EN, ISBN 978-92-79-16558-0. http://ecob.jrc.ec.europa.eu/documents/Maize.pdf (verified 6 February 2018).

Dale, P. 1992. General presentation. In: Report on the seminar on scientific approaches for the assessment of research trials with genetically modified plants, 6-7 April 1992, OECD, Paris.

Dale, P.J., McPartlan, H.C., Parkinson, R., MacKay, G.R., Scheffler, J.A. 1992. Gene dispersal from transgenic crops by pollen. In: The Biosafety Results of Field Tests of Genetically Modified Plants and Microorganisms. Proceedings of the 2nd International Symposium, Goslar. R. Casper and J. Landsmann (eds.). Biologische Bundesanstalt für Land- und Forstwirtschaft, Braunschweig, Germany. 73–78.

DoE, Department of the Environment. 1994. Genetically modified crops and their wild relatives — A UK perspective. Research Report No. 1. DoE.

Eastham, K. and Sweet, J. 2002. Genetically modified organisms (GMOs): The significance of gene flow through pollen transfer. European Environment Agency, Environmental issue report No 28/2001. http://www.eea.europa.eu/publications/environmental_issue_report_2002_28 (verified 6 February 2018).

Eijlander, R., Stiekema, W.J. 1994. Biological containment of potato (*Solanum tuberosum*): outcrossing to the related wild species black nightshade (*Solanum nigrum*) and bittersweet (*Solanum dulcamara*). Sexual Plant Reproduction 7:29–40.

EPA. 2007. Pesticide fact sheet: Tembotrione. US Environmental Protection Agency. https://www3.epa.gov/pesticides/chem_search/reg_actions/registration/fs_PC-012801_01-Sep-07.pdf (verified 6 February 2018).

Erasmuson, A.K., Reader, J.K., Jacobs, J.M.E., Conner, A.J. 2005. Monitoring pollen-mediated gene flow from field trials of transgenic potatoes. In Abstracts of the 16th Biennial Meeting of the New Zealand Branch of the International Association for Plant Tissue Culture and Biotechnology. 47.

Eurostat. 2016a. The EU potato sector - statistics on production, prices and trade. http://ec.europa.eu/eurostat/statistics-explained/index.php/The_EU_potato_sector_-_statistics_on_production,_prices_and_trade (verified 6 February 2018).

Eurostat. 2016b. Crop statistics (from 2000 onwards). http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=apro_acs_a&lang=en (verified 6 February 2018).

Evenhuis, A. and Zadoks, J.C. 1991. Possible hazards to wild plants of growing transgenic plants. A contribution to risk analysis. Euphytica 55:81–84.

Everman, W., Long, C., Kirk, W. 2010. Volunteer potatoes. MSU Extension. http://msue.anr.msu.edu/news/volunteer_potatoes (verified 6 February 2018).

FAO. 2008. Potato and water resources. http://www.fao.org/potato-2008/en/potato/water.html (verified 6 February 2018).

FAO. 2013. Top production, potatoes, 2011. FAOSTAT, Statistics Division, Food and Agriculture Organization of the United Nations. http://faostat.fao.org/site/339/default.aspx (verified 6 February 2018).

FAO. 2015. Statistical Pocketbook. World food and agriculture. Food and Agriculture Organization of the United Nations, Rome, 2015.

FAOSTAT. 2016. FAOSTAT beta. Data on crops. http://faostat.fao.org/beta/en/#data/QC (verified 6 February 2018).

Fernald, M.L. 1970. Gray's maual of botany. A handbook of the flowering plants and ferns of the central and northeastern United States and adjacent Canada. 8th ed. American Book Company, New York, USA.

Fernow, K.H. 1959. Chemical elimination of volunteer potatoes. American Potato Journal 36:407-409.

Firman, D.M. and Allen, E.J. 2007. Agronomic practices. In D. Vreugdenhil, J. Bradshaw, C. Gebhardt, F. Govers, D.K.L. Mackerron, M.A. Taylor, H.A. Ross (eds.). Potato biology and biotechnology: Advances and perspectives. Elsevier B. V., Amsterdam, Netherlands. 719-738.

Food & Water Watch and OFARM 2014. Organic farmers pay the price for GMO contamination. Food & Water Watch and the Organic Farmer's Agency for Relationship Marketing, Issue Brief March 2014. https://www.foodandwaterwatch.org/sites/default/files/GMO%20Contamination%20Farmers%20IB%20March%202014_0.pdf (verified 6 February 2018).

Free, J.B. and Butler, C.G. 1959. Bumblebees. Collins, London, UK.

Gebhardt, C. 2013. Bridging the gap between genome analysis and precision breeding in potato. Trends in Genetics 29:248–256.

Gopal, J. 1994. Flowering behaviour, male sterility and berry setting in tetraploid *Solanum tuberosum* germplasm. Euphytica 72(1):133-142.

Gopal, J. and Ortiz, R. 2006. True potato seed. In J. Gopal, S.M.P. Khurana (eds.). Handbook of potato production, improvement, and postharvest management. Food Products Press, Binghamton, NY, USA.

Gorea, T. 1970. Fertilität und Kreuzbarkeit der Dihaploiden von *Solanum tuberosum* L. und deren F1-Bastarden (Fertility and crossability of *Solanurn tuberosum* L. dihaploids and their Fl-hybrids). Zeitschrift für Pflanzenzüchtung 64:202-220.

Greene, C., Seth J., Wechsler, A.A., Hanson, J. 2016. Economic issues in the coexistence of organic, genetically engineered (GE), and non-GE crops. A report summary from the Economic Research Service, February 2016. https://www.ers.usda.gov/publications/pub-details/?pubid=44044 (verified 6 February 2018).

Gustafson, C.R. 2002. Economics of Producing for an Identity-Preserved (IP) Grain Market, AAE Staff Paper No. 02002, Department of Agribusiness and Applied Economics, Agricultural Experiment Station, North Dakota State University. http://ageconsearch.umn.edu/bitstream/23651/1/ae02002.pdf (verified 6 February 2018).

Haesaert, G., Vossen, J.H., Custers, R., De Loose, M., Haverkort, A., Heremans, B., Hutten, R., Kessel, G., Landschoot, S., Van Droogenbroeck, B., Visser, R.G.F., Gheysen, G. 2015. Transformation of the potato variety Desiree with single or multiple resistance genes increases resistance to late blight under field conditions. Crop Protection 77:163–175.

Hanneman, R.E. 1995. Ecology and reproductive biology of potato: the potential for and the environmental implications of gene spread. In R.J. Fredrick, I. Virgin, E. Lindarte (eds.). Environmental concerns with transgenic plants in centres of diversity: Potato as a model. Proceedings from a regional workshop, Parque National Iguazu, Argentina.

Haverkort, A.J. 1990. Ecology of potato cropping systems in relation to latitude and altitude. Agricultural Systems 32(3):251-272.

Haverkort, A.J., Boonekamp, P.M., Hutten, R., Jacobsen, E., Lotz, L.A.P., Kessel, G.J.T., Vossen, J.H., Visser, R.G.F. 2016. Durable late blight resistance in potato through dynamic varieties obtained by cisgenesis: scientific and societal advances in the DuRPh project. Potato Research 59:35-66.

Haverkort, A.J., Struik, P.C., Visser, R.G., Jacobsen, E. 2009. Applied biotechnology to combat late blight in potato caused by *Phytophthora infestans*. Potato Research 52:249–264.

Hawkes, J.G. 1988. The evolution of cultivated potatoes and their tuber-bearing wild relatives. Die Kulturpflanze 36(1):189-208.

Hawkes, J.G. 1990. The potato: Evolution, biodiversity and genetic resources. Belhaven Press, London, UK.

Hawkes, J.G. 1994. Origins of cultivated potatoes and species relationships. In: J.E. Bradshaw and G.R. Mackay (eds.). Potato genetics, CAB International, Wallingford,UK. 3–42.

Hijmans, R.J., Spooner, D.M., Salas, A.R., Guarino, L., de la Cruz, J. 2002. Atlas of wild potato. Systematic and ecogeographic studies on crop genepools. International Plant Genetic Resources Institute, Rome, Italy.

Holm, L.G., Pancho, J.V., Herberger, J.P., Plucknett, D.L. 1979. A geographical atlas of world weeds. Krieger Publishing Company, Malabar, USA.

Holst-Jensen, A., Rønning, S.B., Løvseth, A., Berdal, K.G. 2003. PCR technology for screening and quantification of genetically modified organisms (GMOs). Analytical and Bioanalytical Chemistry 375:985–993.

Hoopes, R.W. and Plaisted, R.L. 1987. Potato. In W. R. Fehr (ed.). Principles of cultivar development, Volume 2, Crop Species. Macmillan Publishing Company, New York, U.S.A. 385-436.

Hopkins, B.G. 2010. Rotations. In W.H. Bohl and S.B. Johnson (eds.). Commercial potato production in North America. The Potato Association of America Handbook. 2 ed. The Potato Association of America. http://vric.ucdavis.edu/pdf/POTATOES/Commercial%20Potato%20Production%20in%20North%20America%202010.pdf (verified 6 February 2018). 34-35.

Hopkins, B., Hutchinson, P., Patterson, P., Miller, J., Thornton, M. Hafez, S., Alvarez, J. 2004. Cropping Sequence and Rotation: Impact on Potato Production and Soil Condition. Internet report. http://www.unitedpotatousa.com/industry_links/file_61_Idaho%20Cropping%20Sequence%202004.pdf (verified 6 February 2018).

Howard, H.W. 1970. Genetics of the potato, *Solanum tuberosum*. Springer New-York Inc., New York, USA.

ISAAA 2016. ISAAA Brief 51-2015: Executive Summary. http://isaaa.org/resources/publications/briefs/51/executive-summary/default.asp (verified 6 February 2018).

Iwanaga, M. 1984. Potato breeding for combined resistance to tropical pests by the ploidy level manipulation approach:

progress in extraction of haploids with male fertility and 2n pollen. In F.S. Shideler and H. Rincon (eds.). Proceedings of the 6th. Symposium of the International Society of Tropical Root Crops. Lima, Peru. 481-486.

Jackson, S.A. and Hanneman, R.E. 1999. Crossability between cultivated and wild tuber-and non tuber-bearing solanums. Euphytica 109:51–67.

Jansky, S. 2006. Overcoming hybridization barriers in potato. Plant Breeding 125:1–12.

Johnston, S.A. and Hanneman, R.E. 1980. Support of the endosperm balance number hypothesis utilizing some tuber-bearing *Solanum* species. American Potato Journal 57:7–14.

Johnston, S.A., den Nijs, T.P.M., Peloquin, S.J., Hanneman, R.E. 1980. The significance of genic balance to endosperm development in interspecific crosses. Theoretical and Applied Genetics 57:5–9.

Jørgensen, S.A., Vejsnæs, F., Theuerkauf, R. 2012. Pollen availability for honeybees in an agricultural landscape and mitigation of pollen scarcity by planting of bee forage. Abstract of the workshop "Honey bee nutrition", 22. - 23. Oct. 2012, Bled, Slovenia. https://www.apimondia.com/congresses/2013/Pollination-Flora/Plenary-Session/Pollen%20Availability%20For%20Honeybees%20In%20An%20Agricultural%20Landscape%20-%20Asger%20Sogaard%20Jorgensen.pdf (verified 6 February 2018).

Kempen, M., Buurma, J.S., Ondersteijn, C.J.M. 2005. Groene Wegenwacht, bouwsteen voor een sluitende kennisverspreiding. LEI report, Den Haag, Netherlands. http://library.wur.nl/WebQuery/wurpubs/339896 (verified 6 February 2018).

Kim, C., Kim, D.Y., Moon, Y.S., Kim, H., Kim, D.I., Chun, Y.J., Park, K.W., Jeong, S.C., Kim, S.Y. and Kim, H.M. 2010. Persistence of genetically modified potatoes in the field. Journal of Plant Biology 53:395-399.

Koepke-Hill, R.M., Armel, G.R., Wilson, H.P., Hines, T.E., Vargas, J.J. 2010. Herbicide combinations for control of volunteer potato. Weed Technology 24:90-94.

Kumar, R., Kang, G.S., Pandey, S.K. 2006 Induction of fertile flowers in potato (*Solanum tuberosum* L.) by silver thiosulphate anionic complex. Euphytica 149:27-33.

Lawson, H.M. 1983. True potato seeds as arable weeds. Potato Research 26 (3):237–246.

Le Ny, F., Angevin, F., Coleno, F., Lecomte, J., Messean, A. 2011. Rapport d'expertise au conseil scientifique du Haut Conseil des Biotechnologies sur la coexistence des filières OGM / non-OGM. INRA - Université Paris XI, 132 pp.

Lisinska, G. and Leszczynski, W. 1989. Potato science and technology. Elsevier Applied Science Publishers Ltd., London, UK.

Llorente, B., Alonso, G., Bravo-Almonacid, F., Rodríguez, V., Lopez, M., Carrari, F., Torres, H., Flawia, M. 2011. Safety assessment of nonbrowning potatoes: Opening the discussion about the relevance of substantial equivalence on next generation biotech crops. Plant Biotechnology Journal 9(2):136-150.

Love, S. 1994. Ecological risk of growing transgenic potatoes in the United States and Canada. American Potato Journal 71(10):647-658.

Lumkes, L.M. and Beukema, H.P. 1973. The effect of cultivation procedure on the liability to freezing of ground-keepers. Potato Research 16:57-60.

Lutman, P.J.W. 1977. Investigations into some aspects of the biology of potatoes as weeds. Weed Research 17(2):123-132.

Makepeace, R.J. and Holroyd, J. 1978. Weed control. In P.M. Harris (ed.). The potato crop: The scientific basis for improvement. Chapman & Hall, London, UK. 376-406.

Mali, M.S., Khokhariya, B.P., Dabgar, Y.B. 2014. International Journal of Scientific Research 3:423-425.

McGill, G., O'Reilly, C., Thorp, K., Armstrong, S., Gaule, F., Macken, J., Downey, J., Dardis, R., Devlin, B., Leech, T., Mullins, E., 2005. Coexistence of GM and non-GM crops in Ireland. Report of the Working Group on the Coexistence of GM crops with Conventional and Organic Farming. Department of Agriculture and Food, Dublin, Ireland.

McPartlan, H.C. and Dale, P.J. 1994. An assessment of gene transfer by pollen from field grown transgenic potatoes to nontransgenic potatoes and related species. Transgenic Research 3:216–225.

Messéan, A., Angevin, F., Gómez-Barbero, M., Menrad, K., and Rodríguez-Cerezo, E. 2006. New case studies on the coexistence of GM and non-GM crops in European agriculture. European Communities. Technical Report. http://ftp.jrc.es/EURdoc/eur22102en.pdf (verified 6 February 2018).

Miraglia, M., Berdal, K.G., Brera, C., Corbisier, P., Holst-Jensen, A., Kok, E.J., Marvin, H.J., Schimmel, H., Rentsch, J., van Rie, J.P., Zagon, J. 2004. Detection and traceability of genetically modified organisms in the food production chain. Food and Chemical Toxicology 42(7):1157-80.

Muenscher, W.C. 1980. Weeds. Second Edition. Cornell University Press, Ithaca, USA.

Mustonen, L., Peltonen-Sainio, P., Pahkala, K. 2009. Risk assessment for volunteer and seedling GM potatoes in the northernmost European growing areas. Acta Agriculturae Scandinavica Section BSoil and Plant Science 59:552-558.

Newberry, G.D. and Thornton, R.E. 2007. Suppression of volunteer potatoes with maleic hydrazide applications. American Journal of Potato Research 84:253-258.

Obidiegwu, J.E., Bryan, G.J., Jones, H.G., Prashar, A. 2015. Coping with drought: stress and adaptive responses in potato and perspectives for improvement. Frontiers in Plant Science 6:542.

OECD. 1997. Consensus document on the biology of *Solanum tuberosum* subsp. *tuberosum* (potato). OECD Environmental Health and Safety Publications Series on Harmonization of Regulatory Oversight in Biotechnology No. 8. Organisation for Economic Co-operation and Development (OECD), Paris. http://www.oecd.org/science/biotrack/46815598.pdf (verified 6 February 2018).

Olsen, N. and Nolte, P. 2011. Cleaning and Disinfecting Potato Equipment and Storage Facilities. University of Idaho Extension, CIS 1180. https://www.cals.uidaho.edu/edcomm/pdf/CIS/CIS1180.pdf (verified 6 February 2018).

Pallais, N. 1987. True potato seed quality. Theoretical and Applied Genetics. 73:783-92.

PBI *Solanum* Project. 2014. Solanaceae Source. http://www.solanaceaesource.org/ (verified 6 February 2018).

Pérombelon, M.C.M. 1975. Observations on the survival of potato groundkeepers in Scotland. Potato Research 18(2):205-215.

Petti, C., Meade, C., Downes, M., Mullins, E. 2007. Facilitating co-existence by tracking gene dispersal in conventional potato systems with microsatellite markers. Environmental Biosafety Research 6(4):223-236.

Phelan, S., Fitzgerald, T., Grantc, J., Byrneb, S., Meade, C., Mullins, E. 2015. Propensity for seed-mediated gene flow from potato crops and potential consequences for the coexistence of GM and non-GM potato systems. European Journal of Agronomy 67:52–60.

Plaisted, R.L. 1980. Potato. In W.R. Fehr and H.H. Hadley (eds.). Hybridisation of crop plants. American Society of Agronomy-Crop Science Society of America, Madison, Wisconsin, USA. 483-494.

Rahman, A. 1980. Biology and control of volunteer potatoes - a review. New Zealand Journal of Experimental Agriculture 8(3-4):313-319.

Rizov, I. and Rodríguez-Cerezo, E. 2013. Best Practice Documents for coexistence of GM maize and honey production. Publications Office of the European Union, Luxembourg. http://publications.jrc.ec.europa.eu/repository/bitstream/JRC83397/ipts%20jrc%2083397%20online%20final.pdf (verified 6 February 2018).

Rizov, I. and Rodríguez-Cerezo, E. 2015. Best Practice Document for the coexistence of genetically modified soybean crops with conventional and organic farming. Publications Office of the European Union, Luxembourg. EUR 26780 EN, ISBN 978-92-79-58419-0. http://ecob.jrc.ec.europa.eu/documents/ipts_jrc_101485_online.pdf (verified 6 February 2018).

Rizov, I. and Rodríguez-Cerezo, E. 2016. Best Practice Document for the coexistence of genetically modified cotton with conventional and organic farming. Publications Office of the European Union, Luxembourg. EUR 27928 EN, ISBN 978-92-79-39542-0. http://ecob.jrc.ec.europa.eu/documents/BPD-Soybean.pdf (verified 6 February 2018).

Ross, H. 1986. Potato breeding: problems and perspectives. Journal of Plant Breeding, Supplement 13. Advances in Plant Breeding. Parey, Berlin and Hamburg, Germany.

Roulston, T.H., Cane, J.H., Buchmann, S.L. 2000. What governs protein content of pollen: Pollinator preferences, pollen-pistil interactions, or phylogeny? Ecological Monographs 70(4):617-643.

Rowell, A.B., Ewing, E., Plaisted, R.L. 1986. Comparative field performance of potatoes from seedlings and tubers. American Potato Journal 63(4):219-227.

Sanford, J.C. and Hanneman, R.E. 1981. The use of bees for the purpose of inter-mating in potato. American Potato Journal 58(9):481-485.

Schenkelaars, P. and Wesseler, J. 2016. Farm-level GM Coexistence Policies in the EU: Context, Concepts and Developments. EuroChoices 15(1): 5-11.

Scurrah, M., Celis-Gamboa, C., Chumbiauca, S., Salas, A., Visser, R.G.F. 2008. Hybridization between wild and cultivated potato species in the Peruvian Andes and biosafety implications for deployment of GM potatoes. Euphytica 164:881-892.

Seaman, A (ed). 2013. Production guide for organic potato. NYS IPM Publication No. 138. https://ecommons.cornell.edu/bitstream/handle/1813/42897/2016-org-potatoes-NYSIPM.pdf?sequence=5 (verified 6 February 2018).

Sieczka, J. 2010. Cultivation. In Bohl, W.H. and Johnson, S.B. (eds.). Commercial potato production in North America. The Potato Association of America Handbook. 2 ed. The Potato Association of America. http://vric.ucdavis.edu/pdf/POTATOES/Commercial%20Potato%20Production%20in%20North%20America%202010.pdf (verified 6 February 2018). 53.

Skogsmyr, I. 1994. Gene dispersal from transgenic potatoes to conspecifics: A field trial. Theoretical and Applied Genetics 88:770–774.

Sleper, D.A. and Poehlman, J.M. 2006. Breeding field crops. 5th ed. Blackwell Publishing, Ames, IA, USA.

Song, J., Bradeen, J.M., Naess, S.K., Raash, J.A., Wielgus, S.M., Haberlach, G.T., Liu, J., Kuang, H., Austin-Phillips, S., Buell, C.R., Helgeson, J.P., Jiang, J. 2003. Gene RB cloned from *Solanum bulbocastanum* confers broad spectrum resistance to potato late blight. Proceedings of the National Academy of Sciences of the United States of America 100:9128–9133.

Spooner, D.M. 2009. DNA barcoding will frequently fail in complicated groups: an example in wild potatoes. American Journal of Botany 96:1177–1189.

Spooner, D.M. and Bamberg, J.B. 1994. Potato genetic resources: sources of resistance and systematics. American Potato Journal 71:325–337.

Spooner, D.M. and Knapp, S. 2013. *Solanum tuberosum*. Solanaceae Source. A global taxonomic resource for the nightshade family. http://solanaceaesource.org/content/solanum-tuberosum (verified 6 February 2018).

Spooner, D.M., van den Berg, R.G., Rodríguez, A., Bamberg, J., Hijmans, R.J., Cabrera, S.I.L. 2004. Wild potatoes (*Solanum* section *Petota*; Solanaceae) of North and Central America. The American Society of Plant Taxonomists, Ann Arbor, MI, USA.

Steiner, C.M., Newberry, G., Boydston, R., Yenish, J., Thornton, R. 2005. Volunteer potato management in the pacific northwest rotational crops. Washington State University Extensions EB 1993. https://www.ars.usda.gov/research/publications/publication/?seqNo115=185602 (verified 6 February 2018).

Struik, P.C. 2007. Above-ground and below-ground plant development. In D. Vreugdenhil, J. Bradshaw, C. Gebhardt, F. Govers, D.K.L. Mackerron, M.A. Taylor, H.A. Ross (eds.). Potato biology and biotechnology: Advances and perspectives. Elsevier Science B.V., Amsterdam. 219-236.

Symon, D.E. 1981. A revision of the genus *Solanum* in Australia. Journal of the Adelaide Botanic Gardens 4:1-367.

The Potato Genome Sequencing Consortium. 2011. Genome sequence and analysis of the tuber crop potato. Nature 475:189-195.

Thomas, P.E. 1983. Sources and dissemination of potato viruses in the Columbia basin of the Northwestern United States. Plant Disease 67:744–747.

Thomas, P.E., and Smith, D.R., 1983. Relationship between cultural practices and the occurrence of volunteer potatoes in the Columbia Basin. Americal Potato Journal 60:289-294.

Tolstrup, K., Andersen, S., Boelt, B., Buus, M., Gylling, M., Bach Holm, P., Kjellsson, G., Pedersen, S., Østergård, H., Mikkelsen, S.A. 2003. Report from the Danish working group on the co-existence of genetically modified crops with conventional and organic crops. DIAS report Plant Production No. 94. Ministry of Food, Agriculture and Fisheries - Danish Institute of Agricultural Science, Tjele, Danmark.

Treu, R. and Emberlin, J. 2000. Pollen dispersal in the crops maize (*Zea mays*), oil seed rape (*Brassica napus* ssp *oleifera*), potatoes (*Solanum tuberosum*), sugar beet (*Beta vulgaris* ssp *vulgaris*) and wheat (*Triticum aestivum*). A report for the

Soil Association from the National Pollen Research Unit, University College Worcester, UK. http://ibrarian.net/navon/paper/Pollen_dispersal_in_the_crops_Maize__Zea_mays___0.pdf?paperid=2943414 (verified 6 February 2018).

Tuomisto, J. and Huiti, H. 2006. Reducing costs caused by isolation requirements between GM and non-GM potato fields – a method based on GIS. Proceedings of 10th ICABR International Conference on Agricultural Biotechnology: Facts, Analysis and Policies, June 29 - July 2, 2006. Ravello, Italy.

Turley, D. 2001. Understanding the biology and incidence of potato volunteers. British Potato Council, Oxford, UK.

Tynan, J.L., Williams, M.K., Conner, A.J. 1990. Low frequency of pollen dispersal from a field trial of transgenic potatoes. Journal of Genetics and Breeding 44:303–306.

Van de Wiel, C.C.M., Kok, E.J., Scholtens, I.M.J, Smulders, M. J.M., Lotz, L.A.P. 2015. Voorstel voor een co-existentiemonitoringsprogramma t.b.v. het naast elkaar bestaan van genetisch gemodificeerde (GG) en niet-GG teelten in toekomstige praktijksituaties: 2. Aardappel. Wageningen UR Plant Breeding, Wageningen, Netherlands. http://edepot.wur.nl/346890 (verified 6 February 2018).

Van de Wiel, C.C.M. and Lotz, L.A.P. 2006. Outcrossing and coexistence of genetically modified with (genetically) unmodified crops: a case study of the situation in the Netherlands, NJAS 54(1):17-35.

Van der Vossen, E., Sikkema, A., te Lintel Hekkert, B., Gros, J., Stevens, P., Muskens, M., Wouters, D., Pereira, A., Stiekema, W., Allefs, S. 2003. An ancient R gene from the wild potato species *Solanum bulbocastanum* confers broad-spectrum resistance to *Phytophthora infestans* in cultivated potato and tomato. Plant Journal 36:867–882.

Van Droogenbroeck, B., De Vliegher, A., De Loose, M. 2013. Co-existentie in de aardappelteelt: een evaluatie van de specifieke teeltvoorwaarden. Final report. http://pure.ilvo.vlaanderen.be/portal/files/1252839/Coexistentie_in_deaardappelteelt_23042013_finaalOK.pdf (verified 6 February 2018).

Van Swaaij, A.C., Nijdam, H., Jacobsen, E., Feenstra, W.J. 1987. Increased frost tolerance and amino acid content in leaves, tubers and leaf callus of regenerated hydroxyproline resistant potato clones. Euphytica 36:369-380.

Vayda, M.E. 1994. Environmental stress and its impact on potato yield. In J.E. Bradshaw and G.R. Mackay (eds.). Potato genetics, CAB International, Wallingford, UK. 239–261.

Watanabe, K. and Peloquin S.J. 1991. The occurrence and frequency of 2n pollen in 2x, 4x and 6x wild, tuber-bearing *Solanum* species from Mexico and Central and South America. Theoretical and Applied Genetics 82:621-626.

Western Potato Council. 2003. Guide to commercial potato production on the Canadian prairies. Western Potato Council, Portage la Prairie, Manitoba, Canada.

White, J.W. 1983. Pollination of potatoes under natural conditions. CIP Circular 11(2):1-2.

Wright, G.C. and Bishop, G.W. 1981. Volunteer potatoes as a source of potato leafroll virus and potato virus X. American Potato Journal 58:603–609.

Zaheer, K. and Akhtar, H. 2016. Recent advances in potato production, usage, nutrition - a review. Critical Reviews in Food Science and Nutrition 56(5):711-21.

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