Plant Biotechnology: Potential Impact for Improving Pest Management in European Agriculture

Potato Case Study
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History of potato and its use in Europe

The potato originated in the Andes Mountains of South America where it was domesticated 10,000 years ago [12]. In the 16th century, the Spanish introduced the potato to Europe. From Spain, the potato was distributed throughout Europe, but it did not become an important food for some time. For instance, potatoes were denounced from the Scottish pulpit on two accounts: first, they were not mentioned in the Bible and were therefore not fit food for Christians, and second, they were thought to be the forbidden fruit spoken of in Genesis, which caused Adam's fall [12]. As a member of the nightshade family, potatoes were believed to be poisonous, and all sorts of diseases were attributed to it including leprosy and tuberculosis. It was declared that potatoes would exhaust the soil, and since they were produced from a seed tuber rather than from botanical (true) seeds and grew underground, they were considered unnatural. Some Christians concluded that there was little doubt that potatoes were an invention of the devil. As a result, the potato was not immediately accepted by Europeans who had eaten cereals and meat for thousands of years [12].

With its introduction to Germany in the 1620s, the nutritional properties of the potato were finally acknowledged. Frederick the Great, the Prussian ruler, ordered his people to plant and eat them as a deterrent to famine, a common and recurrent problem of that period. The people's fear of poisoning led him to enforce his orders by threatening to cut off the nose and ears of those who refused. Not surprisingly, this was effective and by the time of the Seven Years War (1756-1763) potatoes were a basic part of the Prussian diet [13]. A young French agriculturist, Antoine Augustin Parmentier, made it his mission to popularize the potato in France after his experience as a prisoner of war in Prussia. Parmentier planted a field of potatoes near Paris and surrounded it with guards thereby stirring the curiosity of the Parisians. When night fell, Parisians snuck into the fields and plundered the potatoes while Palmentier ordered his soldiers to look the other way. Thinking them a priceless delicacy, the masses made the potato popular from that moment on [5]. As late as 1771, the potato was so much under suspicion that the French government appealed to the Medical Faculty of Paris for their considered judgment on its merits. Their verdict was that the potato was a good and healthy food, in no way injurious to health, and of great utility [5]. Eventually, the potato became a popular food in Europe and subsequently the potato came back across the Atlantic to North America.

Potato production in the EU occurs on 1.25 million ha. 12 countries account for 97 % of the EU's potato production of 44 billion kg. The value of potato production in these 12 countries is €5 billion. Table 1 summarizes potato production statistics for EU countries and the U.S.

History of late blight as a pest in European potato cultivation

Mexico has been identified as the source of the fungus *Phytophtera infestans* that causes a disease of potatoes known as late blight. The disease was first reported in the U.S. in Philadelphia in 1843 and subsequently spread throughout the country [8]. Late blight was first reported in Europe in Belgium in 1845 and may have been introduced either directly from Mexico or in shipments from the U.S. The fungus spread rapidly from Belgium and by 1845, it had reached England and Ireland as well.

Potatoes were introduced into Ireland in the last years of the sixteenth century. The climate and soils were ideal and allowed abundant production. Because of plentiful potato crops, the population of Ireland had increased to about 8 million in 1845. Irish peasants subsisted almost entirely on potatoes. 40% of the Irish potato crop was destroyed by late blight in 1845 and almost 100% destruction occurred in 1846 [10]. An estimated 1.5 million Irish died of famine and disease and a similar number of people emigrated, mainly to North America [7].

Shipments of seed potatoes from Europe led to the introduction of late blight into the Andes of South America, the original home of the potato [6].

Late blight can occur any time in the growing season but cool humid conditions and prolonged periods of rain are the most conducive for its development. The disease progresses remarkably rapidly once these conditions are met. Late blight pathogen affects all parts of the plant: the leaves, stem, and tubers, or roots. Affected plants emit a distinctive unpleasant odor due to rapid breakdown and decay of the plant tissue. Infected tubers rotting in storage also give off a similar foul odor. Tubers can get infected in two ways: the spores produced on infected leaves can wash down into the soil; tuber infection can also occur at harvest or in storage when tubers contact living spores remaining on infected plants or tubers.

Conventional strategies for late blight control in potato cultivation

Chemical control

Late blight epidemics in Europe stimulated intense investigations about the nature of plant disease and are generally regarded as initiating the development of plant pathology as a discrete discipline [7]. From the time late blight first appeared, attempts were made to control it with chemicals [20]. The earliest materials included compounds such as sodium chloride, lime and sulfur. Late blight continued to be a devastating disease until the 1880s when the first fungicide was discovered. A mixture of copper sulphate and slaked lime (Bordeaux mixture) was found to prevent late blight infections if applied to the potato plant before the fungal spores arrived. In the 1930s, discovery of the dithiocarbamates (EBDCs) produced the first synthetic chemical fungicides for late blight control and provided increased control efficacy in preventing late blight infections. As with the copper fungicides, the first synthetic fungicides had to be applied before the fungal spores landed on the plant. Protectant fungicides kill the pathogen on the plant surface before infection occurs [9].

In the 1970s, new fungicides were introduced that were systemic and could penetrate potato plant tissue and kill the late blight pathogen in the tissue. These curative fungicides could be applied after the spores arrived on the potato plant and were widely used [1].

In 1976, a prolonged drought in Europe significantly reduced potato production leading to shortages and high prices. Consequently, import restrictions were relaxed to allow imports of potatoes from other countries, including large tonnages from Mexico [6]. With them came many new strains of late blight. The new strains displaced the old strains of the fungus across Europe and by the early 1980s problems of controlling late blight began to appear. With the spread of the new mating type to Europe, late blight populations have become more variable. Strains appear to be more aggressive, infect more rapidly, are able to infect at lower temperatures, and complete their life cycles in shorter time [16]. The phenylamide fungicides were not effective on all the new strains. The new strains reproduced by sexual means while the older strains reproduced asexually. When populations were strictly asexual, the fungus had no survival structure to allow it to overwinter in the soil apart from potato tissue. The sexual spores can overwinter independently of potato tissue and survive for years in the soil. The new strains have enabled sexual reproduction with the old ones. The pathogen population has become increasingly fit and more aggressive. The vegetative cycle is taking place at a faster rate. In the past it took 4 to 5 days, but now 3 to 4 days suffice. This means the disease can develop more quickly. The fungus can produce more spores, so there is a greater risk of the disease spreading more quickly [22].

As a result of the introduction of the new strains of the late blight fungus, fungicide use in European potato fields increased. In recent years, UK growers have tended to shorten their spray intervals, which fell from an average of 9.3 days in the early 1990s (8 treatments) to 8.1 days in the late 1990s (10 treatments) [16]. Protectant fungicides still account for more than 90% of the total fungicide input used against late blight [3]. Since it is difficult to predict critical periods for control of the disease, growers avoid risks by applying the protectant fungicides continuously throughout the growing season.

Research in Ireland showed that unsprayed potato plants incurred 100% foliar late blight symptoms while applications of protectant fungicides on a 7-day schedule reduced the incidence to 0.6% [4]. Potato yields were 42% lower in the unsprayed plots [4].

Even with weekly prophylactic sprays, potato production losses still occur since short disease cycles of 2-3 days are now common [15]. Yield losses in conventional crops are probably under 5% [23].

Table 2 summarizes the number of sprays for late blight for each EU country. In Northwestern Europe, weather conditions are particularly favorable for blight and the number of fungicide applications may be up to 16, while in southern, warmer, drier European countries, fewer sprays are needed and a maximum of 8 may be recommended [11].

In 2002, the fungicide use patterns for late blight control in Europe were as follows [28] [24]:

- Italy- The first spray was usually metalaxyl or fluazinam. Afterwards, the normal control strategy of cymoxanil and dimethomorph was used. Overall, 5-8 sprays were applied to potato. Copper was also used, particularly at the end of the season.
- Spain- The first treatment was metalaxyl. When the first symptoms began to appear, cymoxanil and dimethomorph were applied. At the end of the growing season, copper was used.
- Austria- Early crops were sprayed 3-5 times, late crops 8-12 times. The first two sprays were systemic fungicides (metalaxyl, propamocarb) followed by 1-2 applications of dimethomorph to which fluazinam was added depending on the infection pressure. Contact fungicides (mancozeb, fluazinam) were sprayed 2-4 times at the end of the season. The last spray was mostly fluazinam.
- Germany- On average one to two sprays more than in 2001 were needed to control blight. In regions with low disease pressure 3-6 sprays were sufficient to control blight. In regions with high pressure, 7-16 sprays were needed.
- France- In Brittany, the number of treatments ranged from 8 to 12. Cymoxanil and other translaminar products were applied during high pressure. In the Pas-de-Calais and Picardy areas 12-13 sprays were needed to control blight. In the Ardennes-Champagne region, 8-10 sprays were needed. Products containing cymoxanil were used when blight was observed in the field.
- Belgium- Blight was controlled with an average of 13 applications. In July, more than 60% of the applications were made with products that contained cymoxanil or dimethomorph. Fentin containing products were on average sprayed more than 4 times.
- Netherlands- Only 4 fungicide products were registered to control blight in 2002. Fluazinam was the most widely used fungicide; cyazofamid was used on a much smaller scale. Metiram plus cymoxanil and propamocarb plus chlorothalonil were used in situations of high infections.
- Ireland- Fungicides consisted mainly of phenylamides (metalaxyl) followed by fluazinam, or fluazinam alone, and most of the spraying was at 7 day intervals.
- Denmark- 4-6 sprays were needed in seed potatoes, 7-8 in ware potatoes and 10-12 in starch potatoes. Fluazinam and mancozeb plus propamocarb were used more than in 2001, whereas mancozeb and mancozeb plus dimethomorph were used less.
- Sweden- Due to the dry weather during the season, the number of sprays was probably lower than in 2001. It is estimated that blight is controlled with 6-8 sprayings in the south, 4-6 in mid-Sweden, and 2-4 in the north. The standard fungicide is fluazinam.

- Finland- Due to the dry weather at the end of the season, spraying was reduced in comparison to 2001. This resulted in 4-8 sprayings depending on the region. The most widely used fungicides were fluazinam and mancozeb. Mancozeb plus dimethomorph and mancozeb plus propamocarb were used to some extent in the first two applications.
- UK- 8-14 sprays were applied. There is no standard approach to fungicide use in the UK. Some growers use cheap protectant materials such as mancozeb routinely at close intervals throughout the season. Others will apply systemic fungicides early and follow with a product that has some curative activity or use the newer protectants. Early season systemic options included metalaxyl plus mancozeb, oxadixyl plus cymoxanil plus mancozeb, propamocarb plus chlorothalonil, or mancozeb. The principal midseason product was a dimethomorph and mancozeb mixture with mancozeb and fluazinam being the main protectants. The majority of growers used fentin-based products at the end of the season.

The EBDC fungicides including mancozeb have been severely restricted in EU countries since the start of 1995. A major concern of EU potato growers is what to use as a replacement for fentin fungicides as they will not be given Annex 1 listing and will be revoked [24].

Numerous references contain information on fungicide use amounts applied to potatoes in EU countries.

In Denmark in 2000, the average potato acre was treated 6.7 times with fungicides [25]. The average fungicide rate per year was 8 kg/ha. Table 3 shows the breakdown of fungicide use on potatoes in Denmark in 2000.

In 1994 in the Netherlands, the average number of fungicide sprays per growing season was 10.9, which corresponded with a total amount of 10.4 kg per ha. In 2000 and 2003 the average numbers of spraying were 14.6 with a total amount of 13.4 kg per ha, respectively 12.7 times with a total amount 11.1 kg per ha [43]. The overall increase of fungicide use was caused by an increasing infestation pressure from 1994 to 2003, and the emergence of more virulent strains of the late blight pathogen.

In the UK in 1998, it was estimated that 1275 tonnes of fungicides were used on the nations 165,000 hectares of potatoes (7.7 kg/ha) [26]. Table 4 shows the distribution of the UK usage by active ingredient. A study of potato pesticide use patterns in 1994 was conducted for typical growing regions in Germany, Netherlands, UK, and France [31]. 100% of the potato acreage in all four regions were treated with fungicides to control late blight, with 6 sprays applied in Germany and UK, 13 in Netherlands, and 14 in France. The average fungicide use rates were: Germany (6.6 kg/ha), Netherlands (8.0 kg/ha), UK (7.8 kg/ha), and France (927.9 kg/ha). The higher fungicide use rate in France was attributed to more use of mancozeb and less use of fluazinam than in the other countries.

A report from the EU estimated that in 1996, the average use of fungicides in potatoes in the EU was 4.8 kg/ha [35]. Table 5 shows by country the major fungicides used in potatoes in 1996.

The usage data compiled from the above sources were used to compute estimates of the total use of fungicides applied for late blight control in EU countries (see Table 6).

In an average year, it is estimated that farmers in Europe spray up to 8 times to control blight at a cost of ₤150/Ha (ca. 200 euros per hectare) [6].

In the UK, it is estimated that the cost of fungicides for late blight control is ₤20-30 million (30-45 million euros) for fungicides and up to ₤10 million (15 million euros) in lost production [14].

Fungicide price data from Germany indicate that commonly-used combination products including mancozeb+metalaxyl, mancozeb+propamocarb, and mancozeb+dimethomorph cost about €30/ha/application [27]. Fluazinam is estimated to cost approximately €25/ha/application, while single applications of maneb or mancozeb are estimated to cost €9-10/ha/application [27].

These cost estimates have been used in conjunction with estimates of the total number of sprays applied to estimate total fungicide costs and cost of applications for each EU country (see Table 7).

In the U.S., approximately 85% of potato acreage received fungicide applications in 2001 [29]. While close to 100% of the potato acres in Eastern and Midwestern states received fungicide applications, only about 70% of the potato acreage in arid states of the West (such as Idaho) received fungicide applications. The average fungicide application rate in the U.S. in 2001 was 6.8 lb ai per treated acre (7.6 kg per hectare) [29]. Estimated fungicide costs to control potato late blight in the U.S. are $77 million annually [30].

Organic control

Organic potato growers in Europe rely on preventive sprays of copper for late blight control. The use of copper in EU organic production is under continuous review. In 2002, a restriction of 8 kg/ha per year was established for copper [17]. After 2006, the allowed copper use will be reduced to 6 kg/ha. In Scandinavia and the Netherlands, copper treatments are not allowed under state legislation [17]. The lower control efficacy of copper in relation to synthetic chemicals is one of the main reasons that organic potato yields are 30-40% less than from conventional fields [17].

In 2002, organic potato growers in Europe experienced the following late blight conditions [28]:

- Netherlands- Organic crops became heavily infected in July.

- France- In Brittany, organic crops planted mid-April escaped major blight pressure. Susceptible cultivars were effectively protected with 4-6 copper treatments. In the north of France, many organic fields were 100% destroyed from the end of July.
- Denmark- In early July, a blight epidemic occurred in organic crops. The yield of organic potatoes was approximately 20 tonnes/ha.
- Sweden/Finland- Despite the dry weather, blight was a problem in organic crops. Some fields were heavily attacked early in the growing season.

Resistant cultivars are not grown on a large scale because commercially important characteristics such as quality, yield, and earliness are usually not combined with late blight resistance in the same cultivars [19]. Organic growers do not use the highly resistant varieties since the market demands the well-known susceptible varieties [21].

Late blight resistant (GM) potato as a new approach

The use of genetic engineering to produce potatoes that are resistant to late blight infections has been a focus of research at the International Potato Center (CIP) in Peru since the 1980s. CIP's approach has been to insert multiple antifungal proteins into potato to obtain a synergistic effect against late blight fungus [42].

In addition, private companies (Monsanto) and U.S. federal researchers have used genetic engineering techniques to develop potatoes with enhanced resistance to late blight [41]. In Europe, research to develop a genetically engineered potato has been carried out in Germany and Switzerland. In a German study, potatoes were transformed with the addition of genetic material from a soil bacterium. The transformed potatoes produce a fungal inhibitor, which leads to the death of the plant cell, thus preventing further spread of the disease [39]. In a Swiss experiment, potatoes were transformed by introducing a wheat gene that encodes for an enzyme that degrades oxalalic acid into carbon dioxide and hydrogen peroxide [40]. Hydrogen peroxide in the plant tissue is a defense against the blight fungus.

One focus of current research is a wild plant species related to potato from Mexico. This species, *solanum Bulbocastanum* co-evolved with the late blight fungus and has exhibited durable race non-specific resistance to the late blight fungus [33]. However, *S. bulbocastanum* is largely sexually incompatible with potato due to differences in endosperm balance numbers [33]. As a result, it has been extremely difficult to cross breed the two plant species. One alternative to sexual crosses is the uniting of diverse genomes via somatic fusion, which has been effectively used to capture the late blight resistance from *S. bulbocastanum* and has then been passed on to potato breeding lines [32]. The progeny of the somatic hybrids were grown in Mexico where nearly every race of the fungus is found. While nearby potato plants were completely destroyed by late blight, the somatic hybrids were unaffected [32]. In Wisconsin, during experiments where fungicides were not used, one of the *S. bulbocastanum* derived lines topped all test lines with a yield of 1.36 kg/plant (untreated Russet Burbank potatoes yielded 0.86 kg/plant)

[32]. The resistance to late blight of *S. bulbocastanum* has been mapped to chromosome 8 [33].

Cloning of the resistance gene and the transformation of potato cultivars with its insertion could result in complete resistance to late blight in commercial potatoes [34].

Ongoing work with genetic transformation of potatoes with the insertion of the cloned *S. bulbocastanum* gene is ongoing at Plant Research International, a research group within Wageningen University in the Netherlands, and at the USDA-WRRC Potato Biotechnology Lab and the University of Wisconsin in the U.S.

Potential for change of fungicide use and grower's income

Successful introduction of a biotech late blight resistant potato on 100% of current European potato acreage would eliminate the need for EU growers to use 7.5 million kgs of fungicides reducing production costs by €375 million and increasing potato production by 858 million kg worth €99 million. Assuming a €50/ha fee for using the biotech potato results in a net income increase of €417 million. These impact estimates are displayed by country in Tables 7 and 8.

A recent study from the University of Idaho estimated the potential benefit of a genetically modified late blight resistant potato for the major potato-producing regions of the world at $4.3 billion [30]. This study estimated that current potato yield losses to late blight are 5%, current storage losses are 1.2% and that late blight results in a reduced price loss of 3.2%.

The study estimated that the late blight resistant potato would reduce fungicide cost by $136/ha in Europe. The overall benefit to Europe was estimated at $1.936 billion, which includes Eastern Europe as well as EU countries. The study estimated that 25 million kilograms of fungicide use would be eliminated in Europe. The average benefit estimated for Europe was $212/ha, which includes yield increases, reduction in storage rots, improved quality, and reduced fungicide cost.

Table 1a: Potato Production			
	Area (000 Ha)	*Production (million Kg)*	*Value (€ million)*
Austria	23	695	62.6
Belgium	62	2564	205.1
Denmark	38	1543	339.5
Finland	30	733	95.3
France	162	6078	547.0
Germany	282	11503	805.0
Ireland	14	444	79.9
Italy	78	1957	176.1
Netherlands	162	7015	631.4
Spain	116	2957	621.0
Sweden	32	925	231.3
United Kingdom	165	6528	1175.0
Total	1164	42942	4969.2
EU-15	1251	44529	
U.S.	489	19904	3057.0

Table 1b: Potato Production			
	Area (000 A)	*Production (million Lbs)*	*Value ($ million)*
Austria	58	1529	62.6
Belgium	155	5641	205.1
Denmark	95	3395	339.5
Finland	75	1613	95.3
France	405	13372	547.0
Germany	705	25307	805.0
Ireland	35	977	79.9
Italy	195	4305	176.1
Netherlands	405	15433	631.4
Spain	290	6505	621.0
Sweden	80	2035	231.3
United Kingdom	413	14362	1175.0
Total	2911	94474	4969.2
EU-15	3128	97964	
U.S.	1222	43789	3057.0

Source: [36][37][38]

Table 2: Fungicide Sprays for Potato Late Blight Control (2002)	
	# of Sprays
Austria	3 to 12
Belgium	12 to 16
Denmark	8 to 9
Finland	4 to 8
France	8 to 13
Germany	3 to 14
Ireland	8 to 14
Italy	5 to 8
Netherlands	8 to 16
Spain	3 to 4
Sweden	7 to 8
United Kingdom	8 to 14

Source [28][18]

Table 3a: Fungicide Use: Potatoes in Denmark (2000)			
	# Ha Treatments	***Kg Ai/Ha/Trtmt***	***Total Kg***
Dimethomorph	3568	0.500	1784
Fluazinam	52410	0.200	10482
Mancozeb	193399	1.500	290098
Propamocarb	1310	0.992	1299
Total			303663

Table 3b: Fungicide Use: Potatoes in Denmark (2000)			
	# A Treatments	***Lbs Ai/A/Trtmt***	***Total Lbs***
Dimethomorph	8920	0.445	3925
Fluazinam	131025	0.178	23060
Mancozeb	483498	1.335	638216
Propamocarb	3275	0.883	2858
Total			668059

Source: [25]

Total hectares of potatoes in Denmark in 2000: 37613

Table 4a: Fungicide Use: Potatoes in the United Kingdom (1998)		
	# Ha Treatments (000)	*Total Tonnes*
Chlorothalonil	41	31
Cymoxanil/Mancozeb	262	380
Cymoxanil/Mancozeb/Oxadixyl	120	190
Dimethomorph/Mancozeb	100	155
Fentin Acetate/Mancozeb	49	15
Fentin Hydroxide	254	65
Fluazinam	353	52
Mancozeb	117	142
Mancozeb/Metalaxyl	43	59
Other	147	186
Total		1275

Table 4b: Fungicide Use: Potatoes in the United Kingdom (1998)		
	# A Treatments (000)	*Total Tons*
Chlorothalonil	103	34
Cymoxanil/Mancozeb	655	418
Cymoxanil/Mancozeb/Oxadixyl	300	209
Dimethomorph/Mancozeb	250	171
Fentin Acetate/Mancozeb	123	17
Fentin Hydroxide	635	72
Fluazinam	883	57
Mancozeb	293	156
Mancozeb/Metalaxyl	108	65
Other	368	205
Total		1404

Total hectares of potatoes in the United Kingdom is 165,000.
Source: [26]

Table 5a: Major Fungicides Used in Potatoes (1996)		
	Ha (000)	*Total Tonnes*
Austria	26	
Mancozeb		75.5
Denmark	43	
Mancozeb		10.8
Finland	35	
Mancozeb		5.3
France	175	
Cymoxanil		284.5
Mancozeb		925.6
Maneb		156.4
Germany	336	
Mancozeb		392.9
Metirim		154.1
Ireland	24	
Mancozeb		34.3
Italy	91	
Copper		353.7
Cymoxanil		15.0
Oxadixyl		17.3
Netherlands	185	
Fentine		311.1
Mancozeb		549.8
Maneb		413.5
Spain	180	
Copper		47.9
Mancozeb		217.6
Sweden	37	
Mancozeb		27.5
United Kingdom	178	
Oxadixyl		51.5
Cymoxanil		57.0
Mancozeb		570.7

Source: [35]

Table 5b: Major Fungicides Used in Potatoes (1996)		
	A (000)	*Total Tons*
Austria	65	
Mancozeb		83.1
Denmark	108	
Mancozeb		11.9
Finland	88	
Mancozeb		5.8
France	438	
Cymoxanil		313.0
Mancozeb		1018.2
Maneb		172.0
Germany	840	
Mancozeb		432.2
Metirim		169.5
Ireland	60	
Mancozeb		37.7
Italy	228	
Copper		389.1
Cymoxanil		16.5
Oxadixyl		19.0
Netherlands	463	
Fentine		342.2
Mancozeb		604.8
Maneb		454.9
Spain	450	
Copper		52.7
Mancozeb		239.4
Sweden	93	
Mancozeb		30.3
United Kingdom	445	
Oxadixyl		56.7
Cymoxanil		62.7
Mancozeb		627.8

Source: [35]

Table 6a: Fungicide Use for Late Blight Control			
	Hectares (000 Ha)	**Kg/Ha**	***Kg Total (000)***
Austria	23	4.8	110.4
Belgium	62	8.0	496.0
Denmark	38	8.1	307.8
Finland	30	4.8	144.0
France	162	7.8	1263.6
Germany	282	6.6	1861.2
Ireland	14	7.7	107.8
Italy	78	4.2	327.6
Netherlands	162	8.0	1296.0
Spain	116	1.5	174.0
Sweden	32	4.8	153.6
United Kingdom	165	7.7	1270.5
Total	1164	(6.4)	7512.5

Table 6b: Fungicide Use for Late Blight Control			
	Acres (000 A)	**Lbs/A**	***Lbs Total (000)***
Austria	58	4.3	249.4
Belgium	155	7.1	1100.5
Denmark	95	7.2	684.0
Finland	75	4.3	322.5
France	405	6.9	2794.5
Germany	705	5.9	4159.5
Ireland	35	6.9	241.5
Italy	195	3.7	721.5
Netherlands	405	7.1	2875.5
Spain	290	1.3	377.0
Sweden	80	4.3	344.0
United Kingdom	413	6.9	2849.7
Total	2911	(5.7)	16719.6

Source: [25][26][31][35]

Table 7a: Fungicide Cost for Late Blight Control						
	# Ha (000)	*# Sprays/Ha*	**€/Spray/ha**		***€/Ha***	***Total € (000)***
			Appl.	**AI**		
Austria	23	7	9	30	273	6279
Belgium	62	14	9	30	546	33852
Denmark	38	8	9	30	312	11856
Finland	30	6	9	30	234	7020
France	162	10	9	30	390	63180
Germany	282	8	9	30	312	87984
Ireland	14	11	9	20	319	4466
Italy	78	6	9	20	174	13572
Netherlands	162	12	9	30	468	75816
Spain	116	3	9	20	87	10092
Sweden	32	7	9	30	273	8736
United Kingdom	165	11	9	20	319	52635
Total	1164				(322)	375488

Table 7b: Fungicide Cost for Late Blight Control						
	# A (000)	*# Sprays/A*	**$/Spray/A**		***$/A***	***Total $ (000)***
			Appl.	**AI**		
Austria	58	7	4	12	112	6279
Belgium	155	14	4	12	224	33852
Denmark	95	8	4	12	128	11856
Finland	75	6	4	12	96	7020
France	405	10	4	12	160	63180
Germany	705	8	4	12	128	87984
Ireland	35	11	4	8	132	4466
Italy	195	6	4	8	72	13572
Netherlands	405	12	4	12	192	75816
Spain	290	3	4	8	36	10092
Sweden	80	7	4	12	112	8736
United Kingdom	413	11	4	8	132	52635
Total	2911				(129)	375488

Sources: # of sprays [28][18]
Cost/Spray: [27]
Appl: Application Costs

Table 8a: Potential Impacts of Biotech Potato on Production and Income					
	Potato Production[1]		***Production Costs***		***Net Income (€ million)***
	Volume (million Kg)	***Value (€ Million)***	**Fungicide**[2] **(€million)**	**Seed Cost**[3] **(€ million)**	
Austria	+14	+1.2	-6.3	+1.1	+6.4
Belgium	+51	+4.1	-33.9	+3.1	+34.9
Denmark	+31	+6.8	-11.8	+1.9	+16.7
Finland	+15	+1.9	-7.0	+1.5	+7.4
France	+122	+10.9	-63.2	+8.1	+66.0
Germany	+230	+16.1	-88.0	+14.1	+90.0
Ireland	+9	+1.6	-4.5	+0.7	+5.4
Italy	+39	+3.5	-13.6	+3.9	+13.2
Netherlands	+140	+12.6	-75.8	+8.1	+80.3
Spain	+59	+12.4	-10.1	+5.8	+16.7
Sweden	+18	+4.6	-8.7	+1.6	+11.7
United Kingdom	+130	+23.5	-52.6	+8.2	+67.9
Total	+858	+99.2	-375.5	+58.1	+416.6

Table 8b: Potential Impacts of Biotech Potato on Production and Income					
	Potato Production[1]		***Production Costs***		***Net Income ($ million)***
	Volume (million Lbs)	***Value ($ Million)***	**Fungicide**[2] **($ million)**	**Seed Cost**[3] **($ million)**	
Austria	+31	+1.2	-6.3	+1.1	+6.4
Belgium	+112	+4.1	-33.9	+3.1	+34.9
Denmark	+68	+6.8	-11.8	+1.9	+16.7
Finland	+33	+1.9	-7.0	+1.5	+7.4
France	+268	+10.9	-63.2	+8.1	+66.0
Germany	+506	+16.1	-88.0	+14.1	+90.0
Ireland	+20	+1.6	-4.5	+0.7	+5.4
Italy	+86	+3.5	-13.6	+3.9	+13.2
Netherlands	+308	+12.6	-75.8	+8.1	+80.3
Spain	+130	+12.4	-10.1	+5.8	+16.7
Sweden	+40	+4.6	-8.7	+1.6	+11.7
United Kingdom	+286	+23.5	-52.6	+8.2	+67.9
Total	+1888	+99.2	-375.5	+58.1	+416.6

[1] Assumed as 2% increase in current production (Table 1)
[2] See Table 7
[3] Assumed at €50/Ha

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