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Chemical Control of Potato Late Blight in Japan

Shigeru Mitani

Central Research Institute, Ishihara Sangyo Kaisha, Ltd., 2-3-1 Nishi-Shibukawa, Kusatsu, Shiga, 525-0025, Japan

Correspondence: **s-mitani@iskweb.co.jp**

ABSTRACT

Late blight caused by *Phytophthora infestans* (Montagne) de Bary is the most serious disease in Japanese potato cultivation. Heavy infection of foliages and tubers by this pathogen leads to severe losses of potato quality and yield. As a result, control strategies for late blight in Japan often rely on the application of fungicides. The total chemical treated area for potato late blight was 389,485 ha and 15 active ingredients including 55 formulations are currently registered for the control of potato late blight in April, 2007. Because of growing public concerns, a major focus has been placed on ways to protect the environment. Therefore, integrated management of potato late blight plays an increasingly important role for control in Japan. Fungicide use is the most effective measure and will be one of the best long-term solutions in the control of late blight. To meet current requirements such as high efficacy, cost reduction, labor reduction and environmental protection for disease control, new technology has been required. Efforts, such as trying to develop safer and more effective products, formulations, and spray techniques for the control of late blight will open the way for improved control of the disease. This paper reviews potato cultivation, late blight pathogen, potato cultivars, chemical application and fungicides for the control of potato late blight in Japan.

Keywords: fungicide, *Phytophthora infestans*, *Solanum tuberosum*

CONTENTS

POTATO CULTIVATION IN JAPAN

Potato (*Solanum tuberosum* L.) has long been an important farm crop in Japan. It was originally brought into Nagasaki, southern part of Japan in about 1601 by Dutch traders (Takahashi 1994). Potato production on a large scale began after the introduction of American cultivars into Hokkaido, the northern part of Japan, by the Russians in about 1868. At present, potatoes are grown on 87,204 hectares (ha) (spring planting: 84,244 ha + autumn planting: 2,960 ha). The average yield in spring and autumn planting were 33.7 and 15.4 ton/ha, respectively, and the total harvest reached 2,887,641 tons in 2004 (**Fig. 1**; http://www.maff.go.jp/). The largest potato cultivation area in Japan is located in Hokkaido and covers 55,400 ha where it produces about 77.4% of the total national production.

Since Japan is in volcanic region, more than 50% of field soil is classified as andosol (acidic soil). Standard application rate of fertilizer of nitrogen, phosphorous and potassium for potato cultivation in Japan is 50-150 : 80-180 : 80-180 (kg/ha) as N, P_2O_5 and K_2O (Shinto and Matsuo 1988, http://www.agri.pref.hokkaido.jp/, http://www.pre.chiba.jp/, http://www.jrt.gr.jp/). The optimum amount of N, P_2O_5 and K_2O in Nagasaki prefecture, Kyushu district is 130, 70 and 140 kg/ha (Nagao 1994). Crop rotation is an important part of potato management for both high quality and quantity of tubers (Tabuchi *et al*. 1991; Hofmeester 1992; van Loon 1992). In Tokachi district, Hokkaido, potato growers usually rotate crops in a 4-year rotation pattern; potato followed by wheat, sugar beet and beans (e.g. kidney bean, adzuki bean), potato followed by sugar beet, beans (e.g. kidney bean) and wheat, potato followed by sweet corn, wheat and sugar beet, potato followed by wheat, again wheat and sugar beet, or as a 3-year crop rotation pattern; potato followed by wheat and sugar beet, or as a 5-year crop rotation pattern; potato followed by wheat, sugar beet, beans (e.g. kidney bean) and wheat (or green manure) or potato followed by sweet corn, wheat, again wheat and sugar beet (Matsuzaki *et al*. 1994, http://www.hokkaido-jin.jp/, http://www.hojin.or.jp/).

There are two types of planting times (spring and autumn) in Japan divided into a total of four types of potato cultivation (**Fig. 2**): summer, spring, autumn and winter cultivation (Obata 1976; Takahashi 1994). This cultivation system provides a year-round supply of potatoes. In Hokkaido and Tohoku districts and the cool highland of Chubu

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Invited Review

Districts	Spring planting*		Autumn planting**	
	Planted area (ha)	Production (tons)	Planted area (ha)	Production (tons)
Hokkaido	55,400	2,235,000	-	-
Tohoku	5,390	111,900	-	-
Kanto	6,091	138,880	56	723
Chubu	5,312	104,840	196	2,043
Kinki	1,290	15,800	36	285
Chugoku	1,300	19,000	385	4,720
Shikoku	751	11,200	188	2,260
Kyushu	8,710	205,500	1,910	32,100
Okinawa	-	-	189	3,390
Total	84,244	2,842,120	2,960	45,521

*Summer and spring cultivations
** Autumn and winter cultivations

Fig. 1 Potato planted area and production in Japan. Source: http://www.maff.go.jp/

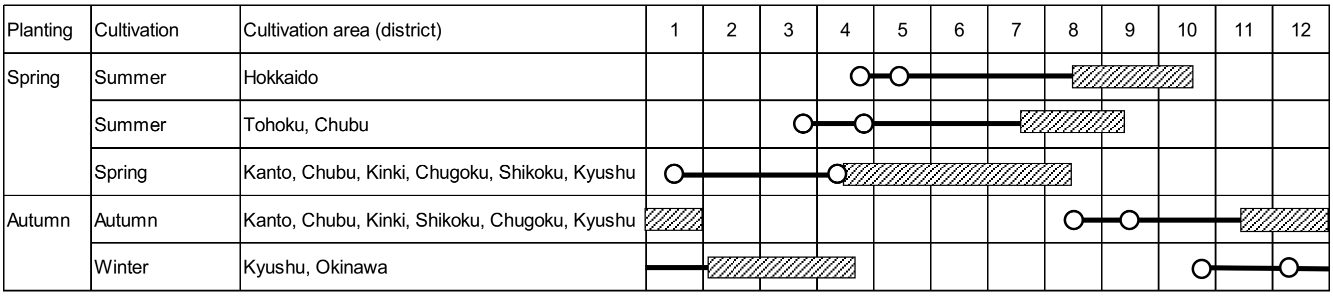

Fig. 2 Growing methods for potato production in Japan. ○Time of planting of seed tubers, ▨ Time of harvesting tubers.
Source: Nohsakumotsu sakugatabetsu seiiku-stage souran (1992) published by the association of agriculture and forestry statistics.

district (i.e. Nagano Prefecture), potatoes (seed tubers) are grown only once a year from spring through autumn (summer cultivation). In the warmer regions of Japan such as Kanto, Chubu, Kinki, Shikoku, Chugoku and Kyushu districts, potatoes are planted from winter to spring and are harvested from spring to early summer (spring cultivation). This cultivation is diverse in terms of time of planting and of harvest tubers. In the much warmer areas of Kanto, Chubu, Kinki, Shikoku, Chugoku and Kyushu districts, they are grown either or both in spring (spring cultivation) and autumn (autumn cultivation). In Okinawa and southern islands of Kyushu districts, potatoes are mainly harvested from February to March (winter cultivation). In some areas of winter and spring cultivations, potatoes are grown with polyethylene mulching allowing the shortening of the harvest period. Spring planting, in particular summer cultivation is the most common planting system in Japan (**Fig. 1**).

The relative shares of major potato cultivars in growing areas in 2003 were 'Dansyakuimo' ('Irish Cobbler', 29.2%), 'May Queen' (13.6%), 'Nishiyutaka' (5.3%), 'Kitaakari' (2.5%), 'Dejima' (1.6%), 'Touya' (0.9%) for table stock, 'Toyoshiro' (12.1%) 'Hokkaikogane' (2.2%), 'Sayaka' (0.8%) were for processed food and 'Waseshiro' (2.5%) and 'Norin 1' (2.3%) were for both table stock and for processed food. 'Konafubiuki' (18.1%) and 'Benimaru' (2.5%) were for starch manufacturing (**Table 1**; http://www.maff.go.jp/, http://www.jrt.gr.jp/).

New potato cultivars have been bred intended to meet the needs of consumers (e.g. taste value, cooking characteristics) and of potato growers (e.g. value for its resistance to pests and diseases, high yields, ease of cultivation, high quality of tubers). Because of public concerns over transgenic crops, researchers focus on the conventional breeding program in Japan. Potato breeding is mainly conducted by the national agricultural research center for Hokkaido region, Kitami agricultural experiment station, Hokuren, federation of agricultural cooperatives and Nagasaki agriculture and forestry experiment station. Except cultivars listed in **Table 1**, a total of 41 cultivars were introduced as variety registration by the ministry of agriculture, forestry and fisheries (MAFF) of Japan since 2000 (http://www.maff.go.jp/).

POTATO LATE BLIGHT

Late blight caused by *Phytophthora infestans* (Montagne) de Bary, an Oomycete is the most serious disease affecting potato production worldwide and Japan as well (Obata

Table 1 The major potato cultivars in Japan.[a]

Cultivar	Parent		Resistant gene[b]	Intended use	Relative share (%)[c]
	Female	Male			
Irish Cobbler	Unknown	Unknown	r	Table stock	29.2
May Queen	Unknown	Unknown	r	Table stock	13.6
Nishiyutaka	Dejima	Choukei 65	r	Table stock	5.3
Kitaakari	Irish Cobbler	Tunika	r	Table stock	2.5
Dejima	Hokkai 31	Unzen	R1	Table stock	1.6
Touya	R392-50	WB77025-2	R1	Table stock	0.9
Toyoshiro	Hokkai 19	Eniwa	R1	Processed food	12.1
Hokkaikogane	Toyoshiro	Hokkai 51	R1	Processed food	2.2
Sayaka	Pentland Dell	R392-50	R1, R3	Processed food	0.8
Waseshiro	Konkei 7	Hokkai 39	R1	Table stock, Processed food	2.5
Norin 1	Irish Cobbler	Deodara	r	Table stock, Processed food	2.3
Konafubiuki	Toyoshiro	WB66201-10	R1, R3	Starch manufacturing	18.1
Benimaru	Lembke Frühe Rosen	Pepo	r	Starch manufacturing	2.5

[a] Ploidy of all cultivars listed here are 4. Source: http://www.maff.go.jp/ and http://www.jrt.gr.jp/
[b] Gene for specific resistance to *Phytophthora infestans*
[c] Share in growing areas in 2003

1974; Thurston and Schultz 1981; Gregory 1983; Shattock 1988; Turkensteen 1996). Heavy infection of foliage and tubers by this pathogen leads to severe losses of marketable yield and grade of potato. The duration of high humidity and of free water due to a prolonged spell of rainfall and cloudy, humid weather leads to the development of this disease in crops (Thurston and Schultz 1981; Shattock 1988; Turkensteen 1996). Leaves and stems are initially infected by contact with diseased tubers or from soil-borne inocula originating from blighted tubers. Tubers become infected by zoospores from zoosporangia washed down by rain into the soil or by direct contact with blighted foliage at harvest (Shattock 1988). Depending on soil climatic conditions, sporangia of *P. infestans* can survive in potato ridges for up to two months (Evenhuis *et al*. 2005).

The development of molecular markers stimulated new insights into the genetic structure of plant pathogen populations (Forbes *et al*. 1998; Cooke and Lees 2004). Methods to differentiate strains of *P. infestans* are based on mating type, allozyme genotype, genomic DNA fingerprint, mitochondrial DNA haplotype (Forbes *et al*. 1998; Kato 2001; Cooke and Lees 2004). As another method, ploidy levels have also been tested in Japan as well (Kaneko and Taga 2006). Recently molecular markers (random amplified polymorphic DNA markers) for identification of genotypes in Japanese isolates were developed (Shirasawa *et al*. 2004) and further improvements are on going.

This pathogen is heterothallic and forms oospores with A1 and A2 mating types. Major changes have occurred in the genetic composition of population of *P. infestans* in Japan since 1987. The dominate genotype of the pathogen prior to 1987 was the A1 mating type (Mosa *et al*. 1993) named US-1 (Koh *et al*. 1994). The A2 mating type named JP1 was first detected in 1987 (Mosa *et al*. 1989) and was dominant in 1989 (Kato *et al*. 1998). Strains of the new A1 mating type are divided into 4 groups: A1-A (renamed JP-2), A1-B (renamed JP-3), A1-C and A1-D, which were also detected in 1996 (Kato and Naito 1997; Kato *et al*. 2002; Gotoh *et al*. 2005). Genotypes JP-2 and JP-3 which are most likely generated by sexual reproduction between JP-1 and JP-2 or related isolates (Akino *et al*. 2005) were widespread since 1999 (Kato *et al*. 2002; Sayama *et al*. 2003; Gotoh *et al*. 2005). Very recently, genotype A1-C was divided into 2 groups (renamed JP-2 and JP-4, respectively) and genotype A1-D was identical to JP-3 (Gotoh *et al*. 2007). As a result, genotypes of *P. infestans* detected in Japan were US-1, JP-1, JP-2, JP-3 and JP-4.

RESISTANT CULTIVARS

Potato has two types of resistance to *P. infestans*. The first is governed by single dominant genes with major effects (specific resistant gene) and the second is governed by many genes (non-specific resistant gene). Since all potato cultivars grown in Japan have no or a few specific resistant genes (R1 and/or R3) which JP-1, JP-2 and JP3 strains can overcome (**Table 1**; Kato 2001; Chaya and Komura 2005; Shimanuki *et al*. 2005), the probability of contribution of specific resistance to control late blight is very low. Although other specific resistant genes also may easily overcome by *P. infestans*, general resistance to *P. infestans* in potatoes can effectively suppress late blight development (Sumino 2002; Umekawa 2004; Chaya and Komura 2005) which allows the reduction of fungicide applications. Japanese researchers therefore are pursuing this type of resistance in breeding program for the control of the disease. As accomplishments of the research, 'Hanashibetsu' (the female parent: W553-4, the male parent: R392-50) and 'Saya-akane' (the female parent: I-853 the male parent: Hanashibetsu) were developed as late blight resistant cultivars (Umekawa 2004). Since some quantitative trait loci for resistance similar to single *R* genes (Gebhardt and Valkonen 2001), specific resistant R2 marker genes were developed (Ohbayashi *et al*. 2006). Using this together with the R1 marker (Ballvora *et al*. 2002), marker assisted breeding for developing late blight potato cultivars is on going.

The mitogen-activated protein kinase (MAPK) cascade is one of the major and evolutionally conserved signaling pathways utilized to transduce extracellular stumuli into intracellular responses among eukaryotes (Ligterink *et al*. 1997). As a basic research accomplishment, the transgenic potato plants that carry a constitutively active form of MAPK kinase driven by a pathogen-inducible promoter of potato showed resistance to *P. infestans* (Yamamizo *et al*. 2006).

CULTURAL PRACTICES

Cultural practices for the control of potato late blight such as eliminating potential inoculum sources (i.e. cull piles and volunteer seedlings), use of healthy seed potatoes, use of resistant varieties where possible, avoidance of excessive application of nitrogenous fertilizer, maintaining good soil coverage of tubers through adequate hilling, killing vines before harvest (so that sporangia on leaves dry out and die), harvesting on sunny days, preventing rot in storage by removing infected tubers before storage, keeping adequate air circulation are known (Thurston and Schultz 1981; Hofmeester 1992; Schöber 1992; van Loon 1992; Turkensteen 1996; Zwankhuizen *et al*. 2000; Schepers 2002) and have been used. Since late blight pathogen has the ability to quick destroy entire field potatoes, it is difficult to achieve satisfactory control by the combination of the cultural practices alone, in Japan. However, these systems contribute the control of late blight as a part of the integrated farming systems which aim for maintain the quality of the environment.

CHEMICAL APPLICATION

The total chemical treated area for potato late blight was 389,485 ha in 2006 (**Fig. 3**). The mean number of fungicide applications per field (per year) in Hokkaido is 6.74 and other prefectures are between 1 (Fukushima, Nigata, Tokyo, Toyama, Yamanashi and Shiga) and 3.05 (Aomori). The initiation of application generally starts from BBCH (Biologische Bundesanstalt, Bundessortenamt und Chemische Industrie) 55-65 (pre to full flowering) until BBCH 85-87 (maturity) with 7-10 day intervals in Hokkaido.

In Hokkaido, farmers usually apply fungicides with boom-mounted sprayers (Hara 2000). In other districts, hand spraying has most often been used for the control of the disease (Miyazaki 1998; Tashiro and Fujita 2000). Japanese conventional spray techniques are based on high pressure (10-20 kgf/cm^2 = 0.98-1.96 MPa), fine droplets (the mean particle size: *ca*. 70-100 μm) and high water volume (1000-1500 L/ha) so that both sides of each leaf and the top of each plant is sprayed (Hara 2000; Tashiro and Fujita 2000; Fujita 2002; Miyahara 2003; Umetsu *et al*. 2004). In Hokkaido, operational change of driven speed of boom-mounted vehicle makes cutting water volume 1000 L/ha to 800 L/ha (Momono and Shimizu 2003). Recently, agrochemical companies tend to get registration using a low volume foliar application (water volume: *ca.* 300-600 L/ha) for both reducing spray drift and saving labor (Hara 2000; Tashiro and Fujita 2000; Fujita 2002; Sumino 2002; Miyahara 2003). Since the addition of appropriate surfactant (e.g. an organosilicone surfactant, Makupika) with foliar fungicide can significantly improve coverage and efficacy (Tosaki 2000; Mitani *et al*. 2006), this type of surfactant will play an important role for the control of late blight using a low volume application in future.

LATE BLIGHT FORECASTS

One of the most difficult aspects of fungicide used in the control of potato late blight is determining the correct time for application (Schöber 1992; Magarey *et al*. 2002; Schepers 2002). Actual fungicide sprayings are carried out based on the weather forecast that is derived from historical weather and disease data (Hara 2000; Ogawa *et al*. 2003). In Hokkaido, spray initiation is carried out based on the Japanese forecasting system FLABS which is derived from the highest, the lowest and average temperatures and, precipitation amount (Kato and Shimanuki 2001; Sumino 2002). This system use is effective to late blight control with a reduction of fungicide input (Sumino 2002). In Europe and the US, highly sophisticated decision support systems (DSSs) are known and have been used (Bruhn and Fry 1981; Magarey *et al*. 2002; Raymundo *et al*. 2002, Schepers 2002). This systems can organize all available information on the pathogen, the weather conditions, plant growth, fungicide selection, cultivar resistance and disease pressures required for decision to control late blight (Magarey *et al*. 2002; Schepers 2002; Yamamichi 2005), DSSs therefore may play an increasing important role in late blight control in the future. Since most DSSs are developed abroad (Kato and Shimanuki 2001; Yamamichi 2005), examination for their model validity and adjustment to design location-specific late blight management strategy in Japan will be required.

FUNGICIDES

The total fungicide cost of managing potato diseases, including late blight in Japan was at 33 million US$ in 2003 (source: Phillips McDougall AgriService 2004). Currently (26 April, 2007), 15 active ingredients including 55 formulations are registered for the control of potato late blight (**Tables 2, 3**; Annual inventory of registered pesticides and their use).

The ethylene-*bis*-dithiocarbamates, or EBDC's (mancozeb, maneb and polycarbamate), especially mancozeb and a number of older products are still widely used, including

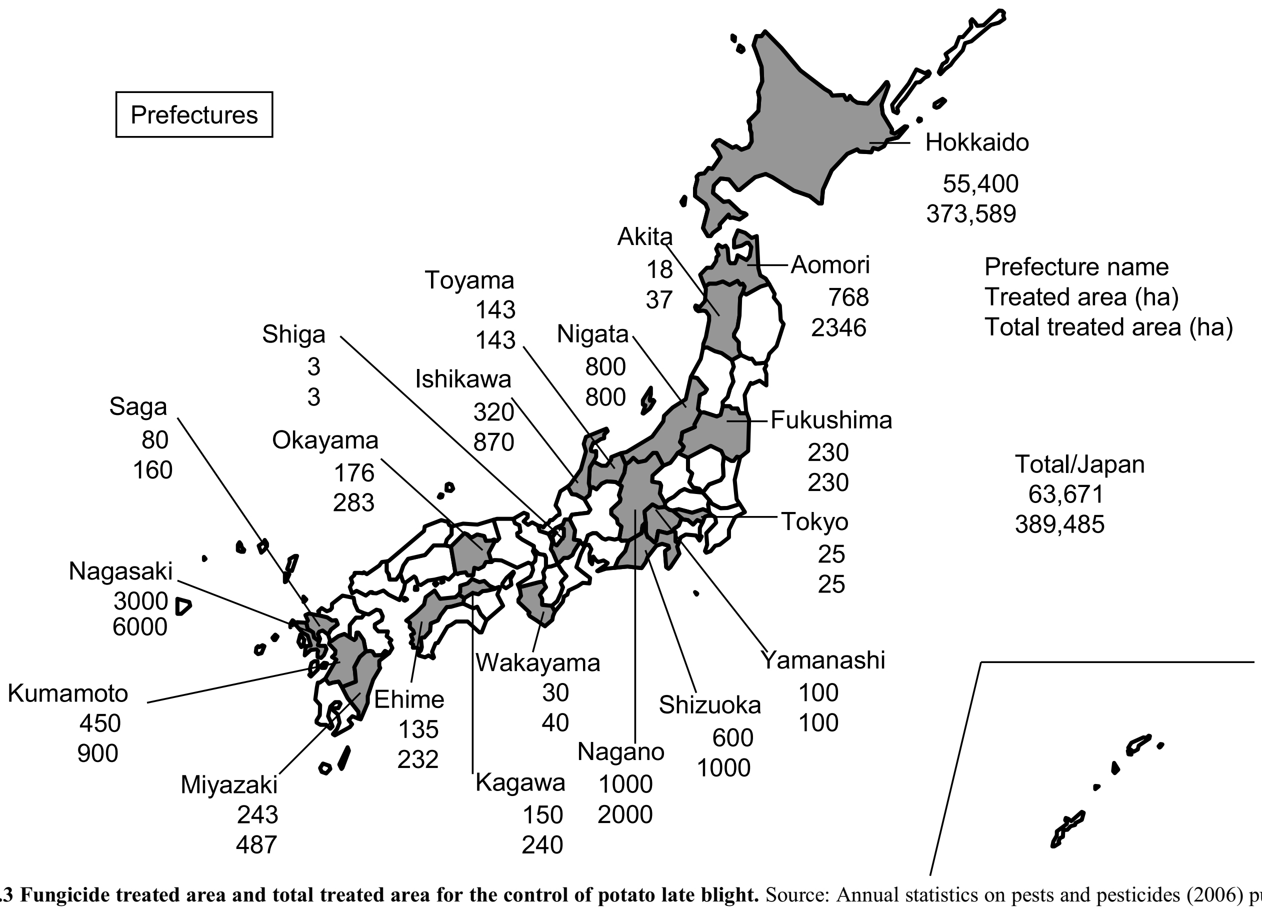

Fig.3 Fungicide treated area and total treated area for the control of potato late blight. Source: Annual statistics on pests and pesticides (2006) published by the Japan plant protection association.

Table 2 Conventional active ingredients for the control of potato late blight registered in Japan.[a]

Common name	Rate[b] (mg a.i./L)	Number of registered products		Mixing partner
		Solo	Mixture	
Mancozeb	1250-1875	4	5	Cymoxanil, Dimethomorph, Iminoctadine tris (albesilate), Metalaxyl, Procymidone
Maneb	1108-1875	3	1	Thiophanate-methyl
Polycarbamate	1250-1875	1	0	
Copper-based products	400-1500	13	10	Chlorothalonil, Dimethomorph, Iprodione, Metalaxyl, Oxadixyl, Oxolinic acid, Procymidone, Sodium hydrogen carbonate, Streptomycin, Sulfur
Calcium oxide	-	1	0	
Chlorothalonil	477-992	3	5	benthiavalicarb-isopropyl, Copper oxychloride, Cymoxanil, Metalaxyl, Oxadixyl
Streptomycin	133-200	3	2	Copper oxychloride, Oxytetracycline
		28[c]	21[d]	

[a] Source: Annual inventory of registered pesticides and their use (2006) published by the Japan plant protection association
[b] Rates for solo products, a.i.: active ingredient
[c] Total number of solo products
[d] Total number of mixture products after delete redundancy (chlorothalonil + copper and streptomycin + copper) in this table

Table 3 Advanced active ingredients for the control of potato late blight registered in Japan.[a]

Common name	Chemical class	Property [b]	Rate [c] (mg a.i./L)	Number of registered products		Mixing partner
				Solo	Mixture	
Metalaxyl	Phenylamide	Systemic	133-200	0	3	Chlorothalonil, Mancozeb, Copper oxychloride
Oxadixyl	Phenylamide	Systemic	80-200	0	2	Copper oxyxhloride, Chlorothalonil
Cymoxanil	Acetamide	Systemic	120-300	0	3	Chlorothalonil, Famoxadone, Mancozeb
Dimethomorph	Cinamic acid	Systemic to Local systemic	250-500	1	2	Copper oxychloride, Mancozeb
Famoxadone	Oxazolidindione	Protective	90-225	0	1	Cymoxanil
Fluazinam	Pyrimidinamine	Protective	250-500	1	1	Fosetyl
Cyazofamid	Phenylimidazole	Local systemic to Protective	50-100	2	0	
Benthiavalicarb -isopropyl	Carboxylic acid amide	Local systemic	50	0	1	Chlorothalonil
				4[d]	12[e] (2[f])	

[a] Source: Annual inventory of registered pesticides and their use (2006) published by the Japan plant protection association
[b] Systemic: movement from root to leaves, local systemic: movement from upper side of leaf to the lower side and *vice versa*, Protective: no movement
[c] Rates for solo products: dimethomorph, fluazinam and cyazofamid, rates for mixture: others, a.i.: active ingredient
[d] Total number of solo products
[e] Total number of mixture products after delete redundancy (famoxadone + cymoxanil) in this table
[f] Total number of products after delete redundancy in this table (famoxadone + cymoxanil) and in table1 (metalaxyl + chlorothalonil, metalaxyl + mancozeb, metalaxyl + copper, oxadixyl + copper, oxadixyl + chlorothalonil, cymoxanil + chlorothalonil, cymoxanil + mancozeb, dimethomorph + copper, dimethomorph + mancozeb, benthiavali-carb -isopropyl + chlorothalonil)

copper-based products, calcium oxide and chlorothalonil (**Table 2**). Theses fungicides are protective fungicides with multi-site modes of action which need a high dose rate (**Table 2**) to obtain a satisfactory effect. Although streptomycin is a bactericide, streptomycin-based products are registered for the control of potato late blight.

More advanced products used for the control of potato late blight include metalaxyl, oxadixyl, cymoxanil, dimethomorph, famoxadone, fluazinam, cyazofamid and benthiavalicarb-isopropyl (**Table 3**). Metalaxyl and oxadixyl are systemic fungicides that provide a good curative as well as protective activity against Oomycete pathogens (Schwinn 1983; Cohen and Coffey 1986; Ozaki *et al*. 1988; Takakuwa 1992). Theses fungicides belong to the same chemical class of phenylamides that specifically inhibit RNA polymerase (Davidse *et al*. 1983; Cohen and Coffey 1986; Davidse 1988). Because of high risk of the appearance of resistant isolates of *P. infestans*, metalaxyl is sold in combination with protective fungicides chlorothalonil, mancozeb or copper oxychloride, and oxadixyl is in combination with chlorothalonil or copper oxychloride (**Table 3**).

Other fungicides are very diverse in terms of their mode of action, efficacy and chemical class. Cymoxanil exhibits good curative activity against diseases caused by Oomycete pathogens (Douchet *et al*. 1977; Klopping and Delp 1980; Schwinn 1983; Cohen and Coffey 1986). Its residual life may be limited for a few days under hot weather conditions, therefore, cymoxanil is sold in combination with protective fungicides such as mancozeb, chlorothalonil or famoxadone in Japan. The mode of action of cymoxanil is not still clear; however, this fungicide inhibits both DNA and RNA synthesis (Ziogas and Davidse 1987).

Dimethomorph exhibits both curative and protective (persistence) activity against diseases caused by Oomycete pathogens (Albert *et al*. 1988; Cohen *et al*. 1995). Its mode of action is thought to be through the inhibition of cell wall synthesis (Kuhn *et al*. 1991; Thomas *et al*. 1992). Famoxadone is a protective fungicide providing a broad spectrum of disease control. It is particularly active against Oomycete pathogens with long persistence activity (Joshi and Sternberg 1996). The mixture, famoxadone with cymoxanil is solely introduced into the market in a mutually reinforcing way, and never alone. Famoxadone inhibits the Q_o center of the cytochrome bc_1 complex activity in the mitochondria respiration chain (Jordan *et al*. 1999).

Fluazinam is a protective fungicide providing a broad spectrum of disease control. This fungicide exhibits excellent persistence activity against diseases caused by Oomycete pathogens (Anema *et al*. 1992; Komyoji *et al*. 1995). The mode of action of fluazinam is the uncoupling of oxidative phosphorylation (Guo *et al*. 1991). Cyazofamid exhibits excellent control of diseases caused by Oomycete pathogens at very low rates of use (50-100 mg/L) compared with all commercial fungicides (Mitani *et al*. 1998, 2002; Ogawa *et al*. 2003; Mitani *et al*. 2005). This fungicide inhibits the Q_i center of the cytochrome bc_1 complex activity in the mitochondrial respiration chain (Mitani *et al*. 2001). Fungicides, which can be applied at 10-14 day application intervals, eliminate the total number of applications and enable the growers to save labor. In the Hokkaido area, fluazinam and cyazofamid are regarded as the only fungicides which can be applied at a 10-14 day interval for the control of potato late blight by the Hokkaido government (Sumino 2002; Mitani *et al*. 2005). These fungicides are also regarded as only fungicides which can be used to control tuber blight by *P. infestans*.

Recently, a number of other products such as amisulbrom (Takahashi *et al*. 2005), azoxystrobin (Godwin *et al*. 1992), benthiavalicarb-isopropyl (Miyake *et al*. 2003, 2005), ethaboxam (Kim *et al*. 2002), fluopicolide (Tafforeau *et al*. 2005; Hadano *et al*. 2006), folpet (Siegel 1971), mandipropamid (Huggenberger *et al*. 2005), metalaxyl M (Nuninger *et al*. 1996), propamocarb hydrochloride (Schwinn 1983; Cohen and Coffey 1986) and BAF-0506 from BASF are under development as fungicides for the control of potato late blight. Very recently, the first registration of benthiavalicarb-isopropyl was received in April, 2006 for use on potato as a combination with chlorothalonil (**Table 3**).

FUNGICIDE RESISTANCE

Resistance to fungicides by plant pathogenic microorganisms is one of the most serious agricultural problems throughout the world. The phenylamide fungicides metalaxyl and oxadixyl were registered officially in 1986 and have provided good control of potato late blight (Ozaki *et al*. 1988). However, control failures of potato late blight due to the emergence of resistant isolates of the pathogens to the phenylamides were observed in a potato-growing area of Hokkaido about three years after their introduction (Takakuwa 1992; Horita and Tanii 1998). A decrease in efficacy of theses fungicides was also reported in Tohoku, Kyushu and Kanto districts (Chu *et al*. 1999; Suga and Nakagawa 2000; Kato *et al*. 2001; Sayama *et al.* 2003). Even where resistance is readily detectable, phenylamides are still being used to contribute to disease control (Takakuwa 1992). No resistant isolates of *P. infestans* have been reported to other fungicides (**Tables 2, 3**) belonging to different chemical classes.

FUTURE PROSPECTS

In order to meet current requirements such as high efficacy, cost reduction, labor reduction and environmental protection, new technology has been required for the control of diseases, pests and weeds (Torii and Terashima 1995; Miyazaki 1998; Hara 2000; Tashiro and Fujita 2000; Tosaki 2000; Fujita 2002; Miyahara 2003; Ogawa *et al*. 2003; Tsuji 2003; Nakamura and Katayama 2004; Umetsu *et al*. 2004). Because of growing public concerns, a major focus has been placed on ways to protect the environment in Japan (Hara 2000; Tashiro and Fujita 2000; Miyahara 2003; Nakamura and Katayama 2004; Umekawa 2004; Umetsu *et al.* 2004). MAFF supports environmentally-friendly agriculture in order to promote agriculture harmonized with nature and to ensure food safety based on the consumer's point of view (http://www.maff.go.jp/). The Japanese ministry of health, labour and welfare (MHLW) established new regulations on residual agricultural chemicals, to be known as the "positive list" system, covering residual agricultural chemicals on 29 May 2006.

Integrated management of potato late blight is a combination of management techniques to keep disease level low and at the same time maintain the quality of the environment (Schöber 1992; van Loon 1992; Schepers 2002; Umekawa 2004; Shimanuki *et al*. 2005). Important tools of integrated control include cultural practice, use of resistant cultivars and fungicide application (Schepers 2002; Umekawa 2004; Shimanuki *et al*. 2005). Since this technique has been met for current requirements, integrated management will play an increasingly important role to control potato late blight in Japan.

Fungicide use is the most effective measure and will be one of the best long term solutions in the control of late blight. The agro-industry, incorporating administrative agencies and organizations related to plant protection have been trying to develop safer and more effective products, formulations, spray techniques (to realize low toxicity to mammals, low impacts on the environment, a low dose rate, and a few number of applications), reduce packing and manufacturing waste. These efforts for the chemical control of potato late blight will open the way for improved control of the disease.

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JAPANESE ABSTRACT

ジャガイモ疫病は *Phytophthora infestans* (Montagne) de Bary によって引き起こされる病害で日本のジャガイモ栽培において最も重要な病害のひとつである。本病の発病が激しい時は茎葉や塊茎が犯され、ジャガイモの収量や品質に大きな影響を及ぼすことから、殺菌剤散布に頼った防除が中心に行われている。日本におけるジャガイモ疫病の化学防除面積は 389,485 ha であり、2007 年 4 月時点で 15 の活性成分と 55 の製品が登録されている。近年、環境保全に対する関心が高まっていることから、日本においても環境保全型防除の重要性が増している。殺菌剤処理は疫病防除に対して今後も最も有効な方法と思われるが、より高い防除効果、処理コストの低減、労働力の低減、環境保全を考慮した新しい技術が必要とされている。その実現のために、より安全で効果的な製品、製剤、散布技術などの開発が続けられている。本稿では日本におけるジャガイモ栽培、疫病菌、ジャガイモ品種、化学防除および殺菌剤についての概要を紹介する。