History of Bacterial Ring Rot of Potato in the Czech Lands and a Proposal for Relaxation of Strict Quarantine Measures

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Abstract

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In the supposed or proven incidence of bacterial ring rot caused by *Clavibacter michiganensis* subsp. *sepedonicus* (*Cms*) in certified seed and commercial potatoes, five periods can be identified in the Czech Lands from 1910 to 2006: (*i*) high incidence of *Cms* in potato crops is claimed (about 1910–1929); (*ii*) very low incidence in certified potatoes and sporadic occurrence in commercial potatoes (about 1930–1985); (*iii*) increasing incidence of *Cms* in certified seed potatoes and its sporadic occurrence in commercial potatoes is assumed (about 1986–1997); (*iv*) a relatively high percentage of potato tuber samples proved to be infected by *Cms*, namely 1.14% in seed potatoes in 1998 and 4.13% in commercial potatoes in 1999 (1998–2004 period); (*v*) progressive decrease of *Cms* incidence to zero in seed potato samples and 0.19% in commercial samples in 2005, followed by a slight increase to 0.15% in seed potatoes and 0.23% in commercial potatoes in 2006 (2005–2006 period). Thus, up to 2006, *Cms* was and is not widely distributed in the CR and is actively and effectively controlled, mainly through the zero tolerance for ring rot bacterium in the seed potato certification program. In the CR, *Cms* has a relatively low capacity for damage and can hardly be considered as a pest of national economic importance. Strictly speaking, *Cms* does not fulfill the criteria for a quarantine organism. If, however, the quarantine status of *Cms* will be maintained, the severe post-entry measures against it should be relaxed.

Keywords: potato; *Clavibacter michiganensis* subsp. *sepedonicus*; bacterial ring rot; incidence of occurrence; Czech Republic; quarantine measures

Clavibacter michiganensis subsp. *sepedonicus* (Spieckermann & Kotthoff 1914) Davis, Gillaspie, Vidaver & Harris 1984 (*Cms*), causative agent of bacterial ring rot (BRR), is a worldwide concern in the production of potatoes for seed and commercial table stock. Reports of *Cms* have come from 31 countries distributed over five continents (Van der Wolf *et al.* 2005). BRR is one of the most important reasons for the rejection of seed lots in potato certification programs. *Cms* is a quarantine organism in EU member states.

Concerns over the pathogen continue to significantly impact global potato export markets, as countries often restrict importation of seed from countries in which the disease is present. Therefore, it is desirable to conduct detailed studies to determine the occurrence of the BRR pathogen, disease intensity and yield losses, and their changes in space or over time with environmental parameters, geographical factors, potato cultivar spectrum and crop management practices. In this paper, an attempt is made to evaluate changes in

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the occurrence of *Cms* in the Czech Lands of Bohemia, Moravia and Silesia (which today comprise the territory of the Czech Republic) in the period 1906–2006, and to suggest and justify a relaxation of the severe quarantine measures against the pathogen.

MATERIAL AND METHODS

The data on the presence of *Cms* in Bohemia, Moravia and Silesia were derived from different sources as follows: (*i*) reports published during 1911–1929; (*ii*) own results of visual evaluation of internal symptoms (considered to be BRR symptoms) on cross sections of tubers of potato samples and preserved hitherto in glass cylinders with formalin fixation since 1926 at the Secondary Agricultural School, Tábor, since 1942 at the State Phytosanitary Administration, Brno, and since 1962 at the South Bohemia University, Faculty of Agriculture, České Budějovice; (*iii*) results of laboratory testing of officially taken potato tuber samples collected from farmer's fields or stores during 1998–2006. Every year, between 3879 and 7571 samples of seed and commercial potatoes were tested, using the procedure normally used in the EU for detection and determination of *Cms*. The procedure (see EC Directive 93/85/EE) allows to detect latent infections of *Cms* in potato tubers (Anonymous 1993).

RESULTS AND DISCUSSION

Period 1910–1929

Distribution, importance and environmental conditions. As to the history of BRR, many parallels seem to exist between the Czech Lands and bordering Germany. Because of the leading position of Germany in plant pathology at the beginning of the 20th century, it is not surprising that Czech phytopathologists dealing with bacterial ring rot of potato were at first strongly influenced by the publications of Appel (1906, 1906/1911), Appel and Kreitz (1907) (all cit. Stapp 1956) and later by studies of Spieckermann and Kotthoff (1914) and Appel (1915a, b). In Germany, 60–70% of hills of potatoes were destroyed in some fields by so-called bacterial ring disease (Bakterienringkrankheit) in 1905. Yields were so low that harvesting of potatoes was not worthwhile in such fields (Appel 1906 – cit. Stapp 1956).

According to Bubák (1911), Kutín (1912) and Straňák (1917), a disease named bacterial ring rot has occurred in potato crops in Bohemia at the beginning of the 20th century. It is noteworthy that no name of the causal agent is stated in the papers of Bubák (1911) and Kutín (1912). Straňák (1917) based his report about "the very high occurrence" of bacterial ring rot in Bohemia on results of the evaluation of samples from potato seed stocks. Unfortunately, he did not present any concrete data about the percentage of diseased tubers per sample as observed visually on cross sections of tubers in winter tests.

Of the Czech Lands, South Bohemia was supposed to be the region most severely threatened by BRR (Bubák 1911; Kutín 1912). In some cases, the disease attacked and destroyed nearly all potato stands (Bubák 1911). On the other hand, Starý and Říha (1928) stated that in the Czech-Moravian Highland, the main seed potato region in the Czech Lands, the potato crops had not been seriously afflicted with BRR until that time.

Baudyš (1929) stated that potato varieties with yellow flesh of the tubers are most affected in the Czech Lands, with a loss in yield as high as 60–70% in some years. According to Starý and Říha (1928), yield losses caused by BRR are comparable to losses caused by bacterial black leg and soft rot.

Supposedly, alternating *wet* and warm weather contributed greatly to the spread of the disease (Kutín 1912). In contrast to this, Baudyš (1929) assumed that development of the disease is supported by *dry* and warm weather. According to present knowledge, BRR development is favoured by high temperature at the end of the growing season and probably also by higher soil moisture (Van der Wolf *et al.* 2005).

All the above cited reports regarding the occurrence of *Cms* in Czech Lands should be taken cautiously. While some of the symptoms observed by Bubák (1911) and Straňák (1917) agree with nowadays description of BRR symptoms, there are also some substantial discrepancies between them (Table 1, Figures 1–3).

Causal agent. At the beginning of the 20th century, there was considerable confusion as to the causal agents of vascular diseases of potato with bacterial origin. At that time, three bacterial vascular diseases of potatoes were known: brown rot or bacterial wilt, occasionally (according to Stapp 1956) also named ring disease, which is caused by *Bacterium solanacearum* Smith 1896 (= *Ralsto-*

Figure 1. Pen drawing by Bubák (1911): "Dwarfing symptoms on potato plant infected by ring rot bacterium. Leaves are crinkled. An under-ground part of stem with longitudinal cracks gradually rots". Repainted by A. Skoumalová

Figure 2. Pen drawing by Bubák (1911). Bacterial ring rot symptom: "An under-ground part of stem with longitudinal cracks where bacteria penetrate into the plant". Repainted by A. Skoumalová

nia solanacearum [Smith 1896] (Yabuuchi et al. 1995); ring disease (Appel's ring disease, German ring disease) caused by a complex of unspecified bacteria; and ring rot (Spieckermann's German potato disease) caused by *Bacterium sepedonicum* Spieckermann & Kotthoff 1914 (= *Clavibacter michiganensis* subsp. *sepedonicus* [Spieckermann & Kotthoff 1914] Davis, Gillaspie, Vidaver & Harris 1984).

Worth mentioning is Smith's view (Smith 1914) that the causal agent of Appel's ring disease is possibly *Bacterium solanacearum* (= *Ralstonia solanacearum*). However, *Ralstonia solanacearum* can be probably excluded as a potential pathogen causing destructive damages in potato crops in Central Europe at the beginning of the 20^{th} century. This is because temperature plays a key role in the geographic distribution of the pathogen and it is rarely found in areas where the mean temperature is below 15°C. However, race 3 of the pathogen, affecting mainly potato and tomato and having a lower temperature optimum of 27°C, has been documented in northern Europe as far north as 56° latitude (Allen *et al.* 2001).

The formerly Czechoslovakia was included by Elliot (1951) in the list of countries with confirmed occurrence of *Cms.* That was probably done based on Straňák's article (Straňák 1917). Nevertheless, according to his article, potato ring rot disease was predominantly diagnosed on the basis of visual disease symptoms. In the vascular ring within the tubers, the author microscopically observed a great number of bacteria in the vessels. Most bacteria had the form of short rods, 0.8 × 0.5 µm in size. Though somewhat larger bacteria, 1.7–1.9 × 1.3 µm in size, were also present, they

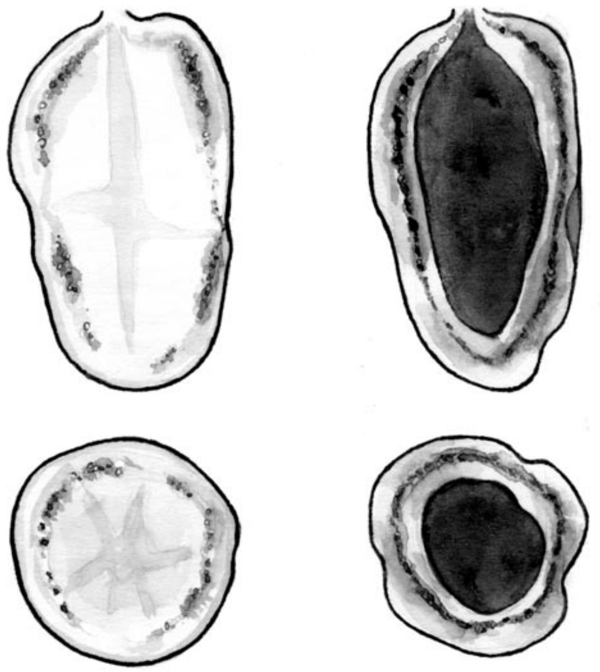

Figure 3. Pen drawing by Bubák (1911). Bacterial ring rot symptoms: "The incipient stage of the disease on the longitudinal and cross section of tuber (left) and the advanced stage (right)". Repainted by A. Skoumalová

appeared not to belong to *Cms*. Straňák (1917) was aware of his incomplete diagnosis since he wrote that the real cause of potato bacterial ring rot is not clear and has still to be solved.

From the quite comprehensive descriptions and illustrations of ring rot symptoms observed by Bubák (1911), Kutín (1912) and Straňák (1917) in Bohemia, it can be concluded that the symptoms and yield losses ascribed only to BRR caused by *Cms*, were in fact caused by a disease complex resulting from the combined activities of *Cms*, *Pectobacterium carotovorum* subspecies and/or virus pathogens such as *Potato leafroll virus* (PLRV), *Potato virus A* (PVA), *Potato virus Y* (PVY), *Potato virus X* (PVX), or the fungal pathogen *Rhizoctonia solani* Kühn 1858 (Table 1). The impact of a combined infection by *Cms* and *Pectobacterium atrosepticum* on potato plants was described by Naumann *et al.* (1986), and Nelson and Torfason (1974) conducted tests to determine the effect of PLRV and *Cms* on expression of disease symptoms and yield of potatoes.

Therefore we can have reason to believe that Bubák (1911), Kutín (1912) and Straňák (1917) have observed and described potato plants which were affected by a complex of pathogens and not by ring rot bacterium alone. This view is indirectly supported by the report of Starý and Říha (1928) that, in their field experiment, "very good results were obtained with control of BRR when seed potatoes infected with *Cms* were treated using seed protectants (*sic*)". Analogically, in Sweden, BRR was described by Wolff as early as 1908, although, according to Holmberg (1966 – cit. Seppänen & Hainämies 1971), BRR was probably confused with other diseases and was not reliably identified until 1956.

Period 1930–1985

In the Czech Lands, as also in other states in Central and Western Europe, a decreased incidence of BRR in the 1930s has been claimed. Only sporadic occurrences of and no yield losses from BRR have been recorded in the Czech Lands and other European countries in that time (Smith *et al.* 1996). In contrast to the alarming situation reported in the previous decades, it was a striking change for the better. This strong reduction of damages by BRR in Europe has usually been explained by the introduction of the certification system for seed potatoes on the one hand, and by ending or

Figure 4. Disease symptoms considered to be bacterial ring rot on potato tubers and preserved hitherto in glass cylinders with formalin fixation since 1926 (left), 1942 (center) and 1962 (right) (Photos: K. Veverka and V. Krezar)

Table 1. Symptoms on potato plants which were erroneously regarded by Bubák (1911) and Straňák (1917) to be caused by *Cms*

Symptoms supposed by Bubák (1911) and Straňák (1917) to be caused by *Cms*	**A possible true causal agent** Reasoning
"Stems are much shorter than healthy ones" (Figure 1) (Bubák 1911).	**PVX, PLRV, PVA, PVY** Dwarfing or stunting are not typical symptoms of BRR (Baer & Gudmestad 2001). On the other hand, severe infection with PVX results in dwarfing of plants (Slack 2001). Plants infected with both *Cms* and PLRV exhibited more pronounced dwarfing (Nelson & Torfason 1974). Foliar symptoms in some cultivars, such as Russet Burbank, may include a dwarf rosette (Baer & Gudmestad 2001).
"… leaflets are smaller and characteristically crinkled" (Figure 1) (Bubák 1911).	**PVA, PVX, PVY** Crinkling is not a typical symptom of BRR. On the other hand, mixed infection by PVA, PVX, PVY and PVX may cause a severe mosaic leading to crinkling, rugosity or necrosis (Slack 2001).
"Black spots are sometimes seen on the leaflets including necroses on the veins. Black spotted leaflets falls off prematurely" (Bubák 1911; Straňák 1917).	**PVY** Black spots on leaves are not typical symptoms of BRR (Baer & Gudmestad 2001). However, when leaves are heavily infected with *Cms*, necrotic lesions start to develop, which are only expanded in susceptible cultivars, but not in resistant ones, due to a hypersensitivity response (Romanenko *et al.* 2002 – cit. Van der Wolf *et al.* 2005). On the other hand, primary symptoms of infection with PVY include necrosis beginning as spots or rings, mottling, yellowing of leaflets, leaf dropping, and premature death of plants. Plants with secondary infection develop a severe necrosis on leaf veins (Slack 2001). Localised rotted lesions on leaflet blades, petioles and stems can be related with infections by soft rot bacteria after injury of superficial tissues (Fahy & Persley 1983).
"Brown coloured splits, which are not similar to rot lesions but rather to healed scars, are seen on an underground part of the stem. … Stems gradually rot from below upwards" (Figures 1 and 2) (Bubák 1911).	*Rhizoctonia solani*, **causal agent of Rhizoctonia canker** If BRR alone is present, the lower stems, both externally and internally, will appear to be perfectly healthy, while some other diseases will show certain characteristic symptoms (Starr & Riedl 1945). Reddish brown lesions on stems and stolons may be caused by *Rhizoctonia solani* (Baker 1974).
"Stems are transparent, frequently brownish coloured and spotted" (Straňák 1917).	Transparent stems are not symptoms of BRR. Severe necroses on stems are found on plants infected with PVY (Slack 2001).
"Attacked plants died down during June and early July" (Bubák 1911; Straňák 1917).	It requires from 55 to 80 days from planting time for ring rot symptoms to appear, depending on the soil temperature (Starr & Riedl 1945). Infection occurs more readily when infected seed is planted in wet soil at temperatures of 17–22°C (Baer & Gudmestad 2001).
In addition to typical ring rot symptoms observed by cutting the tuber crosswise at the stem end, "brown discoloration in the center of the tuber can be seen in the most severe stage of the disease" (Figure 2) (Bubák 1911).	*Pectobacterium* spp.**, causal agents of blackleg and tuber soft rot; secondary opportunistic bacteria and (or) fungi for example** *Fusarium* spp. Brown discoloration in the center of the tuber is not a characteristic symptom of BRR. However, it is known that in advanced stages the combination of ring rot bacteria and soft rot bacteria often causes a rapid breakdown in the central portion of the tuber, so that occasionally only the hollow shell remains (Starr & Riedl 1945; Powelson & Franc 2001). Ring rot symptoms may be masked by secondary infection of tubers by opportunistic organisms. Affected tubers eventually disintegrate completely in the field or in storage and large yield losses may be incurred (Baer & Gudmestad 2001).

limiting the practice to plant cut seed tubers on the other hand (Stapp 1956; Langerfeld 1989; Janse 2006). In the Czech Lands, data obtained from official sources from the period 1930–1985 must be interpreted with caution. In certified potato seed, the diagnosis of *Cms* was based only on foliar and tuber symptoms, whereas commercial potato crops were not inspected.

We had the opportunity to assess internal symptoms on cross sections of tubers of potato samples (considered to be BRR symptoms) originating from Bohemia and Moravia which had been preserved in glass cylinders with formalin fixation since 1926, 1942 and 1962, respectively. Two of the three samples, i.e. from 1942 and 1962, had characteristic ring rot symptoms consisting of cheesy-like decay in the vascular ring (Figure 4). This can be regarded as indirect evidence of *Cms* presence on Czech Lands in that period.

As to the certification system of seed potatoes, it seems to the writer that the efficacy of this system in eliminating *Cms* in European countries should not have been high in the 1930s. In the Czech Lands and Germany, the tolerance for BRR in certified seed potatoes was set as high as 5% to 8%, and 5% respectively, based on visual inspection (Starý & Říha 1928). Such high tolerance could hardly have contributed greatly to lower the incidence of BRR in Czech Lands. Also, doubts that the certification against BRR used in the 1930s had an only low efficacy seem to be justified: the proportion of symptomless potato tubers in which *Cms* can be detected by immunofluorescence ranges from 22% to 41% (De Boer & McCann 1990). On the other hand, potatoes intended for seed were not cut before planting and that seems to be one of the main reasons for BRR not becoming serious in the Czech Lands and other European countries.

In North America, where *Cms* has occurred at one time or another in all potato growing states and provinces of the United States and Canada (De Boer 1987), a zero tolerance for BRR in certified seed potatoes was adopted (Longsdon *et al.* 1957). The diagnosis was based on foliar or tuber symptoms or both and generally was confirmed by a Gram strain test, which lacks specificity. Later on, specific, sensitive and rapid serological diagnostic methods for *Cms* were developed (Slack *et al.* 1978; De Boer & Wieczorek 1984).

In 1976, the European Economic Community (EEC) enacted Council Directive 77/93/EEC on protective measures against the introduction of organisms harmful to plants and plant products. The directive states that Member States shall ban the introduction into their territory of the harmful organisms listed in Annex I, Part A, which, among others, include *Cms*. A similar directive was introduced in the formerly Czechoslovakia.

Period 1986–1995

Bacterial ring rot, which had disappeared for a number of years in Europe, reoccurred in the 1980s for unknown reasons (Janse 2006). Surprisingly, *Cms* was not reliably identified in Czech Lands until 1995. The official EEC procedure for detecting *Cms* in seed potatoes (Directive 80/665/EEC and subsequent Directive 93/85/EEC) has been introduced into practice in the CR in 1995.

Period 1998–2006

Contrary to preceding decades, a relatively high percentage of potato tuber samples proved to be infected by *Cms*, namely 1.14% in seed potatoes in 1998, and 4.13% in commercial potatoes in 1999. Zero incidence of *Cms* in basic and certified seed potatoes and 0.19% in commercial potato lots were achieved in 2005. However, 0.15% of the seed potato samples and 0.23% of commercial samples were positive in the following year, 2006 (Figure 5). The data from these two years confirmed an experience in other countries, i.e. that if the certified tuber samples in a regions tested negative for the presence of *Cms* in some years, it does not mean that the pathogen was eradicated in that region. Several countries have attempted, unsuccessfully, to eradicate the bacterial ring rot bacterium. One of the many reasons for its persistence is certainly the pathogen's ability to persist in such low concentrations in apparently healthy tubers that are below the sensitivity threshold of the recently used detection method (10^3–10^4 cells per ml or resuspended pellet). Therefore, low levels of *Cms* may persist for many generations with no detectable effect on yield or any development of symptoms.

A proposal for relaxation of strict quarantine measures

Cms is universally regarded as a pathogen that justifies stringent quarantine measures and there is a long-held belief that if it were to become established, the costs to the potato industry and

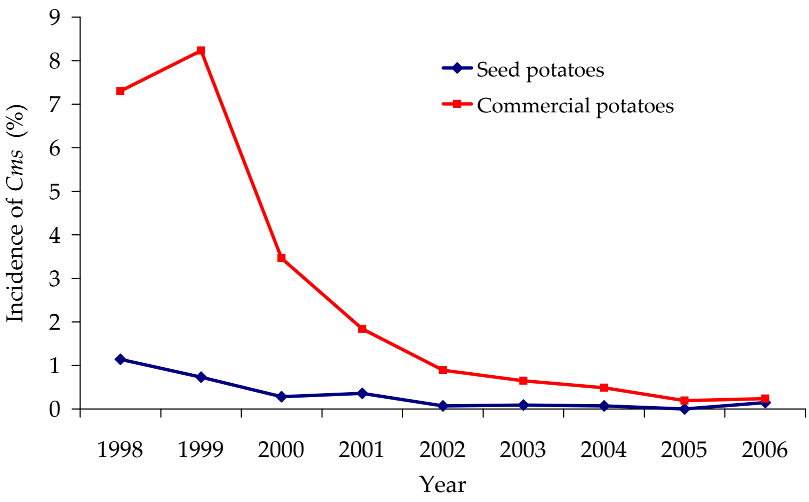

Figure 5. Incidence of ring rot bacterium detected in tuber samples of seed and commercial potatoes in the Czech Republic during 1998–2006

to official plant health services in question would be high (Pemberton 1988). In the International Plant Protection Convention (Anonymous 1992), a "quarantine pest" is defined as "a pest of potential national economic importance to the country endangered thereby and not yet present there, or present but not widely distributed and being actively controlled". Potato ring rot disease has occurred in some parts of the EU and some limited sources of infection still exist. Within the EU Member States, Council Directive 93/85/EEC (Anonymous 1993) outlines the strict measures to be taken against *Cms* in order to: locate it and determine its distribution, prevent its occurrence and spread, and, if found, to prevent its spread and to control it "with the aim of eradication". In connection with quarantine measures against *Cms*, the question arises whether the strict phytosanitary measures against potato ring rot bacterium are still justified.

Quarantine policy and Cms. Nearly thirty years ago, McGregor (1978) noted that, worldwide, many quarantine programs appear to be based on authority without scientific support or verification. Quarantine actions are a matter of public policy and the usefulness of these activities has not been verified.

In general, quarantine policy is one of the more contentious in the agriculture sector. On the one hand, there are doubts about the efficiency of a quarantine system to prevent the entry of exotic devastating agricultural pests and pathogens, coupled with rising volumes of international travel, to new areas (McGregor 1978). On the other hand, there are some who argue that quarantine measures serve as technical barriers to trade (Anonymous 2000). For example, De Boer (1987) states that the regulation by the European Economic Community in Council Directive 77/93/EEC issued in 1976, under which conditions importation of seed potatoes by a member country is permitted from BRR-free areas, possesses difficulties for North American exports to Europe. In North American agricultural areas, farm boundaries are flexible due to land sales and rentals as well as the fact that individual land holdings may not be contiguous. Considering the EEC position, it is entirely possible that the entire EEC market will be closed to Canadian potatoes.

Pest risk analysis. To resolve the question of whether the programme to exclude bacterial ring rot disease of potato from the UK should be continued, cost:benefit analysis was used by Pemberton (1988). At that time he concluded that the overall cost:benefit ratio for exclusion lies within the range 1:60–1:1000 so that the economic case for the current exclusion policy is clearly overwhelming.

In 1994, the Agreement on the Application of Sanitary and Phytosanitary measures (SPS measures) was signed as part of the World Trade Agreement (WTO). This agreement provides a series of rules for WTO members, to ensure that their sovereign rights are not misused for trade protection purposes and do not result in unnecessary barriers to trade. A key concept in the new free trade situation is Pest Risk Analysis (PRA), an objective assessment of the magnitude of the threat from invasion by an additional foreign pest in a defined area, likelihood of its establishment and economic importance if it becomes established. Pest risk management involves developing, evaluating and selection of options for reducing risk (Anonymous 1996).

Table 2. Tentative assessment of pest risk analysis for the potato ring rot bacterium in the CR

PRA criteria	Assessment
Present in PRA area?	Yes
Limited distribution?	Yes
Already under official control?	Yes
Has economic importance?	Yes?/No?

When we sketchily assess PRA criteria for the quarantine of *Cms* in the CR (Table 2), it is evident that the most controversial problem is to evaluate the level of damage from *Cms* or the range of expected economic impact of *Cms*.

Economic importance of *Cms* remains still controversial

Cms can cause damage by direct crop loss during growth and storage, by rejection of infected seed lots and the cost for control measures, by loss of export markets or by difficulties to open new ones. In Europe, *Cms* causes yearly an economic damage of an estimated 15 million Euro (Van der Wolf *et al.* 2005).

In a detailed analysis, Pemberton (1988) estimated the range of losses caused by potato ring rot, which include damage to the growing crop as well as damage in storage, as follows: for the main crop 1–3%, for the early crop 0.1–1% and for the seed crop 0–0.1%. Losses from rejection of certification (value of seed less commercial value) were estimated in the range of 0.5–5%, and losses for export markets in the range of 20–95% for seed, 10–50% for commercial potatoes if unprocessed and 0–5% if processed. According to De Boer (1987), it is the regulation which causes an economic loss far greater than current yield loss due to the disease. De Boer (1987) and Stead and Wilson (1996 – cit. Van der Wolf *et al.* 2005) ventured to say that all statutory control measures have cost more than the actual yield losses.

With reference to papers of Easton (1979) and Müller and Ficke (1974), Smith *et al.* (1996) state that crop losses have been mainly reported from North America and the formerly USSR.

Where potato ring rot occurs in the European Plant Protection Organisation region, the disease appears more sporadically and at a low level of infection. Indirectly, the expenses of disinfecting bags, machinery, stores etc., prohibition of potato cultivation, and restriction of export trade may increase the economic loss.

As for the crop losses mentioned above in the formerly USSR, when Müller and Ficke (1974) reported 15–30% of plants infected and up to 47% crop loss, they only cite a paper by Murzakova from 1966 that *in one* cooperative farm in the Moscow region, 15–30% of the plants were infected in 1961. They further cite a paper of Korsunova from 1960 about results of one field experiment in the Krasnoyarsk region where crop losses of 43.2% to 47.2% were observed after *infected tubers* had been planted.

In the USA, Skaptason (1943 – cit. Stapp 1956) reported BRR from 37 States, and the resultant losses in some instances have been heavy. According to Bonde and Snieszko (1943, 1944 – cit. Stapp 1956), seed potatoes with a relatively high incidence of infection (0.1%) can still give a good yield of commercial potatoes. Easton (1979) stated that epidemics of BRR reduce yields 50% or more in the USA and Canada. Yet for this claim he did not give any experimental or other conclusive piece of evidence. In opposition to this, De Boer (1987), dealing with the relationship between bacterial ring rot and North American seed potato export markets, states that yield losses due to BRR are small and largely limited to tablestock (commercial) crops. Statistical data are not available for yield loss in seed crops due to BRR, but are probably negligible. Economic losses are incurred largely due to the zero tolerance regulation. Losses by individual growers are sometimes large, but happen rarely. In the North American seed industry BRR is kept under control by the zero tolerance certification, but it is this regulation which causes an economic loss far greater than the current loss due to the disease. Recently, Van der Wolf *et al.* (2005) came to the conclusion that, in Europe, the economic damage caused by direct crop losses is low, while the costs due to rejection of infected seed lots, for control measures and by loss of export markets are high. However, when seeds are damaged by cutting or by using picker-type planters, the infection percentage of tubers can be up to 80%.

From the above-mentioned it follows that heavy crop losses due to *Cms* in agricultural practice and under natural conditions are not well documented. However, the high potential economic impact of *Cms* for the potato industry is evident from the reaction of potato cultivars to artificial inoculation with the bacterium. Inoculating potato plants by *Cms* in a field experiment reduced yield up to 51% (Bonde *et al.* 1942; Nelson & Torfason 1974; Nelson & Howard 1982; Sletten 1985; Manzer & McKenzie 1988). Nevertheless, such heavy losses are unusual in practice. The lack of reliable evidence for the potential national economic importance of *Cms* in natural conditions in the EU member states has its reasons, and the main ones are summarised in Table 3.

There is no method of direct chemical or biological control available (Smith *et al.* 1996). So-called "resistant" cultivars have been developed, but were found to be symptomless carriers, harbouring high bacterial populations without the expression of disease symptoms (Bonde & Cowell 1950; Manzer & McKenzie 1988). Following a later suggestion, cultivars that do not express ring rot symptoms but do support multiplication of the pathogen should be labelled as tolerant (De Boer & McCann 1990). The incorporation of tolerance

Table 3. Summary of factors probably responsible for crop losses to potato ring rot not being high under natural conditions of infection

Factors	Remarks
1. *Cms* causes natural infection on potato only.	Weeds and crops other than potato do not play an important role in the epidemiology of BRR in Europe. Earlier publications describing sugar beet as a host could not be confirmed (Van der Wolf *et al.* 2005).
2. BRR is a monocyclic disease.	Propagules of *Cms* are retained inside the diseased plant. Therefore, reinfection from resultant propagules does not occur during the growing season.
3. The most important source of infection and the main means of dispersal and survival of *Cms* are infected seed tubers.	See points 6, 7 and 8 below. In general, weeds and crops grown in rotation with potatoes do not play an important role in the epidemiology of bacterial ring rot in Europe (Van der Wolf *et al.* 2005).
4. Potato seed certified in European states, the USA and Canada does not exceed the appropriate tolerance for *Cms*, i.e 5% to 8% in the 1930s, and later and at present 0.0%.	Testing of tuber samples (200 tubers/sample) will only show relatively high disease incidences, e.g. a 0.5% infection incidence will be detected with only 63% confidence (Van der Wolf *et al.* 2005).
5. Cutting of potato seed and use of pricker-type planters have not been applied by most European growers for the past dozens of years.	In comparison with the use of whole seed, cutting of infected tubers increased the infection rate from 23% to 72% (Starr 1940 – cit. Van der Wolf *et al.* 2005).
6. Under field conditions, the spread of bacterial ring rot bacteria from plant to plant within the growing crop, and from a plot of infected plants to one with healthy plants is usually very low, if any.	According to Van der Wolf *et al.* (2005) there are no indications for plant-to-plant dissemination via soil. *Cms* can also be disseminated by contaminated insects that create wounds, such as aphids and the Colorado beetle, although their role in the epidemiology of *Cms* is unclear.
7. The pathogen can readily sustain itself through one or more winters in volunteer plants. However, it is not able to survive in free soil for a long time once plant residues have disintegrated.	Several attempts to infect potato tubers by growing them in *Cms*-infested soil have failed (Van der Wolf *et al.* 2005).
8. The spread of the pathogen by contamination of healthy potato tubers through contact with infected ones or through contact with contaminated harvesting and handling equipment cannot be excluded. Nevertheless, their importance is comparatively low.	*Cms* cannot penetrate the intact skin of a tuber. For an effective infection *Cms* must enter the vascular tissue. The vascular tissue is exposed when tubers are damaged during harvest, sorting and grading, during cutting of seed and when pre-sprouted tubers are planted (Van der Wolf *et al.* 2005).

to ring rot into potato cultivars, where the pathogen is able to colonise the host tissue in the absence of disease expression, is an acknowledged hazard in the potato industry (Kriel *et al.* 1995). So, to control *Cms* effectively, it is necessary to apply some reasonable restrictive measures.

It has been stated that phytosanitary measures shall be consistent with the pest risk involved and should represent the least measure available (Anonymous 1996). Nevertheless, which of the potential options will be selected for reducing the risk to an acceptable level might be questionable. For instance, in Canada, all potatoes produced by a grower are rejected for certification if BRR is found anywhere in his crop, whereas in some states of the USA only the lot in which BRR is found is rejected for certification (De Boer 1987).

After the introduction of *Cms* into a country, the phytosanitary measures selected have to fall within the goals of statutory control measures, i.e. to prevent its spread and to control it with the aim of eradication (Anonymous 1993). However, even current diagnostic methods of detection of *Cms* in potato seed samples have limited sensitivity. Therefore, to eradicate *Cms* is hardly possible in the condition of the CR and other European countries in the present situation. All things considered, it is doubtful whether it is economically feasible.

In general, weeds and crops grown in rotation with potatoes do not play an important role in the epidemiology of bacterial ring rot in Europe. To manage BRR, the real aim is to prevent the spread of *Cms*. To achieve that, the most important control measure is using the zero tolerance for *Cms* in the frame of a seed potato certification system, although this step does not guarantee absolute freedom from *Cms* in tested seed potato lots. It only means that a given potato seed lot has been tested using the approved procedure and no ring rot bacteria have been detected.

In addition to a supply of seed potatoes labelled as "free from *Cms*", maintaining a series of strict on-farm hygiene requirements is also a subject of official control measures. Where *Cms* is confirmed in potatoes on a production premise, that premise, affected crops and fields, and associated machinery and equipment are designated as contaminated. On production premises designated as contaminated, series of cropping statutory restrictions for potato seed growers must be introduced. Some of them seem to be justified, e.g. control of volunteer potatoes because they mean both important sources of *Cms* inoculum and a risk for maintaining the varietal type in seed potatoes. However, there are questions whether the control of volunteer potatoes must be a subject of statutory measures or could only be a recommendation. In contrast, using only uncut potato seed for planting is not included among statutory restrictions but it is just "strongly recommended to avoid this practice" (Van der Wolf 2005) although it is known that *Cms* is readily spread from infected to non-infected tubers during the cutting of seed potatoes.

CONCLUSION

This study of the nearly hundred-year-old history of *Cms* in Czech Lands has demonstrated that in nowadays common agricultural practice this pathogen has a relatively low capacity for damage to the potato crop, and it can hardly be considered as a pest of national economic importance in the CR. At present, *Cms* is not widely distributed and is actively and effectively controlled through the zero tolerance for bacterial ring rot in the potato certification program. Strictly speaking, *Cms* does not fulfil the criteria for a quarantine organism. If the quarantine status *Cms* will be maintained, the strict post-entry measures against *Cms* should be relaxed.

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