REVIEW ARTICLE

Potato bacterial ring rot pathogen detection and outbreak prevention

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Clavibacter michiganensis subsp. *sepedonicus* (Cms), causing bacterial ring rot (BRR) is one of the most destructive diseases of Potato. It is a soil-borne, gram-positive, non-motile, non-spore-bearing bacterium. It is observed that Cms can grow well in the presence of oxygen as compared to the absence of oxygen therefore it is an aerobic bacterium. Some of the challenges faced due to bacterial ring rot are continuous rejection of potatoes seed/tuber which is continuously affecting potato export markets. Potato tuber is found to be the primary source of inoculum. Latency nature of the disease makes it more difficult to detect at early stage of infection. Even recent diagnostic techniques have limited sensitivity for the detection of Cms in samples of potato seed giving false positive result that can lead to waste of management strategies, time and money. The disease can be diagnosed by using serological methods gram stain, which will denote the presence of Cms pathogen. The pathogen of BRR can be detected with the support of ELISA, PCR, LAMP, and many other techniques that remain undetected due to its latency nature, out of which LAMP is found to be more effective and affordable as it does not require laboratory complex devices and it is comparatively simple, fast, easy to use that can prevent further infection by early-stage detection of the BRR pathogen. PCR methods are more sensitive than other serological methods. From PCR MP (Melting profiles) method, electrophoretic patterns could be identified as well as can distinguish each of the 50 isolates from the other isolates by analyzing with the applied restriction enzyme. Cms can be managed by using disease-free seed or certified seeds, removing debris, host plants, and the use of disinfectants like ammonia, iodine, and chlorine-containing compounds.

Key Words: *Bacterial ring rot; Clavibacter michiganensis subsp. sepedonicus; Enzyme-linked immunosorbent assay; PCR; Lamp; Potato; Latent infection; Geographical distribution*

INTRODUCTION

Bacterial Ring Rot is caused by seed-borne plant pathogen *Clavibacter michiganensis* subsp. sepedonicus. It is one of the most destructive diseases of the potato crop (*Solanum Tuberosum* L). The pathogen was first time described in Germany in 1905. The name of the disease is based on its symptomatic internal appearance and inside breakdown in the vascular ring of a contaminated tuber [1]. It is a soil-borne, gram-positive, aerobic, non-motile, non-spore-bearing bacterium, forming yellow colored velvety and smooth colonies [2]. Cms was previously re-classified from Clavibacter sepedonicus to *Clavibacter michiganensis* subsp. sepedonicus that grows best but slowly at room temperature 70-degree to 75-degree Fahrenheit and can survive below freezing [3]. Symptoms include yellowing, wilting, and stunting of the plant, in infected tubers ooze, which can be seen, which helps to detect the pathogen. Potato is the fourth most significant food crop in the world after Maize, Rice, and Wheat. In comparison to any major food crop, it provides more food per unit area [4]. Therefore, it is necessary to detect the pathogen and control the spread of disease. Cms is hard to eradicate as the pathogen can remain viable on instruments and tools used in potato production. It mainly spreads through the use of contaminated tubers and plants with Cms.

LITERATURE REVIEW

Geographic distribution

The origin of this vascular pathogen is still unknown but was first described in Germany in 1905 [5]. It was found to be widespread across North America in 1940. It was first detected in 2003 in Britain which has been eradicated now and defined in northern Europe. It has been reported from 31 countries distributed over 5 different continents. Generally distributed in North America, Northern Europe, Asia, China, and Russia, invades the xylem of the crop through wounds or natural opening, damaging the tissues of the plant and tubers [6]. Now, the disease is sporadically found in cool, northern latitudes of North America especially in Canada and northern USA with only one finding in Mexico. Quarantine regulation in Europe has also minimized cases in yearly surveys, mainly in certified seeds. In some countries such as Bulgaria, Estonia, Finland, Germany, Greece, Hungary, Latvia, Lithuania, Netherlands, Norway, Slovakia, Sweden, and Turkey occasional occurrence were reported. Previous outbreaks were completely controlled in Austria, Belgium, Cyprus, Denmark, France, Spain, and UK (England and Wales). However, the disease was found in areas where formal seed certification is not implemented like parts of northern, western, and central Russia, Ukraine, Poland, and Romania. It was also found in Asia, although its distribution was not clearly known. In Africa, Australia, or South America, BRR has never been established. According to recent studies, the disease spread has been observed in the warmer climate countries, causing the death of the whole plant thus resulting in major economic losses [7]. In Poland, 17.7%, 6%, and 5.7% of seed certification failed because of ring rot in the years 1999–2001.

Economic impact of bacterial ring rot

Bacterial ring rot causes serious economic losses and found in most of the countries as mentioned on the Table 1. The major reason for the rejection of potatoes seed is bacterial ring rot, continuously affecting potato export markets. Zero tolerance in quarantine and seed certification regulation causes more economic loss than yield loss by disease [8].

Cms causes economic damage yearly in Europe of about 15 million Euros [9]. With reference to Pemberton (1988) analysis, losses from certification during export for commercial potatoes were estimated to be (10-50%) (If untreated), (0-5%) (If treated), and (20-95%)for seed. In North America and Canada, the disease reduces 50% or more yields, but he did not provide any experimental evidence for this claim. And (15%-30%) of plants are infected, with 47% crop losses in Russia by Muller and Ficke. Hukkanen reported (41%-56%) direct losses due to infection in vascular tissue by Cms, rotting of tubers, and wilting of the plant. Indirect economic losses involve expenses of disinfectants, machineries, storage, and restriction in export trade and potato cultivation [10].

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TABLE 1

Current distribution of *Clavibacter michiganensis* subsp. Sepedonicus pathogen in the EU

Country	Pathogen status (Absence)	Pathogen (Presence or transience)	References
Austria	Absent, pest eradicated		EPPO (2020)
Algeria	Absent		CABI and EPPO (1997)
Belgium	Absent, eradicated		EPPO (2020)
Bulgaria		Present,few occurrences	EPPO (2020)
China		Present, localized	CABI and EPPO (1997)
Croatia	Absent, confirmed by the survey		EPPO (2020)
Cyprus	Absent, eradicated		EPPO (2020)
Denmark	Absent, eradicated		Bradbury (1986)
Egypt	Absent, unconfirmed presence record(s)		EPPO (2020)
Estonia		Present,restricted distribution	EPPO (2020)
Finland		Present, restricted distribution	Bradbury (1986)
France	Absent, eradicated		CABI and EPPO (1997)
Germany		Present, few occurrences	CABI and EPPO (1997)
Greece		Present, widespread	EPPO (2020)
Hungary		Present, few occurrences	EPPO (2020)
Ireland	Absent, confirmed by the survey		EPPO (2020)
Italy	Absent, confirmed by the survey		EPPO (2020)
Israel	Absent		EPPO (2020)
Japan	Present		Bradbury (1986)
Latvia		Present, restricted distribution	EPPO (2020)
Lithuania		Present, restricted distribution	EPPO (2020)
Malta	Absent, confirmed by the survey		EPPO (2020)
Netherlands	Transient under eradication		NPPO of Netherlands (2013)
Nepal		Present	Bradbury (1986)
North Korea		Present	Bradbury (1986)
Pakistan		Present	Bhutta (2008)
Poland		Present, restricted distribution	Bradbury (1986)
Romania		Present, restricted distribution	CABI and EPPO (1997)
Russia		Present, widespread	CABI and EPPO (1997)
Slovakia		Present, few occurrences	EPPO (2020)
Slovenia		Present, restricted distribution	EPPO (2020)
Spain	Absent, pest eradicated		EPPO (2020)
Sweden		Present, restricted distribution	Bradbury (1986)
Turkey		Present, few occurrences	Bradbury (1986)
United Kingdom	Absent, pest eradicated		EPPO (2020)
Vietnam	Absent, unconfirmed presence record(s)		EPPO (2020)

Host range

Clavibactter michiganensis subsp. *sepedenicus* has a variety of hosts, belonging to the family Solanaceae, including Tomato and eggplant, out of which Potato (Solanum tuberosum) is the most economically important and main host. On Tomato crops, natural infection was reported for the first time [11]. Apart from the Solanaceae family it also infects groundnut, ginger, mulberry, and many other ornamental plants. It was isolated from Sugar Beet roots [12]. Weeds of the Solanaceae family that are hairy nightshade (*Solanum sarrachoides*) and buffalo bur (*Solanum rostratum*) may act as a host for the Cms [13].

Detection of bacterial ring rots pathogen

Detection of BRR is sometimes failed due to latency nature of the disease, where symptoms are not visible during the early stage. In such cases, the disease can be diagnosed by the use of serological methods like ELISA or gram stain, which will denote the presence of Cms pathogen [14]. Some other strategies like DNA enhancement by the polymerase chain response have been introduced, but not widely utilized till now [15,16]. By the utilization of continuous PCR additional sensitivity can be achieved [17].

Visual observations

Symptoms and signs of ring rot: Bacterial ring rot symptoms are developed by many factors including environment and genotype [18]. Characteristic symptoms include gradual stunting and wilting of the plant, limited to the leaf margin [19], swelling, cracking and brown discoloration of vascular tissue and oozing of bacteria from the vascular ring of the tubers are mostly common (Figure 1). Expression of the disease may vary widely with potato cultivars and environmental conditions. Highly infected plants may die in severe cases. Symptoms of BRR are similar to brown rot symptoms but can be distinguished by bacterial ooze [20]. Highly infected plants may die in severe cases. Symptoms of BRR are similar to brown rot symptoms but can be distinguished by bacterial ooze [21].

Foliar symptoms: Symptoms in plants initially develop light green color leaves to grey and brown resulting in necrosis that is visible in the lower leaves. Shortened internodes are the first symptom of ring rot of potato with bunchy appearance and interveinal chlorosis (yellowing of leaves, between their veins) and the margin of the leaflet may roll upwards.Wilting of leaves also known as green wilt occurs due to the presence of bacterium in xylem

vessels [22]. Symptoms can vary; start as wilting of the lower leaves which progresses up to the upper portion of the plant until the whole plant dies prematurely (Figure 2).

Figure 1) *a) BRR symptoms in tubers; internal rot associated with the vascular ring, bacterial ooze b) upright stem flagging by Ontario CropIPM c) necrosis in leaf margin, interveinal necrosis (Courtesy: T.A. Zitter, Cornell University)*

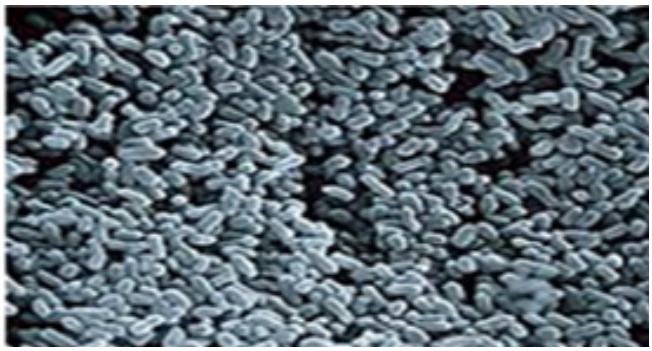

Figure 2) *Bacterial cell of Clavibactter michiganensis subsp. sepedenicus by Dr. Solke H. de Boer, CFIA*

Tubers: On potato tubers, if the infection is latent symptoms can show up after several months of storage. On tubers, there are brown cracks with red edges [23]. Often it shows cracking externally and swelling with the presence of decay organisms. Some of the tubers of an infected plant become completely disintegrated. Initial symptoms of tubers can only be observed by cutting the tuber transversely near the heel end. At the stolen end disease tuber shows smooth, hyaline, rich yellow to dull patches in the vascular tissue [24]. The tuber eyes are also infected and killed, the pith disintegrates more rapidly than the cortex and a shell is left. Such infected tubers are mostly found in storage rooms than the field. This bacterium of BRR produces a slimy ooze of polysaccharides within the infected potato tissues that help the pathogen to survive for a longer period as it protects the bacterium from environmental stresses [25].

Microscopic study of bacterial ring rot

The genome of *Clavibactter michiganensis* subsp. *sepedenicus* first sequenced [26]. For the development of symptoms, plasmid pCS1 is essential, but for host recognition genes are required, on the chromosome proficient colonization, disease, and concealment or avoidance of plant safeguard are found [27]. this bacterium does not produce spore or mycelium. The chromosome of the bacterium is (3.26 Mb) profoundly comparable among all *Clavibacter* subspecies, (50 kb) roundabout/circular plasmid (pCS1) and (90 kb) linear plasmid (pCSL1) are completely conveyed by Cms strains. The type 3 secretion system (T3SS) is absent in Gram-positive Clavibacter microorganisms that move effectors into plant cells [28]. Have depicted the disease cycle by *Clavibacter*. Many DNA-based molecular methods have been introduced during recent years like PCR, LAMP, ELISA and many more to diagnose pathogen causing bacterial ring rot in potato. The studies also demonstrate that Cms shows a prominently low level of intraspecific variety and the majority of the molecular strategies could separate among subsp. group yet came up short on the goal to identify hereditary variation inside subsp. With the help of the PCR MP Method successful differentiation of 50 isolates of Cms is possible utilizing Apal, BamHI, Xmal, HindIII, and Pstl restriction enzyme. PCR methods are more sensitive (Approx 100 times) than other serological methods. From PCR MP (Melting profiles) method, electrophoretic patterns could be identified as well as can distinguish each of the 50 isolates from the other isolates by analyzing with the applied restriction enzyme. PCR MP Method can identify the bacterial strain that can be utilized for epidemiological studies of the different pathogen, apart from the isolate of Cms as a primary source of infection. Detection techniques like molecular methods based on PCR, Immunofluorescence microscopy, and hybridization, are found to have adequate partial ability to effectively separate cms isolate. Differentiation between the Cms isolates cannot be done using most of the molecular methods [29]. Cms and Cmm isolate disclosed 94.7% similarities obtained from an electrophoretic pattern [30,31]. Rep-PCR is found to be effective for differentiation between the subsp. not within the subsp (31). The Cms isolate was classified into a virulent and virulent by utilizing molecular methods. Serological detection methods-ELISA, immunofluorescence, immunofluorescence colony staining is used for detection of Cm Subsp. sependonicus. Monoclonal antibodies to an extracellular polysaccharide and cell wall antigen gave better specificity and were extremely efficient in indexing potatoes that are asymptomatic in nature for the presence of Cms. DNA-based detection and detection of Cms can be done by direct DNA hybridization which is focused mainly on plasmid sequences of Cms. The Loop-mediated isothermal amplification (LAMP)-Notomi, gives ideas related to DNA based test that can be used in field test, it doesn't need a temperature cycle and by using a simple heater it can be carried out at constant temp, it is found to be more sensitive than other PCR based methods. However, there are some limitations like LAMP methods can detect all subsp. Of Clavibacter and it will show positive for other subsp. While detecting Cms [32] due to which additional detection method is necessary to carry out while using this method. In the colorimetric assay of LAMP, if the Cms sample in the reaction tube shows yellow color, it is a positive result, which shows the presence of *Clavibacter* pathogen whereas no color refers to a negative result [33]. Amplification temp is found to be 63°C for GMO analysis, for diagnosis of Cms, the optimal amplification temperature determined is 70°C. The Lamps method is considered to be an effective method for field diagnosis as it is simple, affordable, fast, user friendly and does not require laboratory complex devices with the help of colorimetric LAMP method, calcein staining, lateral flow test strip(LFD), turbidity detection and gel electrophoresis it can detect the pathogen and is a fast diagnosis method [34].

Biology of the pathogen

Ring Rot Pathogen identification is an important step toward the management of the BRR disease. It is a gram-positive, aerobic, non-motile, non-spore-bearing bacterium measuring 0.5–1.0 µm in size. Cms are usually transmitted by tubers of potatoes but can also enter through wounds and hydathodes present in the plant [35]. Cms can grow well in presence of oxygen, but slow growth can be observed in absence of oxygen (anaerobic condition), its optimal temperature for growth is 20^0C-30^0C cannot resist high temperature [36]. The slow growth of Cms hampers isolation methods. The morphology of pathogens varies in cells and colonies, requiring high levels of experience and knowledge for their recognition. They cannot be easily diagnosed, particularly in latent form. The first genome sequence released was found to be length ~3.26 Mb+two plasmids pCL1, 95 kb and pCS1, 50 kb, the content of guanine and cytosine is 72.6% nucleotide base (Figure 3).

Epidemiology

Bacterial Ring Rot disease can be managed by understanding the infection process, survival ability, and latent period of a bacterial pathogen. This is a seed-borne disease, slightly infected tubers are the primary source of inoculum, especially when it is shown, give rise to several disease plants which produce infected tubers and disseminated to other production units. In a few cases, the tubers can also get infected during packaging or in-store and via contaminated surfaces of equipment used in potato production. Cms can live for a long period in both dry and cool climates. Although it is a soil-borne disease the bacterium cannot subsist well in the soil without linked by decomposed tissue of potato [37].The pathogen can transfer

systemically through vascular tissue from tubers to the stems and then into progeny tubers through stolen, bacterium can be detected in stems 3-4 weeks after growing infected tubers. The pathogen has been found to survive for 1-2 years in tuber debris attached to many surfaces and materials, predominantly at low humidity and low temperature. Cms cannot survive in water for a longer period; it is relatively short, extending only for a few weeks as reported [38]. The symptoms and maximum disease occurrence were dependent on cultivar as well as location, which have been shown by the proportional hazards model [39].

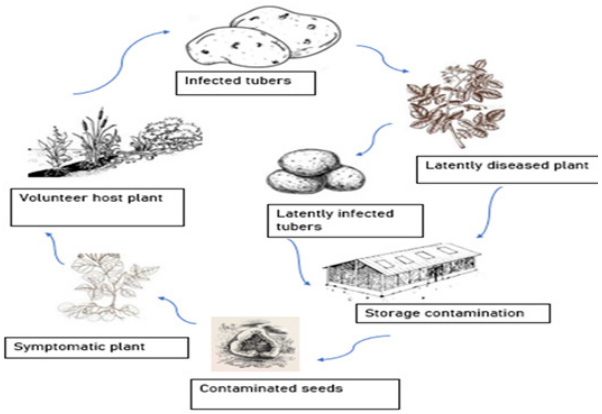

Figure 3) *Disease cycle of bacterial ring rot of potato (Clavibacter michiganensis subsp. Sepedonicus)*

DISCUSSION

Life cycle

C. michiganensis subsp. sepedonicus is a gram-positive bacterium [40]. It is club-molded, pleomorphic, short rot. The color of isolated colonies is a rich yellow, velvety, and smooth [41], through injuries Cms enter the xylem vessels in which they multiply and contaminate the potato plant. Cms is a soil intruder microorganism, it transfers from one individual stolon to another through water system/irrigation water or by vectors, for example, Colorado beetle of potato and flea. It can also survive on the surface of the water as long as 10 days and 5 years in a dried and cold environment [42]. The microorganisms hibernate in tuber seeds and favor high temp towards the finish of the developing season. The bacterium survives in seeds, plant debris, crates, sacks, and on rural supplies. In potatoes, the beginning phases of disease are generally hard to recognize, Cms colonizes the plant's vascular framework in the host, most eminently vascular ring of potato tubers. Sometimes the healthy tuber also gets infected from decomposing mass of rotting tubers in-store or from containers of potatoes/sacks (Figure 4).

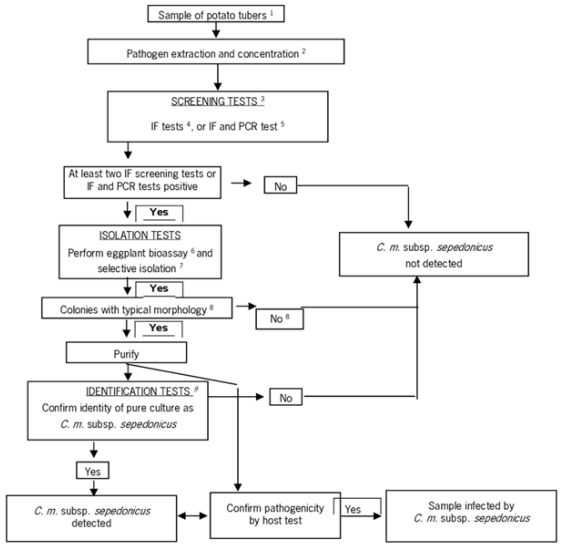

Figure 4) *C. michiganensis subsp. sepedonicus bacterium detection and identification of potato tubers by Wolf et al. [1]*

Disease spread: Ring rot important means of spread can be infected stolen, contaminated storage, machinery, debris, or any tools that have been contaminated by rotting ooze. Vertical transmission is the main mechanism of spread from infected tubers, Horizontal transmission occurs through the use of contaminated tools or equipment, storage, and grading [43]. Potato Ring Rot spread and factors affecting the development of the disease were studied in detail [44]. Some experimental evidence shows insects can transmit the disease that is found under experimental conditions by Colorado beetles(Leptinotarsa decemlineata), green peach aphids (Myzus persicae), grasshoppers (Melanoplus differentialis), and black blister beetles (Epicauta pennsylvanica) whereas plant to plant spread is comparatively low in the field [45]. When seeds that are infected are grown, pathogen (Cms) move from the seed into the stem and lower leaf of potato plant through vascular [46]. At the point when seeds that are contaminated developed, a bacterium (Cms) move from the seed into the stem and lower leaf of potato plant through vascular [47]. During harvest inner indications available finish of the capacity time frame. There is some indication that the spread of the pathogen through waterlogged soils can lead to secondary disease development in the field and through irrigation water [48].Pathogenicity Determinants and Resistance. The chromosome of *Clavibactter michiganensis* subsp. *sepedenicus* codes for various antibiotic-related genes, just as numerous genes pertinent to microbial nature. Some qualities include it can withstand low iron and oxidative stress [49]. Due to their huge job in resistance to UV radiation focuses on, the super oxidase dismutase's and catalase qualities are possibly leftovers of other epiphytic *Clavibacter* species [50-54]. Cms is a hemi biotrophic bacterium that depends on the host plant for growth and reproduction, absorbs nutrients like carboxylic acids and sugars from the cell wall of the xylem vessels, and encompassing parenchymatic cells are then hydrolysed by the articulation of celluloses and other extracellular catalysts, including pectic lyase, xylanases, polygalacturonate, and other endoglucanases, prompting development symptoms followed by growth and colonization. Potato cultivars with immunity are not currently available or no useful resistance to ring rot is found. The idea of cultivar tolerance to ring decay of potato isn't yet perceived and few know about the situation with most usually developed cultivars as for their susceptibility to contamination and colonization under shifting ecological conditions. Expression of ring rot symptoms in potato cultivars may vary in their proneness, between cultivars less variety in their susceptibilities to inactive contaminations is noticed (McCann and De Boer, 1990). Symptomless carriers of Cms such as tolerant cultivars which do not show any symptom are rejected from seed confirmation plans in North America by McKenzie and Manzer 1988. Promotion of the wild potato species Solanum acaule was found to be susceptible to latent infection by bacterium at 15°C but seemed resistant to contamination at 25°C [55-57].

Problems, Future scope of Bacterial ring rot study. The Ring rot disease is highly persistent and contagious additionally latency in nature making it difficult to detect at early stage, resulting in increase of incidence rate. Only in few places, it has been eradicated successfully till now (Table 2). Low sensitive methods cannot detect the pathogen therefore; it requires highly sensitive method that is costly and complex. The slightly infected cut tubers act as a primary source of inoculum and in few cases due to their latent nature Cms remain undetected for a generation without showing any symptoms [58-62]. And such latent tubers give rise to the diseased plant resulting in the production of the non-symptomatic latent tuber. Using many genotyping techniques, consensus regarding low genetic variation among Cms isolates has been confirmed by scientific research teams [63-65]. Specific chemical or biological methods to control Cms are still not available [66-68]. The resistant cultivar was introduced, but then it was found those resistant cultivars to be symptomless carriers of the pathogen without showing any symptom [69]. Therefore, quarantine rules and regulation are imposed all over the world to prevent entry of exotic devastating pathogen. Many quarantine programs in worldwide are without any verification or scientific proof but based on authority [70]. Quarantine policy is one of the combative matters in sector of agriculture but still usefulness of some policies is still not verified. Therefore, some doubts are raised related to effectiveness of quarantine system to prevent entry of harmful pathogens and pests with rising no. of international travels. According to Anonymous in 2000 some thinks quarantine measure act as technical fences to trade. In the year 1987, de Boer gave a perfect example, he mentioned that in 1976, European Economic Community (EEC) in Council Directive 77/93/EEC issued a regulation in which it was given that the country people can import potato seeds only from areas free from BRR, holds problems for North American exports to Europe. They hold large agricultural areas that may not be contagious but

due to EEC regulation there is possibility to closure of Canadian potatoes to entire EEC market. In Canada strict rule was imposed, if Bacterial ring rot is found wherever in his crops whole production will be rejected for certification; however in some places of the USA only severe infection found is rejected for certification De Boer. The future study of bacterial ring rot can eradicate these kinds of rejection and prevent losses due to BRR during potato seed certification process of strict post-entry measures against Cms. Ring Rot Management/Control: Potato ring rot can be controlled through the safe distribution of infection-free potato seed, strict use of quarantine, and seed certification guidelines that guarantee zero capacity to bear the disease during seeds import inspection including regular testing to prevent infection [71]. For latent infection, laboratory testing should be done, as it can prevent the spread of disease by detecting early and eliminate the infected seeds. Tubers should be imported from only those countries, which can show regular surveys and tests. Implementation of sanitation practices, crop rotation, and disinfection of fields are the important practices to control BRR. Disinfectants like ammonia, Chlorine, and iodine-containing compounds are effective against the bacterium [72]. Frequently clean and sterilize all machinery, containers, equipment kit, packing, storage facilities, and other tools used in the production of potatoes used during potato production. A combination of Degaclean and Clarmarin and peracids with the catalase inhibitor KH10 wipe out the bacterium in wastewater present in the commercial processing plant [73]. Weeds that act as a host for Cms are removed from the field and control of potato volunteers is important. Whole potato seed rather than cut seed reduces the spread of disease. Sanitizing agents that are used should be registered for commercial use. Make sure safety recommendations for workers and labeled are followed. Many countries carry out pre and post-harvest inspections of potato stocks for detection of disease symptoms supplemented by laboratory and nucleic acid diagnostics. Local and imported seeds are reviewed yearly to look for dormant infection by The Department of Agriculture, Environment and Rural Affairs. Tubers that are suspected to carry the diseases should be tested in a laboratory or by the certification agency, Cms is difficult to detect due to its latent nature. Therefore, tubers need to be regularly screened using methods such as ELISA (enzyme-linked immunosorbent assay), IFAS (indirect fluorescent antibody staining), and other various molecular-based procedures that are sensitive to identify the pathogen [74].The use of intensive methods reduced the occurrence of ring rot pathogen, contaminated wash water from infected ware, tuber parts can transfer the bacterium to ensuing parcels washed in similar water during packing. Disinfect and change the water between lots from different origins. Four main objectives to control Cms:

- To decide whether the pathogen is available in the nation and if present, find it and decide its management,
- To prevent its spread.
- To eliminate invasions.
- To kill the pathogen from potato cultivation frameworks in regions where it is available.

TABLE 2

List of different subspecies of *Clavibacter michiganensis* bacterium along with their bacterial strains, host, distribution and disease caused by the particular pathogen

Sl. No.	Subspecies	Strain	Host plant	Disease	Distribution	Survival	References
1.	*Clavibacter michiganensis* subsp. *sepedonicus* (1984)	ATCC33113T (=NCPPB 3664T)	Potato	Bacterial ring rot	North America, Northern Europe, China, and Russia	Debris, Seed/ Tuber, Storage	Manzer andGenereux,1981
2.	*Clavibacter michiganensis* subsp. *insidiosus* (1984)	CFBP 2404T (=LMG 3663 = NCPPB 1109T)	*Medicago sativa* (Lucerne, alfalfa)	Wilting and stunting	Africa, Asia, North America, South America, Oceania	Debris	McCulloch,1925
3.	*Clavibacter michiganensis* subsp. *michiganensis* (1984)	LMG 7333T (=NCPPB 2979T)	Tomato	Canker and bacterial wilt	Serbia, Africa, China, India, South Africa, Asia, Armenia	Seed, Debris	Davisetal.,1984; Strider, 1969
4.	*Clavibacter michiganensis* subsp. *nebraskensis* (1984)	NCPPB 2581T	Maize	Blight disease	North America Canada, USA, South Dakota, Kansas	Seed, Debris,	Vidaver and Mandel,1974
5.	*Clavibacter michiganensis* subsp. *phaseoli* (2014)	CFBP 8627T (=LMG 27667T)	Bean	Leaf yellowing	South America, China	Seed	Gonzalez and Trapiello,2014
6.	*Clavibacter michiganensis* subsp. *tessellarius* (1984)	ATCC 33566T (=NCPPB 3664T	Wheat	Leaf spot and freckles, Mosaic disease	U.K, North America	Tuber, Contaminated equipment's	Carlson and Vidaver,1982

CONCLUSION

The main objective of Cms research is to study the epidemiology of the pathogen and develop management measures against ring rot of potato. Bacterial ring rot is found to remain an economically significant disease worldwide causing a high amount of losses. It is found that farmers play an important role in every activity from building up a nation to rising its economic value but unfortunately due to limited knowledge and technologies they are also spreading diseases throughout the world unknowingly which is becoming a serious matter. So, to control such disease spreading it is necessary to train farmers, provide ideas, knowledge, introduce new technologies and explain proper potato cultivation practices like using healthy seed, cleaning tools, machinery, and planting in soils free from diseases. In case no effective chemical, biological control measure or resistance potato cultivar is available it is recommended to rely on safe production and distribution of potato tubers or seeds that are free from infection. Use only certified seed of potatoes and follow control measures strictly to prevent spread of BRR; it will not just help the growers to produce disease-free seeds and plants but will also slowly help in eradication of ring rot and other diseases.

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