Print ISSN : 0972-8813
e-ISSN : 2582-2780

[Vol. 19(1), January-April, 2021]

Pantnagar Journal of Research

(Formerly International Journal of Basic and Applied Agricultural Research ISSN : 2349-8765)

G.B. Pant University of Agriculture & Technology, Pantnagar

PANTNAGAR JOURNAL OF RESEARCH

Vol. 19(1) January-April, 2021

CONTENTS

Potato Dry Rot: Pathogen, disease cycle, ecology and management

SANJAY KUMAR[1], PARVINDER SINGH SEKHON[1] and AMANPREET SINGH[2]

[1]*Department of Plant Pathology,* [2]*Department of Agronomy, Punjab Agricultural University, Ludhiana*

ABSTRACT: Potato dry rot is an emerging disease in field as well as in cold storage and a major threat to global production of potato. The disease caused by different *Fusarium* species such as *F. culmorum*, *F. sambucinum*, *F. oxysporum*, *F. solani* and *F. avenaceum* etc. It causes 25-60% loss in yield in the field as well as in cold storage. *Fusarium* survives on infected host debris in the soil in the form of chlamydospores as saprophytes. *Fusarium* spp. cannot enter the tubers through lenticels or in the absence of injury. The infection is possible only when the potato skin is cracked. Dry rot develops in high humidity (>80%) and temperature of 15 to 20°C after one month of storage is most favorable conditions however, it can also develops even at low temperatures. An integrated disease management (IDM) program provides the appropriate harvesting conditions to prevent tuber injury and appropriate storage conditions. Disease free seed tuber and registered synthetic fungicides and post-harvest treatments are recommended for effective dry rot control. Recently, several organic and inorganic salts are generally recognized as safe (GRAS) and biological agents alternative to synthetic fungicides which could eventually be integrated into dry rot management strategies.

Key words: Potato dry rot, *Fusarium* species, Injury, Integrated disease management, Biological agents

The potato (*Solanum tuberosum* L.) is an important source of calories, proteins and fats for humans. It is grown in 155 countries and more than a billion people around the world consume potatoes (FAOSTAT, 2019). Total world production of potatoes was estimated at 388,191,000 tonnes in 2017 (Anon, 2019a). India ranked second in terms of production and third in terms of area with a production of 52,588.98 tonnes (Anon, 2019b). In Punjab, the total area was 106.07 thousand hectares and production was around 2869.95 thousand tonnes (Anon, 2020). In India, potato producer states are Gujarat, Haryana, Uttar Pradesh, Punjab, Assam, Karnataka, West Bengal, Bihar, Madhya Pradesh and Jharkhand. Potato tubers are easily penetrated by pests and pathogens, and these agents can survive, reproduce and spread because the tubers are rich in nutrients (Delgado *et al.,* 2017; Lal *et al.,* 2020b; Tiwari *et al.,* 2020a, b).

Pathogens that include fungi, viruses, bacteria, nematode and insects can cause various infections at different stages of the production, processing and storage of potatoes (Atallah and Stevenson, 2006; Fiers *et al.,* 2012; Kumar *et al.,* 2019, 2020).Tuber rot is caused by various diseases such as downy mildew (*Phytophthora infestans*), pink rot (*P. erythroseptica*), leaks (*Pythium ultimum* var. *Ultimum*) and dry rot (*Fusarium* spp.). Among many diseases, dry rot of potatoes is an emerging disease of tubers both in the field and cold storage (Theron and Holz, 1991; Bojanowsky *et al.,* 2013). It is incited by *Fusarium* species. Worldwide, more than 13 *Fusarium* species are causing dry rot disease in potato (Cullen *et al.,* 2005). It is a major potato disease worldwide which causes post-harvest rot and seed rot after planting (Leech and Webb, 1981; Hanson *et al.,* 1996). Karimi (1970) reported that *F. oxysporum* was a pathogen in the provinces of Fars and Damavand. *F. solani* and *F. sulpherum* were the causal fungi of dry rot in Iran (Ershad, 1995; Nasr-Esfahani, 1998). However, Ali *et al.,* (2005) found that *F. graminearum* was a pathogen in North Dakota. An injury allows the pathogen associated with the soil to enter in the tubers. This disease generally occurs when the tubers are injured during mechanical harvesting and grading. The tubers become susceptible to the disease and the spread of the disease continues after two and three months of storage (Guenthner, 2001).

Significant yield loss of 6 to 25% has been recorded by several authors (Wharton *et al.,* 2006; Stevenson *et al.,* 2001; Heltoft *et al.,* 2016). In the United Kingdom, 50% of crop storage was affected by dry rot; while in the south-east of England 100% of seed stocks were affected (Bradshaw *et al.,* 2001). A post-harvest loss was 28% in Gansu province, China, where 88% tubers had been affected by dry rot (He *et al.,* 2004). In India, potato dry rot was first observed in the cultivar Kufri Ashoka at cold storage in Sehore, Madhya Pradesh, and more than 90% of the tubers were affected when they were taken out after six months of storage. The symptoms have also been observed in the cultivar Kufri Bahar (1-2%) in the cold store of Shahabad, Haryana (Sagar *et al.,* 2011). Due to the uncertainty of resistance sources and control of this disease has been achieved through the post-harvest application of various fungicides (Secor and Gudmestad, 1999, Mecteau *et al.,* 2002). However, since many pathogens have become resistant to fungicides (Desjardins *et al.,* 1993; Holley and Kawchuk, 1996; Platt,

1997), it may lead to increase the incidence and severity of the disease (Secor and Gudmestad, 1999). This review includes symptoms of potato dry rot, pathogens, the disease cycle, ecology and integrated disease management strategies.

SYMPTOMATOLOGY

The first symptoms appear as darker lesions on the surface of the tubers after about a month of storage (Peters *et al.,* 2008b). The lesions extend in all directions and can bend into concentric rings when the underlying dead tissue contracts (Figure 1a) (Howard *et al.,* 1994, Stevenson *et al.,* 2001; Kumar *et al.,* 2016). The underlying areas of necrotic tissue visible in light or dark chocolate brown are characteristic of the internal symptoms of *Fusarium* spp. (Cullen *et al.,* 2005). The causal agent enters the tubers through the injury and often leads to complete rot. The hollow areas below the rotten area are generally lined by *Fusarium* mycelium which varies from white to brown (Figure 1b) (Kumar and Sekhon, 2016). The high relative humidity may increase the soft rot bacterial (*Pectobacterium* spp.) infection in cold storage and cause wet rot (Powelson *et al.,* 1993; Stevenson *et al.,* 2001; Secor and Salas, 2001; Secor and Gudmestad, 1999).

PATHOGEN

Fusarium spp. belongs to the Ascomycota division, and sexual state of several *Fusarium* species is unknown (Nelson *et al.,* 1981). *Fusarium* species identified as main causal agent include *F. solani*, *F. sambucinum*, , *F. sulphureum*, *F. coeruleum, F. roseum*, *F. avenaceum*, *F. oxysporum* and *F. culmorum* (Stevenson *et al.,* 2001; Cullen *et al.,* 2001,2005). Major species were such as *F. solani* in Iran and South Africa (Theron and Holz, 1989; Nasr-Esfahani, 1998). F. *coeruleum* in the United Kingdom (Hide *et al.,* 1992), *F. coeruleum* and *F. sambucinum* in North America and parts of Europe (Secor and Salas, 2001; Du *et al.,* 2012) and *F. solani* in the United Kingdom (Peters *et al.,* 2004), and *F. graminearum* and *F. sambucinum* in north central United States have been reported. Other minor species have also been identified such as *F. acuminatum*, *F. Equiseti, F. crookwellense*, *F. sporotrichioides, F. scirpi*, *F. tricincum* (Cullen *et al.,* 2005; Hanson *et al.,* 1996), *F. oxysporum* f. sp. *tuberose*, *F. torulosum*, *F. graminearum* (Gachango *et al.,* 2012a,b).The relative frequency of *Fusarium* spp. varies with geographical location and also by other factors, such as the cultivar used and fungicides (Peters *et al.,* 2008a).

INOCULATION TECHNIQUE AND DISEASE ASSESSMENT

Recently, Chen *et al.* (2020) developed a simple inoculation technique PSW (plastic screw wounding) to screen potato breeding lines for resistance to dry rot of potato. Different inoculation methods have been developed for pathogenicity studies (Leach and Webb, 1981; Estrada Jr. et al., 2010; Peters *et al.,* 2008a,b; Gashgari and Gherbawy, 2013; Talgo and Stensvand, 2013; Du *et al.,* 2012; Stefanczyk *et al.,* 2016; Valluru *et al.,* 2006). Autoclaved vaseline is useful for screening the cultivars and confirm the reaction of *Fusarium spp.* on different cultivars (Mejdoub-Trabelsi *et al.*, 2012; Ibrahim *et al.,* 2014; Akhtari *et al.,* 2017; Mshelia, 2018). Langerfeld (1987) proposed a rating scale of 1-9 for assessment of dry rot severity (Figure 2). The rot volume is calculated using the formula given by Heltoft *et al.* (2015).

MORPHOLOGY AND MOLECULAR CHARACTERIZATION OF *FUSARIUM* SPECIES

Fusarium spp. produces a white dense mycelium which may develop brown, blue and purple pigmentation with age. It forms macro-conidia, micro-conidia and chlamydospores in culture (Howard *et al.,* 1994). Microconidia are generally not present in culture, while chlamydospores and macro-conidia are present (Howard *et al.,* 1994). Three species were identified as *F. avenaceum*, *F. culmorum* and *F. sambucinum* from predominant growing areas of Punjab (Figure 3) (Kumar *et al.,* 2016). *F. culmorum* which formed whitish to yellow, tan or pale orange suppressed mycelium (Figure 4b), but became brown to dark brown to red-brown with

Fig. 1: Symptoms of potato dry rot a) lesions enlarge in all directions and wrinkle in concentric rings b) Cavities underlying the rotted tissue lined with *Fusarium* mycelium

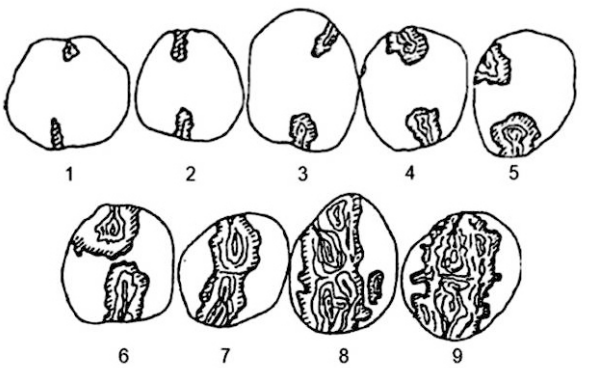

Fig. 2: Disease rating scale for assessment of potato dry rot severity (Langerfeld, 1987)

Fig. 3: Culture of *Fusarium* species associated with dry rot of potato

age. Micro-conidia were not produced. Size of macro-conidia varied from 3.1-7.0 x 24-50 µm with 3-4 septa (Figure 4a) and chlamydospores were formed in the hyphae too. (Figure 4c) (Kumar *et al.,* 2016). *F. avenaceum* formed aerial mycelium which varied from light yellow to grayish rose on PDA medium. Size of micro-conidia varied from 1.6-2.8 x 7.5-21 µm with 0-2 septa whereas, the size of macro-conidia ranged from 3.3-5.1 x 49-85 µm with 3-5 septa (Figure 4d) (Kumar *et al.,* 2016). While colony colour of *F. sambucinum* was fluffy whitish to light white mycelium. Micro-conidia were oval shaped (Figure 4e) and macro-conidia were straight to slightly curve. Size of micro-conidia varied from 1.7-3.2 x 5.0-14.5 µm with 0-1 septa and that of macro-conidia varied from 2.8-5.9 x 19-50 µm with 3-4 septa (Figure 4f) and chlamydospores were in chain (Figure 4g) (Kumar *et al.,* 2016).

Accurate identification is very important to understand the epidemiology of pathogen as well as from the management point of view. Currently, polymerase chain reaction (PCR) techniques which can make use of ITS (internal transcribed spacers) regions of DNA ribosomes (rDNA) are mostly preferred (Atallah and Stevenson, 2006). This region of size range from 0.28 to 0.6 kb which is made up of two non-coding regions (Gardes *et al.,* 1991, Gardes and Bruns, 1993) and can easily amplified by universal primers (White *et al.,* 1990). Several PCR (RT-PCR and ISA-PCR) based techniques have been developed to detect the *Fusarium* spp. such as *F. avenaceum* (Turner *et al.,* 1998), *F. coeruleum*, *F. culmorum* (Nicholson *et al.,* 1996) and *F. sulphureum* (Cullen *et al.,* 2005). Three species (*F. avenaceum*, *F. culmorum* and *F. sambucinum*) were confirmed by using ITS species specific primers (Fcoer, Fsulp, JIA and Fco1) (Kumar *et al.,* 2016). Gherbawy *et al.* (2019) identified *F. sambucinum*, *F. verticillioides*, *F. oxysporum* and *F. incarnatum* based on morphological characters and β-tubulin gene sequence. However, a specific primer pair (TEF-Fs4-forword and TEF-Fs4-reverse) has been used for identification of *F. solani* in Egypt (Hussein *et al.,* 2020).

DISEASE CYCLE

Dry rot is tuber and soil borne disease (Choiseul *et al.,* 2001; Cullen *et al.,* 2005; Peters *et al.,* 2008 a,b). *Fusarium* spp. can persist for many years in the soil (Al-Mughrabi, 2010) and crop residues serve as the primary inoculum. The pathogen enters into tuber through injury during harvesting (Stevenson, 2001). The infected seed tubers result in soil infestation around progeny tubers (Adams and Lapwood, 1993). Progeny tubers are not usually infected until the penetration of pathogen occurs through wounds.

Dry rot develops in high humidity (>80%) and temperature of 15 to 20°C after one month of storage is most favorable conditions (Secor and Salas, 2001). Dry rot also develops even at low temperatures (4-10°C) (Stevenson *et al.,* 2001; Kumar *et al.,* 2016). *F. sambucinum* affects stored potatoes and causes seeds to rot after planting (Lacy and Hammerschmidt, 1993; Wharton *et al.,* 2006) (Figure 5).Transmission from seed tubers to progeny tuber is affected by the related pathogen. The transmission of *F. sulphureum* to the progeny tuber is greater from infected seed tubers while *F. coeruleum* from rotted mother tubers (Choiseul *et al.,* 2001; Cullen *et al.,* 2005; Bojanowski *et al.,* 2013). *F. sulphureum* sporulates more easily on stems, whereas *F. coeruleum* on surface of rotted seed tubers (Choiseul *et al.,* 2001; Cullen *et al.,* 2005). Tivoli *et al.* (1986a) reported that *F. sambucinum* causes extensive lesions in spite of wound type, while *F. coeruleum*, *F. arthrosporioides*, *F. Culmorum* and *F. graminearum*, only do so when the wound is deeper than 2 mm.

ECOLOGY

Fusarium survives on infected host debris in the soil in the form of chlamydospores as saprophytes (Nelson *et al.,* 1981). When the germination of conidia aborted, certain species can strengthen the cell walls of conidia to form chlamydospore in conidia (Tivoli *et al.,* 1983). *Fusarium* spp. cannot enter the tubers through lenticels or in the absence of injury. Positive correlation was found between the injury and dry rot incidence (Kumar *et al.,* 2016). Pathogens cause infection if the potato peels is ruptured (Stevenson *et al.,* 2001). Lesions near the site of infection may be limited by a layer of constantly deposited subcutaneous wound cells (O'Brien and Leach, 1983;

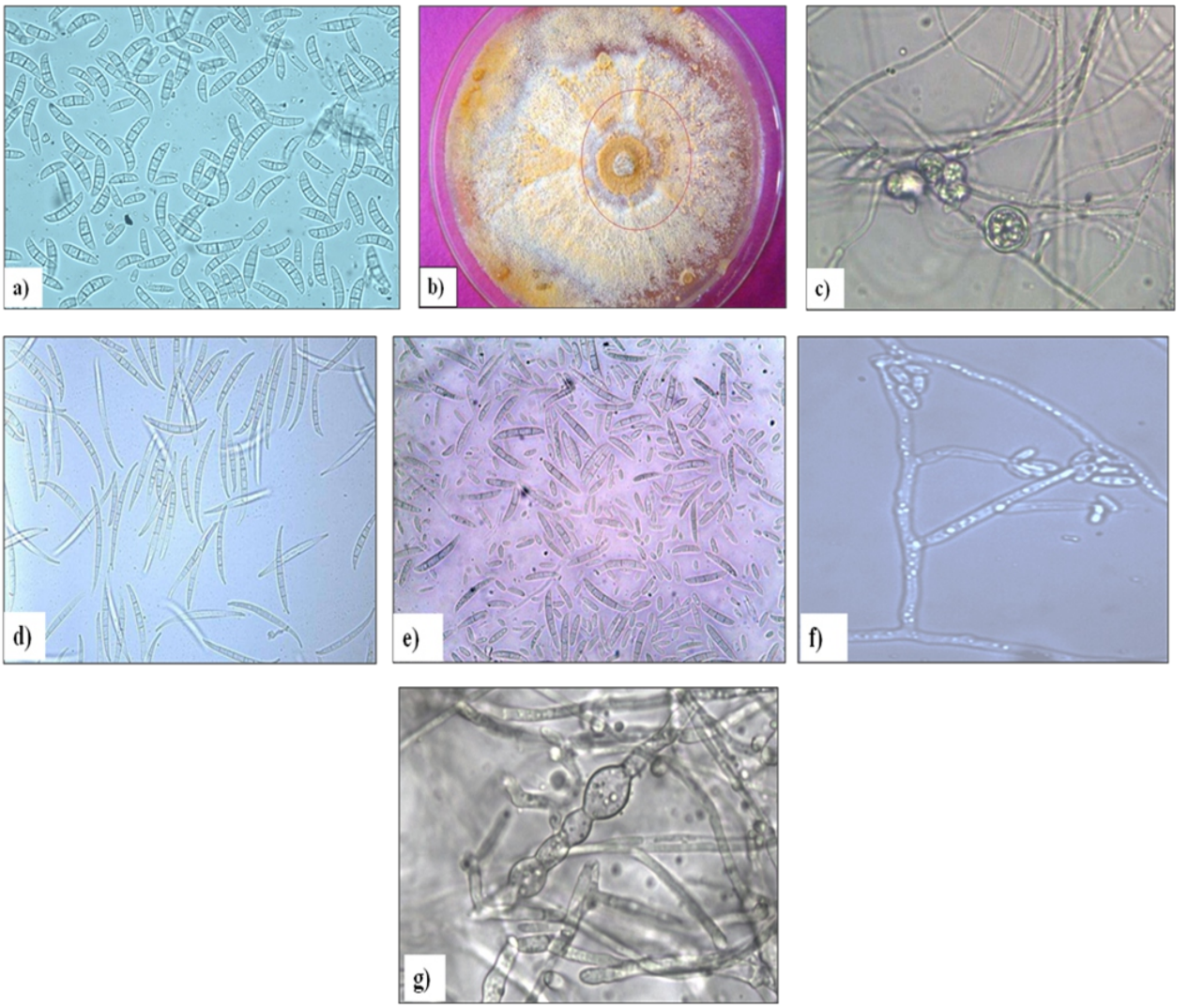

Fig. 4: Morphological characteristics of *Fusarium* species a) Macroconidia of *F. culmorum* b) Orange sporodochia of *F. culmorum* c) Chlamydospores form in the hypha of *F. culmorum* d) Macroconidia of *F. avenaceum* e) Macroconidia and microconidia of *F. sambucinum* f) Microconidia of *F. sambucinum* on phialide g) Chlamydospores of *F. sambucinum* in chain

Stevenson *et al.,* 2001). Wound healing can minimize the severity of dry rot by separating infected sites and preventing widespread damage (Stevenson *et al.,* 2001). Tuber tissue infected with *F. sambucinum* has been shown to accumulate many sesquiterpenes such as phytoalexin, rishitin, fatimin, phytuberin and fituberol (Ray and Hammerschmidt, 1998). Although no correlation has been observed between the total concentration of sesquiterpene or concentration of each sesquiterpene in tissue and resistance to dry rot (Ray and Hammerschmidt, 1998), but genetic research has shown a correlation between rishitin tolerance, rishitin metabolism and virulence by *F. sambucinum* (Desjardins and Gardner, 1991; Desjardins *et al.,* 1992). An increase in the content of lignin, polyphenol oxygenase and peroxidase activities have also been observed in tissues infected with tuberculosis. These increases are more correlated with the amount of infected tissue than with the resistance of the infected tissue (Ray and Hammerschmidt, 1998). Lignin accumulation does not prevent the progression of dry rot (Ray and Hammerschmidt, 1998).

MANAGEMENT

Cultural practices and storage

Harvesting of tubers plays a very important role in controlling the dry rot disease. A minimum injuries and wounds on the harvested tubers prevent the entry of *Fusarium* species. The contamination of the tubers during storage is mainly due to the increase in dust from storage facilities (Tivoli and Bedin, 1982). The good ventilation is crucial for wound healing in tubers right after harvest (Knowles and Plissey, 2008), which gives enough time for

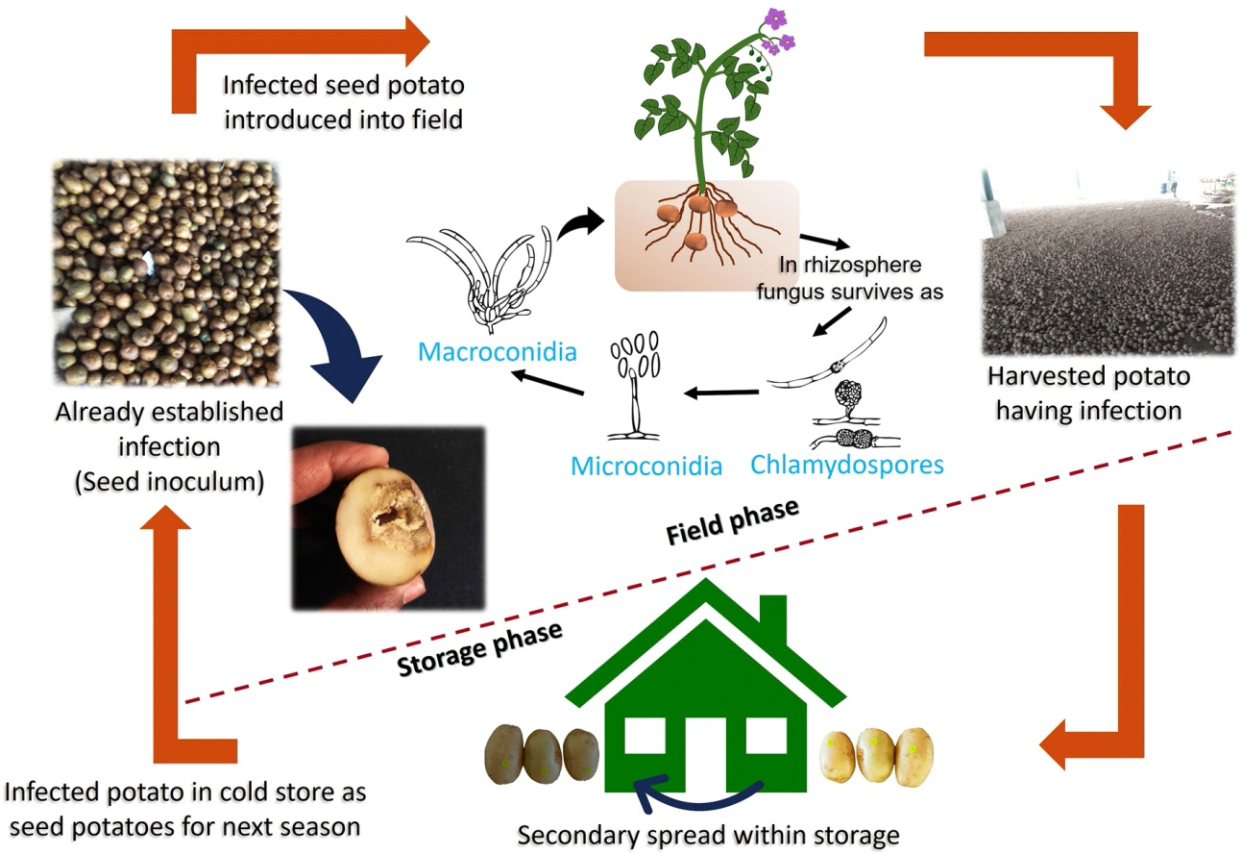

Fig. 5: Disease cycle of potato dry rot including field phase and storage phase

healing and reduce the infection (Knowles and Plissey, 2008). The tubers physiological age also plays a very important role and confers resistance. Tivoli *et al.* (1986b) reported that young potato tubers showed greater resistance to dry rot.

The tuber pulp temperature in a range between 10 to 18°C is accurate for harvesting (Knowles and Plissey, 2008).It is also recommended that the tubers should be harvested between 1 to 2 weeks after the killing of vine to allow the skin to mature (Knowles and Plissey, 2008), although Carnegie *et al*. (2001) did not observe any positive effect of the interval between the destruction of the leaves and the harvest. However, they observed a decrease in the severity of dry rot when the tubers were harvested earlier. After harvest, the tubers should be exposed to conditions conducive to wound healing. Suitable conditions for rapid curing during storage are high humidity (95-99%), pulp temperatures of 13-16°C, and good ventilation to avoid condensation on tubers (Knowles and Plissey, 2008). After a curing period (7-10 days), the temperature and relative humidity should be reduced to 2-5°C (10°C for tubers) or 90-95% (Howard *et al.*, 1994; Knowles & Pliss, 2008). Before cutting the seed tubers with sharp objects, the tubers should be heated to speed healing and minimize injury.

Crop rotation is not a good alternative to resist the dry rot disease (Fiers *et al.,* 2012; Bojanowski *et al.*, 2013). Carter *et al.* (2003) observed that there was no significant difference in the severity of dry rot when crop rotation of potato by any of the crops likes Italian ryegrass, Red clover, Barley or Italian red clover. Three-year crop rotation with red clover, barley, and potatoes did not significantly reduce the severity of dry rot (Peters *et al.,* 2004). Moreover, strains of *Fusarium* spp. from potatoes, alfalfa, clover, and cereals have been shown to cause potato tuberculosis, suggesting that crop rotation may harbor pathogenic *Fusarium* strains that could cause potato disease and vice versa (Peters *et al.,* 2008b). Wale *et al.* (2008) observed that application of lime in the field reduced dry rot severity. Another interesting cultural practice is soil solarization, whereby covering soil with thin plastic, the temperature of moist soil is increased. In Iran, Saremi *et al.* (2011) demonstrated that the solar energy of the soil significantly reduced the population

density of *Fusarium* spp. after 6 weeks of treatment. However, strong solar irradiation and high temperatures are needed to raise the soil temperature sufficient to control it. Organic fertilizers could be an important tool to control pathogens transferred by the soil (Fiers *et al.,* 2012, Zaccardeli *et al.,* 2013). It was found that white mustard intercrop and manuring significantly improve the tuber health and reduced dry rot disease (Glen-Karolczyk *et al.,* 2018). The CO_2 level should be in proper range for controlling dry rot in cold storage (Pinhero *et al.,* 2009).

Biological control

The use of antagonistic microorganisms to control plant diseases is considered an attractive alternative to fungicides (Wharton *et al.,* 2006). Bioagents such as Pseudomonas Migula spp., Enterobacter Hormaeche & Edwards spp. and Pantoea (Schisler and Slininger, 1994), *Burkholderia cepacia* (Recep *et al.,* 2009), *Trichoderma harzianum* (El-Kot, 2008), *Paecilomyces lilacinus*, *T. polysorum* (Kubar *et al.,* 2019), *P. fluorescens* (Slininger *et al.,* 2004; Schisler et al. 2016; Vatankhah *et al.,* 2019), *P. cepacia* (Burkhead *et al.,* 1994), *Bacillus cereus* (Sadfi *et al.,* 2002), *Glomus irregular* mycorhizza (Ismail *et al.,* 2011; Ismail and Hijri, 2012) and brown algae – *Sargassum vulgare* (Nawaim *et al.,* 2017) have been used in controlling the dry rot. Al-Mughrabi (2010) also observed that *P. fluorescens* Migula and *E. cloacae* were effective under field conditions. Moreover, combinations of two different bioagent strains were found more effective than a single strain (Schisler *et al.,* 1997). However, Al-Mughrabi (2013) launched a bio-pesticide (Bio-save 10LP & 11LP (*P. syringae*)) in USA for controlling the silver scurf and dry rot.

Daami-Remadi *et al.* (2006b) and Wharton and Kirk (2014) reported that *B. subtilis* was found highly effective under the most favorable conditions. The isolates of *T. viride*, *T. asperellum, T. harzianum*, *T. virens*, and *T. inhamatum* controlled *F. sambucinum* in inoculated tubers when stored at 24°C for 4–6 weeks (Aydýn, 2019). Khedher *et al.* (2020) investigated *Bacillus subtilis* V26 for biocontrol potential and growth-promoting effect against *Fusarium* species. The preventive application of V26 significantly decreased dry rot severity 21 days post-inoculation. An endophytic *B. subtilis* with salicylic acid is an eco-friendly approach to cope with storage rot during (Lastochkina *et al.,* 2020). Mohammadi *et al.* (2020) found that volatile compound of *Talaromyces flavus* 136 inhibited the growth of *F. solani* under *in vitro* conditions.

Chemical control

Management of *Fusarium* dry rot is achievable in two phases (i) before planting and (ii) before storage. In the 1950s, the organic mercury compound (Semean Bel) was effective against dry rot. Twenty years later, benzimidazole group of fungicide (thiabendazole) was introduced to control potato diseases (Leach and Nielsen, 1975). Thiabendazole fungicide used in both pre- and post-harvest management, was one of the most effective way to manage the dry rot (Bojanowski *et al.,* 2013; Gachango *et al.,* 2012b). Extensive use of thiabendazole developed resistance against *F. sambucinum* while rest of *Fusarium* species namely *F. culmorum*, *F. equiseti*, *F. sporotrichioides*, *F. solani*, *F. acuminatum*, *F. oxysporum* and *F. avenaceum* were susceptible to thiabendazole (Ocamb *et al.,* 2007; Gachango *et al.,* 2012b). After the development of resistance, various synthetic fungicides such as carbendazim, fenpiclonil, imazalil, nuarimol, prochloraze and sisthane have been reported (Bojanowski *et al.,* 2013). Several workers have also been used combination of fungicides as a post-harvest application (Carnegie *et al.,* 1990; Carnegie *et al.,* 1998; Daami-Remadi *et al.,* 2006b, 2010).Treatment of seed tuber is also used to control potato dry rot (CRAAQ, 2009). Fludioxonil was used as a seed treatment, and showed potential reduction of pathogen infection from soil around the tubers (Bains *et al.,* 2001). Fludioxonil alone or in combination with mancozeb as a seed treatment was found effective (Wharton *et al.,* 2007). In Canada, resistance to fludioxonil has been reported in *F. sambucinum* and *F. coeruleum* (Peters *et al.,* 2008c), and *F. oxysporum* and *F. sambucinum* in Michigan (Gachango *et al.,* 2011a, b, 2012b). Metiram (Leach and Nielsen, 1975) and mancozeb alone (Cwalina-Ambroziak and Czajka, 2006) or in combination with thiophanate-methyl or flutolanil (Wharton *et al.,* 2007) were found effective as seed treatment.

Systemic fungicides are absorbed by the roots when applied through furrow irrigation, and move toward the shoots, and protect plants against leaf diseases and promotes healthy tuber development (Hamm *et al.,* 2008). Some fungicides include mefenoxam (Ridomil Gold), phosphorus acid (Phostrol™), azoxystrobin (Amistar™, Quadris™) and mefenoxam + chlorothalonil (Ridomil™) (Zitter, 2010) registered in the United States to control potato dry rot. Gachango *et al.* (2012b) concluded that 228 strains of *Fusarium* were sensitive to difenoconazole, whereas insensitivity to fludioxonil was detected only for strains of *F. sambucinum* and *F. oxysporum*. Kumar *et al.* (2016) reported that carbendazim and mefenoxam + mancozeb were found most effective against potato dry rot under both *in vitro* and *in vivo* conditions. However, Sandipan *et al.* (2016) revealed that carbendazim and benomyl were found effective in inhibiting the fungal growth at concentration of 100µg/ml, whereas among non-systemic fungicides Methoxyethyl mercury chloride (MEMC) significantly inhibited the fungal growth at concentration of 1000 µg/ml.

The several organic and inorganic salts are generally recognized as safe (GRAS) alternative to synthetic

fungicides (Mecteau *et al.,* 2002). Under *in vitro* condition, inhibition of mycelial growth and spore germination of *F. sambucinum* and *F. solani* var. *coeruleum* with application of salts were found be effective (Mecteau *et al.,* 2002, 2008; Kolaei *et al.,*2012). Another GRAS compound, sodium silicate showed anti-fungal activity of *F. sulphureum in vitro* and reduced dry rot lesions under *in vivo* conditions (Li *et al.,* 2009a). Among these salts, sodium metabisulfite and potassium metabisulfite showed 100% inhibition of *Fusarium* spp. under *in vitro* conditions (Kolaei *et al.,* 2012). Other salts such as sodium carbonate, sodium bicarbonate, ammonium sulfate, magnesium sulfate, potassium sulfate, sodium sulfate, aluminum chloride and calcium and potassium phosphorus have also been effective under *in vitro* conditions (Lobato *et al.,* 2008; Kolaei *et al.,* 2013). Among the GRAS compounds, vegetable essential oils have been shown *in vitro* and *in vivo* against some *Fusarium* species (Hay *et al.,* 2019; Raigond *et al.,* 2019). Carvone vapors reduce dry rot incidence caused by *F. sulphureum* but not by *F. solani* (Hartmans *et al.,*1995). Cineol vapor and peppermint essential oil significantly reduce root rot when injected with two strains of *F. sambucinum* (Vaughn and Spencer, 1994). Other essential oil of Oregano, thyme, Dictamnus and marjoram completely inhibited the growth of *F. coeruleum* (Daferera *et al.,* 2003). Garlic oil as foliar spray was found effective in reducing *F. solani* severity (Bang, 2007). The emulsifier concentrates of fennel, peppermint and caraway essential oil were highly toxic to *F. oxysporum* (Mahmoud *et al.,* 2008). Water cinnamon extract also inhibited the fungal growth of *F. sambucinum* and reduced dry rot severity (Mvuemba *et al.,* 2009).

Induction of natural resistance in plants using elicitors has been more attentions over recent years. There are some elicitors involved in induced resistance against postharvest diseases (Krol *et al.,* 2015; Romanazzi *et al.,* 2016a, b), among them, β-amino butyric acid (BABA), sodium silicate and chitosan have been classified as GRAS by the FDA (Niu *et al.,* 2016; Romanazzi *et al.,* 2017). Hua-Li *et al.* (2017) reported that lesion diameter of *F. sulphureum* was significantly reduced after BABA treatment at 100mm for 3d and showed that expressions of *Tri* gene and trichothecene production was reduced. Chitosan is discovered as an antifungal agent (Feliziani *et al.,* 2013; Romanazzi *et al.,* 2002), and applied as powder as well as in solution (Romanazzi *et al.,* 2013). An application of chitosan has been reported to reduce the size of lesions in potatoes against *F. sulphureum* and *F. solani* (Li *et al.,* 2009a, b; Olivieri *et al.,* 2009; Sun *et al.,* 2008). El Mohamedy *et al.* (2017) showed that chitosan reduced the mycelial growth of *F. solani* when added to PDA medium at 1.0 g/L under *in vivo* conditions. A recent study showed that chitosan @0.25% concentration completely inhibits *F. sambucinum* growth and prevents the other physiological losses in tubers. Chitosan was effective in managing dry rot in a dose-dependent manner in potato cultivar Kufri Jyoti and Kufri Chipsona (Raigond *et al.,* 2019). Mejdoub Trabelsi *et al.* (2019) applied Chitosan at 4.0 g/L of acetic acid distilled water solution under *in vitro* and *in vivo* conditions, and found to be very effective against *F. oxysporum*, *F. sambucinum*.

As a strong oxidant, ClO_2 is an A1 level broad-spectrum, which is efficient and safe disinfectant of sterilization and preservation that recommended worldwide by WHO and FAO, and also be approved by FDA as the recognized food preservative (Chen *et al.,* 2016). Chlorine dioxide could be rapidly adsorbed on the surface of dangerous organisms, effectively restrain pathogens and reduce the rot of vegetables and fruits. Thus, ClO_2 is internationally recognized for the excellent performance and much better effected food preservative (Gomez-lopez *et al.,* 2007). In addition, ClO_2 can effectively prevent methionine to synthesize ethylene in fruits and vegetables, and destroy the synthetic ethylene to delay fruit senescence and long-term fresh fruits and vegetables. Li *et al.* (2017) reported that ClO_2 (0.75ug/mL)was found significantly effective in inhibiting the growth of *F. sulphureum*, which is safe in cold storage. Recently, cationic amylose-hexadecyl ammonium chloride inclusion complex (Hex-Am) @400 µg/ml as an antimicrobial film at the wound site was found to be an effective antifungal treatment for *F. sambucinum in vitro* and in situ (Hey *et al.,* 2019). Recently, the superiority of IMZ (Isomelezitose) was demonstrated by Slininger *et al.* (2020) with respect to cell survival during drying and storage, but also with respect to the ability of cells to quickly return to active growth and to suppress potato dry rot disease, when provided with favourable conditions.

CONCLUSION

The Integrated disease management (IDM) program provides appropriate harvesting conditions to prevent tuber injury and appropriate storage conditions. Disease free seed tuber and synthetic fungicides that are registered and post-harvest treated are recommended for effective dry rot control. Therefore, additional information on these aspects is needed to develop an effective strategy to combat potato dry rot in main production areas, especially in breeding program for development of resistant or tolerant varieties. Successful dry rot management will inevitably depend on additional research and development efforts between scientists and industry to implement an integrated strategy towards effective and sustainable dry rot management.

REFERENCES

Adams, M. J. and Lapwood, D. H. (1993). Transmission of *Fusarium solani* var *coeruleum* and *F. sulphureum* from seed potatoes to progeny tubers

in the field. *Annuals of Applied Biology,* 103:411-417.

Akhtari, K., Ashirbad, M. and Kunja, B. S. (2017). Studies on fungi associated with storage rot of sweet potato (*Ipomoea batatas* L.) root tubers in Odisha, India. *International Journal of Microbiology and Mycology*, 5:1–7.

Ali, S., Rivera, V. V. and Secor, G. A. (2005). First report of *Fusarium graminearum* causing dry rot of potato in North Dakota. *Plant Disease*, 89:105.

Al-Mughrabi, K.I., Vikram, A., Peters, R.D., Howard, R.J., Grant, L., Barasubiye, T., Lynch, K., Poirier, R., Drake, K.A., Macdonald, I.K. and Lisowski, S.L. (2013). Efficacy of *Pseudomonas syringae* in the management of potato tuber diseases in storage. *Biological Control*, 64:315–322. https ://doi.org/10.1016/j.

Al-Mughrabi, K. I. (2010). Biological control of *Fusarium* dry rot and other potato tuber diseases using *Pseudomonas fluorescens* and *Enterobacter cloacae*. *Biological Control,* 53:280–284.

Anonymous, (2020). Area and production of potato in Punjab, retrieved from http://www.indiastat.com.

Anonymous, (2019a). Production of potato in world, retrieved from http://www.faostat.com.

Anonymous, (2019b). Area and production of potato in India, retrieved from http://www.indiastat.com.

Atallah, Z. K. and Stevenson, W. R. (2006). A methodology to detect and quantify five pathogens causing potato tuber decay using Real-Time Quantitative Polymerase Chain Reaction. *American Phytopathological Society*, 96:1037-49.

Aydýn, M. H. (2019). Evaluation of some *Trichoderma* species in biological control of potato dry rot caused by *Fusarium sambucinum* Fuckel isolates. *Applied Ecology and Environmental Research*, 17(1):533–546. https :// doi.org/10.15666 /aeer/1701_53354 6.

Bains, P. S., Bennypaul, H., Kawchuk, L. M. and Holley, J. D. (2001). Fludioxonil (Maxim®) provides effective control of *Fusarium* dry rot of potatoes (*Fusarium* spp.). *Canadian Journal of Plant Pathology,* 23:184.

Bang, U. (2007). Screening of natural plant volatiles to control the potato (*Solanum tuberosum*) pathogens *Helminthosporium solani*, *Fusarium solani*, *Phoma foveata* and *Rhizoctonia solani*. *Potato Research*, 50, 185–203.

Khedher, B. S., Mejdoub-Trabelsi, B. and Tounsi, S. (2020). Biolgical potential of *Bacillus subtilis* V26 for the control of Fusarium wilt and tuber dry rot on potato caused by *Fusarium* species and the promotion of plant growth. *Biological Control*, 152:104444.

Bojanowski, A., Avis, T. J., Pelletier, S. and Tweddell, R. J. (2013). Management of potato dry rot. *Postharvest Biology and Technology*, 84: 99–109.

Bradshaw, N. J., Turner, J. A. and Elcock, S. J. (2001). Potatoes: A Survey of diseases 2000/01. Ministry of Agriculture, Fisheries and Food Report. pp. 30-33.

Burkhead, K. D., Schisler, D. A. and Slininger, P. J. (1994). Pyrrolnitrin production by biological control agent *Pseudomonas cepacia* B37W in culture and in colonized wounds of potatoes. *Applied and Environmental Microbiology,* 60: 2031–2039.

Carnegie, S. F., Cameron, A. M., Lindsay, D. A., Sharp, E. and Nevison, I. M., (1998). The effect of treating seed potato tubers with benzimidazole, imidazole and phenylpyrrole fungicides on the control of rot and skin blemish diseases. *Annual* of *Applied Biology*,133:343–363.

Carnegie, S. F., Ruthven, A. D., Lindsay, D. A. and Hall, T. D. (1990). Effects of fungicides applied to seed potato tubers at harvest or after grading on fungal storage diseases and plant development. *Annual of Applied Biology*, 116:61–72.

Carnegie, S.F., Cameron, A.M. and Haddon, P. (2001). The effect of date of haulm destruction and harvest on the development of dry rot caused by *Fusarium solani* var. *coeruleum* on potato tubers. *Annals of Applied Biology* 139:209–216.

Carter, M. R., Kunelius, H. T., Sanderson, J. B., Kimpinski, J., Platt, H. W. and Bolinder, M. A. (2003). Productivity parameters and soil health dynamics under long-term 2-year potato rotations in Atlantic Canada. *Soil Tillage Research,* 72:153–168.

Chen, D., Nahar, K., Bizimungu, B., Soucy, S., Peters, R. D., De Koeyer, D. and Dickison, V. (2020). A simple and efficient inoculation method for Fusarium dry rot evaluations in potatoes. *American Journal of Potato Research*, https ://doi.org/10.1007/s1223 0-020-09774 -4.

Chen, S. F., Guo, P. Y. and Ruan, B. (2016). Effects of stable chlorine dioxide on chlorophyll a and antioxiant enzymes of *Microcystis flosaquae*. *Journal of Central South University (Science and Technology)*, 47(2):414–419.

Choiseul, J., Allen, L. and Carnegie, S. F. (2001). The role of stem inoculum in the transmission of *Fusarium sulphureum* to potato tubers. *Potato Research*, 44:165-172.

Cullen, D. W., Lees, A. K., Toth, I. K. and Duncan, J. M. (2001). Conventional PCR and real-time quantitative PCR detection of *Helminthosporium solani* in soil and on potato tubers. *European Journal of Plant Pathology*, 107:387- 398.

Cullen, D. W., Toth, I. K., Pitkin. Y., Boonham, N., Walash, K., Barker, I. and Lees, A. K. (2005). Use of quantitative molecular diagnostic assays to investigate *Fusarium* dry rot in potato stocks and soil. *Phytopathology*, 95:1462-1471.

Cwalina-Ambroziak, B. and Czajka, W. (2006). Chemical control as a factor decreasing the infestation of potato tubers by pathogenic fungi. *Progress Plant Protection,* 46:660–663.

Daami-Remadi, M., Ayed, F., Jabnoun-Khiareddine, H., Hibar, K. and El Mahjoub, M. (2006a). Comparative susceptibility of some local potato cultivars to four *Fusarium* species causing tuber dry rot in Tunisia. *Journal of Plant Science,* 1:306–314.

Daami-Remadi, M., Jabnoun-Khiareddine, H., Ayed, F. and El Mahjoub, M. (2006b). *In vitro* and *in vivo* interaction of four fungicides with the *Fusarium* species complex causing tuber dry rot in Tunisia. *Plant Pathology Journal*, 5:362–367.

Daami-Remadi, M., Ayed, F., Jabnoun-Khiareddine, H., Hibar, K. and El Mahjoub, M. (2010). *In vitro*, *in vivo* and *in situ* evaluation of fungicides tested individually or in combination for the control of the *Fusarium* dry rot of potato. *Internation Journal of Agricultural Research*, 5:1039–1047.

Daferera, D.J., Ziogas, B.N. and Polissiou, M.G. (2003). The effectiveness of plant essential oils on the growth of Botrytis cinerea. *Fusarium* sp. and *Clavibacter michiganensis* subsp. *michiganensis*. *Crop Protection,* 22:39–44.

Delgado, L., Schuster, M. and Torero, M. (2017). Reality of food losses: a new measurement methodology. IFPRI discussion paper 1686. International Food Policy Research Institute (IFPRI), Washing- ton, DC.

Desjardins, A.E. and Gardner, H.W. (1991). Virulence of *Gibberella pulicaris* on potato tubers and its relationship to a gene for rishitin metabolism. *Phytopathology*, 81:429–435.

Desjardins, A.E., Christ-Harned, E.A., McCormick, S.P. and Secor, G.A. (1993). Population structure and genetic analysis of field resistance to thiabendazole in *Gibberella pulicaris* from potato tubers. *Phytopathology*, 83: 164–170.

Desjardins, A.E., Gardner, H.W. and Weltring, K. M. (1992). Detoxification of sesquiterpene phytoalexins by *Gibberella pulicaris* (*Fusarium sambucinum*) and its importance for virulence on potato tubers. *Journal of Indian Microbiology,* 9:201–211.

Du, M., Ren, X., Sun, Q., Wang, Y. and Zhang, R. (2012). Characterization of *Fusarium* spp. causing potato dry rot in china and susceptibility evaluation of chinese potato germplasm to the pathogen. *Potato Research*, 55:175– 184. https ://doi.org/10.1007/s1154 0-012-9217-6.

El-Kot, G. A. N. (2008). Biological control of black scurf and dry rot of potato. *Egypt Journal of Phytopathology*, 36:45–56.

El Mohamedy, R. S. R., Shafeek, M. R., Shaheen, A. M., Abd El Samad, E. H., Salama, D. M. and Risk, F. A. (2017). Field application of plant resistance inducers (PRIs) to control important root rot diseases and improvement growth and yield of green bean (*Phaseolus vulgaris* L.). *Australian Journal of Crop Science*, 11:496–505. https ://doi. org/10.21475/ ajcs.17.11.05.p260.

Ershad, D. (1995). Fungi of Iran. Agricultural Reseach, Education and Extension organization, 874p.

Estrada, R., Gudmestad, N. C., Rivera, V. V. and Secor, G. A. (2010). *Fusarium graminearum* as a dry rot pathogen of potato in the USA: Prevalence, comparison of host isolate aggressiveness and factors affecting aetiology. *Plant Pathology*, 59:1114–1120.

FAOSTAT, (2019). Food and agriculture data. https ://www.fao.org/faost at/en/data/QCinf o.

Feliziani, E., Smilanick, J. L., Margosan, D. A., Mansour, M. F., Romanazzi, G., Gu, S. and Rubio, A. Z. (2013). Preharvest fungicide, potassium sorbate, or chitosan use on quality and storage decay of table grapes. *Plant Disease,* 97:307–314.

Fiers, M., Edel-Hermann, V., Chatot, C., Le Hingrat, Y., Alabouvette, C. and Steinberg, C. (2012). Potato soil-borne diseases. *Agronomy for Sustainable Development*, 32:93–132.

Gachango, E., Hanson, L. E., Rojas, A., Hao, J. J. and Kirk, W. W. (2012b). *Fusarium* spp. causing dry rot of seed potato tubers in Michigan and their sensitivity to fungicides. *Plant Disease*, 96:1767-74.

Gachango, E., Kirk, W. and Schafer, R. (2012a). Effects of in-season crop-protection combined with postharvest applied fungicide on suppression of potato storage diseases caused by oomycete pathogens. *Crop Protection*, 41:42-48.

Gachango, E., Kirk, W., Hanson, L., Rojas, A. and Tumbalam, P. (2011a). First report of *Fusarium torulosum* causing dry rot of seed potato tubers in the United States. *Plant Disease*, 95:1194.

Gachango, E., Kirk, W., Hanson, L., Rojas, A., Tumbalam, P. and Shetty, K. (2011b). First report of in-vitro fludioxonil-resistant isolates of *Fusarium* spp. causing potato dry rot in Michigan. *Plant Disease*, 95:228.

Gardes, M, White., T. J, Fortin, J. A., Bruns, T. D. and Taylor, J. W. (1991). Identification of indigenous and introduced symbiotic fungi in ectomycorrhizae by amplification of nuclear and mitochondrial ribosomal DNA. *Canadian Journal of Botany*, 69:180-190.

Gardes, M. and Bruns, T. D. (1993). ITS primers with enhanced specificity for basidiomycetes application to the identification of mycorrhizae and rusts. *Molecular Ecology*, 2:113-118.

Gashgari, R.M., and Y.A. Gherbawy. (2013). Pathogenicity of some Fusarium species associated with superficial blemishes of potato tubers. *Polish Journal of Microbiology* 62:59–66.

Gherbawy, Y. A., Hussein, M. A., El-Dawy, E. G. A., Hassany, N. A. and Alamri, S. A. (2019). Identification of *Fusarium* spp. Associated with Potato Tubers in Upper Egypt by Morphological and Molecular Characters. *Asian Journal of Biochemistry, Genetics and Molecular Biology*, 2(3):1-14.

Gleń-Karolczyk, K., Boligłowa, E. and Antonkiewicz, J. (2018). Organic fertilization shapes the biodiversity of fungal communities associated with potato dry rot. *Applied Soil Ecology*, 129:43-51.

Gómez-López V. M, Devlieghere, F., Ragaert, P. and Debevere, J. (2007). Shelf-life extension of minimally processed carrots by gaseous chlorine dioxide. *International Journal of Food Microbiology*, 116 (2):221–227.

Guenthner, J. F. (2001). The International Potato Industry. Woodhead publishing limited Cambridge England, 222p.

Hamm, P. B., Boyston, R. A., Hoy, C. W., Stevenson, R. W. and Hutchison, P. J. S. (2008). Applying pesticides. In: Johnson, D.A. (Ed.), Potato Health Management. APS Press, St. Paul Minnnesota, Pp. 113-121.

Hanson, L. E., Schwager, S. J. and Loria, R. (1996). Sensitivity to thiabendazole in *Fusarium* species associated with dry rot of potato. *Phytopathology*, 86:378-84.

Hartmans, K. J., Diepenhorst, P., Bakker, W. and Gorris, L. G. M. (1995). The use of Carvone in agriculture: sprout suppression of potatoes and antifungal activity against potato tuber and other plant diseases. *Indian Crop Production*, 4:3–13.

Hay, W.T., Fanta, G.F., Rich, J.O., Schisler, D.A. and Selling, G.W. (2019). Antifungal activity of a fatty ammonium chloride amylose inclusion complex against *Fusarium sambucinum*; control of dry rot on multiple potato varieties. *American Journal of Potato Research*, 96:79–85. https ://doi.org/10.1007/ s1223 0-018-9683-8.

He, S. Q., Jin, X. L., Wei, Z. Q., Zhang, T. Y., Du, X. and Luo, D. G. (2004). Isolates and identification of pathogens causing dry rot of potato tubers in Ding Xi prefecture of Gansu province. *Journal of Yunnan Agriculture University (Natural Science)*, 19:550–52.

Heltoft, P., Moltebert E. L., Naerstad, R. and Hermansen, A. (2015). Effect of maturity level and potato cultivar on development of Fusarium dry rot in Norway. *Potato Research*, 58:205–219.

Heltoft, P., Brurberg, M. B., Skogen, M., Le, V. H., Razzaghian, J. and Hermansen, A. (2016). *Fusarium* spp. causing dry Rot on potatoes in Norway and development of a real-time PCR method for detection of *Fusarium coeruleum*. Potato Research, 59 (1):67-80.

Hide, G. A., Read, P. J. and Hall, S. M. (1992). Resistance to thiabendazole in *Fusarium* species isolated from potato tubers affected by dry rot. *Plant Pathology*, 41:745-748.

Holley, J. D. and Kawchuk, L. M. (1996). Distribution of thiabendazole and thiophanatemethyl resistant strains of *Helminthosporium solani* and *Fusarium sambucinum* in Alberta potato storages. *Canadian Plant Disease Survey,* 76:21–27.

Howard, R. J., Garland, J. A. and Seaman, W. L. (1994). Diseases and pests of vegetable crops in Canada. The Canadian Phytopathological Society and the Entomological Society of Canada, Ottawa.

Hua-Li, Xue., Yang, Bi., Yuan-Yuan, Z., Calderón-Urrea, A., Hu-Jun, W., Lu-Mei, P., Yi, W. and Yong-Cai, Li. (2017). Effects of elicitors on trichothecene accumulation and Tri genes expression in potato tubers inoculated with *Fusarium sulphureum*. *European Journal of Plant Pathology*, 148(3):673-685.

Hussein, M. A., Gherbawy, Y. and El-Dawy, E. G. A. (2020). Characterization, pathogenicity and enzymatic profile of Fusarium solani associated with potato tubers in Upper Egypt. *Archives of Phytopathology and Plant Protection,* 53 (11):495-508.

Ibrahim, M., Shehu, K., Sambo, S., Tukur, U., Umar, I A. and Tafinta. I. Y. (2014). Identification of fungi associated with storage rots of Irish potato (*Solanum Tuberosum* L.) tubers in Sokoto Metropolis. *Annals of Biological Sciences,* 2:1–4.

Ismail, Y. and Hijri, M. (2012). Arbuscular mycorrhisation with *Glomus irregulare* induces expression of potato PR homologues genes in response to infection by *Fusarium sambucinum*. *Functinal Plant Biology*, 39(3):236–245.

Ismail, Y., McCormick, S. and Hijri, M. (2011). A fungal symbiont of plant-roots modulates mycotoxin gene expression in the pathogen *Fusarium sambucinum*. *PLoS ONE*, 6:e17990.

Karimi, A. (1970). Wilt of potato plants and dry rot of potato tubers. Iran Journal of Plant Patholo*gy*, 6:35-52.

Knowles, N. R. and Plissey, E. S. (2008). Maintaining

tuber health during harvest, storage, and post-storage handling. In: Johnson DA (ed) Potato health management. St. Paul Minnesota, APS Press, pp 79–99.

Kolaei, E. A., Cenatus, C., Tweddell, R. J. and Avis, T. J. (2013). Antifungal activity of aluminium-containing salts against the development of carrot cavity spot and potato dry rot. Annuals of Applied Biology, 163:311–317. https ://doi.org/10.1111/aab.12056.

Kolaei, E. A., Tweddell, R. J. and Avis, T. J. (2012). Antifungal activity of sulfur-containing salts against the development of carrot cavity spot and potato dry rot. *Postharvest Biology Technology,* 63:55–59.

Król, P., Igielski, R., Pollmann, S. and Kępczyńska, E. (2015). Priming of seeds with methyl jasmonate induced resistance to hemi-biotroph *Fusarium oxysporum* f. sp. *lycopersici* in tomato via 12-oxo-phytodienoic acid, salicylic acid, and flavonol accumulation. *Journal of Plant Physiology*, 179:122–132.

Kumar, R., Kaundal, P., Arjunan, J., Sharma, S. and Chakrabarti, S.K. (2020). Development of a visual detection method for Potato virus S by reverse transcription loop- mediated isothermal amplification. *3Biotech*, 10:213. https ://doi. org/10.1007/s1320 5-020-02214 -4.

Kumar, R., Tiwari, R. K., Jeevalatha, A., Kaundal, P., Sharma, S. and Chakrabarti, S. K. (2019). Potato viruses and their diagnostic techniques: an overview. *Journal of Pharmacognosy and Phytochemistry*, 8(6):1932–1944.

Kumar, S. and Sekhon, P. S. (2016). *Fusarium* spp. causing dry rot of potato and their chemical management. *Plant Disease Research*, 31:59-65.

Kumar, S., Sekhon, P. S. and Kaur, J. (2016). Status and etiology of potato dry rot in Punjab under cold store conditions. *Potato Journal*, 43:183-192.

Lacy, M. L. and Hammerschmidt, R. (1993). *Fusarium* dry rot. Michigan State University Extension Bulletin. E-2448.

Lal, M.K., Kumar, A., Raigond, P., Dutt, S., Changan, S.S., Chourasia, K.N., Tiwari, R.K., Kumar, D., Sharma, S., Chakrabarti, S.K. and Singh, B. (2020). Impact of Starch Storage Condition on Glycemic Index and Resistant Starch of Cooked Potato (*Solanum tuberosum*) Tubers. Starch Stärke. https ://doi. org/10.1002/STAR.20190 0281.

Langerfeld, E. (1987). Methoden bei der Prüfung der Reaktion yon Kartoffelsorten gegen Lagerfäuleerreger der Gattung Fusarium. In: E. Forsund (Ed.), potato disease assessment keys. European Association for Potato Research, section for pathology, Committee for Disease Assessment, pp. 101-110.

Lastochkina, O., Baymiev, A., Shayahmetova, A., Garshina, D., Koryakov, I., Shpirnaya, L., Pusenkova, L., Mardanshin, I., Kasnak, C. and Palamutoglu, R. (2020). Effects of endophytic *Bacillus Subtilis* and salicylic acid on postharvest diseases (*Phytophthora infestans*, *Fusarium oxysporum*) development in stored potato tubers. Plants 9:76.

Leach, S. and Webb, R. (1981). Resistance of selected potato cultivars and clones to *Fusarium* dry rot. *Phytopathology*, 71:623-29.

Leach, S. S. and Nielsen, L. W. (1975). Elimination of fusarial contamination on seed potatoes. *American Journal of Potato Research,* 52:211-218.

Li, M. T., Shi Long, S., Jin, W., Xi Z. C., Jian Xin, Li., Shou, Q. Ge. And Xia, Tian, J. C. (2017). Effects of chlorine dioxide on morphology and ultrastructure of *Fusarium sulphureum* and its virulence to potato tubers. *International Journal of Agricultural and Biological Engineering*, 10 (5):242-250.

Li, Y. C., Bi, Y., Ge, Y. H., Sun, X. J. and Wang, Y. (2009a). Antifungal activity of sodium silicate on *Fusarium sulphureum* and its effect on dry rot of potato tubers. *Journal of Food Science*, 74:213–218.

Li, Y. C., Sun, X. J., Bi, Y., Ge, Y. H. and Wang, Y. (2009b). Antifungal activity of chitosan on *Fusarium sulphureum* in relation to dry rot of potato tuber. *Agricultural Science China*, 8:597–604.

Lobato, M. C., Olivieri, F. P., Gonzalez Altamiranda, E. A., Wolski, E. A., Daleo, G. R., Caldiz, D. O. and Andreu, A. B. (2008). Phosphite compounds reduce disease severity in potato seed tubers and foliage. *European Journal of Plant Pathology,*122:349–358.

Mahmoud, G. A., El-Tobgy, K. M. K. and Abo-El-Seoud, M. A. (2008). Utilisation of biocides for controlling pest attacks on potato tubers. *Archives* of *Phytopathology and Protection*, 43:251–258.

Mecteau, M. R., Arul, J. and Tweddell, R. J. (2002). Effect of organic and inorganic salts on the growth and development of *Fusarium sambucinum*, a causal agent of potato dry rot. *Mycology Research,* 106:688–696.

Mecteau, M. R., Arul, J. and Tweddell, R. J. (2008). Effect of different salts on the development of *Fusarium solani* var. *coeruleum*, a causal agent of potato dry rot. *Phytoprotection*, 89:1–6.

Mejdoub-Trabelsi, B., Jaboun-Khiareddine, H. and Daami-Remadi, M. (2012). Effect of *Fusarium* species and temperature of storage on the susceptibility ranking of potato cultivars to tuber

dry rot. *Pest Technology*, 6:41-46.

Mejdoub-Trabelsi, B., Touihri, S., Ammar, N., Riahi, A. and Daami-Remadi, M. (2019). Effect of chitosan for the control of potato diseases caused by *Fusarium* species. *Journal of Phytopathology*, 168(1):18-27.

Mohammadi, S., Taghizadeh, Z., Alaie, H. and Mohamadi, R. B. (2020). *In vitro* investigation of antagonistic potential of *Talaromyces flavus* against *Fusarium solani* the causal agent of Fusarium dry rot of potato. *Bioagrica*, 1 (1):1-8

Mshelia, I. Y. (2018). Survey and control of postharvest fungal rot pathogens of Irish potato (*Solanum tuberosum* L.) in Biu local government area, Borno state. *International Journal of Interdisciplinary Research and Innovations*, 6:689-697.

Mvuemba, H. N., Green, S. E., Tsopmo, A. and Avis, T. J. (2009). Antimicrobial efficacy of cinnamon, ginger, horseradish and nutmeg extracts against spoilage pathogens. *Phytoprotection*, 90:65-70.

Nasr-Esfahani, M. (1998). *Fusarium* species associated with dry rot of potato tubers in Esfahan. *Iran Journal of Plant Pathology*, 34:225-232.

Nawaim, A., Nefzi, A., Jabnoun-Khiareddine, H. and Daami-Remadi, M. (2017). Control of Fusarium dry rot incited by *Fusarium oxysporum* f. sp. *tuberosi* using *Sargassum vulgare* aqueous and organic extracts biological control of soil borne pathogens. *Journal of Microbial and Biochemical Technology*, 9:200–208. https ://doi.org/10.4172/1948-5948.10003 66.

Nelson, P. E., Toussoun, T. A. and Cook, R. J. (1981). *Fusarium*: diseases, biology and taxonomy. (Eds.) USA: The Pennsylvania State University Press.

Nicholson, P., Lees, A. K., Maurin, N., Parry, D. W. and Rezanoor, H. N. (1996). Development of a PCR assay to identify and quantify *Microdochium nivale* var. *majus* in wheat. *Physiological and Molecular Plant Pathology,* 48:257-271.

Niu, L. L., Bi, Y., Bai, X. D., Zhang, S. G., Xue, H. L., Li, Y. C., Wang, Y. and Calderón-Urrea, A. (2016). Damage to *Trichothecium roseum* caused by sodium silicate is independent from pH. *Canadian Journal of Microbiology*, 62:161–172.

O'Brien, V. J. and Leach, S. S. (1983). Investigations into the mode of resistance of potato tubers to *Fusarium roseum* '*sambucinum'*. *American Potato Journal*, 60:227-233.

Ocamb, C. M., Hamm, P. B. and Johnson, D. A. (2007). Benzimidazole resistance of *Fusarium* species recovered from potatoes with dry rot from storages located in the Columbia basin of Oregon and Washington. *American Journal of Potato Research*, 84:169–177.

Olivieri, F. P., Lobato, M. C., Gonzalez Altamiranda, E., Daleo, G. R., Huarte, M., Guevara, M. G. and Andreu, A. B. (2009). BABA effects on the behaviour of potato cultivars infected by *Phytophthora infestans* and *Fusarium solani*. *European Journal of Plant Pathology*, 123:47–56.

Peters, J. C., Lees, A. K., Cullen, D. W., Sullivan, L., Stroud, G. P., Cunnington, A. C. (2008b). Characterization of *Fusarium* spp. responsible for causing dry rot of potato in Great Britain. *Plant Pathology*, 57:262–271.

Peters, R. D., MacLeod, C., Seifert, K. A., Martin, R. A., Hale, L. R., Grau, C. R. and MacInnis, S. (2008a). Pathogenicity to potato tubers of *Fusarium* spp. isolated from potato, cereal and forage crops. *American Journal of Potato Research,* 85:367–374.

Peters, R. D., Platt, H. W., Drake, K. A., Coffin, R. H., Moorehead, S., Clark, M. M., Al- Mughrabi, K.I. and Howard, R.J. (2008c). First report of fludioxonil-resistant isolates of *Fusarium* spp. causing potato seed-piece decay. *Plant Disease*, 92:172.

Peters, R. D., Sturz, A. V., Carter, M. R. and Sanderson, J. B. (2004). Influence of crop rotation and conservation tillage practices on the severity of soil-borne potato diseases in temperate humid agriculture. *Canadian Journal of Soil Science*, 84:397–402.

Pinhero, R. G., Coffin, R. and Yada, R. Y. (2009). Post-harvest storage of potatoes. In: Advances in potato chemistry and technology. Elsevier, pp 339–370.

Platt, H. W. (1997). Resistance to thiabendazole in *Fusarium* species and *Helminthosporium solani* in potato tubers treated commercially in eastern Canada. *Phytoprotection*, 78:1–10.

Powelson, M. L., Johnson, K. B. and Rowe, R. C. (1993). Management of diseases caused by soil-borne pathogens. In: Rowe RC (Ed) Potato Health Management, American Phytopathological Society, St. Paul, Minnesota, pp 149-158.

Raigond, P., Sagar, V., Mishra, T., Thakur, A., Singh, B., Kumar, V., Gupta, V.K., Dutt, S. and Changan, S.S. (2019). Chitosan: a safe alternative to synthetic fungicides to manage dry rot in stored potatoes. *Potato Research*, 62:393–409. https ://doi.org/10.1007/s1154 0-019-9421-8.

Ray, H. and Hammerschmidt, R. (1998). Responses of potato tuber to infection by *Fusarium sambucinum*. *Physiological and Molecular Plant Pathology*, 53:81–92.

Recep, K., Fikrettin, S., Erkol, D. and Cafer, E. (2009). Biological control of the potato dry rot caused by

Fusarium species using PGPR strains. *Biological Control*, 50:194–198.

Romanazzi, G., Feliziani, E., Baños, S. B. and Sivakumar, D. (2017). Shelf life extension of fresh fruit and vegetables by chitosan treatment. *Critical Reviews in Food Science and Nutrition*, 57:579–601. https ://doi.org/10.1080/10408 398. 2014.900047 4

Romanazzi, G., Feliziani, E., Santini, M. and Landi, L. (2013). Effectiveness of postharvest treatment with chitosan and other resistance inducers in the control of storage decay of strawberry. *Postharvest Biology and Technology*, 75:24–27. https ://doi.org/10.1016/j.posth arvbio.2012.07. 007.

Romanazzi, G., Nigro, F., Ippolito, A., Di Venere, D. and Salerno, M. (2002). Effects of pre and postharvest chitosan treatments to control storage grey mould of table grapes. *Journal of Food Science*, 67:1862–1867.

Romanazzi, G., Sanzani, S. M., Bi, Y., Tian, S. P., Martínez, P. G. and Alkan, N. (2016a). Induced resistance to control posthar- vest decay of fruit and vegetables. *Postharvest Biology and Technology*, 122:82–94.

Romanazzi, G., Smilanick, J. L., Feliziani E. and Droby, S. (2016b). Integrated management of postharvest gray mold on fruit crops. *Postharvest Biology and Technology*, 113:69– 76.

Sadfi, N., Chérif, M., Hajlaoui, M. R. and Boudabbous, A. (2002). Biological control of the potato tubers dry rot caused by Fusarium roseum var. sambucinum under greenhouse, field and storage conditions using Bacillus spp. isolates. *Journal of Phytopathology*, 150:640–648. https :// doi.org/10.1046/j.1439-0434.2002.00811 .x.

Sagar, V., Sharma, S., Jeevalatha, A., Chakrabarti, S. K. and Singh, B. P. (2011). First report of *Fusarium sambucinum* causing dry rot of potato in India. *New Disease Reports,* 24: 5.

Sandipan, P.B., Solanki, B.P., Patel, N.N., Patel, R.L., Verma, P.D. and Desai, H.R. (2016). Efficacy of different fungicides against dry rot pathogen of potato caused by *Fusarium* sp. under *in vitro* condition. *Cercetari Agronomice in Moldova*, 49:69-74.

Saremi, H., Okhovvat, S. M. and Ashrafi, S. J. (2011). *Fusarium* diseases as the main soil borne fungal pathogen on plants and their control management with soil solarization in Iran. *African Journal of Biotechnology,* 10: 18391–18398.

Schisler, D. A and Slininger, P. J. (1994). Selection and performance of bacterial strains for biologically controlling Fusarium dry rot of potatoes incited by *Gibberella pulicaris*. *Plant Disease*, 78:251–255. https ://doi.org/10.1094/PD-78-0251.

Schisler, D. A., Slininger, P. J. and Olsen, N. L. (2016). Appraisal of selected osmoprotectants and carriers for formulating gram-negative biocontrol agents active against Fusarium dry rot on potatoes in storage. *Biological Control*, 98:1–10. https ://doi.org/10.1016/j.biocontrol. 2016.03.009.

Schisler, D. A., Slininger, P. J. and Bothast, R. J. (1997). Effects of antagonist cell concentration and two-strain mixtures on biological control of *Fusarium* dry rot of potatoes. *Phytopathology*, 87:177–183.

Secor, G. A. and Gudmestad, N. C. (1999). Managing fungal diseases of potato. *Canadian Journal Plant Pathology,* 21:213-21.

Secor, G. A. and Salas, B. (2001). *Fusarium* dry rot and *Fusarium* wilt. In: Stevenson W R, Loria R, Franc G D, Weingartner D P (Eds.), Compendium of Potato Diseases. APS Press, St. Paul, Minnesota, pp. 23-25.

Slininger, P. J., Cote, G. L., Shea-Andersh, M. A., Dien, B. S. and Skory, C. D. (2020). Application of isomelezitose as an osmoprotectant for biological control agent preservation during drying and storage. *Biocontrol Science and Technology*, 1-21.

Slininger, P. J., Burkhead, K. D. and Schisler, D. A. (2004). Antifungal and sprout regulatory bioactivities of phenylacetic acid, indole-3-acetic acid, and tyrosol isolated from the potato dry rot suppressive bacterium *Enterobacter cloacae* S11:T:07. *Journal of Indian Microbiology and Biotechnology,* 31:517–524.

Stefańczyk, E., Sobkowiak, S., Brylińska, M. and Śliwka, J. (2016). Diversity of *Fusarium* spp. associated with dry rot of potato tubers in Poland. *European Journal of Plant Pathology*, 145:871–884.

Stevenson, W.R., Loria, R., Franc, G.D. and Weingartner, D.P. (2001). Compendium of structure and genetic analysis of field resistance to thiabendazole in *Gibberella pulicaris* from potato tubers. *Phytopathology*, 83:164-70.

Sun, X. J., Bi, Y., Li, Y. C., Han, R. F. and Ge, Y. H. (2008). Postharvest chitosan treatment induces resistance in potato against *Fusarium sulphureum*. *Agricultural Science China*, 7: 615–621.

Talgo, V. and Stensvand, A. (2013). A simple and effective inoculation method for *Phytophthora* and fungal species on woody plants. Bulletin OEPP/EPPO Bulletin 43:276–279.

Theron, D. J. and Holz, G. (1989). *Fusarium* species associated with dry and stem end rot of potatoes in South Africa. *Phytophylactica,* 21:175-81.

Theron, D. J. and Holz, G. (1991). Prediction of potato dry rot based on the presence of in soil adhering to

tuber at harvest. *Plant Disease*, 75:126-30.

Tivoli, B., Abdul Razzaq, K., Jouan, B. and Lemarchand, E. (1986a). Comparative study of the infectious capacities of the different species or varieties of *Fusarium* responsible for the dry rot of potato tubers. *Potato Research*, 29:13–32.

Tivoli, B., Corbiere, R. and Jouan, B. (1983). Influence of temperature and humidity on the behavior in the soil of 3 species or varieties of *Fusarium* responsible for the dry rot of the potato tuber. *Agronomy*, 3, 1001-09.

Tivoli, B., Deltour, A., Molet, D., Bedin, P. and Jouan, B. (1986b). Identification of *Fusarium roseum* var. *sambucinum* resistant to thiabendazole, isolated from potato tubers. *Agronomy*, 6:219–224.

Tiwari, R. K., Kumar, R. and Sharma, S. (2020a). Continuous and emerging challenges of silver scurf disease in potato. International Journal of Pest Management. https ://doi.org/10.1080/ 09670874.2020.17953 02.

Tiwari, R. K, Lal, M. K., Naga, K. C., Kumar, R., Chourasia, K. N., Subhash, S., Kumar, D. and Sharma, S. (2020b). Emerging roles of melatonin in mitigating abiotic and biotic stresses of horticultural crops. *Scientia Horticulturae*, 272:109592.

Turner, A. S., Lees, A. K., Rezanoor, H. N. and Nicholson, P. (1998). Refinement of PCR-detection of *Fusarium avenaceum* and evidence from DNA marker studies for phenetic relatedness to *Fusarium tricinctum*. *Plant Pathology,* 47:278-288.

Valluru, R., Christ, B. J., Haynes, K. G. and Vinyard, B. T. (2006). Inheritance and stability of resistance to *Fusarium* tuber rot in Tetraploid potatoes. *American Journal of Potato Research*, 83:335–341.

Vatankhah, M., Saberi Riseh, R., Moradzadeh, E. M., Sedaghati, E., Alaie, H. and Afzali, H. (2019). Biological control of Fusarium dry rot of potato using some probiotic bacteria. *Journal of Agricultural Science and Technology*, 21(5):1301–1312

Vaughn, S. F. and Spencer, G. F. (1994). Antifungal activity of natural compounds against thiabendazole-resistant *Fusarium sambucinum* strains. *Journal of Agricultural Food Chemistry,* 42:200–203.

Wale, S., Platt, H. W. B. and Cattlin, N. D. (2008). Diseases, pests and disorders of potatoes. Academic, London.

Wharton, P. S. and Kirk, W. (2014). Evaluation of biological seed treatments in combination with management practices for the control of *Fusarium* dry rot of potato. *Biological Control*, 73:23-30.

Wharton, P., Hammerschmidt, R. and Kirk, W. (2007). *Fusarium* dry rot Mich. State Univ. Ext. Bull. E-2995, East Lansing, MI.

Wharton, P. S., Tumbalam, P. and Kirk, W. W. (2006). First report of potato tuber sprouts rot caused by *Fusarium sambucinum* in Michigan. *Plant Disease*, 90:1460.

White, T. J., Bruns, T., Lee, S. and Taylor, J. W. (1990). Amplification and direct sequencing of fungal ribosomal RNA genes for phylogenetics. In: Innis M A, Gelfand D H, Sninsky J J and White T J (Eds.) *PCR Protocols: A Guide to Methods and Applications*. Academic Press, Inc., New York. pp. 315-322.

Zaccardelli, M., De Nicola, F., Villecco, D. and Scotti, R. (2013). The development and suppressive activity of soil microbial communities under compost amendment. *Journal of Soil Science and Plant Nutrition*, 13 (3): 730–742.

Zitter, T.A. (2010). Potato Fungicides (Labels & Rates/A). Cornell University Cooperative Extension. http://tinyurl.com/3jdh6ar.

Received: April 18, 2021
Accepted: April 30, 2021