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REVIEW

Will *Macrophomina phaseolina* spread in legumes due to climate change? A critical review of current knowledge

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Abstract

The response of climate change to the existing biotic stresses in legumes especially fungal diseases is a key global concern. The legumes are attacked by several yield-limiting fungal diseases, and dry root rot (DRR) or charcoal rot (CR) caused by *Macrophomina phaseolina* is an important disease in legumes. There have been noteworthy scientific reports on the issue of how climate change is expected to be accountable for the survival and spread of *M. phaseolina* in legumes and other crops. In particular, microsclerotia, which are the source of primary inoculum, play an important role in the life cycle of *M. phaseolina*, help in survival and spread as well as disease initiation and development. Adaptation strategies through crop management (rotating field and cropping practices, use of chemicals and bio-fungicides) and development of resistant varieties through breeding could be developed, evaluated and pooled to partially cope with the impact of *M. phaseolina* in legumes. The adaptation strategies can support to alleviate some of the climate change impacts in disease spread in legumes; however, eventually, there is a boundary as to how far leguminous crops can adapt to the changing climate and can combat with the DRR/CR, which is essential for durable food security. Understanding the current status of spread of *M. phaseolina* in legumes due to climate change and limitations of the existing mitigation strategies is important, and there are many breaks for the future study. This review discusses the current status of significance of *M. phaseolina* in legumes, impact of climatic factors on its life cycle, survival and spread in different leguminous crops, adaptation strategies and impact of climate change on it as well as highlights important knowledge gaps for potential future research.

Keywords DRR/CR · Epidemiology · Climatic factors · Genetic variability · Adaptation strategies

Introduction

Current studies have proved that agriculture is vulnerable to climate change. Higher temperatures due to global warming tend to reduce the yield of crops and favor the pest and disease emergence and proliferation (Ghini et al. 2012). Climate changes are likely to affect survival rates and spread of the pathogens in diverse patho-systems, modify host susceptibility, resulting in changes in the impact of diseases on crops (Sharma et al. 2019). Earlier reports showed that increase in temperature, CO_2 concentration and drought due to climate change resulted in increased incidence/severity of crown & root rot and spot blotch diseases of wheat in Australia and South Asia (Sharma et al. 2007; Melloy et al. 2010).

The legumes, which are known for their best food supplements for the vegetarian populace, due to their high content of quality dietary protein (~25–28%), and other essential nutrients, minerals and micronutrients (Veni et al. 2016) specially in the developing countries, are challenged by several biotic and abiotic stresses especially in the present era of climate change. Among the biotic stresses, fungal disease, dry root rot (DRR)/charcoal rot (CR) caused by *Macrophomina phaseolina* (Tassi) Goid is one of the important diseases of food legumes worldwide (Indira and Gayatri 2003; Zhang et al. 2011). The pathogen has a widespread host range, causing economically important diseases in cereals and pulses. The pathogen infects approximately all food legumes, and inflicts severe yield losses predominately in chickpea (*Cicer*

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arietinum L.), soybean (*Glycine max* L.), mungbean (*Vigna radiata* (L.) R. Wilczek), pigeon pea (*Cajanus cajan* L. (Mill sp.) and urdbean (*Vigna mungo* (L.) Hepper) (Iqbal and Mukhtar 2014).

The pathogen is favored by warm climate and low water stress. Earlier, it was restricted to few crops; however, due to climate change, i.e., water scarcity during cropping period due to reduced rainfall and global rise in temperature, several minor pathogens may attain the status of major pathogens, and DRR/CR is no exception. It has become a serious emerging problem in legumes throughout the world including India, Myanmar, Pakistan (Khan and Shuaib 2007; Lodha and Mawar 2020), Sub-Saharan Africa (Songa and Hillocks 1996) and USA (Wrather and Koenning 2006). The work done on various aspects of DRR/CR, including its management on legumes and other crops, has been already reviewed extensively (Gupta et al. 2012a; Lodha and Mawar 2020). This review discusses the available literature on MP with reference to its significance in legumes, infection cycle and impact of higher temperature and water stress on it, and spread of MP in legumes and its adaptation to other crops, disease management and knowledge gaps.

The economic impact of MP in legumes

Macrophomina phaseolina is both seed and soil-borne pathogen, infects seeds of several pulses and causes significant reduction of seed germination and viability (Bhattacharya et al. 1994; Sarita et al. 2014). The pathogen also causes seed infection during storage and deteriorating the seeds which results in substantial losses. The pathogen was responsible for seed deterioration in some stored legumes such as mungbean, urdbean, chickpea, soybean, pigeon pea and caused ~ 40% seed loss in South Asian countries (Rahman et al. 1999; Kumar and Singh 2000; Singh and Kumar 2002; Ali et al. 2010; Patil et al. 2012; Haider and Ahmed 2014; Ashwini and Giri 2014). The pathogen has reduced the seed germination and protein content (12.3%) of mungbean seeds (Kaushik et al. 1987; Patil et al. 1990). Relative humidity coupled with atmospheric temperature has a major role in the seed deterioration of legumes by MP, and increase in both the factors resulted in more infection, as infection percentage of seeds varied across the countries (Mbofung et al. 2013).

The pathogen also caused both pre-emergence and postemergence mortality in legumes. Foliar infection results in reduction in pod size, poor seed set which ultimately leads to the reduction in yield. Yield losses up to 30% in India (Kaushik et al. 1987; Raghuchander et al. 1993) and 44% in Pakistan (Bashir and Malik 1988) have been reported due to DRR in the mungbean. In urdbean and chickpea, it caused ~ 40% disease incidence in India (Indira and Gayatri 2003; Lakhran et al. 2018). During 1994, the estimated yield loss due to CR in soybean was 1.2 million metric tons in the top 10 soybean-producing countries (Wrather et al. 2001). Afterward, during 2003, a severe epidemic of soybean's CR was reported in Iowa, USA (Wrather and Koenning 2006).

In addition, the average annual yield loss of grain soybean was 30–50% from Missouri (USA) (Wyllie 1988), and up to 80% from India (Gupta and Chauhan 2005). Under the hot and dry climatic conditions, many agricultural crops are predisposed to the infection and colonization by MP, resulting in drastic yield losses in chickpea (Lakhran et al. 2018), soybean (ElAraby et al. 2007) and sunflower (Khan 2007). The pathogen infected the common bean, pigeon pea, soybean and cowpea in Kenya (Songa and Hillocks 1996), but percent disease incidence or economic yield loss has not been estimated. However, CR caused 10% yield loss of cowpea production in Niger and Senegal, West Africa, which estimated value was about $US 146 million (Ndiaye et al. 2010). Besides, MP has also reduced the production of mungbean sprouts in the European countries (Fuhlbohm et al. 2013).

Disease cycle

Macrophomina phaseolina is a pathogen of warm climate, attacks hosts predominantly under low rains and with increased temperature up to 35–40 °C (Sarr et al. 2014). Pathogen completes disease cycle through four phases, i.e., germination, penetration, parasitic and saprophytic phase (Dhingra and Sinclair 1978, Fig. 1). The pathogen survives for maximum up to 3 years in the soil and in crop's debris in the form of microsclerotia (Su et al. 2001), which act as the source of primary inoculum during favorable conditions (Tonin et al. 2013). Microsclerotia (aggregation of hyphal cells) are spherical to oblong, black to chocolate brown, which germinate to produce hyphae during favorable conditions (28–35 °C).

When host is under water stress, these microsclerotia germinate on the root surface, produce appressoria and penetrate epidermal cell walls of the host through natural opening (Olaya and Abawi 1996). However, sometime during seed emergence, MP also infects through cotyledons, small rootlets or via root surface injuries. The hyphae infect the host-plant's roots which enter the cortical tissue and grow intercellularly. Once the hyphae spread inside the root system, they infect vascular tissue, and produce mycelia and sclerotia (pathogenic phase of the fungus—Fig. 1) inside the vascular tissue, and plug the xylem vessels (Babu et al. 2007). This prevents water and nutrients from being transported from root to the upper part of the plants, resulting in wilting of the host, or dies permanently due to systemic infection.

During the infection process, several mechanical pressures and enzymatic reactions occur which leads to the production of toxins, viz., botryodiplodin/phaseolinone, which further leads to disease development (Bhatt and Vadhera

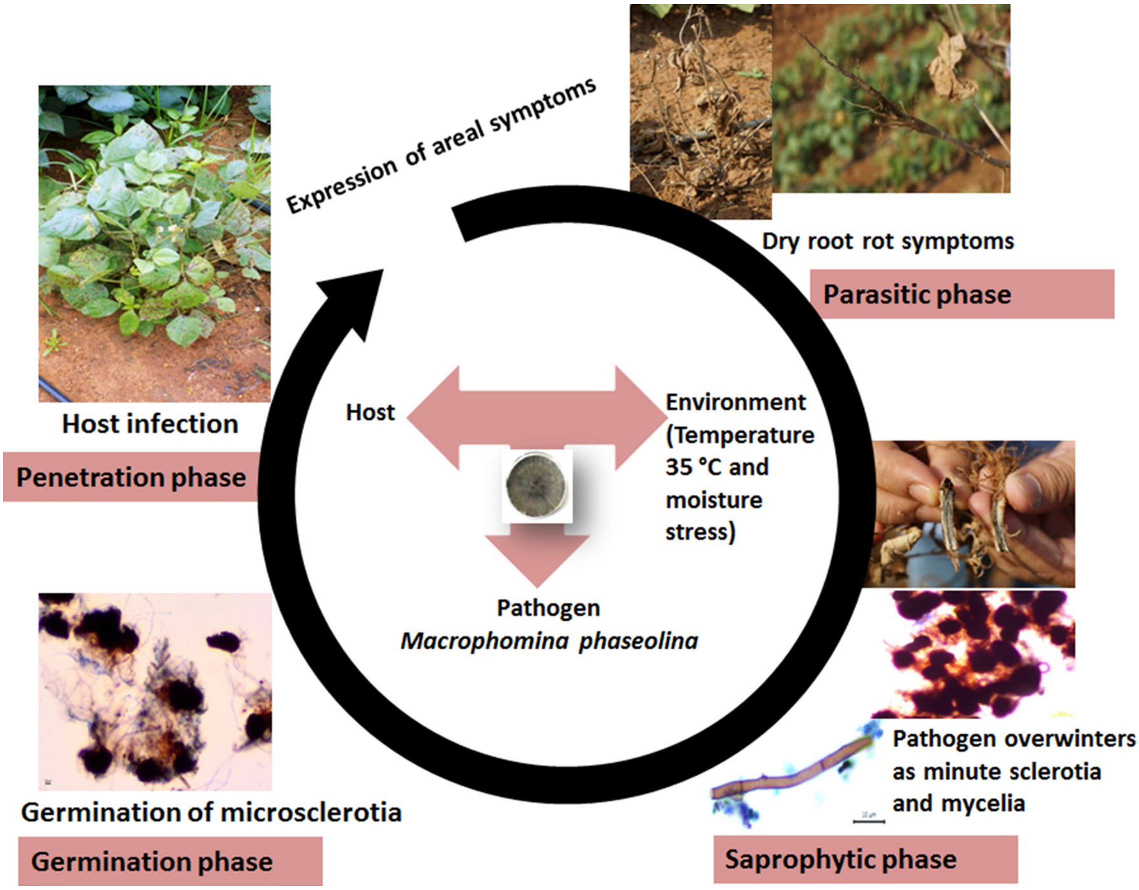

Fig. 1 The disease cycle of dry root rot/charcoal rot pathogen, *Macrophomina phaseolina*

1997; Abbas et al. 2019). With the progression of disease, infected plants dry up, and root decay with shredded appearance. Charcoal-brown lesions on the roots and stems with production of dark mycelia, and black microsclerotia are reported as the prominent disease symptoms. Mycelial colonization followed by microsclerotia formation occurs in the host tissue, once the host's tissue starts to decompose. These microsclerotia are released into the soil after decay of plant debris, and the infection cycle continues (Fig. 1). In the field, microsclerotia enable the MP to survive in the adverse climatic conditions. Therefore, microsclerotia play an important role in the life cycle and epidemiology of MP, and in disease initiation and development. Soil moisture, temperature and relative humidity are the main environmental factors that influence the survival and spread of this pathogen.

Role of the temperature in disease infection/development caused by MP

Current estimates of climate change indicate future rise in the global temperatures of 1 °C by 2025 and 3 °C by 2050 (Philipp and Edwards 2020), which will increase the survival and spread of thermophilic/drought pathogens. Drought and pathogenic fungi are important stress factors affecting the plant health. Drought is either no rain during the cropping period (Wilhite and Glantz 1985) or natural disaster of below-average rainfall in cropped areas, resulting in less atmospheric, surface water or groundwater supply for the longer period (Getis and Fellmann 2000). In developing countries, a prediction of future climate change led to drought to become more frequent and has become an important factor affecting crops (Valdes-Pineda et al. 2014).

Macrophomina phaseolina is a high-temperature loving pathogen, and its microsclerotia survive for a longer period under the higher temperatures and water stress conditions (Chamorro et al. 2015). In the infection cycle of MP, germination, penetration and parasitic phases are affected by the temperature. In the tropical humid climates, DRR/CR is becoming more intense with increase in temperature and moisture stress (Lodha and Mawar 2020). It has been reported that an increase in temperature (35–40 °C) triggers the pathogenic nature of microsclerotia and makes hosts vulnerable for infection (Olaya and Abawi 1996). This is due to, at the higher temperatures coupled with drought conditions, MP produces large number of microsclerotia (Akhtar et al. 2011), and also, increase in temperature causes increase in hydrolytic enzymes inside the microsclerotia which makes sclerotia more conducive for the infection (Kaur et al. 2012b). This evidence was supported by the findings of Kaur et al. (2012a), who reported the higher incidence of CR in pigeon pea was due to such atmospheric conditions.

In soybean-growing areas in the Central India, epiphytotics of CR occurred at temperature of 35–40 °C (Agarwal and Goswami 1974), and infection rate of ashy stem blight/DRR caused by MP in cowpea (Ratnoo et al. 1997) and other legumes (Lalita and Ahir 2020) was also highly favored by the higher temperatures (28–40 °C). In addition, recent reports revealed that the incidence of DRR and CR respective in chickpea and soybean in the tropical regions has extended many folds in last 2–3 years due to the prevalence of higher temperatures (35–40 °C) (Keote and Reddy 2019; Ishikawa et al. 2019). Hence, due to increase in temperature, shift in the geographical distribution, virulence pattern and emergence of MP in the new areas may be predicted in near future (Arias et al. 2011). Consequently, the adaptation of MP at larger numbers of crops may also increase in the future. Thus, alteration in temperature may affect susceptibility of the host-virulence mechanism of the pathogen (Ghini et al. 2012).

Role of other climatic factors in disease infection/development caused by MP

Soil moisture: If global temperature continues to rise, it will affect the rainfall resulting in intense water shortage. The WHO has estimated that half of the world's population will be living in water-stressed areas by 2025. Due to reduced rainfall, under water stress (10–40% soil moisture), MP becomes more virulent for the infection of legumes, as has been studied in sunflower (Tossi and Zazzerini 1990) and in sorghum (Arora and Pareek 2013). Low soil moisture promotes the survival of microsclerotia for the longer period of time, resulting in increased saprophytic activity (Dhingra and Sinclair 1978; Maheswari and Ramakrishnan 1999); on the contrary, high soil moisture ($<80\%$) deters the microsclerotia survival (Arora and Pareek 2013). The highest survival of the microsclerotial population was recorded at 0–5 cm soil depth (Lodha 1993), and 25% soil moisture led to maximum infection in chickpea, and in soybean due to MP (Ratnoo et al. 1997; Wokocha 2000; Patel and Anahosur 2001).

Edaphic factors: Edaphic factors have also been reported to influence the life cycle of MP which alter the disease incidence. Sandy soil supported more infection by MP to legumes than the clay soil, as 78.33 and 51.56% wilting of chickpea have been reported in sandy and clay soils, respectively (Raj Krishan et al. 1999). The variable wilting percentage may be due to the physical and chemical properties of the soil, which alter the host–pathogen interaction, and such edaphic may be responsible for the occurrence of DRR/CR (Bashir 2017).

Relative humidity: Little work has been done on the effect of relative humidity on infection cycle of MP in legumes, in terms of disease initiation and development. A laboratory investigation revealed that MP grew efficiently at RH of 80–100%, and it declined at the lower humidity level (Ali et al. 1998). However, the role of RH in disease infection and development is still unclear.

Carbon dioxide: In addition to the temperature and water stress, CO_2 is also an important factor affecting the growth and multiplication of the pathogens. Presently, CO_2 concentration in the atmosphere is 410 ppm and it is the highest since the start of agriculture, and is increasing by 2.3 ppm annually (Dong et al. 2020). The increase in CO_2 level will encourage the production of plant bio-mass and promote the growth of pathogenic microbes (Chakraborty et al. 2000). Under controlled conditions, increase in CO_2 resulted in increased germination and production of microsclerotia of MP (Wyllie et al. 1984); however, elevated CO_2 had no significant role on DRR incidence in chickpea as has been reported by Sharma (2012). In Brazil, rice blast and downy mildew of soybean increased with increased CO_2 concentration (Goria 2009; Lessin and Ghini 2009), while severity of soybean rust reduced with increasing CO_2 concentration (Lessin and Ghini 2011). Therefore, due to greenhouse gases, CO_2 is rising day by day, and rising CO_2 levels can affect DRR/CR spread and incidence in legumes at global level needs to be confirmed by conducting more experiments in the control conditions.

The spread of DRR/CR in legumes and climate change

The spread of pathogens is the result of dynamic processes involving host availability, susceptibility of host, pathogenic virulence and congenial climatic conditions over a long period of time. Influence in the climatic factors alters the diversity and distribution of the pathogens as well as disease spread in diverse eco-climatic regions. Climate has a major role in spread and infection of MP, which is a temperature loving pathogen and shows significant correlation with the soil moisture, relative humidity and temperature (Dhingra and Sinclair 1978).

Macrophomina phaseolina is a polyphagous pathogen, and has a wide range of geographical distribution. In legumes, earlier DRR/CR was major disease of soybean in India (Gupta et al. 2012a), but due to increase in temperature it has become an emerging disease of chickpea, mungbean and urdbean in the tropical regions (Khan and Souaib 2007; Su et al. 2001; Lalita and Ahir 2020). DRR/CR is also spreading in legumes in the South Asia, and Southeast Asia (Su et al. 2001; Gupta and Chauhan 2005), USA (Wrather and Koenning 2006) and presently posing a major threat in the African (Ndiaye et al. 2010) and European countries (Fuhlbohm et al. 2013). In soybean, the disease has spread in several states of the USA (ElAraby et al. 2007) and in the African countries (Songa and Hillocks 1996). In India, DRR/CR in legumes is distributed in the tropical regions, i.e., central and southern part of the country, but due to the future prediction of rise in temperature, it may spread in the northern parts of the country including temperate regions.

Worldwide, MP infects more than 500 crop species (Su et al. 2001; Iqbal and Mukhtar 2014). In addition to the food legumes, other dry season crops infected by MP are alfalfa (*Medicago sativa* L.), moth bean (*Vigna unguiculata* L. Walp.), peanut (*Arachis hypogaea* L.), corn (*Zea mays* L.), pepper (*Capsicum annuum* L.), sorghum (*Sorghum bicolor* (L.) Moench) and cluster bean (*Cyamopsis tetragonoloba* L.) in areas where maximum temperature goes up to 35–40 °C (Diourte et al. 1995; Lodha et al. 2002). The pathogen also infects the cool season crops such as potato (*Solanum tuberosum* L.), cabbage (*Brassica oleracea* L., *Beta vulgaris* L.), sweet potato (*Ipomoea batatas* (L.) Lam.) and sunflower (*Helianthus annuus* L.) where maximum temperature goes up to 25 °C (Suriachandraselvan et al. 2005).

Indeed, drought and rain periods during the crop cycles are deeply changing across the traditional agricultural areas worldwide, as reported by "The Intergovernmental Panel on Climate Change" (IPCC) reports in the last 15 years (IPPC 2007). One of the examples of that is the increase in rain periods during summer in some of the EU Mediterranean growing areas which were characterized by hot and dry summer up to 10 years ago. That has deeply changed the interaction between crops and climate in the different continents and *Macrophomina* specialization toward the crops in the last 15 years reflects this climate trend (Manici et al. 2014).

In contrast to the other soil-borne fungal pathogens that survive and proliferate in moisture conditions, MP survives in regions where change in climate results in higher temperatures and longer moisture stress (Saleh et al. 2010; Arora and Pareek 2013). Mediterranean countries are known for longer, dry, hot summers with no rain and relatively shorter, frosty rainy winters (Goldreich 2003). These types of climatic conditions favor the growth and multiplication of MP, and as a result, several crops such as strawberry, melon and cotton are attacked by the pathogen, causing substantial economic losses (Zveibil and Freeman 2005).

In the past, the yield production of crops had been considerably negligible due to MP attack in those provinces, where earlier it was isolated only occasionally (Yang and Navi 2005; Zhang et al. 2011). Besides, MP, in the 1980s and 1990s that impacted on several arable crops apart from legumes, includes sunflower, sorghum, cotton and soybean (Dhingra and Sinclair 1978; Wrather 1995) that has been reported to accountable for adaptation and losses in the last decade in several other horticultural crops, viz., vine, melon and strawberry (Aviles et al. 2008). In recent years, the adaptation of MP to horticultural crops such as strawberry (Koike 2008; Sanchez et al. 2016; Baggio et al. 2019) and melon (Cohen et al. 2016) which is threatening the horticultural production in California, Florida and in many other specialized horticultural cropping areas such as Chile (Sanchez et al. 2013) or Israeli (Chamorro et al. 2015) or Australia (Gomez et al. 2020) has been reported.

In Israel, MP has developed into the main threat to strawberry cultivation, and has become a key pathogen of importance in the other strawberry growing countries in the Mediterranean region (Freeman and Gnayem 2005). There, farmers adapt strawberry crop as an annual crop, and grow year after year without rotation. The pathogen proliferates in the remaining plant materials, generates inoculums for the following season's crops. This, mutually with elevated temperatures of the soil, creates most favorable conditions for the proliferation and contagion of strawberry by MP (Chamorro et al. 2015). The pathogen threatening the sunflower production in Italy under water stressed conditions was also pathogenic on other crops like soybean, safflower, sorghum and melon (Manici et al. 1995). They also reported that at lower temperatures isolates of MP from north Italy (colder areas) grew superior to the other isolates, and also displayed excellent adaptability to 40 °C.

Climate change alters the plant–pathogen–environment interactions in different eco-climatic zones, resulting in a new distribution pattern. For the determining worldwide geographical distribution of the diseases, lower temperatures are often more significant than the higher temperatures. Consequently, for pathogens which are presently limited by low temperature, enhancement in the temperatures may cause a better ability to overwinter at high latitudes and also can be extended the range of pathogens (Hill and Dymock 1989). In this regard, no records are available for the impact of climate change on the spatial and temporal distribution of MP/DRR/CR in legumes and needs to be addressed. This will give knowledge on the distribution pattern of DRR/CR across the country and impact of climate change which will help in disease control strategies.

Role of pathogenic and genetic variability in adaptation of MP, and climate change

In the tropical and semiarid tropical areas, increase in temperature and water stress are expected to degrade the soil conditions (Bullok 1999). Investigation on the genetic variability of MP populations in mid-latitude areas suggests that the spreading probability of this pathogen would rise in combining years (Csondes et al. 2012). Since the microsclerotia can survive for a longer period of time and their germination and adaptation to specific crops may increase over a period of time (Kaur et al. 2013). Hence, an increase in variability is expected due to climate change (Tok et al. 2018).

Morphological variations among the isolates of MP have raised queries about possible alteration in pathogenic and genetic diversity in pathogen isolated/ associated with different cropping systems. Genetic variations in MP isolates isolated from different hosts such as cowpea (Muchero et al. 2011), peanut (Okwulehie 2001), sunflower (Aboshosha et al. 2007), beans (Mayek-Perez et al. 2002), sorghum (Das et al. 2008), soybean (Jana et al. 2005) and chickpea have been studied. Su et al. (2001) found that MP isolates from a given host were genetically similar to each other but distinct from those obtained from other hosts.

Likewise, MP also showed pathogenic variability among isolates collected from various hosts including legumes from different locations in Pakistan (Iqbal and Mukhtar 2014), India (Kumar et al. 2017) and Kansas, USA (Jimenez 2011). It was observed that the fungal population had the ability to change within 3 years from its original population as reported for *Mycosphaerella graminicola* (Chen and McDonald 1996). This is because of the sexual nature of pathogens and also of the use of different hosts in the same field. Perhaps, the same assumption can be drawn here in the case of MP, replacing genotypes with plant species. The high rate of genetic variability in MP isolates in response to altered temperature allowing it to adopt the new environment (Reyes-Franco et al. 2006; Almeida et al. 2008).

Adaptation strategies in legumes against MP and future outlook

Leguminous crops are vulnerable to a large number of foliar, root rot and wilt diseases; however, DRR/CR is the disease of utmost importance which may flourish enormously due to climate change in near future, and it requires more research efforts. Climate change is envisaged in the form of extremes variation in the weather, i.e., drier and hotter summers, and less irregular rainfall in different geographical regions which will provide more favorable conditions for MP to complete its life cycle on leguminous plants and other hosts.

The present review revealed that climate change especially will have an important role in MP spread and development in legumes and other crops from one region to another region. High temperature and low soil moisture may increase disease incidence in the traditional areas and in new niches where the crops may be introduced, i.e., rice fallows in northeastern plain zones of India and Myanmar. The pathogenic and genetic variability among MP isolates has been explained for different hosts and few showed genetic adaptation due to alteration in temperature and crop rotation. However, more investigations are required on the genetic adaptation of MP with reference to different hosts under changing climate. Thus, understanding defense gene response in the host population may be of great significance for determining plants' potential for adapting to climate change (Garrett et al. 2006). Studies have been conducted to identify the disease resistance genes sensitive to the higher temperatures for wheat rust (Chakraborty et al. 2011), and some other viral and bacterial diseases; however, no reports are available for DRR/CR. Therefore, future investigation is required to search the defense genes in legumes sensitive to the higher temperatures against DRR/CR.

Since higher temperatures and low soil moistures make MP more favorable for disease development in legumes; therefore, disease mitigation strategies should require adjustment under the increase in temperature and drought period. In particular, use of chemical fungicides (Pawar et al. 2015; Athira 2017) and bio-fungicides (Shahid and Khan 2016; Latha et al. 2017) has shown potential efficacy against DRR/CR and can be used as seed treatment or soil application prior to the sowing. Conversely, as far as MP is concerned, other schools of thought mentioned that these mitigation strategies are not effective nor economically acceptable for mitigation, because they are not economically sustainable, except for horticultural crops in greenhouse or other niche crops with high economic value, certainly not for legumes or any other field crop, and overall poor.

Therefore, cultural practices such as crop rotation with non-host annual crops (wheat and rice) can be adopted as an economic method for DRR/CR management (Singh et al. 1990). But, crop rotation may cause emergence of new races of the same pathogen by altering genetics of MP, and it may be able to become pathogenic to infect a number of additional hosts due to climate change adaptation (Almeida et al. 2008). Therefore, along with the crop rotation, soil solarization and soil amendments with zinc sulfate or neem cake or residues of *Brassica*-mixed farmyard manure (Ansari 2010; Latha et al. 2017) can be recommended in order to eradicate microsclerotia/MP populations from the soil.

In addition, if fungicides are used, the climate change may influence their efficacy (Juroszek and von Tiedemann 2011); hence, there is a need to investigate the effect of climate change on the efficacy of chemicals, their residue in the soil/plant and development of resistance in MP populations to the fungicides. Besides, in the changing climate scenario, pathogens are likely to produce more virulent strains, and management strategies should focus on this by identifying more aggressive antagonists.

As far as host-plant resistance is concerned, in the developing countries, the legume breeding programs do not have potential strategies and sufficient resources for the development and deployment of resistant varieties against DRR/CR associated with climate change. There are few resistant/tolerant sources against DRR/CR available for mungbean (Choudhary et al. 2011; Haseeb et al. 2013;

Khan et al. 2016), urdbean (Iqbal et al. 2003), soybean (Talukdar et al. 2009; Pawlowski et al. 2015) and chickpea (Gupta et al. 2012b; Khan et al. 2013) in South Asia, but these resistant sources were region specific; therefore multi-location trials, at hot spot locations, to evaluate and identify the resistant sources at larger scale are needed to cope against MP strains existing in diverse eco-climates and the potential strains likely to emerge with climate change. This will help breeders in improving breeding approaches that will enable durable resistance over broader agro-climatic areas. In addition, rising atmospheric temperature and CO_2 also influences the resistance behavior of genotypes (Chakraborty and Datta 2003) by changing the pathogen behavior (Kimball 1985); therefore, the newly developed breeding lines of legumes against MP should be evaluated under conditions of elevated temperature and CO_2 and water stress in order to get durable resistant lines for their utilization/implication in climate change scenario.

In addition to the adoption of improved cultivars of legumes against DRR/CR, weather-based disease forecasting models are needs to be developed. It will assist to identify the meteorological factors like temperature and rainfall which will be significantly correlated with the disease. It will also help in the prediction of future scenarios of disease epidemics. Based on the future scenarios of disease epidemics, disease control strategies can be recommended and ⁄or improved so that suitable approaches may be developed prior to disease attack. Using these forecasting models and recent biotechnological approaches, regional impacts of climate change on disease management strategies need a relook in understanding the emerging scenario of host pathogen interactions. Thus, for effective management of the pathogen, distribution period of pathogens should be carefully investigated so that sound approaches may be developed prior to disease outbreak. In addition, understanding of period of overwintering of MP and its attack to the crops will probably facilitate the legume growers to apply prophylactic control measures at the right time in order to reduce the crop losses.

Compliance with ethical standards

Conflict of interest The authors declare no conflict of interest.

Ethical responsibilities I hereby declare that the review article compiled by myself is original and has not been published elsewhere and also simultaneously has not been submitted for the publication elsewhere.

Human and animal rights The article does not contain any human and animal rights.

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