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Review Article

Epidemiology and Management Strategies of Common Bean Anthracnose Disease (*Colletotrichum lindemuthianum* Sacc. & Magn) in Ethiopia: A Review

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ABSTRACT

Bean anthracnose, caused by *Colletotrichum lindemuthianum* (Sacc. & Magn) Lams-Scrib.,is one of the most widespread and economically important fungal diseases of the common bean. The disease is prevalent in areas that experience cool and wet weather conditions, causing up to 100% yield loss. Besides infecting *Phaseolus vulgaris, Colletotrichum lindemuthianum* also attacks other legumes like mung bean (*P. aureus*), cowpea (*Vigna sinensis*), and broad bean (*Vicia faba*). The disease causes symptoms to appear on leaves, stems, pods and seeds. The pathogen can survive in seeds for up to five years, and is also known to overwinter in crop debris. Seed infection is the primary means by which the pathogen spreads. Therefore, the production and the use of certified seeds is one control measure that is effective in dealing with the disease. Fungicidal seed treatment and foliar application as well as cultural and biological methods are very important for bean anthracnose management. Further information on biology and survival of *C. lindemuthianum* is needed to devise more effective management strategies. In this review attention were given to the biology and management options, with an emphasis on the future research priorities.

Keywords: Common bean; Seed treatment; Management strategies; Crop diseases

INTRODUCTION

The common bean (*Phaseolous vulgaris L.*) is the most important food grain legume consumed worldwide [1]. Faba bean is grown and consumed mainly in developing countries in Africa, Asia and Latin America. Its production in sub-Saharan Africa is around 3.5 metric tons ha^{-1} with 62% being produced in East African countries namely Burundi, DR Congo, Ethiopia, Kenya, Rwanda, Tanzania and Uganda [1]. Faba bean is can grow for all over the world for its edible, dry, fresh and green beans. Production is expanding slowly based on population growth with the highest usage in poor developing countries, where beans provide an alternative to meat as a source of low-cost protein. The faba bean crop is well suited to low input systems as they can be stored for long periods without refrigeration and provide an excellent nutritional complement [2].

Common bean is an important legume crop in the daily diet of more than 300 million of the world's population [3]. It has been rated as the second most important source of the human diet and the third most important source of calories in all agricultural commodities produced in eastern Africa [4]. In the 2013/14 cropping season pulses covered 14.04% (1.7 million ha) of the grain crop area and 11.37% (about 2.9 million tons) of the grain production was drawn from the same crops (FAO). In Ethiopia, the common bean is mainly cultivated in the Eastern, Southern, South-western and Rift Valley Regions [5,6]. The crop was grown next to faba bean (*Vicia faba*) on area production (2.63%) about 326465.88 hectares in Ethiopia [7]. The national average yield of common bean is low and was estimated at 1.40 t ha^{-1}, the yield of improved varieties on research sites is ranged from 2.5 to 3.0 tons ha^{-1} [7,8]. This crop is also widely grown intercropping with maize and sorghum, mainly as a source of valuable and cheap protein substitute to supplement the cereal diet, which is deficient in some essential amino acids for the rural poor farmers and many of the urban dwellers in the country. Common bean is a good source of income for small-scale farmers and obtain higher prices than cereals in the local market. In addition, the country used to earn a good share of its foreign currency from faba bean export and still has the potential, if production is substantially improved beyond the local demand [8] .

The low yield of common beans could be attributed largely to low

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adoption of improved agricultural technologies, drought, diseases and insect pests, lack of improved cultivars, poor cultural practices and shortage of land and environmental degradation. From those constraints, diseases are known to be the major factors affecting the production and productivity as well as the quality of the crop [9]. Common bean is attacked by a wide range of diseases that affect leaf, stem, root and seed. The major diseases that are affecting common bean production in Ethiopia include anthracnose (*Colletotrichum lindemuthianum* (Sacc. & Magnus) Lams.-Scrib), rust (*Uromyces appendiculatus*), common bacterial blight (*Xanthomonas phaseoli*), halo blight (*Pseudomonas syringae pv. phaseolicola*), angular leaf spot (*Phaeoisariopsis griseola*), Ascochyta blight (*Ascochyta phaseolorum*) and bean common mosaic virus [10]. Among them, Anthracnose (*Colletotrichum lindemuthianum*) (Sacc. & Magnus) Lams.-Scrib, is a destructive disease worldwide [11].

Anthracnose is one of the most serious diseases attacking common beans in cool weather in Ethiopia. The infected seeds are the most important means of *Colletotrichum lindemuthianum* dissemination, which explains its worldwide distribution [12]. The crop is vulnerable to attack by the pathogen at all growth stages of the crop, from seedling to maturity, depending on the environmental conditions that are essential for the initiation and further development of the disease. Bean anthracnose causes an estimated yield loss of up to 63% in Ethiopia [13-15].

In western parts of Ethiopia, anthracnose is the most destructive disease of white seeded common bean due to high rainfall intensity and warm temperature and it makes the crop out of production [10]. Previously, Mohammed and Somsiri reported that the intensity of anthracnose on white-type common beans was higher in Ethiopia [16].

The first step in the management of seed-borne diseases is generally to eradicate or reduce the pathogen inoculum in the seed production field [17]. Seed treatment is also an important measure for the control of anthracnose [13]. Moreover, the utilization of resistant varieties has been the best way to manage the disease, it is one of the most economical and effective methods of anthracnose management. The use of resistant varieties not only ensures protection against diseases but also saves time, energy and money spent on other management practices. The resistant varieties can be the simplest, practical, effective and economical method of disease control. Chemical control should form part of disease management practice and applications of contact or systemic foliar fungicide are the most important for the management of bean anthracnose [15]. The assessment of the efficacy of seed dressing and foliar fungicides like benlate, benomyle, difenoconazole, mancozeb and carbendazim has been carried out in Ethiopia [13,15]. Difenoconazole is effective in controlling common bean anthracnose. This efficacy was due to the protective and systemic mode of action that reduced primary and secondary infection [13].

Folpan, a protective fungicide that is commonly applied for the control of several fungal diseases including anthracnose of cucumbers, melons, pumpkins, squash, tomatoes and common beans, has a multi-site activity, which provides an excellent management option [18]. Fitsum reported that the possibility of using Flopan as a foliar spray and *Pseudomonas fluorescens* as a seed treatment, decreased anthracnose disease symptoms effectively in common bean plants and also recorded increased seed yield under field conditions. Recent studies showed that integrated management of crop diseases is getting increased attention as an environmentally sound approach. Thus, integrated disease management is considered the most effective approach to minimizing the yield losses of anthracnose. The integration of soil solarization, Mancozeb as seed treatment and Carbendazim foliar spray were found to be effective in reducing the bean anthracnose epidemic [14]. Susceptible varieties of anthracnose, Mexican-142 and Awash-1, which are preferred for their good canning quality and high market price, are still popular among farmers in the Central Region and some other parts of the country [9,13]. It has been confirmed that infection of such susceptible varieties in favorable environmental conditions leading to an epidemic could result in 100% yield loss [9]. In the past few decades, the frequency and severity of the disease have increased in many parts of the world including Ethiopia and have been a serious threat to bean production [15].

Hall emphasized that the use of clean seeds could be a potentially powerful control measure in areas where strict standards of seed health can be maintained. Seed treatment is also an important measure for the control of anthracnose [13-19].

However, in Northeastern Ethiopia, the effect of common bean resistant and susceptible cultivars integrated with seed treatment and foliar application fungicides has received comparatively little attention and has not been adequately studied so far. Understanding disease intensity and different management practices will help to develop an integrated and sustainable diseases management package for faba bean production. Therefore, this paper aimed to review the economic importance and management strategies as effective control strategies to suppress the common bean anthracnose disease pathogen and to provide an overview of research directions, which ultimately may help to tackle the common bean anthracnose disease in Ethiopia, thus enhancing common bean production and productivity.

LITERATURE REVIEW

Common bean (*Phaseolus vulgaris L.*)

Common bean (*Phaseolus vulgaris L.*) is an annual crop. It belongs to the Fabaceae family. The genus *Phaseolus* comprises 55 species. It is an important grain legume grown within the boundary between two climatic zones, the tropics and subtropics, with its primary center of diversity in Mexico, Southern Peru, Bolivia and Argentina. It was introduced in East Africa and Brazil by Portuguese. A wide diversity of common bean cultivars is available in developing countries for production and crop improvement for adaptation to biotic and abiotic stress; where the crop expresses wide variability in terms of maturity ranging from 60-150 days. According to CIAT, common bean is the most vital grain legume in human diets [20]. It is a major source of protein, carbohydrates and valuable micronutrients for more than 300 million people in the tropics. In sub-Saharan Africa, over 200 million people grow beans as a primary staple food and the most crucial source of calories after maize. It enhances health-promoting aspects of the diet thus vital in mitigating health risks for diseases such as obesity, cancer, diabetes and heart disease. Pulse crops provide an economic advantage to small farm holdings as an alternative source of protein, cash income and food security. Although cereal crops are most important in Ethiopian agriculture in providing a staple diet to the population, pulses are also important components of crop production. Among legumes, common beans constitute a significant part of the human diet in Ethiopia. Apart from this, the common bean has been cultivated as a field crop for a very long time and hence, it is an important food legume produced in the country. There is a wide range of common bean types grown in Ethiopia including mottled, red, white and black varieties. The most commercial varieties are pure red and pure white-colored beans and these are becoming the most commonly grown types with increasing market demand. Red bean types are the most favored and most commercially accepted varieties including Red Melka, a mottled medium-sized red; Red Wolaita, a medium-sized pure light red; and Nasser, a small pure dark red variety. In Ethiopia, red beans are preferred by rural consumers and there is a wide range of reds, red mottled varieties that are produced and sold in the rural markets. White beans are sold almost exclusively for the export markets; the leading white bean varieties include Awash-1, Awash Melka and Mexican 142, all of which are small white beans. The white beans are often referred to as white pea beans, due to their small size and round shape; they are otherwise known as navy beans. White beans are popular in industrialized nations, such as the USA and UK, as they are used to prepare pre-cooked canned 'baked beans'.

The pathogen

Anthracnose is perhaps the most economically important and widespread disease of the common beans. According to PABRA, anthracnose ranks second as the most important common bean disease in Eastern and Central Africa (ECA); Southern Africa (SA) and Sub-Saharan Africa [18-22]. Angular leaf spot ranks first while Common Bacterial Blight (CBB) comes third. The symptoms of the disease were first detected in 1875, in Germany [23]. *Colletotrichum lindemuthianum* (Sacc. and Magn) Scrib, causing the disease had, however, been collected by mycologists as early as 1843. The fungus is known to have races that vary from, country, region, location and variety to another [20,21]. Today, the disease is reportedly one of the most important and widely distributed throughout the world. It is found in Latin America, Asia, Europe, USA and Africa [21]. In Africa, it is particularly important in Uganda, Kenya, Tanzania, Rwanda, Burundi, Ethiopia and DR Congo.

The fungal names are given according to principles and rules of the International Code of Botanical Nomenclature (ICBN) although there is still some controversy about the designated names for some fungi. The *C. lindemuthianum* classification was made by Alexopoulos and Mims [22]. In this case, most authors agreed that *C. lindemuthianum* belongs to Family, Melanconiaceae; Order, Melanconiales; Sub class, Coelomycetidae; Class, Deuteromycetes; Sub Division, Deuteromycotina; Division Amastigomycota; Kindom Myceteae; Super Kindom, Eucariota [23].

Economic importance of bean anthracnose

Anthracnose is the most serious disease attacking common bean in cool weather in Latin America, and Africa [20,24]. Field losses due to seedling, leaf, stem and pod infections are up to 90% under climatic conditions favorable to the disease in these regions. Yield losses due to bean anthracnose can reach 90%-100% when susceptible genotypes are grown in conditions favorable for the pathogen during the growing season. Complete crop failure can occur on young bean plants and production is reduced because of poor seed germination, poor seedling vigour and low yields. There are also marketing losses, which are attributed to seed necrotic spots and blemishes, which lower the seed/bean quality rating and salability [25].

Sharma reported maximum disease incidence and severity occurrence on highly susceptible cultivars on both seed-borne infection and background contamination [26]. Also, the disease drastically affects the growth parameters and yield components in susceptible cultivars causing a significant reduction in the yield of both the crops raised from internally infected seeds and under background or surface contamination. The seed-borne infection causes more yield losses than background contamination. Further, the pod infection has a direct effect on seed quality [26]. Common bean is vulnerable to attack by *C. lindemuthianum* from seedling to maturity, depending on the prevalence of favorable environmental conditions that are essential for the initiation and further development of the disease.

Host range

Colletotrichum lindemuthianum is known to be the causal agent of bean anthracnose on a large number of legumes, including common beans (*Phaseolus vulgaris L.*), climbing bean (*Phaseolus coccineus*), lima bean (*Phaseolus lunatus*), tepary bean (*Phaseolus acutifolius*), cowpea (*Vigna unguiculata*) and broad bean (*Vicia faba*). However, the major host of *C. lindemuthianum* is the common bean, whereas the rest of the bean types are considered to be slightly susceptible.

Biology and morphology of the pathogen

Biology of the pathogen: *Colletotrichum lindemuthianum* deploys a complex life cycle, which has various development phases and two ways to take food. Every phase may be seen as unique, differentiated stages that let the fungus survive. In the imperfect form of *C. lindemuthianum*, the reproduction is asexual, the spores are produced inside an acervulus and immerse in water-soluble pre-formed mucilage [23,28]. The development of fungal spores shows a biphasic behavior, which means two lifestyles, as a saprophyte and biotroph; therefore, the fungus has been classified as hemibiotroph. In the saprophytic lifestyle, the fungus grows in any carbon source, including crystalline cellulose, which may be easily converted into molecules of fuel by extracellular lytic enzymes. On the other hand, as a biotroph lifestyle, the fungus has the ability to the feeding of nutrients outright to living plants.

As a saprophytic fungus, the spore germination process begins with the spore adhesion to the plant surface under adequate humidity conditions; specifically correct aqueous content in the spore envelope (mucilage). At this level, the oval spores of the fungus round off by water absorption and active growth. Later, the germinating tube is formed (germinule phase), and the hyphae elongates to colonize the substrate. The aerial mycelia appear then the fungal reproductive structures are formed where the spores are stored [23].

Glomerella cingulata f.sp. Phaseoli and *Colletotrichum lindemuthianum* are the teleomorph and anamorph stages of the pathogen, respectively, causing anthracnose in the common bean. Information concerning the pre-penetration events and symptoms resulting from infection by the teleomorph of *Glomerella cingulata* f.sp. On *Phaseolus* were scarce. It has been reported that teleomorph *G. cingulata f.sp. Phaseoli* produces milder symptoms compared with those induced by anamorph *Colletotrichum lindemuthianum*. *Glomerella cingulata* f.sp. Phaseoli infection may be explained by the less aggressive nature of the sexual form of the fungus [29,30]. The genetic diversity of *C. lindemuthianum* resembles those of sexually reproduced fungal populations rather than of populations undergoing asexual reproduction [31]. Although such evidence constitutes a strong indication that sexual reproduction may occur naturally in the field, there is a great deal of uncertainty concerning this aspect. In the absence of a sexual phase, the genetic variability of *C. lindemuthianum* could be rationalized by the existence of a parasexual cycle, chromosome polymorphism and CATs.

Morphology of the pathogen: Acervuli may be present on pods, leaves, stems and branches. The acervuli extend up to 300 µm in diameter. They may enter epidermal or sub-epidermal structures, disrupting the outer epidermal cell walls of the host. Occasionally, cells of acervuli develop setae which are brown, septate and slightly swollen at the base tapering gently to a rounded paler apex. Setae are 4-9 µm wide and usually <100 µm long. Conidia are borne on acervuli (conidiomata) on the host on the margin of the acervuli or in the culture, embedded in a mucilaginous substance [32]. Conidia are unicellular, hyaline and cylindrical with both ends obtuse or narrow and truncate base. They are uninucleate and usually have a clear vacuole-like body near the center. The conidia measurement ranges from 11-22 × 2.5-5.5 µm and is formed on disbranched unicellular hyaline or pale brown cylindrical conidiophores (0-60 µm long) [33].

Bean anthracnose symptoms

Anthracnose can infect all plant parts including stems, leaves, pods and seeds. Early anthracnose symptoms are dark brown to black sunken lesions on the seeds, cotyledons and stems. The growth of the plants is stunted due to infection. Diseased areas may girdle the stem and eventually kill the seedlings. Small pink spores are produced in the lesions in moist conditions and may spread from stems to the leaves. Symptoms on leaves occur as linear, dark brick-red to black lesions on the lower leaf surface along the veins at the primary and trifoliate leaf stage. The discoloration appears on the upper leaf surface, as the disease progresses. Leaf symptoms are often not obvious and plants may appear normal until the disease is advanced. This is because the infection is initially restricted to the lower leaf surface. Dark brown eyespots also develop on the stem and young seedlings. Infection may cause the stem to rot and die [34]. The most obvious symptoms of anthracnose are on the pods. Small reddish-brown to black blemishes and distinct circulated dish-brown lesions are typical symptoms on the pods. Mature lesions are surrounded by a circular reddish-brown to the black border with a grayish-black interior [35,36]. Symptoms on the seeds are yellowish to brown sunken lesions [35].

Colletotrichum lindemuthianum is primarily a seed-borne pathogen, which can attack all aerial plant parts and may cause yield losses as high as 100% [35,37]. Infected seed is therefore the main means of pathogen dispersal from year to year, while frequent rain, especially when accompanied by wind or splashing rain, in addition to the movement of machinery, animals, and humans through the field are important for local dispersion of the conidia [35]. The higher the number of pods infected the higher the number of seeds infected.

Pathogenic variability

Colletotrichum lindemuthianum has been reported to possess a very high degree of genetic variability in different parts of the world. The race structure of *C. lindemuthiaum* is highly variable and new ones reportedly keep emerging time after time [38]. The existence of this variability and the emergence of new pathogen races of this pathogen results in the continuous breakdown of genetic resistance [39]. *C. lindemuthianum* has high genetic variability, manifested by the presence of numerous physiological races. The significant genetic variability of the crop is one of the most serious obstacles in combating this pathogen because it prevents the durability of resistant cultivars [40,41]. Pathogenic variability and genetic instability that exists in species of *Colletotrichum* were studied with the mechanisms of conidial anastomosis, the sexual cycle, the parasexual cycle, and mutations caused by the presence of transposable elements.

Life cycle

Fungal plant pathogens exhibit two main modes of nutrition: Biotrophy, where nutrients are obtained from living host plant cells, and necrotrophy, where nutrients are obtained from dead host cells, which have been killed by the fungus. *C. lindemuthianum* is a hemibiotroph and exhibits both of these forms of nutrition as it infects its host *Phaseolus vulgaris* [42]. The life cycle is completed and it starts all over again [23]. *C. lindemuthianum* is classified as a hemibiotrphic fungus because of the succession of these two phases during the infection cycle [43-45].

Biotrophic phase

Plant-parasitic fungi alter their hyphal morphology in response to structural and physiological features of the host surface soon after germination. They form infection structures (germ tubes, appressoria, infection pegs) that accomplish crucial stages of pathogenesis, including attachment, host recognition, penetration, proliferation and nutrition [46]. Adhesion of micro-organisms to the surface of a host plant part plays a crucial role in colonization by maintaining the organism in a favorable environment for growth.

During infection of common beans by the fungal pathogen *C. lindemuthianum*, the spore and appressorium adhere firmly to the plant surface [47]. Adhesion of *C. lindemuthianum* spores to the plant surface may be a crucial factor in the spread of disease during spore dispersal in the field, which is thought to be caused largely by splashing water during heavy rains [35,48]. The important function of adhesion may be to anchor the spore in an environment suitable for germination, which is stimulated by substances from the plant and in which physical contact of the germ tube with the plant surface can trigger appressorium formation [49]. *Colletotrichum* species may enter the plant and then go through a quiescent phase, remaining latent until conditions are favorable for them to continue development. One of the fascinations of the genus *Colletotrichum* lies in the range of post-appressorial infection strategies, in which various species have evolved [28,50,51]. Young and Kauss demonstrated that 20% to 50% of spores suspended in water adhere to bean hypocotyls within one hour [47]. Such type of adhesion may be non-specific; this is because conidia also adhere to a polystyrene surface.

Basic compatibility that is an interaction between a susceptible cultivar of common bean and any virulent strain of *C. lindemuthianum* begins with the adhesion of conidia to the aerial part of the bean plant. Conidia then germinate and differentiate to form an appressorium developed for mechanical penetration. After penetration, the infection cycle is characterized by two successive phases. In the first phase, lasting 3 to 4 days, the fungus grows biographically inside the infected epidermal cells. During this phase, referred to as the biotrophic phase, the fungus differentiates infection vesicles and primary hyphae. The second phase, which corresponds to the appearance of anthracnose symptoms, is completed 6 to 8 days after inoculation.

Conidia that reach the plant surface may germinate within 6-9 hours under favorable environmental conditions, and form germ tubes and appressoria. Different *C. lindemuthianum* strains can easily penetrate the host cuticle in different ways. These include natural openings, wounds formed during different operations or by pathogen attack, and direct penetration of the cuticular barrier by mechanical or enzymatic chemical means. Appressoria of *C. lindemuthianum* penetrate the bean cuticle directly by their mechanical force. This successful penetration might be due to the presence of appressorial melanin.

Necrotrophic phase

The necrotrophic stage of development is linked to the increased expression of plant cell wall degrading enzymes such as endo-Polygalacturonases (endo-PG) and pectin lyases. The secretion of these enzymes by *C. lindemuthianum* both in culture and during pathogenesis has been investigated. After several days, cell walls are degraded mainly due to the high content of tannins.

During the necrotrophic phase, the fungus develops secondary hyphae that grow both intracellular and intercellular and thus act like a typical necrotrophic pathogen and cause heavy degradation of host cell walls and death of cells [43,44]. In this phase of *C. lindemuthianum*, its physiology changes by producing thin secondary hyphae [28]. This type of infection normally coincides with the development of disease and conspicuous anthracnose symptoms together with masses of fungal sporulation [52].

Epidemiology of bean anthracnose

Survival of the pathogen: Epidemiological parameters that are responsible for the outbreaks of bean anthracnose have been studied in different parts of the world [53]. The fungus survives between crops in crop residue and can be easily disseminated *via* seed, air and water. *C. lindemuthianum* remained viable for five years or more in air-dried diseased tissues or infected seeds stored at 4°C [52]. The fungus could survive or overwinter in the field with infected materials without losing their viability if they kept dry. The pathogen fails to overwinter under natural field conditions under wet conditions [54].

Optimum environment: The ideal environment for conidial growth and tissue infection is a temperature of 13 to 26°C with an optimum of 17°C and with higher than 92% humidity [35]. Extended precipitation during the crop season highly favors the development of bean anthracnose. Periods of heavy rain accompanied by wind are responsible for the spread of in the field because rain promotes the release of different types of fungal spores, including *C. lindemuthianum* and is particularly important in the release of anthracnose spores since they are embedded in a mucilaginous substance on the acervuli [55]. Also, the pattern of bean anthracnose spread closely follows the pattern of major *C. lindemuthianum* rainfall during the crop season [54]. Finally, its life cycle is completed and it starts all over again [23,56].

DISCUSSION

Management of bean anthracnose

Bean anthracnose is usually introduced to a production field by infected seeds or by machinery during cultivation or harvesting. Prevention is the best way to manage bean anthracnose [57]. It is managed through the use of the disease-free certified seed, crop rotation (of 2 to 3 years), field sanitation cultural measures, use of resistant varieties and chemical application. The most effective one is host resistance durable. Therefore, state that, the integration of host resistance with other control methods would be more sustainable [12]. Host plant resistance is also the most affordable approach for small-scale resource-poor farmers.

Cultural practices

Cultural control aims at the reduction of initial inoculum and spread of secondary inoculum. Cultural control is easy to use by farmers. It involves the use of the anthracnose-clean seed, crop rotation, sanitation, varietal mixtures and also use of ridges and weed management. The disease can be managed by using pathogen-free common certified seed, resistant varieties, crop rotation for at least 2 to 3 years as well as field sanitation. In addition, fields should not be worked when plants are wet because fungal spores are easily spread from diseased to healthy plants under these conditions [54].

Physical methods

Soil solarization through covering the soil with transparent plastic sheeting for one month before sowing reduces the *C. lindemuthianum* in the soil and resulted in the reduction of both severity and incidence of anthracnose [14]. A hot-water seed treatment by soaking at 17.78°C to 22.22°C for 15 hours followed by another soaking at 47.22°C for 25 minutes has been reported to kill the fungus in infected seeds without reducing germination [58].

Host resistance

The use of resistant host varieties has been the most important and cost-effective approach for the management of bean anthracnose pathogen [59]. Although disease resistance is an important option for anthracnose management, the high variability of the isolates of the pathogen limits the effectiveness of resistance and often lacks stability and/or durability. The presence of physiological races of this pathogen is believed to be a problem to produce cultivars resistant to multiple physiological races [57].

Different resistance genes of common beans were identified towards bean anthracnose and then to be incorporated into other susceptible bean varieties with some other desirable characteristics. For example, the Andean origin *Co-1* (A) gene and *Co-2* (Are) gene were incorporated into susceptible common bean but the resistance of the genes was broken after some time due to the occurrence of new *C. lindemuthianum* physiological races [60,61]. It has been suggested that bean anthracnose can also be managed by using mixtures of susceptible and resistant bean cultivars or multi-linear cultivars [54]. Ntahimpera reported that disease incidence was constantly lower in plots with 25% and 50% resistance cultivars as opposed to 10% resistance cultivars [62].

Biological control

Biological control is a promising tool to maintain the current level of agricultural production while reducing the release of polluting chemical pesticides to the environment. Masoomeh indicated that eight bacterial isolates (*Bacillus subtilis* subsp. *subtilis, B. atrophaeus, B. tequilensis, B. subtilis* subsp. *spizizenii, Streptomyces cyaneofuscatus, S. flavofuscus, S. parvus,* and *S. acrimycini*) showed promising inhibition on mycelial growth of *C. lindemuthianum*, and thus, these isolates were selected for greenhouse experiments [63]. The disease management rate using these selected endophytic bacteria varied from 40% to 76.80% in the greenhouse without any negative effects on different growth performance. The result suggests that these selected endophytic bacteria are the potential to be used as biocontrol agents [63]. Amin also indicated that *Pseudomonas fluorescens, Trichoderma harzianum* and *Trichoderma viride* suppressed the growth of *Colletotrichum lindemuthianum* through seed treatment [15].

Chemical control

Mancozeb seed treatment at a rate of 3 g/kg seeds followed by carbendazim foliar spray at a rate of 0.5 kg/ha and Carbendazim seed treatment at a rate of 2 g/kg seeds followed by carbendazim foliar spray at a rate of 0.5 kg/ha have been suggested to reduce anthracnose severity and incidence [15].

In Ethiopia, varying levels of anthracnose severity were maintained by spraying benomyl at a rate of 0.4 kg/ha at different time intervals. Combination and rotation of fungicides are more effective than continually using a single compound. Tesfaye and Pretorius revealed that the application of difenoconazols as a foliar spray, or benlate seed treatment followed by foliar application of difenoconazols reduced bean anthracnose incidence and severity, and increase grain yield

Integrated management of bean anthracnose

The management of anthracnose in common beans has been carried out by using some fungicides in some parts of the country and the integrated disease management of bean anthracnose was investigated by using the effect of soil solarization and techniques of the timing of fungicide applications as the main component for the integrated disease management of anthracnose in eastern Ethiopia [15]. The first opportunity for the management of seed-borne diseases is to eradicate or reduce the pathogen inoculums in the seed production field [17,64].

CONCLUSION

Management strategies used to minimize seed-borne infection in the seed production field include cultural, host resistance, and biological and chemical control methods. *C. lindemuthianum* has high pathogenic variability and new physiological races of the pathogen are frequently reported. Thus, integrated disease management is considered the most effective approach to minimizing the yield losses due to bean anthracnose. Tesfaye and Pretorius, also reported that fungicide application where appropriate, in combination with other anthracnoses management tactics such as genetic resistance, multiline, sanitation and other cultural practices, would enhance the overall efficiency of bean production in Ethiopia. In general, integrated disease management is more advantageous than the use of single treatment methods to manage bean anthracnose and, thereby, increase the yield of the common bean crop sustainably.

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