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Review Article

Sclerotinia sclerotiorum on bean and potato in Sinaloa: Etiology, epidemiology and alternatives for management

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ABSTRACT

White mold (*Sclerotinia sclerotiorum*) is the main disease of bean and potato in Sinaloa. In the present review, the symptoms and signs of the disease as well as cultural and morphological characteristics of the teleomorph of the pathogen, its ecology and the epidemiology of the disease are addressed. The implementation of a prediction system which includes the carpogenic germination of the sclerotia and the phenology of both bean and potato for the management of the disease is described. This system considers soil temperature ranging from 13 to 19 °C a at depth of 2.5 cm in the soil and the flowering stage in both bean and potato to do the first spray application of synthetic fungicide to prevent the disease. *In vitro* studies indicated that *Trichoderma harzianum*, *T. viride* and *T. atroviride* reduced mycelial growth rate of *S. sclerotiorum*. The same antagonistic species exerted control of white mold under field conditions, where an increment of 40% of yield was observed in the treated plots, with respect to those treated with fungicide fluazinam. Future lines of research focusing on the ecology of the pathogen and management of the disease including the antagonistic fungi in the prediction system are suggested.

Key words: *Phaselus vulgaris*, *Solanum tuberosum,* apothecia, *Trichoderma.*

Introduction

In Mexico, bean (*Phaseolus vulgaris*) and potato (*Solanum tuberosum*) crops covered an area of 1,472,462 and 60,102 ha in 2022, respectively. Bean production

reached 965,371 t with a value of 16,984 million pesos, while potato production yielded 1,878,976 t valued at 16,173 million pesos (SIAP, 2022). In Sinaloa, during the same year, 58,925 ha of beans were planted, yielding 165,475 t with a production value of 3,271 million pesos. For potatoes, 11,975 ha were planted, producing 403,923 t valued at 3,363 million pesos. Fungal diseases stand out as a limiting factor for both crops in Sinaloa. For instance, beans are affected by root rots (*Fusarium* spp., *Rhizoctonia solani*, *Pythium* spp., *Macrophomina phaseolina*, and *Sclerotium rolfsii*), white mold (*Sclerotinia sclerotiorum*), rust (*Uromyces appendiculatus* var. *appendiculatus*) (Rodríguez-Cota *et al.*, 2022), and powdery mildew (*Erysiphe diffusa*) (Félix-Gastélum *et al.*, 2011). Regarding bacterial diseases, common blight (*Xanthomonas axonopodis* pv. *phaseoli*) (Rodríguez-Cota *et al.*, 2022) and halo blight (*Pseudomonas syringae* pv. *phaseolicola*) (Félix-Gastélum *et al.*, 2016) are prominent.

Sclerotinia sclerotiorum is a phytopathogen that affects 408 species belonging to 278 genera and 75 families. Most susceptible species are in the subclass Dicotyledonae of angiosperms, although it can also attack several members of the subclass Monocotyledonae (Boland and Hall, 1994; Islam *et al.*, 2021; Jahan *et al.*, 2022). It can also occur as an endophyte in cereals such as rice (*Oryza sativa*), wheat (*Triticum aestivum*), maize (*Zea mays*), barley (*Hordeum vulgare*), and oat (*Avena sativa*) (Tian *et al.*, 2020). Annual losses due to white mold in the United States exceed $200 million (Bolton *et al.*, 2006). In Sinaloa, the disease has been reported in eggplant (Cebreros-Sánchez and Sánchez-Castro, 1998) and beans (Rodríguez-Cota *et al.*, 2022), with losses of 50%, while in potatoes they can reach 30%. Despite this, no applied research has been conducted on disease management. This review describes white mold symptoms in beans and potatoes in northern Sinaloa, the morphological characteristics of *S. sclerotiorum* teleomorph, its ecology, and disease epidemiology, as well as management strategies used in other parts of the world. It also outlines the current situation of disease management in Sinaloa and future research directions needed for efficient control of white mold in beans and potatoes in this region.

Symptoms and signs of the disease

Bean and potato plants infected by *S. sclerotiorum* display typical white, cotton-like mycelium on the infected tissue surface. The mycelium produces cellulases and pectinases, which are involved in the infection process and cause plant tissue rot (Fernando *et al.*, 2004; Bolton *et al.*, 2006). It also produces oxalic acid, which has toxic effects on host tissue (Hegedus and Rimmer, 2005). In the field, wilted plants show watery lesions on stems, leaves, and pods. Infected tissue is covered with whitish mycelium. In advanced stages, mycelial aggregations occur, which

mature and transform into black sclerotia of various shapes, ranging from 0.5 to 1.7 cm. These are found mainly on the whitish tissue surface, although they can also be found inside stems (Hooker, 1981).

Morphological characteristics of the causal agent (*S. sclerotiorum*) of white mold in Sinaloa

White mold on beans and potatoes occurs year after year in Sinaloa. Colonies of *S. sclerotiorum* isolated on potato dextrose agar (PDA) are white, cotton-like, regular, with slightly elevated growth. Sclerotia form a double ring in the Petri dish, both in the center and at the edge near the dish wall (Figure 1A). Although

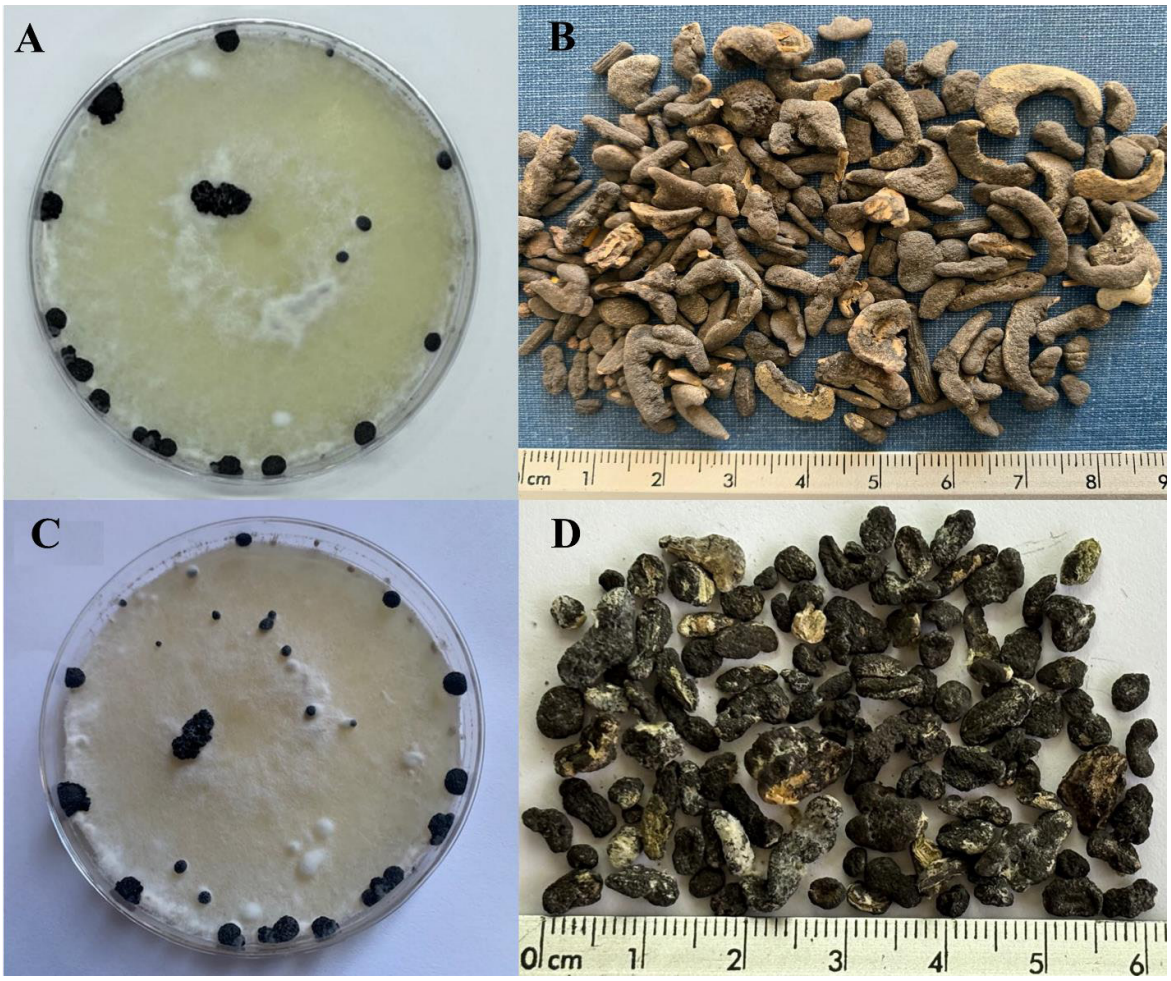

Figure 1. Mycelial growth and sclerotia of *Sclerotinia sclerotiorum*. A) Fungal growth obtained from bean with sclerotia forming a double circle on PDA in a Petri dish; B) Light brown sclerotia produced on bean plants in the field; C) Fungal growth obtained from potato plant with scattered sclerotia on PDA in a Petri dish; D) Black sclerotia produced on potato plants in the field.

fungal colonies from potatoes were similar to those from beans, sclerotia were produced sporadically on PDA (Figure 1C). Several species of *Sclerotinia* have been reported as phytopathogens, but in this region, only *S. sclerotiorum* has been identified as the causal agent (Mora-Romero *et al.*, 2016). The fungus survives the summer through sclerotia, which measure 0.5 to 1.7 cm in length when produced on beans (Figure 1B) and 0.3 to 1.0 cm when produced on potatoes (Figure 1D), and produce one to several light brown apothecia 0.5 to 0.8 cm in diameter (Figure 3D). Apothecia are more common in potato fields, likely due to high humidity levels generated by sprinkler irrigation systems. The hymenium of the apothecia has asci measuring 85.0 to 160.0 µm by 3.0 to 5.5 µm (Figure 3B) and hyaline paraphyses; the ascospores are also hyaline, unicellular, ovoid to elliptical, and measure 5 to 7.0 µm (Figure 3C).

Field observations in Sinaloa indicate that in beans, the disease frequently initiates at the base of plant stems (Figure 2A), suggesting that the initial infection likely occurs through direct germination of sclerotia (myceliogenic). From there, the symptom progresses to stems, leaflets, and pods (Figure 2B and 2C) where cottony, whitish mycelium forms, causing soft rot and initiating sclerotia formation (Figure 2D). This observation agrees with previous studies where sclerotia germinate to produce mycelium that infects plants (Abawi and Grogan, 1979; Lane *et al.*, 2019).

In potatoes, sclerotia have been observed inside stems (Figure 3A), as well as fungal apothecia on the soil surface (Figure 3D) with asci (Figure 3B) containing eight ascospores (Figure 3C). Infected inflorescences falling onto leaves have also been observed, from which initial disease symptoms originate (Figure 3E) and progress to invade the rest of the plant parts (Figure 3F). Stems on the ground showing disease symptoms and signs have also been observed (Figure 3G), where infection may originate from direct germination of sclerotia.

Ecology of *S. sclerotiorum*

S. sclerotiorum is a soil-dwelling fungus that survives through sclerotia (Sousa-Melo *et al.*, 2019). The outer layer of sclerotia consists of melanin-containing cells (Butler *et al.* 2009), protecting the fungus from ultraviolet light, toxic metals, lytic enzymes, and antagonistic microorganisms (Butler and Day, 1998; Thomma, 2003). In some bean-cultivated soils, averages of 0.6 to 6.2 sclerotia per kg of soil have been found (Schwartz and Steadman, 1977). Soil temperature, pH, and moisture seem to have a limited effect on sclerotia survival, but the biological component has a greater impact on their survival in soil (Adams and Ayers, 1979). Sclerotia quantity in soil can increase in two ways: a) secondary sclerotia production and b) production on the host (Adams and Ayers, 1979).

The fungus's wide host range (Toby *et al.*, 2023) and susceptible monocultures lead to increased sclerotia populations in soil. Sclerotia survival varies with depth;

Figure 2. Symptoms and signs of white mold in beans. A). Disease symptoms initiating at the base of the plant stem; B). Progression of symptoms and signs on stems; C). Symptoms and signs on pods; D). Whitish stems invaded by *S. sclerotiorum* with mycelial aggregation and abundant sclerotia.

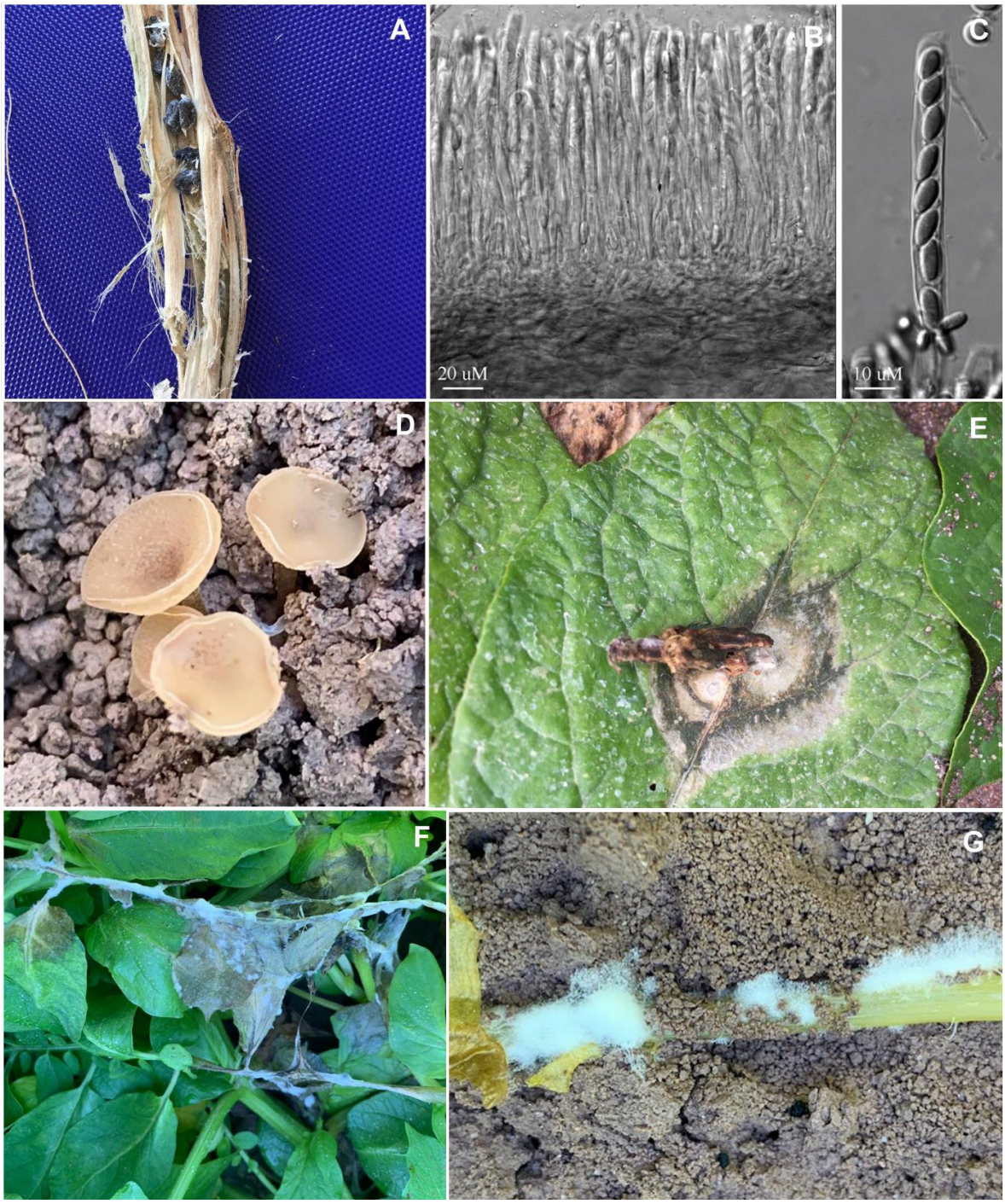

Figure 3. Teleomorph structures of *S. sclerotiorum*, symptoms and signs of white mold. A). Potato stem with sclerotia inside; B). Fragment of apothecial hymenium with asci, ascospores, and paraphyses; C). Ascus containing eight ascospores; D). Apothecia produced by sclerotia on soil surface; E). Initial symptom of white mold on potato leaf originating from an infected inflorescence; F). Soft rot of leaves and presence of mycelium on infected tissue; G). Stem on soil colonized by the fungus with abundant whitish mycelium.

studies showed that sclerotia placed deeper than 10 to 30 cm remained viable longer than those at 5 cm (Cosic *et al.*, 2012). It was also reported that *S. sclerotiorum* sclerotia viability at 0, 5, and 10 cm decreased with depth (Duncan *et al.* 2006). Other studies indicated that *S. sclerotiorum* sclerotia remain viable in soil for eight to 10 years (Coley-Simth and Cooke, 1971). It was demonstrated that 3.2 sclerotia per m² can cause 95% incidence in kidney beans under field conditions (Suzui and Kobayashi, 1972). However, 0.2 sclerotia per kg of soil could cause moderately severe white mold levels in beans (Schwartz and Steadman, 1977). Ascospores constitute the primary inoculum source, germinating and colonizing senescent tissue, from which the fungus invades different plant parts (Hossain *et al.*, 2023).

S. sclerotiorum spreads from one field to another or between regions in several ways: a) as mycelium attached to seed surfaces, b) farming equipment (Zubieta-Coronado, 2021), animals, or humans (Starr *et al.*, 1953). About 2% of sclerotia ingested by sheep remain viable after passing through their digestive system, suggesting that this type of livestock and other animals can spread sclerotia to pathogen-free areas (Brown, 1937). Irrigation water is another means of sclerotia dissemination, where they remain viable for 10 to 21 days (Steadman *et al.*, 1975). However, long-distance spread occurs through mycelium-infected seeds in sunflower (*Helianthus annuus*) (Young and Morris, 1927), cabbage (*Brassica oleracea* var. *capitata*), cauliflower (*Brassica oleracea* var. *botrytis*), kale (*Brassica oleracea* var. *sabellica*) (Neergaard, 1958), clover (*Trifolium* sp.) (Dillon-Weston *et al.*, 1946), beans (Starr *et al.*, 1953), and peanuts (*Arachis hypogaea*) (Porter and Beute, 1974). Air as an element for ascospore dissemination has also been considered in recent years (Leyronas, 2019; Reich *et al.*, 2024).

Epidemiology of white mold in beans and potatoes

White mold epidemics in beans and potatoes initiate from ascospores produced in apothecia originating from sclerotia (Abawi and Grogan, 1979; Cook *et al.*, 1975; Schwartz and Steadman, 1978; Clarkson, *et al.*, 2003). In Sinaloa, damage has been observed on potato stems at the furrow bottom; bean plants also show damage at the stem base, occurring through direct sclerotia germination. Thus, apothecia production by sclerotia in beans is essential for epidemic development (Abawi and Grogan, 1979). In contrast, in some Canadian regions, sclerotia can produce mycelium directly to cause infection below soil level in sunflowers, although infection can also occur through ascospores from apothecia (Hung and Hoes, 1980). Only apothecia on the soil surface at 2.0-3.0 cm depth release ascospores, as apothecial stipes do not exceed 3.0 cm in length, and those at greater depths do not emerge above the soil surface and do not release ascospores into the air, as light intensity is insufficient for their formation (Sun and Yang, 2000). An epidemic's

onset does not necessarily occur from ascospores produced in a particular field but can come from neighboring fields, including some weeds like dandelion (*Taraxacum officinale*) and clover (*Trifolium* spp.) (Cooke *et al.*, 1975). The first apothecia appear when the crop covers 100% of the soil surface and evaporation decreases (Abawi and Grogan, 1979).

Exposure of sclerotia to extreme drought and high temperatures has been observed to have a detrimental effect on apothecia production by sclerotia; however, they remain viable for three years at a depth of 20 to 25 cm in the soil (Peltier *et al.*, 2012). Hao *et al.* (2007) demonstrated that carpogenic germination of sclerotia occurred between 15 and 20°C, when soil water matric potential was -0.03 to 0.07 MPa; but no apothecia were produced at temperatures above 26°C (Clarkson *et al.*, 2003). Apothecia produce ascospores whose dispersal from the point of origin can vary from 25 cm (Suzui and Kobayashi, 1972) to several km (Leyronas *et al.*, 2019), and the optimal temperature for their germination on bean flowers with free moisture is 21°C (Shahovesi and del Río-Mendoza, 2020). It has also been established that ascospores are released at 15°C in continuous light and darkness and relative humidity regimes of 90 to 95% and 65 to 75% with the release of 7.6 x 10^5 ascospores per apothecium in 20 days. The release of *S. sclerotiorum* ascospores in the field has been observed at midday (Harthill, 1976; Raynal, 1990), which could be related more to temperature than to daylight (Clarkson *et al.*, 2003).

Management of white mold

White mold management has involved solarization (Ferraz, 2003; Supriya *et al.*, 2017; Juliatti *et al.*, 2019), crop rotation, and chemical control (Kurozawa and Pavan, 1997). Due to low levels of host resistance to the pathogen, a wide range of fungicides has been used to control the disease. For example, in the United States, Canada, Australia, China, and Europe, boscalid, fluazinam, fluxapyroxad, pyraclostrobin, penthiopyrad, picoxystrobin, prothioconazole, trifloxystrobin, tetraconazole, and thiophanate-methyl are used (Matheron and Porchas, 2004; Bradley *et al.*, 2006; Wang *et al.*, 2015). The biological effectiveness of procymidone and fluazinam was demonstrated in controlling white mold in soybeans when applied at the beginning of flowering and 15 days after flowering began (Hideki-Sumida *et al.*, 2015). In Sinaloa, carbendazim, benomyl, methyl thiophanate, and fluazinam are used to control the disease in beans and potatoes (Rodríguez-Cota *et al.*, 2022; Personal communication, Ing. Joel González; Pasa, SA de CV, Los Mochis, Sinaloa), achieving 85-90% control efficacy in both crops when applied preventively. Fungicides boscalid+pyraclostrobin, carbendazim, fluazinam, fludioxonil+cyprodinil, and prochloraz showed *in vitro* effectiveness in inhibiting mycelial growth of *S. sclerotiorum*, as did biorational products: salicylic

acid, hydrogen peroxide, and grapefruit seed extract (Ayala-Armenta *et al.*, 2015). There is no field evidence on the biological effectiveness of these substances except for carbendazim and fluazinam (Rodríguez-Cota *et al.*, 2022).

Regarding biological control, the activity of antagonistic agents is affected by abiotic and biotic factors such as temperature, soil type and moisture, pH, pesticides, organic matter, soil microorganisms, plant species, among others, leading to these agents being less effective than synthetic chemical fungicides (Smolińska and Kowalska, 2018).

Several fungal species have shown biological control with mycoparasitic activity against *S. sclerotiorum*, with *Coniothyrium minitans* standing out (Huang and Hoes, 1976; McQuilken *et al.*, 1995; Zeng *et al.*, 2012b; Patel *et al.*, 2020). Spraying fungal conidia during flowering reduced white mold incidence in beans by 56% (Huang *et al.*, 2000). Additionally, incorporating the mycoparasite on the soil surface before soybean planting reduced disease severity by 68% and the number of sclerotia by up to 95.3% (Zeng *et al.*, 2012a). The optimal temperature for mycoparasite growth was 15 to 20°C and a pH of 4.5 to 5.0 (Zeng *et al.*, 2012b).

Preliminary studies on biological control of the causal agent of bean white mold in Sinaloa demonstrated the *in vitro* inhibitory effect of endemic *Trichoderma harzianum*, *T. viride*, and *T. atroviride* from northern Sinaloa against *S. sclerotiorum* obtained from beans (Félix-López, 2016). Additionally, in a semi-commercial field experiment, *Trichoderma* strains were applied to bean seeds at planting; a second application was made in the furrow irrigation system. A reduction in white mold incidence and severity was observed, along with a 40% yield increase compared to the regional control, where two applications of the fungicide fluazinam were made (Personal communication Ing. Fernando Urías; Asociación de Agricultores del Río Sinaloa Poniente, Guasave Sinaloa).

Studies on the efficacy of *Trichoderma* in controlling *S. sclerotiorum* in the field are limited (Knudsen *et al.*, 1991; Zeng *et al.*, 2012a); however, in beans, *Trichoderma asperellum* at a dose of $2x10^{12}$ conidia per mL reduced the number of apothecia and white mold severity (Geraldine *et al.*, 2013). *T. hamatum* reduced disease incidence by 31 to 57%, resulting from sclerotia colonization and reduced apothecia production by the pathogen in cabbage (*Brassica oleracea* var. *capitata*) (Jones *et al.*, 2015). In cucumber (*Cucumis sativus*), *T. harzianum* T39 reduced stem and fruit rot in greenhouses (Elad, 2000); while the T22 strain of the same antagonist decreased the disease severity index by 38.5% (Zeng *et al.*, 2012a).

Regarding antagonistic bacteria, *Bacillus cereus* and *B. subtilis* affected *S. sclerotiorum* mycelial growth and reduced white mold incidence in sunflower (Zazzerini, 1987). *B. subtilis* BY-2 controlled the same disease in rapeseed (*Brassica napus*) when applied to seeds and during flowering; incidence in bacteria-treated plots ranged from 8.9 to 11.8%, while in untreated plots, it ranged from 18.1-22.9%

(Hu *et al.*, 2014). Two weekly applications of *B. cereus* SC reduced canola stem rot by *S. sclerotiorum* by 6.5 to 9.3%, while control plots had 20.0 to 29.8% incidence (Kamal *et al.* 2015). The efficacy of bean seed treatment with *Bacillus* sp. B19, *Bacillus* sp. P12, and *B. amyloliquefaciens* B14 in controlling white mold was also demonstrated (Sabaté *et al.*, 2018).

Survival of *S. sclerotiorum* and disease incidence

Sclerotia constitute the pathogen's survival structure during summer in Sinaloa, as both beans and potatoes develop during autumn-winter, contrary to other agricultural areas where they survive the winter and crops develop during spring-summer.Previous studies indicated that carpogenic germination of apothecia can occur between 5 and 25°C, when soil water matric potential is -0.03 to 0.07 MPa (Hao, *et al.*, 2007). Field observations in northern Sinaloa indicate that these temperatures at 2.5 cm soil depth occur from the first week of December (Figure 4). These conditions coincide with the flowering stage of both beans and potatoes; additionally, 100% of the soil surface is covered by plant foliage, reducing evaporation, mainly in potatoes whose varieties grow exuberantly and are irrigated

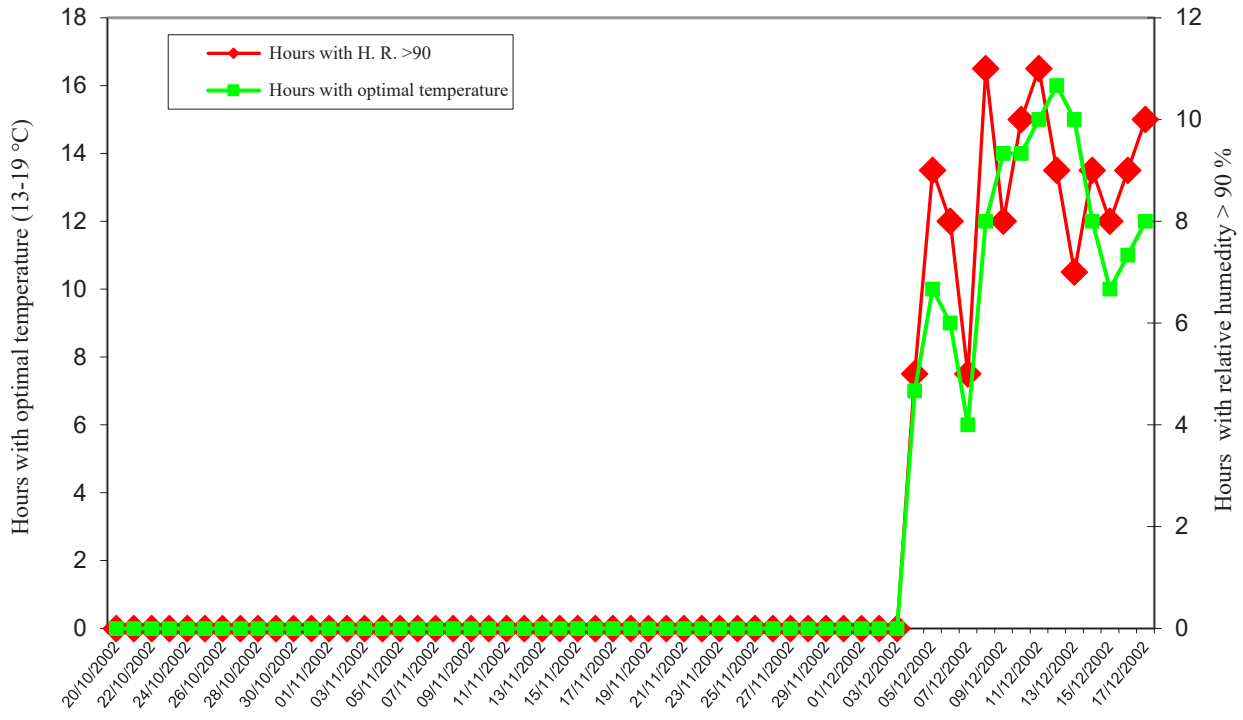

Figure 4. Daily periods with optimal soil temperature (2.5 cm depth) for germination of *S. sclerotiorum* sclerotia and periods with relative humidity ≥ 90% in northern Sinaloa from October 20 to December 03, 2002.

by sprinklers, resulting in leaf wetness periods up to 17 hours daily in the lower part of the canopy of the plants and permanent moisture on the soil surface near saturation. These climatic variables and crop phenology favor apothecia formation and subsequent ascospore release, which penetrate and infect senescent flowers that detach and fall onto plant leaves and stems where initial disease symptoms are observed. Symptoms and signs of the disease are also frequently observed at the stem base in bean plants or on potato stems on the soil at the furrow bottom; in these cases, primary infection could occur from direct sclerotia germination (Hossain *et al.*, 2023).

Although it has been reported that exposure of sclerotia to drought and temperatures of 30°C does not favor apothecia production by sclerotia, they remain viable and germinate through mycelium formation (Abawi and Grogan; 1979). These climatic conditions occur in potato fields that are not planted in the spring-summer cycle in Sinaloa and are subjected to tillage for planting in the autumn-winter agricultural cycle. In this case, sclerotia at 5 cm soil depth are exposed to 40°C and low moisture levels (15 bars) (Sifuentes-Ibarra *et al.*, 2021) in fallow fields during summer; although 50% of the fields are planted with sorghum, where the temperature could be lower than 40°C.

Management of white mold in beans and potatoes in Sinaloa

In Sinaloa, a system was recently implemented where the first preventive application of synthetic fungicides in bean and potato fields is recommended when soil temperature at 2.5 cm depth varies from 13 to 19°C. These conditions occur during the first week of December in Ahome municipality, coinciding with increased periods of relative humidity ≥ 90% (Figure 4). For beans, these conditions occur when the first supplementary irrigation has been applied, the crop covers 100% of the soil surface, and flowering has begun with the accumulation of 630 heat units in the Noroeste variety. The first fungicide application should be made seven days after temperatures of 13 to 19°C are recorded, which favors apothecia formation and ascospore release.

These criteria also apply to white mold management in potatoes, where moisture conditions in both foliage and soil are favorable for apothecia formation, ascospore release, and disease progression due to sprinkler irrigation systems. As in beans, preventive fungicide applications in potatoes begin seven days after soil temperature at 2.5 cm depth varies from 13 to 19°C and the crop presents the first inflorescences; at this stage, the soil is completely covered by foliage, reducing evaporation of moisture supplied by irrigation systems. Fungicides carbendazim, benomyl, methyl thiophanate, and fluazinam are used for disease control under these conditions (Rodríguez-Cota *et al.*, 2022). Based on this disease management

system, two applications are recommended for beans during the crop cycle, and up to three applications at seven-day intervals are recommended for potatoes, mainly in varieties with prolonged flowering periods. Infected senescent flowers infected by ascospores frequently fall onto plants where initial disease symptoms appear. Due to soil moisture levels, damage also occurs on stems and senescent leaves with subsequent production of sclerotia that survive up to five years (Ben-Yephet *et al.*, 1993). In Sinaloa, soils used for potato monocultures show increased populations of sclerotia, which produce primary inoculum consisting of ascospores cycle after cycle.

FUTURE LINES OF RESEARCH

Although *S. sclerotiorum* attacks economically important crops in Sinaloa, studies on its ecology have not been developed there. Research on this topic has been conducted mainly in the United States, where beans and potatoes are cultivated during spring and summer, contrasting with Sinaloa where these crops are grown during the autumn-winter cycle. This indicates potential research areas related to planting cycles and regions where temperature and different moisture regimes affect sclerotia at various depths, as well as the activity of antagonistic microorganisms under these conditions.

Regarding white mold control, fungicides have traditionally been used. However, these molecules induce resistance in the causal agent and contaminate the environment. In the search for environmentally friendly strategies to control the disease, the biological effectiveness of native *Trichoderma* species should be determined. This approach is crucial for identifying fungal species in the region, determining their *in vitro* effectiveness, and understanding the antagonist's modes of action against the pathogen under these conditions, such as mycoparasitism, antibiosis, resistance-inducing genes, and pathogen enzyme deactivation. The greater the number of modes of action of *Trichoderma* species, the more efficient and long-lasting the control over the pathogen will be, aspects that synthetic chemical fungicides do not possess (Infante *et al.*, 2000).

Another point to address is investigating the biological effectiveness of *Trichoderma* species in planta under greenhouse and field conditions, including induced resistance (Bisen *et al.*, 2016). In the field, the effect of applications to seed tubers at planting time and subsequent applications through the sprinkler irrigation system during each irrigation throughout crop growth should be determined.

The reduction in sclerotia viability of *Sclerotinia* species is likely due to the action of beneficial microorganisms (Williams and Western, 1965). Hence the importance of testing the efficacy of *Trichoderma* species applied at harvest time for both beans and potatoes. Thus, when fields are tilled, the sclerotia inoculated

with antagonistic species to the white mold fungus would by incorporated to the soil. It would also be necessary to determine sclerotia viability at different soil depths, as well as the effect of soil temperature and moisture throughout the year; simultaneously determining *Trichoderma* incidence levels on the *sclerotia* and their capacity to germinate directly and through apothecial production. The extensive study of biological control agents is evident, with research limited to *in vitro* and greenhouse conditions, but little has been directed towards field conditios (Córdova-Albores *et al.*, 2021), and even less regarding this fungus and crops in northwestern Mexico.

The effectiveness of the fungus *Coniothyrium minitans* against white mold has been demonstrated elsewhere (Huang and Hoes, 1980; McQuilk *et al.*, 1995; Zeng *et al.*, 2012b); the efficacy of preventive applications against *S. sclerotiorum* ascospore germination on bean and potato inflorescences should be determined in Sinaloa, as this phenological stage in both crops occurs during winter, when temperatures range from 5 to 25°C, favoring ascospore release by the pathogen and potential colonization of this structures by the antagonistic fungus (Clarkson *et al.*, 2003). However, *C. minitans* application on crop residues with the antagonistic on sclerotia may not be effective in reducing their viability since summer temperatures in Sinaloa reach up to 40°C at the soil surface, contrasting with other producing areas where the mycoparasite is applied to crop residues in early autumn with temperatures around 20 °C (Zeng *et al.*, 2012b).

Regarding antagonistic bacteria, *Bacillus cereus* and *B. subtilis* were found to control sunflower stem rot caused by *S. sclerotiorum* (Zazzerinim, 1987). A similar effect was observed when *B. subtilis* BY-2 was applied as seed treatment or sprayed during flowering against the same disease in canola (Hu *et al.*, 2014). These findings lead to the search for such bacteria in Sinaloa and the determination of their efficacy in controlling white mold in beans and potatoes.

To complement the white mold management scheme, studies on phenology of bean and potato varieties should be conducted to determine the heat unit accumulation necessary for flowering initiation, as when this phenological stage coincides with favorable environmental conditions for ascospore, release and infection of senescent flowers, which detach and fall onto plants, initiating the first disease symptoms. Additionally, the flowering period varies in both beans and potatoes, undoubtedly influencing the presence of substrate for ascospore infection in disease development. Compiling information on this topic will contribute to greater efficacy of fungicides and biocontrol agents in disease management.

Conclusions

White mold of beans and potatoes is one of the most important diseases affecting these crops in Sinaloa. Although studies on the ecology of the causal agent and disease epidemiology have been conducted elsewhere, research on these topics in this region is incipient. In this regard, implementing a management system that integrates soil temperature and crop phenology has allowed efficient use of fungicides for disease control; however, new research avenues are opening up concerning bean and potato variety phenology, determining heat units required for the onset of flowering in commercial varieties, which is important for white mold epidemic progression. Additionally, the control scheme should investigate the biological effectiveness of endemic *Trichoderma* species in disease management from *in vitro* to semi-commercial plots experimentation and subsequent transfer to commercial fields.

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