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Review

Mitigating against Sclerotinia Diseases in Legume Crops: A Comprehensive Review

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Abstract: Legumes are essential foods for man and animal. They contribute to food security globally. However, they are negatively affected by Sclerotinia diseases caused by *Sclerotinia sclerotiorum*, which infects over 600 plant species. There is a limited number of review studies on the management of the *Sclerotinia sclerotiorum* disease in legume crops. Here, we explore earlier studies on the occurrences, yield losses, and other negative effects caused by *Sclerotinia* spp. in legumes. Additionally, we studied the various strategies used in controlling *Sclerotinia sclerotiorum* diseases in legume crops. We conclude that the impact of Sclerotinia diseases on legume crops causes an economic loss, as it reduces their quality and yield. Among the management strategies explored, genetic control is challenging due to the limited resistance among germplasm, while biological agents show promising results. Fungicide application is effective during outbreaks of Sclerotinia diseases. Lastly, this review has uncovered gaps in the current knowledge regarding the alleviation of Sclerotinia diseases in legume crops.

Keywords: Sclerotinia pathogen; sclerotial formation; legume disease; biological control; chemical control; plant resistance

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1. Introduction

Legumes are ranked third among flowering plants, and they cover 800 genera consisting of 20,000 species [1]. Legumes play central roles largely in food security, ecological sustainability, and crop diversification [2–8]. Hence, the role of grain legumes in ensuring global food and nutritional security cannot be underestimated, as they serve as food and feed, and are rich sources of protein. Specifically, legumes such as cowpea, jack bean, and soybean are insinuated as the meat for the poor, are substituted as protein sources for the rural poor, and are substantial sources of protein (ranging from 20 to 30% dry weight), vitamins, and minerals [9–11]. In other parts of the world, legumes such as cowpea and soybean are used for fortifying babies' food to improve nutritional levels in diets [12–15]. Several clinical studies have been conducted on the intake of legumes [16–18], with data showing declines in cholesterol, threats related to coronary heart disorder, and type 2 diabetes. Moreover, secondary metabolites are produced by grain legumes, which promote human health [19]. Although legume consumption promotes health, its recommended levels per day have been questioned. Current research establishes that an intake of 50 g per day in adults results in reducing occurrences of coronary heart diseases while saving on cost [20]. Similarly, an intake of 55–70 g per day reduces the risk of hypertension [21]. Hence, it is recommended that we integrate reasonable quantities of legumes into our diet. Also, in farming, legume crops are essential in cereal cropping systems for destroying pathogen in soils while ensuring nitrogen fixation, which accounts for over 70% of the nitrogen required of the plants [22,23]. Thus, it reduces the need for fertilizer application, resulting in a decrease of greenhouse gas emissions [24]. The current agricultural production demand for low input couples with sustainable production systems that support the environment and economies [25]. Specifically, legumes accounts for nearly half of the world's nitrogen fixation, averaging 20–2000 kg N fixed ha^{-1} year $^{-1}$ [26]. Recent studies call for the reintroduction of integrating legumes into crop rotations, based on the positive effects on yields and the quality of features on succeeding crops [27,28]. The yield of wheat was found to be increased after growing legumes, compared to those that were grown after wheat [29]. Consequently, legumes are an ideal crop to be integrated into crop rotation systems, since they promote the growth of other crops such as cereals [30]. Nevertheless, conservation rotation promotes the occurrence of *Sclerotinia sclerotiorum* in common beans compared to conventional rotation [31]. *Sclerotinia* disease can cause serious yield loss and seed quality problems. However, there is limited literature on the *S. sclerotiorum* in legume crops. Specifically, this review seeks to provide detailed information on *Sclerotinia sclerotiorum* development, its infection, and its effects on the yield of legume crops. Also, it presents the response characters of legume crops to *S. sclerotiorum* infections. Ultimately, this study aims to provide a comprehensive update on managing *S. sclerotiorum* in legumes.

2. *Sclerotinia sclerotiorum* Development and Infection Process

2.1. Sclerotia, Its Development and Survival

Sclerotia formation has been designated three discrete periods (initiation, development, and maturation), and the later stages have been broadened into four categories (condensation, enlargement, consolidation, and pigmentation) [32–34]. These various stages embrace biochemical, metabolic, physiological, and morphological transformations, and are influenced by both endogenous and exogenous challenges—for example, ultraviolet radiation, temperature, toxic metals, microbial rivals, and competitors [35,36]. A number of factors, such as temperature, humidity, and wet incubation, are implicated in the germination of sclerotia, as well as the development of ascospore [37–39].

The development of sclerotia in *S. Sclerotinia* is accompanied by the formation of liquid droplets [40] that are seen on the surface of the aerial hyphae, and progress as the sclerotia grow. At the development stage, the exudate droplets are visible by the naked eye on the surface of the hyphae, alongside maturity features such as pigmentation [32]; once the droplets attain maximum capacity, they cease to cultivate. The decrease of moisture, gelling, and the desiccation of the cell walls may involve condensing water from the exudates of the surface of the sclerotia [41]; however, they are only found in the culture due to soil absorption, air-drying effects, and reutilizing sclerotia development [42]. Sclerotial growth is hindered by non-nutritional elements, such as environmental fluctuations (humidity, temperature, light, pH), the metabolites' organic compounds, metabolism, and organic compounds [32]. For instance, the growth and pathogenicity of *S. Sclerotinia* are influenced by lower temperatures [43].

The survival of *S. Sclerotinia* in the soil varies, and is influenced by floods, drought, burial in soil, and excessive soil moisture [44,45]. Also, several other features, such as excessive soil moisture associated with high temperatures and reduced oxygen, limit the existence of sclerotia. Flooding is most essential to sclerotia survival, and it can lead to its decay within 14–45 days [46,47]. The depth at which the sclerotia is placed in the soil affects its survival. Several research studies have demonstrated that sclerotia placed in the upper layers (5 cm) survive less than those placed at a deeper depth (10–30 cm) [47,48]. However, they can improve survival for several years (above five) because they have special abilities that make them resistant to hostile environmental conditions and chemicals [44]. The formation of apothecium and its infection is influenced by the degree of ploughing, and deeper ones decrease sclerotia density [49]; however, this is in contrast to soybean stem rot caused by *S. sclerotiorum* [50]. In summary, the survival period of sclerotia has been known to range from 1 to 5 years [51–53], and even from 5 to 11 years [54–56]; this makes it more challenging to control *S. sclerotiorum*.

2.2. Sclerotinia sclerotiorum Infection Process

The infection process of *S. sclerotiorum* is determined by the host, the pathogen, and the environment (Figure 1). However, the role of the environment is crucial in disease establishment and progression. For instance, sclerotia will yield apothecia when conditions (moisture and light) are met. Again, *S. sclerotiorum* ascospore will germinate and cause infection under leaf wetness [39]. The spores released by the apothecia infect the flowers, and the infection is promoted by the plant's canopy [57]. Later on, the infection may be noticed on the leaves and petioles or blossoms, and then spread to the stems. The stem turns greyish-white and soft. The disease progression results in stems becoming bleached as a result of the stem girdle with lesions, resulting in the wilting and death of the plant [58,59]. Usually, pods of legume plants show whiteness in colour, with a smaller size and few seeds, and they may contain sclerotia. Again, plants may also show signs of stunted growth, premature ripening, and lodging [60]. A high effect of the disease is recorded during the critical stages of blossoming, pod development and grain filling, and symptoms become obvious after flowering. Heavily affected leaves progressively become yellow and brown, and finally drop. Infection on the stems leads to dark brown or pale, water-soaked lesions closer to the soil line. Conversely, different symptoms of the fungus are exhibited by different legume crops.

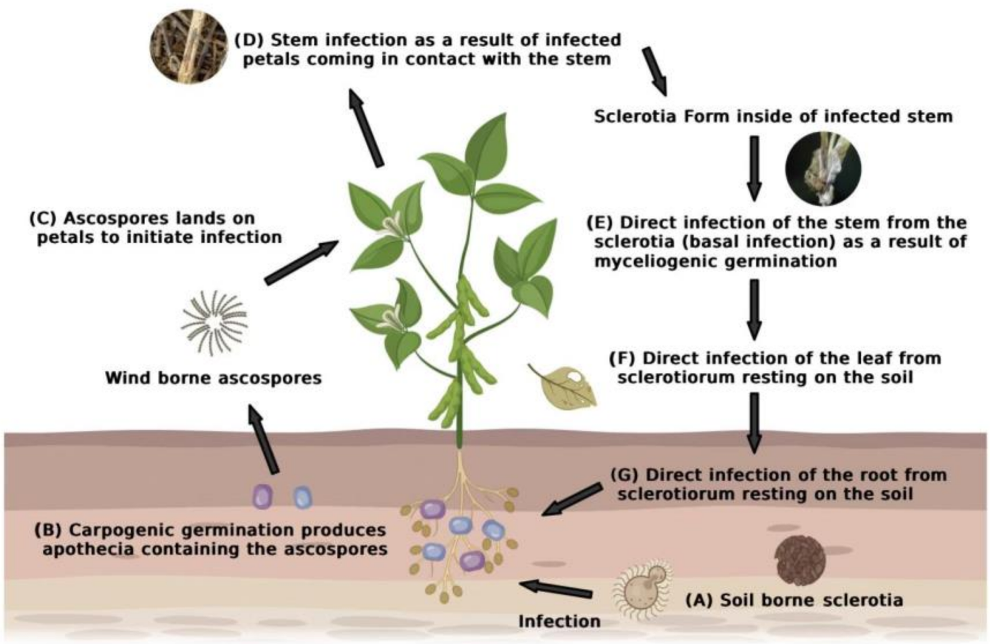

Figure 1. Infection process of *S. sclerotiorum.*

3. *Sclerotinia* Disease Occurrence and Yield Losses Caused in Legume Crops

3.1. Pathogens and Host Species

Sclerotiniaceae is a family of the genus sclerotinia. The genus *Sclerotinia sclerotiorum* (Lib.) de Bary is efficient in colonizing a diverse host range of over 600 plant species [61], attracting over 60 different names [62]. *Sclerotinia* species attack a wide range of field crops, fruits crops, vegetables, trees, shrubs, ornamental types, and weeds, accounting for yield reductions globally. *Sclerotinia* spp. are mostly labelled as causing white mold, crown rot, and stem rot in grain legumes, depending on the crop infested [63,64]. The species have been narrowed to three, viz *Sclerotinia sclerotiorum*, *Sclerotinia minor* Jagger, and *Sclerotinia trifoliorum* [65], as supported by other researchers [66,67]. The data on genetics, variation, and anatomical and cultural features make the concept of the three species valid [62]. Out of these types, *S. sclerotiorum* is noted as the most economically harmful [56,61].

Several pathogens attack legume crops worldwide, including fungi belonging to the genus *Sclerotinia*, with a wide host variety. Legumes are not spared the negative consequences of Sclerotinia disease. It is known for causing disease among legumes such as groundnut (*Arachis hypogaea* L.), soybean (*Glycine max* L.), common bean (*Phaseolus vulgaris* L.), faba bean (*Vicia faba* L.), alfalfa (*Medicago sativa* L.), red clover (*Trifolium pratense* L.), chickpea (*Cicer arietinum* L.), and lupin (*Lupinus albus* L.) [64,68–74]. These common legumes are known as grain or food legumes [75]. *Sclerotinia sclerotiorum* causes a huge economic loss, specifically in legume crops [76]. For example, *S. sclerotiorum* causes yield reduction, accounting for over USD 200 million every year in soybean in America [77]. Usually, it reduces crop yield, and the seed price is reduced as there are high levels of contamination in the harvested seeds due to the presence of sclerotia [60,72,78].

3.2. Yield Losses and Other Negative Effects by Sclerotinia spp.

The general impacts of *S. sclerotiorum* on plant growth have been observed. For instance, *S. sclerotiorum* on plants results in the reduction in the fresh and dry weight of the plant's shoot and root, with increases in inoculum levels [79]. Similarly, when plants are infected with *S. sclerotiorum*, it results in the reduction of its chlorophyl content [79]. This is attributed to the degeneration of the chloroplast, as the sclerotinia infection is linked to the secretion of the oxalic acid (OA) by the pathogen which causes the rupturing of the chloroplast membrane. The seed viability and its vigour are negatively affected by *S. sclerotiorum*, and it is progressive and depends on the inoculum pressure.

Sclerotinia species affect several crops, including legumes such as groundnut, soybean, common bean, faba bean, alfalfa, red clover, and chickpea. These legumes are affected by either one or two of the *Sclerotinia* species, with varying degrees of yield losses (Table 1). Yield losses due to Sclerotinia diseases in grain legumes vary depending on the prevailing environmental condition; however, more than 50% losses have been recorded (Table 1). Yield losses caused by the disease are within 147–355 kg/ha [78]. It also causes indirect losses, such as reducing the dry weight and oil content of groundnut kernels, and reducing the quality of the pod and fodder. *S. sclerotiorum* leads to a decrease in their yield components (number of seeds per pod, number of pods per plant, and the 100-seed weight) while affecting their seed quality [62,76]. There is a linear relationship between the degree of infection of *S. sclerotiorum* and the yield reduction for affected crops [60]. Several attempts have been made to develop and release cultivars exhibiting enhanced resistance [80,81].

In summary, *Sclerotinia* species cause a serious economic loss to legumes, by reducing their yields and seed quality. The effects of the *Sclerotinia* species are largely established by the ecological circumstances (humidity, pH, temperature), biological elements (parasitism, host susceptibility), and soil elements (depth). Sclerotinia disease in plants is considered a key problem of concern globally as it reduces yields by 50% [82]. However, there is limited information as to the economic loss and the global spread of *Sclerotinia* species in lupins, faba beans, and red clover.

Table 1. *Sclerotinia* spp. disease cause and yield losses estimated in legumes.

Crop (Species) Name	*Sclerotinia* spp.	Disease Name	Yield Loss (%)	Reference
Alfalfa (*Medicago sativa* L.)	*Sclerotinia sclerotiorum*	Blossom blight	Up to 100%	[83]
	Sclerotinia trifoliorum Erikss	Sclerotinia crown and stem rot (SCSR)	2–30%	[84]
Chickpea (*Cicer arietinum*)	*Sclerotinia sclerotiorum*	Stem rot	up to 100%	[85,86]
Common bean (*Phaseolus vulgaris* L.)	*Sclerotinia sclerotiorum* (Lib.) de Bary	Stem rot/White mold	30–100%	[73,87,88]
Faba bean	*Sclerotinia trifoliorum* Eriks	Stem rot	Up to 100%	[70]
(*Vicia faba* L.)	*Sclerotinia sclerotiorum*	White mold	-	[89]
Groundnut (*Arachis hypogaea* L.)	*Sclerotinia minor* Jagger/*S. sclerotiorum*/*Sclerotium rolfsii* Sacc	Sclerotinia blight	Over 50% yield losses	[68,90]
Lupin *(Lupinus angustifolius L.)*	*Sclerotinia sclerotiorum*	Stem rot	16 and 35%	[91]
Lentil (*Lens culinaris*)	*Sclerotinia sclerotiorum*	Sclerotinia white mold		
Pea (*Pisum sativum* L.)	*Sclerotinia sclerotiorum*	White mold	-	[92]
Red clover (*Trifolium pratense* L.)	*Sclerotinia trifoliorum*	Sclerotinia crown and stem rot	Huge loss to foliage and seeds	[71]
Soybean (*Glycine max* L.)	*Sclerotinia sclerotiorum* (Lib.) de Bary	Sclerotinia stem rot	>60% yield losses	[72]
Sword bean (*Canavalia gladiate* L.)	*Sclerotinia sclerotiorum*	Sclerotinia rot		[93]

4. Response of Legume Crops to *Sclerotinia sclerotiorum* Infection

4.1. Plant Symptoms

The symptoms observed on infested legume plants vary, subject to the host plant, prevailing environmental conditions, and infection pathways. The symptoms shown by the plants are uneven, and are usually evident at the flowering stages [58,76]. Different symptoms are observed by different plants infected by *S. sclerotiorum* [94]. However, the leaves of most infected plants are water-soaked, spreading towards the petiole and towards the stem as a result of cell death [55]. As the disease progresses, the infested plant develops a white cottony growth on the stem, followed by sclerotia development [54,59].

4.2. Physio-Biochemical Performance to Sclerotinia sclerotiorum Infection

The physiology and central metabolism of legume crops are crucial for their response to *S. sclerotiorum*. They respond to the attack of the pathogen by slowing down or impeding the possible damage. Once legume crops are infected by *S. sclerotiorum*, it triggers the crop defense system to reduce damage by upregulating the pathways of defense-related genes and downregulating the genes linked to metabolic pathways [95,96]. At this stage, the legume crop's energy is geared towards identifying the *S. sclerotiorum* and signaling its defense [56]. Secondary metabolites, such as phenolic and phytoalexins [96], and signaling compounds [97,98], are then produced.

The secondary metabolites (SMs) are involved in a number of processes, such as plant defenses and the termination of infections [99,100]. Legumes have SMs such as phytoalexin, saponins, polyphenolic, and alkaloids in varying content among plant species [101,102]. These SMs gather temporarily at diverse parts of the legume plant, subject to the nature of the stress. To illustrate, there is a high presence of phytoalexins in the leaves when there is a need for antimicrobial action against the phytopathogens [103]. The metabolite oxalic acid also appears to be employed by *S. sclerotiorum* as a broad-spectrum pathogenicity factor. Infection assays of OA-deficient *S. sclerotiorum* strains on a range of hosts including *G. max*, *P. vulgaris*, *Solanum lycospersicum*, *Brassica napus*, *Helianthus annuus*, and *A. thaliana* resulted in substantially reduced virulence, demonstrating that OA plays an important role in the infection strategy of *S. sclerotiorum* across a wide range of host species [104]. These broad-spectrum pathogenicity factors may contribute to the ability of *S. sclerotiorum* to infect a wide range of plant hosts.

Other studies endorse that in legumes (common bean and soybean), genes of enzymes and non-enzymes including peroxidase (POX), glutathione peroxidase (GPx), polyphenol oxidases (PPO), catalase (CAT), superoxide dismutase (SOD), and ascorbate peroxidase (APX) are linked to the metabolism of ROS, and regulate the formation and performance of the cell wall [97,105]. Thus, they influence the occupancy of the pathogen on the host (legumes).

5. Control Strategies for Managing *Sclerotinia sclerotiorum* Infection

5.1. Biological Control of Sclerotinia Diseases in Legumes

Biocontrol presents an alternative for the management of *S. sclerotiorum* by microbes, due to the quest for environmentally friendly options for chemical pesticide usage [106,107] in the absence of host resistance. Strains of bacteria, fungi, nematodes, viruses, and insects are used as biological control agents (BCAs) for managing pathogens. Thus, BCAs are integral components of sustainable agriculture [108,109]. A number of BCAs are identified to control *S. sclerotiorum*, thus leading to a substantial volume of study on the possible biocontrol for *S. sclerotiorum*. For instance, BCAs such as *Trichoderma* spp. [110–112] and *Coniothyrium minitans* [112] are known to control *S. sclerotiorum* in legume crops (Table 2).

Specifically, *Coniothyrium minitans* is effective in controlling *S. sclerotiorum* in soybean (Table 2). It is commercially available globally in the formulation of Contans WG. In soybean plants, the application of *Coniothyrium minitans* effectively limits apothecia and sclerotia formation by 81% and 50%, respectively [113], while in common beans it reduces the incidence of *S. sclerotiorum* by 90% [114] (Table 2). The spraying of *C. minitans* conidia

(5×10^6 mL^{-1}) on alfalfa plants for three conservative years resulted in a percentage of diseased pods from 42–72% to 29–38% [115] (Table 2).

Several species of *Bacillus* are implicated in plant growth-promoting rhizobacteria, and are utilized as BCAs [116] while improving the nutritional properties of *Amaranthus hypochondriacus* Linn [117]. Similarly, these bacteria have been proven by some researchers [112,118] to have antagonistic effects on the incidence of *S. sclerotiorum* in some legume crops (Table 2). For instance, *Bacillus* sp. B19 and *Bacillus* sp. P12, under a growth chamber, promoted germination ability by 15% while increasing the root and stem length of common beans [118]. Under a growth chamber, *Bacillus subtilis* impeded the formation of apothecia and sclerotia by 91% and 30%, respectively [113].

Again, Trichoderma, a soil-borne fungus, plays a key role in anti-phytopathogen-employing mechanisms such as antibiosis, induced systematic resistance, mycoparasitism, and competition [119]. Most of the *Trichoderma* spp. exhibit the parasitism of *S. sclerotiorum* sclerotia and decrease apothecia mass [120]. This is achieved by suppressing *S. sclerotiorum* by interfering with the growth of hyphal, parasitising the sclerotia and limiting the formation of apothecia [121,122] without affecting the microbial community [123]. *Trichoderma asperellum* reduces the apothecia quantity and severity of *S. sclerotiorum* in common beans at rate of 2×10^{12} spores mL^{-1} per plot for 2 years during field experiments [120]. Moreover, in chickpeas, *T. hamatum* and *T. koningii* resulted in a grain yield of over 50% [124] (Table 2). A strain of *T. harzianum* T-22 saved soybean plants in the field from *S. sclerotiorum*, and reduced its severity by 38.5% [112]. However, the commercialization of Trichoderma bioproduct is challenged by inconsistent performance under field conditions and controlled environments [125]. There is a huge amount of data on the use of biological agents in controlling *S. sclerotiorum* in legumes. On the contrary, there is limited information as to how *S. sclerotiorum* interacts and resists biocontrol agents. The antifungal action of propolis extract and oregano essential oil declines disease severity by 40% and 60%, respectively, highlighting the potential of biofungicides in controlling *S. sclerotiorum* [126].

Table 2. Biocontrol agents used in controlling *S. sclerotiorum* in crops.

Species	Environment	Effects	Tested Crop/Pathogens	Reference
Streptomyces albulus CK-15	In vitro	Inhibits germination and formation of sclerotia and the growth of mycelia	*Sclerotinia sclerotiorum*	[127]
Streptomyces species (*S. griseus*, *S. rochei* & *S. sampsonii*)	In vitro & In vivo	Controls the disease by reducing the viability and germination of sclerotia	Green bean	[128]
Bacillus sp. FSQ1	In vivo	Inhibits the growth and infection	Common bean	[129]
Trichoderma harzianum ESALQ-1306 & *Trichoderma asperellum* BRM-29104	Field	Controls *S. sclerotiorum*	Common bean	[123]
Trichoderma hamatum & *T. koningii*		Improves grain yield by 50–100% by controlling Fusarium wilt	Chickpea	[124]
Bacillus velezensis	Greenhouse	Inhibit disease growth	Lettuce	[130]
Arthrobacter FP15		Diminishes disease symptoms	Lettuce	[131]
Bacillus amyloliquefaciens	In vitro & Greenhouse	Impedes mycelium growth and limits lesion size	Tomatoes	[132]
Bacillus sp. B19 & *Bacillus* sp. P12	Growth chamber	Improves crop germination potential by 15% and increases root and stem length	Common bean	[118]
Pseudomonas chololoraphis PA-23	Greenhouse & In vitro	Suppresses *S. sclerotiorum*	Lettuce	[133]
Coniothyrium minitans	Growth chamber	Reduce disease incidence by 90%	Common bean	[114]
Pseudomonas aeruginosa; *Bacillus subtilis*; & *Trichoderma harzianum*	Greenhouse	Induced systematic resistance, and suppression of oxalic acid production	Pea	[134]
Bacillus amyloliquefaciencs	In vitro	Limits the effects of pathogens	Fungal pathogens	[135]
Trichoderma asperellum	Field	Reduction of S. sclerotiorum apothecia number and disease severity	Common bean	[120]
Bacillus subtilis	Growth chamber	Limit formation of apothecia by 91% and sclerotia by 30%	Soybean	[112]
Coniothyrium minitans	Growth chamber	Lower apothecia and sclerotia by 81% and 50% respectively	Soybean	[112]
Streptomyces lydicus	Growth chamber	Decrease apothecia by 100% and sclerotia by 30%	Soybean	[112]
Trichoderma harzianum T-22	Field	Decrease the disease severity index (DSI) by 38.5%	Soybean	[112]
Pseudomonas brassicacearum DF41	Greenhouse & In vitro	Suppresses *S. sclerotiorum*	Canola	[136]
Pseudomonas chololoraphis sp. PA-23	Greenhouse	Suppresses *S. sclerotiorum*	Canola	[113]
Trichoderma asperellum & *Clonostachys rosea*	Greenhouse	Reduction in apothecium counts	Common bean	[121]
Mycotoxins (*roridin A* & *roridin D*)	In vitro	Inhibitors of *S. sclerotiorum*	*Sclerotinia sclerotiorum*	[137]
Coniothyrium minitans	Field	Suppress pod rot from 42–72% to 29–38%	Alfalfa	[115]

5.2. Genetic Improvement of Host Resistance to *S. sclerotiorum*

The identification of resistance source in legumes to *S. sclerotiorum* is urgent to ensure the progress of the legume industry. Attempts have been made to develop protocols to screen gene pools (cultivars, landrace and plant introductions) under different environments, to identify resistant genotypes [88,138–140]. Unfortunately, a low level of resistance is exhibited by legumes to *S. sclerotiorum*. For instance, in soybeans, a total of 285 out of 8596 lines were identified as resistant [74], whereas 12 accessions out of 519 common bean germplasm were resistant [141]. Molecular markers have aided in identifying legumes exhibiting partial resistance [141,142].

Analyses of the tolerance of legumes to *S. sclerotiorum* have shown partial resistance among legumes such as common bean [142] and soybean [143]. A number of previous researchers have reported on mapping quantitative trait loci linked to *S. sclerotiorum* resistance among legume crops, including common bean [144,145], groundnut [146], chickpea [86], and soybean [147,148]. However, some legume crops, such as faba bean, lentil, and lupin, have their transcriptome available publicly, but there is limited information on studies carried out to elucidate the quantitative trait locus linked to *S. sclerotiorum* resistance.

With the nature of the pathogen, the breeding programs have low success rates, with no commercial variety available for legume crops (such as soybean, alfalfa, red clovers and faba beans) being resistant to *S. sclerotiorum* [59,149–153]. On the contrary, groundnut has a commercial variety resistant to the disease, saving the United Sates USD 5 million yearly [154]. Recent studies have identified resistant genes *GmGST* of glutathione transferase and *GmCH1* of chitinase via cloning, which increase resistance to *S. sclerotiorum* in soybean [155,156]. Similarly, the silencing of the endo-polygalacturonase gene (*SsPG1*), cellobiohydrolase gene (*SsCBH*), and oxaloacetate acetylhydrolase gene (*SsOAH1*) in *B. napus* led to a reduction in disease by 40%, showing the path in managing the disease via host-induced gene silencing [157]. In common bean, genomic regions WM2.2a and WM2.2b are linked to playing a role in resistance, of which the latter triggers physiological resistance and the former with avoidance mechanisms [158]. Thus, the genes serve as a ground to assist marker-assisted breeding against the disease. The use of cultivars resistant to *S. sclerotiorum* will reduce dependence on fungicide application [159].

5.3. Chemical Control of Sclerotinia Diseases in Legumes

Fungicides are widely used to manage *S. sclerotiorum* [160]. This has resulted in a range of fungicides—such as demethylation inhibitors, anilinopyrimidines, benzimidazoles, triazole, strobilurin, pyridine-carboxamide, dicarboxamides, iprodione, and succinate dehydrogenase inhibitors (SDHIs)—on the market, in an attempt to reduces its associated effects on crop yield and quality [160–165]. The fungicides' active ingredients are picoxystrobin, fluazinam, tetraconazole, pyraclostrobin, boscalid, penthiopyrad, trifloxystrobin, fluxapyroxad, prothioconazole, thiophanate methyl, and prothioconazole [76,166–171]. The most frequently used fungicides in controlling *S. sclerotiorum* are dicarboximides and benzimidazoles, with countries reporting some strains showing resistance [172]. In legume crops, a number of fungicides are recommended to manage *S. sclerotiorum*. For example, in groundnut dicarbixamides, SDHIs and aminipyridines are recommended [173,174]. Chemical fungicides do pose a threat to humans and the environment; hence, there is a search for more safe chemicals which has resulted in a ban on thiophanate methyl and prothioconazole in Europe. Other researchers confirm that the resistance of *S. sclerotiorum* isolates to these fungicides is seen only in laboratory-induced variants [175]. However, it is advisable to rotate fungicides with diverse ways of actions such as fluazinam and procymidone, since they did not lose the sensitivity until now [176]. The decision on fungicide application is dependent on the economic analysis between its cost and the menace of the disease. To achieve a high impact of the fungicide application, it is required that the moisture level in the field, crop stage, canopy thickness, and the weather forecast for a week ahead be studied. For example, applying fungicides during the bloom period offers the best result. It limits the spread of infection by ascospores in fields. Hence, the time in the flowering periods of legume crops is critical. Others have observed inconsistent results on fungicide efficiency by varying the application time and the type of the fungicides [159,177,178].

Chemicals have been applied to avoid the presence of the disease, and are considered uneconomical by farmers [174,178]. For instance, to achieve a lower rate of disease incidence in soybeans, after the application of thriophanate methyl at either R1 (beginning flower) or R2 (full flowering) there is a need to do a second application two weeks later [179]. Also, they increase farmers' production costs, as well as cause negative consequences on the ecology as a result of their toxic remains [107,178]. Notwithstanding this, fungicide application is successful and effective in managing *S. sclerotiorum* [76,180], especially during a disease outbreak in the field. Moreover, the application of machine learning could aid to estimate the *S. sclerotiorum* disease threshold, to inform spraying decisions [39].

6. Conclusions and Future Perspective

In this review, we provided a comprehensive overview of *S. sclerotiorum* and its impact on legume crops. Much has been unveiled for the pathogen's sclerotia, its development, and its survival. We highlighted the strategies available to mitigate the effects of Sclerotinia diseases on legume crops. We conclude that the successful control of the disease demands execution, and a combination of multiple methods largely depending on chemical, biocontrol and genetic resistance.

The harm caused by *S. sclerotiorum* on legumes are huge, requiring that new, efficient and effective control measures need to be developed against the pathogen. Hence, an effective control strategy needs to be adopted, with an increased display of preventive action against yield loss while promoting crop quality and avoiding resistance to fungicides. In-depth knowledge of the formulation, delivery, and efficient screening protocols under different environments (growth chamber, green house, and field) with consistent results is essential for adopting commercial products for fungicide and biocontrol. Moreover, it is essential to categorize *S. sclerotiorum* strains during trials, so as to foster the development of resistant cultivars. Future work could provide a detailed understanding of the use of BCAs and the reduced quantity of fungicides, to study their synergistic effects. These approaches could be integrated into cultural practices in an attempt to mitigates the effects of Sclerotinia diseases in legumes. Lastly, advanced breeding techniques could be explored for accelerating the development of legume crops resistant to *S. sclerotiorum*.

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