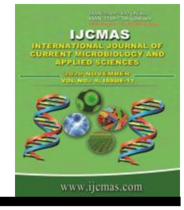
Int.J.Curr.Microbiol.App.Sci (2020) *9*(11): 1247-1267

International Journal of Current Microbiology and Applied Sciences
ISSN: 2319-7706 **Volume 9 Number 11 (2020)**
Journal homepage: http://www.ijcmas.com



Review Article https://doi.org/10.20546/ijcmas.2020.911.147

A Review on Symptomatology, Epidemiology and Integrated Management Strategies of Some Economically Important Fungal Diseases of Soybean (*Glycine max*)

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Keywords

Soybean diseases, seed and seedling diseases of soybean, Rhizoctonia root rot, Pod blight, Rhizoctonia aerial blight/ web blight, Charocal rot, Rust disease and collar rot

Article Info

Accepted:
10 October 2020
Available Online:
10 November 2020

ABSTRACT

Among different production constraints in soybean, the most serious being diseases. These diseases are caused principally by fungi or bacteria however fungal diseases causing greater threat to the crop production. The damage caused by foliar diseases is mostly of minor importance except diseases like soybean rust, Pod blight, Rhizoctonia aerial blight or web blight etc. which can reduce yields when weather conditions favor disease development. Correct identification and early detection are critical in the proper management of soybean diseases. In this review we are discussing about economic importance, symptomatology, causal organism, disease cycle, epidemiology and integrated management of some economically important fungal diseases of soybean *viz.* Seed and seedling diseases of soybean, Rhizoctonia root rot, Pod blight, Rhizoctonia aerial blight or web blight, Charocal rot, Rust disease and collar rot.

Introduction

Soybean is valued globally for its relatively high-quality oil and protein, which comprise approximately 20 and 40% of the soybean, respectively (Clemente and Cahoon 2009). Due to high protein content, soybean is known as "poor man's meat". Seeds of soybean also contain about 33% carbohydrates, up to 16.6% of which are soluble sugars (Hou *et al.*, 2009). Among the grain legumes, it has the greatest potential of producing the cheapest source of food protein (Rao and Reddy, 2010). A frequent soybean protein consumption lowers the cholesterol levels and also reduces the risk of coronary heart disease (FDA, 1999; Henkel, 2000). Moreover, it improves the glucose tolerance in some diabetic patients (Messina, 1999).

Currently, India ranks fourth in respect to production of soybean in the world. The crop helps earn valuable foreign exchange (Rs. 62000 millions in 2012-13) by way of soya meal exports. Soybean has largely been responsible in uplifting farmer's economic status in many pockets of the country. It usually fetches higher income to the farmers owing to the huge export market for soybean de-oiled cake (FICCI).

Unfortunately, soybean is susceptible to many diseases and pests that can cause significant yield losses. Although potential threats to soybean production vary by growing regions some pathogens are consistent causes for concern. Anthracnose, bacterial diseases, brown spot, charcoal rot, frog eye leaf spot, Fusarium root rot, pod and stem blight, Purple seed stain & Cercospora leaf blight, Rhizoctonia aerial blight, Sclerotium blight, Seedling diseases, Soybean rust, Virus diseases and a few other diseases have been reported in India (Wrather *et al.*, 2006). Another report states major biotic stresses of soybean crop in India are diseases like yellow mosaic virus, rust, rhizoctonia, anthracnose, etc., and insect pests like stem fly, gridle beetle, and various defoliators (Agarwal *et al*., 2013). In India, the Asian soybean rust disease was first reported on soybean in 1951 (Sharma and Mehta, 1996). Frog eye leaf spot (*Cercospora sojina*), rust (*Phakospora pachyrhizi*), powdery mildew (*Microsphaera difJusa*) and purple seed stain (*Cercospora kikuchii*) were recorded in moderate to severe form is prevalent in North Eastern Hill region (Prasad *et al.*, 2003).

Identification followed by prevention of the diseases is the first step towards management of diseases. Increased knowledge about the location and quantity of the pathogen in relation to weather conditions provides numerous benefits to growers and researchers by providing more accurate timing of disease management. The economic impact of these diseases has spurred research on their biology, epidemiology, and management. Some of the important soybean diseases along with their epidemiology and management aspects are described in this review.

Seed and seedling diseases of soybean

Seedlings diseases have been a major constraint to Soybean (*Glycine max* (L.) Merr.) production in North America. From 2006 to 2009, seedling diseases ranked third among diseases and pests that reduced soybean yield in United States and Canada (Olutoyosi and Carl, 2017).

Seedling diseases of soybean (Glycine max) can be common under cool and moist soil conditions and may be caused by a complex of pathogens in North Dakota (Bradley, 2008).

Symptoms

Seed and seedling disease is caused by a complex of organisms, which mainly includes:

Phytophthora-infected seedling stems are soft and water-soaked. Overall, infected seedlings will be wilted and stunted (Crop Protection Network, 2015). At the primary leaf stage (V1), infected stems appear bruised and soft, secondary roots are rotted, the leaves turn yellow, and plants frequently wilt and die (Malvick, 2018).

Pythium- The characteristic symptom of most Pythium infections is soft, brownish-colored, rotting tissue (Malvick, 2018). Emerged plants may be killed before the first true leaf stage. These plants have a rotted appearance. Diseased plants may easily be pulled from the soil because of rotted roots (Crop Focus, 2013).

Rhizoctonia- Infection is characterized by a shrunken, reddish-brown lesion on the hypocotyl at or near the soil line. Infection may be superficial, causing no noticeable damage, or may girdle the stem and kill or stunt plants. Causes loss of seedlings (damping-off) in small patches or within rows; is usually restricted to the seedling stage (Crop Focus, 2013).

Fusarium - Causes light- to dark-brown lesions on soybean roots that may spread over much of the root system. May attack the tap root and promote adventitious root growth near the soil surface, and may also degrade lateral roots, but usually does not cause seed rot (Crop Focus, 2013).

Causal organism

Phytophthora sojae is a fungal-like pathogen that survives in soil for up to five to 10 years in association with decomposed soybean tissues. Soybean is the only known crop host for this pathogen. It is favored by saturated, warm soil. *Phytophthora sojae* is an oomycete pathogen of soybean, classified in the kingdom Stramenopiles. It causes 'damping off' of seedlings and root rot of older plant

Super kingdom: Eukaryota
Kingdom: Stramenopila
Phylum: Oomycota
Class: Peronosporomycetidae
Order: Pythiales
Family: Pythiaceae
Genus: Phytophthora (Tyler, 2007).

Pythium is a soilborne, fungal-like pathogen. Several different species damage soybeans. The various species of *Pythium* that infect soybean have a wide host range that can include corn and many other crops. *Pythium* tend to be favored by cool and soil, but some species may do more damage in warm soils (Malvick, 2018)

Rhizoctonia solani is a common pathogen with a wide host range. The most common strains of this pathogen (anastamosis groups, AG) that infect soybean are AG-2-2 and AG-4. AG groups can have different optimal conditions for infection.

Hyphal branch originates from distal dolipore septum with a characteristic constriction at the branching point. Conidia, clamp connections, rhizomorphs, and cultural pigmentations other than brown are never observed. Basidiomal structure of sexual state is characterized by a vertically branching hymenium succeeded by layers of elongated basidia slightly wider than basal hyphae.

Domain: Eukarya
Kingdom: Fungi
Subkingdom: Dikarya
Phylum: Basidiomycota
Subphylum: Agaricomycotina C
Class: Agaricomycetes
Order: Ceratobasidiaceae
Family: Cantharellales
Genus: Rhizoctonia (Ajayi-Oyetunde and Bradley, 2018)

Fusarium seed and seedling blight of soybean is caused by a complex of different species that may prefer different conditions. For example, some species may prefer warm and dry soils and others may prefer cool and wet soils. Some Fusarium species may also have a broad host range that includes corn and wheat (Malvick, 2018).

Disease cycle

The major stages in life cycles of most root-infecting oomycete species of Pythium and Phytophthora are similar. The asexual cycle is characterised by the production of sporangia. Sporangia may germinate either directly in liquid or on a surface to produce a germ tube (direct germination) or may differentiate by a process of cytoplasmic cleavage to form uninucleate, biflagellate zoospores (indirect germination). The released zoospores swim in water in search of host tissues (seeds, roots, stems or leaves) where they settle and encyst. The cyst germinates by developing a germ tube that may penetrate the host either directly, or via an appressorium or appressorium-like structure. The sexual cycle generates thick walled oospores that are adapted for over-wintering and survival under harsh environmental conditions. Oosporogenesis involves the production of a female oogonium and a male antheridium that grows towards and fuses with the oogonium. Fertilisation occurs through the emptying of some of the contents of the antheridium into the oogonium, leading to the development of an oospore, which has a thick inner wall. This resting spore can exhibit extended dormancy and can over-winter in the soil and then germinate under suitable conditions to produce single or multiple germ tubes. These germ tubes can then form sporangia thereby recapitulating the asexual cycle of the pathogen (Van *et al.,* 2003).

Rhizoctonia solani isolates generally do not produce vegetative or asexual spores, and the role of basidiospores as an inoculum source for the seedling diseases they incite on soybean is unknown. Its survival in the soil is aided by the formation of long-lived 'nutrient-independent propagules' called sclerotia. For most Rhizoctonia infections to occur, sclerotia must first germinate to form mycelia that grow towards the host plant (Ajayi-Oyetunde and Bradley, 2018).

Epidemiology

General conditions that promote seed and seedling disease diseases include wet, poorly-drained, and compacted soils. However, the different pathogens have different optimal conditions. Seed and seedling diseases may be enhanced by slow germination and growth of soybeans, poor quality seed, and plant stress (Malvick, 2018).

Phytophthora root rot occurs across many environments, but is most common in warm (>60°F/15°C) and wet conditions, while Pythium Prefers cold soil temperatures (<60°F). High-residue fields, and heavy or compacted soils are at higher risk because of cooler, wetter conditions (Crop Focus, 2013).

Fusarium root rot is often associated with stressed plant (Crop Protection Network, 2015).

Integrated management

Bacillus subtilis (6 g/kg), *Pseudomonas fluorescens* (6 g/kg), *B. subtilis+P. fluorescens* (6 g/kg), *Trichoderma viride* (6 g/kg), *T. harzianum* (6 g/kg), thiram+ carbendazim (2 g/kg). Seed treatments with bioagents and fungicides while significantly bringing down seed borne fungi and seedling mortality both under laboratory and field conditions, enhanced seed quality, germination, vigour and yield (Rajeswari and Kumari, 2009).

Fungicide seed treatments vary in efficacy, and products that control Pythium and Phytophthora diseases (such as ethaboxam, metalaxyl (-M), and mefenoxam) do not affect *Rhizoctonia* and *Fusarium* species. Similarly, fungicides that are effective against *Rhizoctonia* and *Fusarium* have little effect on oomycetes (Crop Protection Network, 2015).

Pioneer Premium Seed Treatment helps protect against all of these stand-reducing pathogenic fungi. Pioneer offers several fungicide, insecticide and biological seed treatment choices to help meet specific local needs for stand protection. Allegiance® for

Pythium and Phytophthora control, and 2) EverGol™ Energy (new for 2013), a next-generation technology with multiple modes of action for enhanced protection against a broad spectrum of early-season disease pathogens, including *Rhizoctonia*, *Fusarium* and *Pythium* (Crop Focus, 2013).

Pod blight disease of soybean

Estimates of max. reductions in seed yield were 16-26% (av. 19.7%). Yields were typically reduced as the pods became infected in USA (Backman *et al.,* 1982).

Estimated yield reduction of soybean (thousand metric tonnes) due to Anthracnose /Pod Blight disease in 2006 was 45.3 (Argentina), 220 (Brazil), 1663.5 (China), 117.6 (India), 0.3 (Paraguay), 492.9 (USA).

Anthracnose occurs regularly in Delhi, Uttarakhand, Himachal Pradesh, Madhya Pradesh, and Rajasthan. This pathogen can attack soybean from early seedling stage to maturity. It reduces yield by causing pod blight in various parts of India (Wrather *et al.*, 2010).

Symptoms

Infected seeds become shriveled, mouldy and brown. Laterally the infected tissues are covered with black fruiting bodies of the fungus. Under high humidity symptoms on leaves are veinal necrosis and premature defoliation occurs (Borah, 2019).

The fungus cause anthracnose on leaves and blight on pods. Infected pods were shriveled and contain no seed (pod blanking) or more two seeded pods, with shriveled moldy seeds (Koelkar, 2017).

Causal organism

Anthracnose/Pod Blight of soybeans caused by *Colletotrichum truncatum* (Schwein.) Andrus & W.D. Moore reported as a disease of above ground parts.

Conidia were falcate, tapered towards the apex, hyaline, unicellular and aseptate, with variable dimensions, formed in the acervuli, usually produced on the top of dark brown to black stromata (Rogerio *et al.,* 2017).

Domain: Eukaryota
Kingdom: Fungi
Phylum: Ascomycota
Subphylum: Pezizomycotina
Class: Sordariomycetes
Subclass: Sordariomycetidae
Family: Glomerellaceae
Genus: Colletotrichum
Species: *Colletotrichum truncatum*

Disease cycle

The life styles of *Colletotrichum* species can be broadly categorised as necrotrophic, hemibiotrophic, latent or quiescent and endophytic; of which hemibiotrophic is the most common (De Silva *et al.,* 2017).

Epidemiology

Do and Paik, 1987 reported in their findings that appressoria formation of *C. truncatum* was promoted in light treatment than in dark treatment, reasonable pH of pH6-pH8.

Integrated management

Benomyl followed by carbendazim, thiram and captan were highly effective *in vitro*. *In vivo*, benomyl followed by zineb, captan and thiram gave good control. Among 7 varieties screened under artificial epiphytotic conditions, varieties JS-22 and PKV-1 were highly resistant; variety MACS-13 was also resistant (Ghawde *et al.,* 1996). The most economical treatment found with highest C: B ratio (1:14.45) was the fungicide Carbendazim followed by the fungicides

Carbendazium + Mancozeb (C:B ratio, 1:8.92) (Jagtap *et al.,* 2012).

Future approaches in disease management

Jagtap *et al.,* 2012 reported use of aqueous leaf extracts of garlic, tulsi and onion which inhibited 81.82%, 65.17% and 60.31% growth of *C. truncatum*.

Rhizoctonia aerial blight /web blight of soybean

Estimated reduction in soybean yield (thousand metric tonnes) in 2006 due to Rhizoctonia aerial blight were 300 (Brazil), 1188.2 (China), 39.2 (India), 12.5 (USA) (Wrather *et al.,* 2010).

Aerial Blight/ web Blight of soybean caused by a fungus i.e. *Rhizoctonia solani* Kuhn (Teleomorph: *Thanatephorus cucumeris* (Frank) (donk) is a serious problem in soybean and considered to be menacing and causes heavy losses in yield particularly in warm and humid part of the country.

Aerial blight is an important disease of soybean, in USA and other soybean growing countries including India and causes substantial losses in yield. Several estimates of yield losses due to disease have been estimated. Aerial blight caused by *Rhizoctonia solani* is one of the most soil borne diseases of soybean particularly in the northern zone comprising the states of Haryana, Punjab, Uttar Pradesh and Uttarkhand (Kumar *et al.,* 2016).

Symptoms

Foliar symptoms often occur during late vegetative growth stages on the lower portion of the plant following canopy closure. Initially leaf symptoms appear as water-soaked, grayish green lesions that turn tan to brown at maturity. The pathogen may infect leaves, pods, and stems in the lower canopy. Reddish-brown lesions can form on infected petioles, stems, pods and petiole scars. Long strands of web-like hyphae can spread along affected tissue and small (1/16 to 3/16 in. in diameter), dark brown sclerotia form on diseased tissue (Faske and Kirkpatrick, n.d.).

Causal organism

The anamorph or imperfect stage of pathogen causing aerial blight in soybean is *Rhizoctonia solani* Kühn.

Domain Eukarya
Kingdom Fungi
Subkingdom Dikarya
Phylum Basidiomycota
Subphylum Agaricomycotina C
Class Agaricomycetes
Order Ceratobasidiaceae
Family Cantharellales
Genus Rhizoctonia
Species: *R. solani*

R. solani include septate hyphae, multinucleate cells in young hyphae, brown colouration of mature hyphae, right-angled hyphal branching, constriction at the point of branching, dolipore septa that permits unrestricted cell-to-cell movement of cytoplasm, mitochondria and nuclei, production of monilioid cells, and sclerotia of uniform texture (Ajayi-Oyetunde and Bradley, 2018).

Disease cycle

Rhizoctonia solani isolates generally do not produce vegetative or asexual spores, and the role of basidiospores as an inoculum source for the seedling diseases they incite on soybean is unknown. Its survival in the soil is aided by the formation of long-lived 'nutrient-independent propagules' called sclerotia. For most Rhizoctonia infections to occur, sclerotia must first germinate to form mycelia that grow towards the host plant (Ajayi-Oyetunde and Bradley, 2018).

Epidemiology

The epidemiology of aerial blight may be divided into two phases, one before and one after canopy closure. The first phase is soil borne and determines the number of potential disease foci in the crop canopy. The second phase is leaf borne and is important to the expansion of disease foci. During the growing season, patterns of rainfall between the two phases are an important determinant of the development of aerial blight (Yang *et al.*, 1990).

High soil moisture (80%) and 25 0C temperature were the most favourable for root rot development while web blight was best favoured at >85% relative humidity coupled with 25 0C temperature. Continuous leaf wetness for at least 6 hrs was essential for disease initiation, while increase in leaf wetness duration for 6-12 hrs showed corresponding disease incubation period observed with further increase in leaf wetness (Kumar *et al.,* 2016).

Integrated management

The use of resistant varieties is the cheapest, easiest, safest and most effective method to manage the aerial blight disease. The efforts through conventional breeding so far made in developing commercial cultivars resistant to aerial blight (Kumar *et al.,* 2016).

Rotate with poor or non-host crops such as corn or grain sorghum for two-years and avoid narrow row widths and high plant populations are good management practices (Faske and Kirkpatrick).

Simulations from a soyabean growth model (SOYGRO) indicated that higher yields could be expected with wider row spacings during drought years (Joye *et al.,* 1990).

Charcoal rot of soybean

Charcoal rot was most severe in the dry areas of Argentina, Bolivia, Brazil, India, Paraguay, and the United States. Estimated reduction of soybean yields (thousand metric tonnes) due to Charcoal rot in 2006 were 905 (Argentina), 500 (Bolivia), 360 (Brazil), 1.6 (Canada), 39.2 (India), 1.6 (Paraguay), 697.6 (USA) (Wrather *et al.,* 2010).

In India Charcoal rot was one of the diseases of Soybean causing most yield losses in 2006. Charcoal rot has accounted for more yield loss in India since 2004 due to erratic rainfall and greater periods of drought. It has caused the most damage to soybean in the major soybean states of Madhya Pradesh, Maharashtra, Rajasthan, and Karnataka. Yield losses have been as high as 77% in some fields (Wrather *et al.,* 2010). The charcoal rot, which is used to be a minor disease of soybean until 2004 in India, became a serious pest due to altered weather conditions particularly on the account of longer drought spells during crop growth period (Gupta *et al.*, 2012).

Symptoms

On seedlings, after emergence, symptoms can be visible on cotyledons as brown to dark spots. Sometimes, the margins of the cotyledons become brown to black and shed at an early stage. From the unifoliate leaf stage onwards, the symptoms appear on emerging hypocotyls of infected seedlings as circular to oblong, reddish-brown, lesions that may turn dark brown to black after several days. These lesions may extend up the stem. Infected seedlings may die if hot and dry conditions persist. The pathogen causes lesions on the roots, stems, pods and seeds. Foliar symptoms progress from top of the plant downwards. Leaves of infected plants remain smaller than normal and subsequently turn yellow prior to wilting.

A reddish-brown discolouration of the vascular elements of roots and lower stem precedes the premature yellowing as the fungus spreads up the stem during the season. The infected mature and dry pods are covered with locally or widely distributed black bodies (microsclerotia).

After the death of the plant, numerous, minute, pinhead-sized microsclerotia appear, which can be seen readily when the epidermal tissue of the lower stems and roots is peeled from the affected parts. The infected crop in the field exhibits premature yellowing in scattered patches (Gupta *et al.,* 2012).

Causal organism

Macrophomina phaseolina is a soil inhabiting organism capable of infecting soybean at any crop growth stage, but usually, it infects at post flowering stage. The fungus is also seed-borne in many crops including soybean. It produces microsclerotia in root and stem tissues of host plants, which enable it to survive in soil for 2–15 years and act as primary source of inoculum. The pycnidiospores in Macrophomina are ellipsoid to obovoid and measure 20–24 · 7–9 μm (Gupta *et al.,* 2012).

Domain: Eukaryota
Kingdom: Fungi
PhySubphylum: Pezizomycotina
Class: Dothideomycetes
Order: Botryosphaeriales
Family: Botryosphaeriaceae
Genus: Macrophomina
Species: *Macrophominaphaseolina*

Disease cycle

The pathogen mainly produces either microsclerotia (primary source of inoculum) or pycnidia. The pathogen life cycle begins with microsclerotia germination into the soil. Under favorable environmental conditions (low water potential and high soil temperature) and in the presence of the host plants, microsclerotia germinate and produce a mass of hyphal threads. The hyphae grow towards the host's roots and colonize the seedlings roots during the first weeks of seed germination. When plants approach the end of the growing season and pathogen enters into its necrotrophic phase, plants show symptoms like wilting and necrosis due to blockage of vascular bundles with microsclerotia, enzymes activity and secretion of pathogenic toxins. The most diagnostic symptom of charcoal rot in invaded soybean plants is the black and dusty speckled appearance of microsclerotia on stems, pods and seeds as well as interior tissues like vascular, cortical, and pith tissues (Hemmati *et al.,* 2018).

Epidemiology

Meyer *et al.,* 1974 in his findings found that disease was greatest at 30-35˚C, although some infections occurred on soybean seedlings at 20-25˚C. Infected seedlings may serve as a latent source of inoculum of the mature plant phase over a wide temperature range. With increase in number of viable *M. phaseolina* propagules, the disease seedlings also increased.

Seedlings can be infected in years when soils are exceptionally dry and soil temperatures are continuously above 35C for 2–3 weeks. The germination of microsclerotia in soybean fields is favoured by dry soils, high soil C: N ratios of amendments, low bulk density (Gupta *et al.,* 2012).

Fig.1 (A)-(B) Soybean seeds infected by Pythium sp. Image: Borah, 2019; (C) cotyledons affected by Phytophthora root Rot Image: Borah, 2019; (D)-(E) Seedlings affected by Rhizoctonia root Rot Image: Borah, 2019; (F) Seedlings affected by by *Fusariumsp* Image: Borah, 2019.*;* (G) Disease cycle of *Phytophthora sp*. and *Pythium sp.*Van *et al*., 2003; (H) Disease cycle of *Rhizoctonia solani'* Image: Ajayi-Oyetunde and Bradley 2018; (I) Disease cycle of *Fusarium* Image: Dweba *et al*., 2017

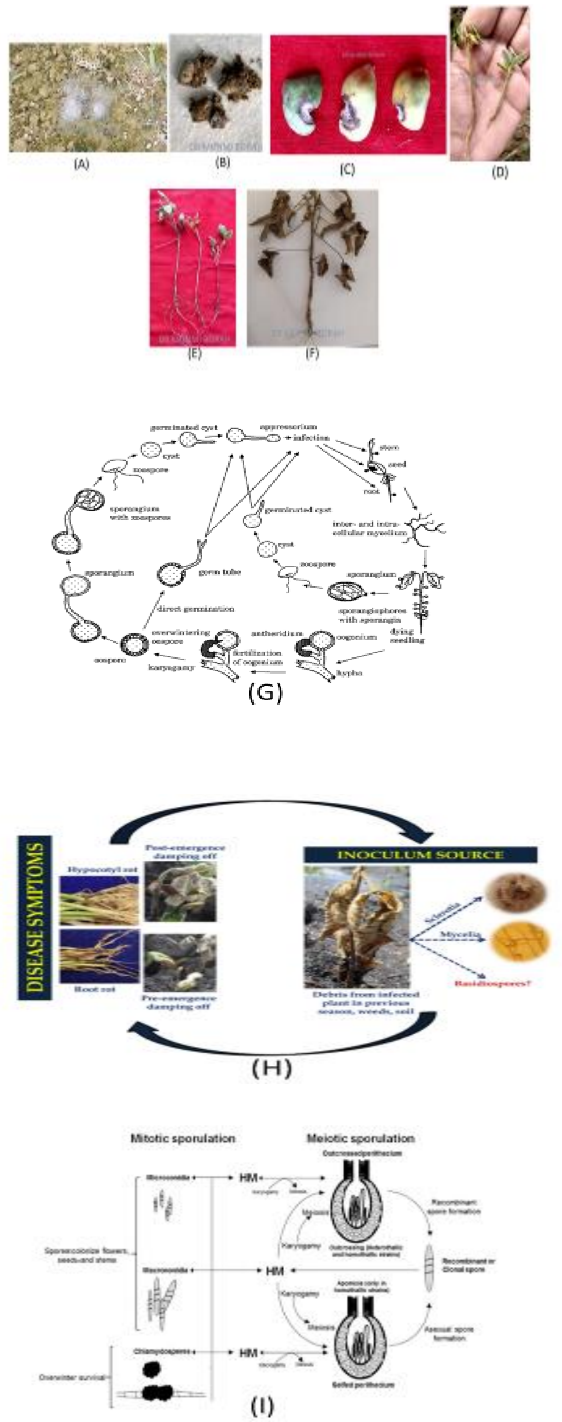


Fig.2 (A)Symptoms on Cotyledons; Image; Kolekar, 2017; (B) Symptoms on leaf, Image ; Kolekar, 2017; (C) Symptoms on pods; Image; Kolekar, 2017.; (D) Disease cycle of *Colletotrichum*

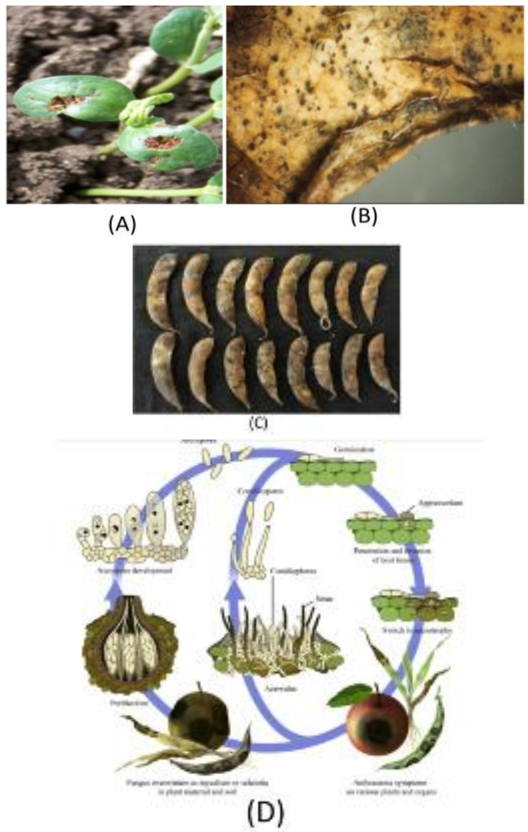


Fig.3 (A) Web-like hyphae of *Rhizoctonia solani* spreading along the stem of soybean Image: Faske and Kirkpatrick, n.d.; (B) Water soaked, greenish lesions Image: Faske and Kirkpatrick, n.d.; (C) Mature sclerotia of *Rhizoctonia solani* on soybean petiole Image: Faske and Kirkpatrick, n.d.; (D) Disease cycle of *Rhizoctonia solani*
Image: Ajayi-Oyetunde and Bradley, 2018

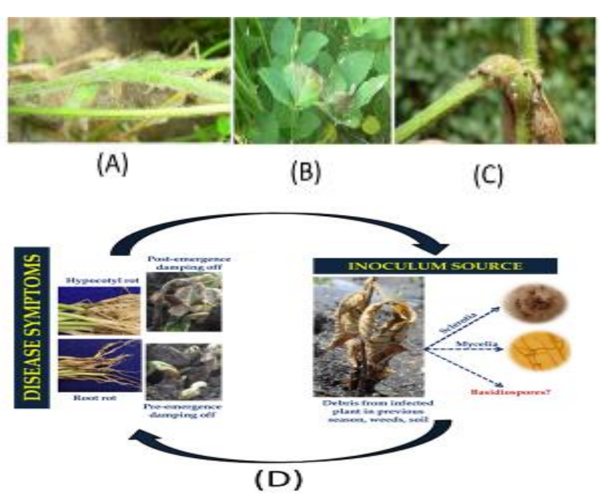


Fig.4 (A) Stunted / wilted plants Image : Crop Protection Network; (B) A reddish-brown discolouration of the vascular elements of roots and lower stem ;(C) Disease cycle of *Macrophomina phaseolina* Image Hemmati *et al.*, 2018

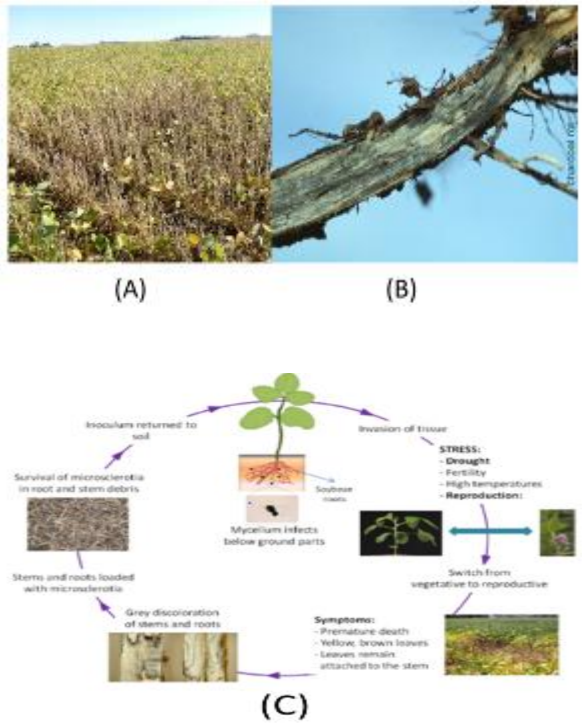


Fig.5 (A)-(B) Symptom of rust on Soybean leaf Image: Rupe and Sconyers, 2008; (C) Disease cycle of *Phakopsora pachyrhiz;* Image: Goellner *et al.*, 2010)

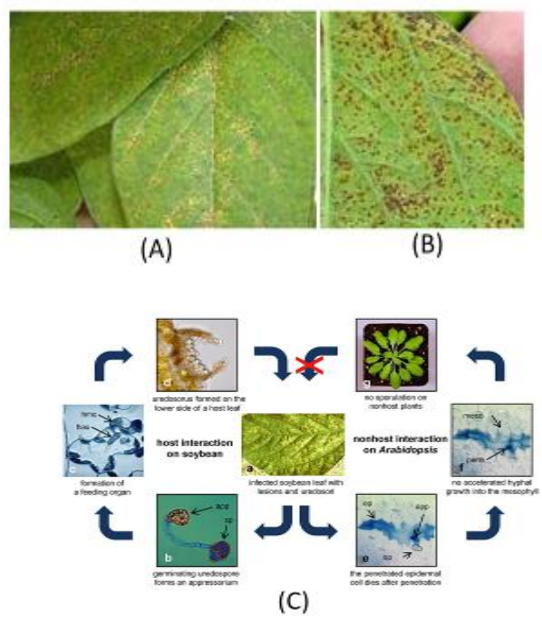


Fig.6 Collar rot of soybean showing sclerotia at the collar region of the plant Image: Borah, 2019

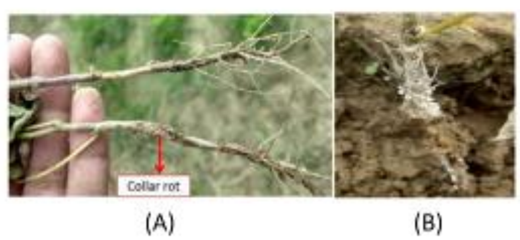
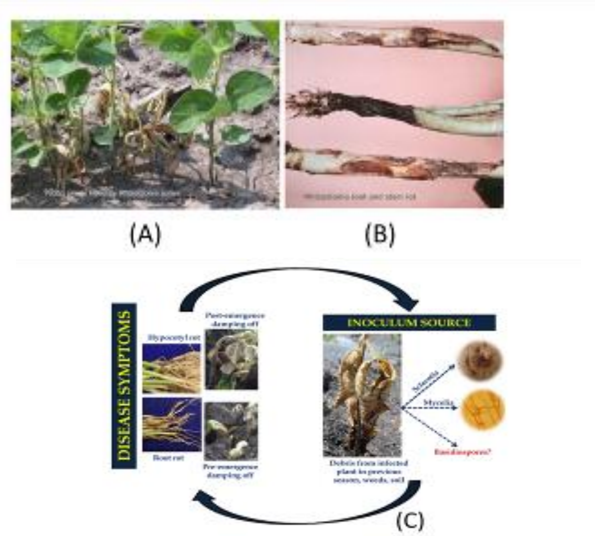


Fig.7 (A) Young plants killed by *R. solani* Image: Malvick, 2018'; (B) Rhizoctonia root and stem rot Image: Malvick, 2018; (C) Disease cycle of *Rhizoctonia solani*, Image: Ajayi-Oyetunde and Bradley, 2018



Integrated management

Charcoal rot disease can be controlled by organic amendments such as farmyard manure, neem and mustard cake (Rathore, 2000; Gupta *et al.,* 2012).

Soil fumigation with sodium methyldithio carbamate reduced populations of the pathogen on soybean residue and in the roots of plants grown in field plots (Kittle and Gray, 1982; Gupta *et al.*, 2012).

Seed treatment with captan at 3 g⁄kg or thiram at 3 g⁄kg or thiram + carbendazim (2: 1) at 3 g⁄kg or thiram + carboxin at 2 g⁄kg seed (Gupta and Chauhan, 2005; Gupta *et al.*, 2012).

In India, use of *T. viride* or *Trichoderma harzianum* as a seed treatment (4–5 g⁄kg seed) has been recommended for the management of charcoal rot in soybean (Gupta and Chauhan 2005). Seed treatment with *Pseudomonas aeruginosa* reduced infection of *M. phaseolina* by 14–100%, depending on the strain of bacterium and the variety of soybean used (Ehteshamul-Haque *et al.*, 2007; Gupta *et al.*, 2012).

Seed infection of *M. phaseolina* was completely inhibited by dipping the seeds for 5 min in ginger, garlic and neem extracts (Hossain *et al.,* 1999; Gupta *et al.,* 2012).

Future approaches in disease management

The role of RNA interference (RNAi) in the development of disease-resistant varieties and further suggested that such goal can be achieved in a more selective and robust manner with the success of genetic engineering techniques. In this regard, RNAi has emerged as a powerful tool to overcome the threats posed by viruses, fungi and bacteria.

Possibilities may be explored to utilize RNA mediated gene silencing technology like RNAi by supreesing the specific gene(s) governing susceptibility to charcoal rot in soybean for successful management of the disease (Wani *et al.*, 2010; Gupta *et al.*, 2012).

Rust disease of soybean

Soybean rust caused by *P. pachyrhizi* has been a serious disease in Asia for many decades. It appeared in Africa in 1997, and in the Americas in 2001 (Rupe and Sconyers, 2008).

Soybean rust is one of the worst soybean diseases in India and may reduce yields up to 100% depending on the time of infection, variety planted, and climate. Initially, soybean rust was restricted to the northeastern states of India and the hills of Uttar Pradesh and West Bengal prior to 1977 and caused little loss of soybean yield. Around 1993, it spread to other areas such as Madhya Pradesh, Maharashtra, Rajasthan, Karnataka, Andhra Pradesh, Himachal Pradesh, Tamil Nadu, and Kerala. It usually develops in India from the third week of July to the last week of September. This pathogen survives on volunteer and winter-sown soybean in southern India and then spreads to soybean in more northern areas during the rainy season.

The estimated reduction of yield in 2006 due to Soybean Rust in different countries are reported to be 45.3 (Argentina), 2000(Bolivia), 4720(Brazil), 6368.9(China), 78.4(India), 1.9(Paraguay), 24.59 (USA) in thousand metric tonnes (Wrather *et al.,* 2010).

Symptoms

The first symptoms of soybean rust caused by *Phakopsora pachyrhizi* begin as very small brown or brick-red spots on leaves. Often the first lesions appear toward the base of the leaflet near the petiole and leaf veins. This part of the leaflet probably retains dew longer, making conditions more favorable for infection. Lesions remain small (2-5 mm in diameter), but increase in number as the disease progresses. Pustules, called uredinia, form in these lesions, mostly on the lower leaf surface, and they can produce many urediniospores. Soybean rust urediniospores are pale yellow-brown to colorless, with an echinulate (short spines) surface ornamentation. As more and more lesions form on a leaflet, the affected area begins to yellow, and eventually the leaflet falls from the plant. Yield losses as high as 30 to 80% have been reported, but the amount of loss depends on when the disease begins and how rapidly it progresses. Besides leaves, soybean rust can also appear on petioles, stems, and even cotyledons, but most rust lesions occur on leaves (Rupe and Sconyers, 2008).

Causal organism

The plant pathogenic basidiomycete fungi *Phakopsora pachyrhizi* and *Phakopsora meibomiae* cause rust disease in soybean plants. *Phakopsora pachyrhizi* originated in

Asia–Australia, whereas the less aggressive *P. meibomiae* originated in Latin America

Domain Eukaryota;
Kingdom Fungi;
Phylum Basidiomycota;
Order Uredinales;
Class Urediniomycetes;
Family Phakopsoraceae;
Genus Phakopsora (Goellner *et al.*, 2010).

Disease cycle

Interaction of *P. pachyrhizi* with its host soybean and the nonhost plant Arabidopsis. a) Upon infection *P. pachyrhizi* forms uredia which are located mainly on the lower side of the leaf. Newly formed uredospores are dispersed by wind. b) Spores landing on leaves germinate and form an appressoria as depicted in the interference contrast micrograph. c) Intercellular hyphae form haustorial mother cells (hmc) from which haustoria (hau) develop inside mesophyll cells. d) The life cycle of *P. pachyrhizi* is completed with the formation of uredospores in uredia. e) In the nonhost interaction between the fungus and Arabidopsis uredospores germinate, form appressoria and penetrate epidermal cells as known from the host type of interaction.

Similarly penetrated epidermal cells of host and nonhost plants die, as indicated after trypan-blue staining. f) Fungal growth is restricted at the mesophyll boundary. Pictures shown in e and f are optical sections from the same infection site focused either on the epidermal or mesophyll layer. g) *P. pachyrhizi* is unable to complete its life cycle and does not sporulate on wild-type Arabidopsis plants. sp, uredospore; app, appressorium; epi, epidermal cell; hau, haustorium; hmc, haustorial mother cell; penh, penetration hypha; meso, mesophyll cell (Koch *et al.,* 1983; Goellner *et al.,* 2010).

Epidemiology

The temperature in the range of 15-25˚ C in the presence of free moisture on the leaf surface is essential for the germination of uredospore. The maximum infection was found at 20-25˚C with 10-12 hours dew period (Sharma and Gupta, 2006).

Generally, infection occurs when leaves are wet and temperatures are between 8°C and 28°C, with an optimum of 16°C to 28°C. At 25°C, some infection occurs in as little as 6 hours of leaf wetness, but 12 hours are optimal. After infection, lesions and pustules with urediniospores can appear within 7 or 8 days, and the next infection cycle is set to begin. Besides the environment, plant age affects soybean rust epidemics.

Usually, rust lesions are not found on soybean until flowering, unless there are high inoculum levels early in the season. This may be due to greater susceptibility of plants to rust as the host enters the reproductive stages, it may be because in lower parts of the canopy spores are more protected from UV radiation, or it may be because conditions in the canopy become more humid as the canopy closes. In any event, lesions can form at any growth stage, but major increases in disease do not occur until after flowering (Rupe and Sconyers, 2008).

Integrated management

There are three basic management tactics that can play a role in reducing soybean rust epidemics: fungicides, genetic resistance, and cultural practices. At present, fungicides are the only highly effective tactic, but long-term management will probably depend more on resistance, in combination with fungicides and changes in cultural practices (Rupe and Sconyers, 2008).

Future approaches in disease management

Joint combination of systemic and multisite fungicides uses and genotypes with partial resistance, this strategy might be promising in future (Juliatti *et al.*, 2017).

Biotechnological approaches like non host resistance, gene silencing are the other future approaches for disease management (Godoy *et al.*, 2016).

Collar rot disease of soybean

Root rot and collar rot are the important diseases of soybean, in Vidarbha region of Maharashtra (Khodke and Raut, 2010).

Collar rot of soybean caused by Sdewthimrolfsii, has attained the major status in many soybean cultivating areas of northern Karnataka. Survey conducted in ten taluks of northern Karnataka during kharif 2002-03 indicated maximum disease incidence of 9.80% in Dharwad and traces in Bidar and Athani taluks (Prabhu, 2003).

Symptoms

Infection occurs at or just below the soil surface. Yellowing or wilting of plants is the first symptom. Leaves turn brown, dry and often cling to dead stem. Numerous tan to brown spherical sclerotia form on infected plant material (Borah, 2019).

Causal organism

Collar rot caused by *Sclerotium rofsii* Sacc. (Anamorph) appears during seedling stage

Domain: Eukaryota
Kingdom: Fungi
Phylum: Basidiomycota
Subphylum: Agaricomycotina
Class: Agaricomycetes
Subclass: Agaricomycetidae
Order: Polyporales
Family: Atheliaceae
Genus: Athelia
Species: *Atheliarolfsii* (Teleomorph)

At least two types of hyphae are produced. Coarse, straight, large cells (2-9um x 150-250um) have two clamp connections at each septation, but may exhibit branching in place of one of the clamps. Branching is common in the slender hyphae (1.5-2.5um in diameter) which tend to grow irregularly and lack clamp connections. Slender hyphae are often observed penetrating the substrate.

Sclerotia (0.5-2.0mm diameter) begin to develop after 4-7 days of mycelial growth. Initially a felty white appearance, sclerotia quickly melanize to a dark brown coloration (Fichtner, n.d.).

Disease cycle

When the cottony growth of the fungus comes into contact with susceptible roots, leaves or stems, direct penetration occurs, but the fungus can also infect through wounds. It produces chemicals that cause soft rots in 2-4 days after infection. When the soft rots girdle the stem, the foliage wilts and death of the plant follows soon after.

The fungal growth can easily be seen with the naked eye. About 7 days after infection, the cottony growth begins to form sclerotia. These are 0.5-2 mm diameter and made up of tightly packed strands of the fungus. They are white becoming light brown as they mature. Sclerotia keep the fungus alive when there are no plants to infect. They remain alive for several years in soil or potting mix. Other than sclerotia, the fungus can survive between crops in the remains of plants. The life cycle is given below (Pestnet, n.d.).

Epidemiology

Sclerotia serve as the principle overwintering structures and primary inoculum for disease. Persisting near the soil surface, sclerotia may exist free in the soil or in association with plant debris. Those buried deep in the soil may survive for a year or less, whereas those at the surface remain viable and may germinate in response to alcohols and other volatiles released from decomposing plant material. Thus, deep plowing serves as a cultural control tactic by burying sclerotia deep in the soil. High temperatures and moist conditions are associated with germination of sclerotia. High soil moisture, dense planting, and frequent irrigation promote infection (Fichtner, n.d.).

Integrated management

Deep ploughing in summer, crop rotation with maize or sorghum, Destroy infected stubble (Kisan Suvidha).

Belkar and Gade, 2013 reported that seed treatment with Pseudomonas fluorescens @ 10g/kg of seed + Bradyrhizobium japonicum @ 20g/kg of seed + Pseudomonas striata @ 20 g/kg of seed was effective with minimum disease incidence i.e. 8.86%, 13.33%, 20.00% at 20 DAS and 17.73%, 33.33% and 40.00% at flowering, respectively.

Ansari, 2005 reported that from seed treatment with *Trichoderma viride* at 4 g/kg, *Pseudomonas fluorescens* at 10 g/kg, recommended chemicals thiram+carbendazim (2:1) at 3 g/kg, and an untreated control, Treatment with biological control agents produced more sturdy and vigorous plants than those treated with chemicals and untreated control.

Seed treatment and soil application of fungicides, bioagents and its combinations were found effective in increasing seed germination and reducing pre and post emergence mortality. Maximum germination was achieved due to seed treatment with treatment T7 (Thiram+Carbendazim + Trichoderma @ 3+1+4 g/kg) i.e. 89.15, 81.33 and 83.14 per cent in consecutive three years followed by seed treatment with Thiram + Carbendazim 3+1 g/kg (T-6) (Khodke and Raut, 2010).

Rhizoctonia root rot of soybean

Economic importance of the disease (in India and abroad)

Rhizoctonia root and hypocotyl rot, caused by *Rhizoctonia solani* Kuhn [teleomorph *Thanatephorus cucumeris* (Frank) Donk], is an important disease of soybean [Glycine max (L.) Merr.] (Zhao *et al.*, 2005).

Rhizoctonia root and stem rot is a common soybean disease that typically causes most damage to seedlings, but can also damage older plants. It can kill and stunt plants to result in significant yield losses, or the lesions can be superficial and have minimal effects on plant health. Rhizoctonia is a fungal pathogen that infects many different plants in the northern U.S., but only some types of this pathogen infect soybean (Malvick, 2018).

Symptoms

Rusty-brown, dry sunken lesions on stems and roots near the soil line are a characteristic symptom of Rhizoctonia infection. Lateral roots may be decayed.

Seedlings or older plants may develop these infections and become stunted, yellow, and may wilt. The infections can be superficial and cause no clear damage to plants, or they can girdle the stem and kill or stunt plants (Malvick, 2018).

Causal organism

Rhizoctonia solani (a soilborne fungus). This fungus has a wide host range that may include soybean, corn, alfalfa, and other crops; but only some types of this pathogen infect soybean. The most common strains of this pathogen (anastamosis groups also referred to as 'AG') that infect soybean are AG-2-2 and AG-4. Different AG groups can have different optimal conditions for growth and infection (Malvick, 2018).

Hyphal branch originates from distal dolipore septum with a characteristic constriction at the branching point. Conidia, clamp connections, rhizomorphs, and cultural pigmentations other than brown are never observed. Basidiomal structure of sexual state is characterized by a vertically branching hymenium succeeded by layers of elongated basidia slightly wider than basal hyphae.

Domain Eukarya
Kingdom Fungi
Subkingdom Dikarya
Phylum Basidiomycota
Subphylum Agaricomycotina C
Class Agaricomycetes
Order Ceratobasidiaceae
Family Cantharellales
Genus Rhizoctonia (Ajayi-Oyetunde and Bradley, 2018)

Disease cycle

Rhizoctonia solani isolates generally do not produce vegetative or asexual spores, and the role of basidiospores as an inoculum source for the seedling diseases they incite on soybean is unknown. Its survival in the soil is aided by the formation of long-lived ‘nutrient-independent propagules’ called sclerotia. For most Rhizoctonia infections to occur, sclerotia must first germinate to form mycelia that grow towards the host plant (Ajayi-Oyetunde and Bradley,2018).

Epidemiology

Rhizoctonia root and stem rot occurs primarily in early to mid summer. Infected plants typically appear in patches in a row or field. Several different conditions can favor this disease including, high soil moisture, warm soil temperatures, soil types with high amounts of organic matter, and delayed emergence. Plant stress from herbicide or hail injury or the soybean cyst nematode (SCN) also may favor this disease (Malvick, 2018).

Integrated management

Planting resistant cultivars would be an effective and environmentally sound strategy to minimize economic losses from this disease (Zhao *et al.*, 2005).

Encourage seedling health with good agronomic practices and the use of high quality seed. Avoid or reduce plant stress, for example from herbicide injury and SCN infection. Crop rotation and tillage may be of value where disease has been severe. Some seed treatment fungicides may reduce Rhizoctonia infection for a few weeks after planting. Soybean cultivars may have different levels of tolerance, but none are fully resistant to this disease (Malvick, 2018).

In conclusion: the correct identification and early detection are critical in the proper management of soybean diseases. We have discussed about economic importance, symptomatology, causal organism, disease cycle, epidemiology and integrated management of some economically important fungal diseases of soybean *viz.* seed and seedling diseases of soybean, Pod blight, Rhizoctonia aerial blight or web blight, Charocal rot, Rust disease, collar rot and Rhizoctonia root rot disease of soybean. Seed and seedling diseases of soybean are more prevalent when wet season follows planting.

The disease can cause economic loss due to weak and less vigorous plants leading to poor crop stand establishment. Rhizoctonia aerial blight disease can cause significant yield loss in soybean when conditions favor disease development. The charcoal rot disease is more severe when plants are under stress from moisture or nutrients, excessive plant densities, soil compaction, improperly applied pesticides, nematodes or other pathogens. Although good progress in research on charcoal rot in soybean has been made during the past decade, still systematic studies are required to bridge the gap in knowledge of physiological variability and pathogenicity. Rust fungi, being a biotrphic pathogen, requires integrated management approach, owing to its high yield loss. If host is available, it can occur all the year round and it occurs in major soybean producing regions of the world. The fungus *Colletotrichum truncatum* (Schwein.) causing pod blight causing severe economic loss as pods get heavily infested, which requires an integrated management approach. *Rhizoctonia bataticola* and *Sclerotium rolfsii* causes root rot and collar rot in Soybean and is considered as economically important diseases of Soybean.

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How to cite this article:

Munmi Borah and Bishakha Deb. 2020. A Review on Symptomatology, Epidemiology and Integrated Management Strategies of Some Economically Important Fungal Diseases of Soybean (*Glycine max*). *Int.J.Curr.Microbiol.App.Sci.* 9(11): 1247-1267.
doi: https://doi.org/10.20546/ijcmas.2020.911.147