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Review Article

Cyst Nematode (*Heterodera glycines*) Problems in Soybean (*Glycine max* L.) Crops and Its Management

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Soybean is a leguminous crop that originated from Southeast Asia, and it was domesticated in the northeastern parts of China. Recently, it has been highly produced in the United States of America, Brazil, and Argentina for cooking oil, protein, fiber and for the manufacturing of plastics, lubricants, candles, varnishes, soaps, and biodiesel. Nevertheless, in warm, moist, sandy soil conditions, its production is highly challenged by soybean cyst nematodes (*Heterodera glycines*). It caused more than 30% of soybean yield loss either alone or associated with other soybean pests under suitable environmental conditions. The second-stage juvenile (J_2) of this pest inserted its stylet and penetrated into the cells to get its nourishment, shelter, and reproduction site on the soybean roots. Economically, the damage it caused was highly important because it had a wide host range and lacked adequate management methods. Hence, the reason behind the writing of this chapter is to explore the different published scientific papers related to soybean cyst nematode's economic importance, distribution, symptoms, biology, life cycle, interaction with other pathogens, different management approaches, and its prospects. This chapter shall also embrace the advanced biotechnological innovations that help in achieving effective soybean cyst nematode management that will mitigate its infections in soybean production and will also serve as an asset for the researchers. This review chapter, in addition, plays a vital role in exploring necessary information concerning soybean cyst nematode management.

1. Introduction

The soybean is a leguminous crop that originated from Southeast Asia, and it was domesticated in northeastern China. However, for the moment, the United States of America (USA), Brazil, and Argentina are the leading producers of soybean by producing 81.40% of the total world production [1], while China is the leading importer of soybean by importing more than 60% [2]. Globally, 166.33 million metric tons of soybean were estimated to be imported in 2020/2021 across the countries. Among them, China alone was partly importing approximately 100 million metric tons [3]. It is widely grown for its food and feed values, such as cooking oils, proteins, fibers, and for manufacturing of lubricants, plastics, varnishes, candles, soaps, and biodiesels [4]. Nevertheless, its productions and productivities are limited by a wide range of plant-parasitic nematodes [5]. Soybean parasitic nematodes are most severe, problematic, and destructive in warm moist sandy soil conditions than the other soil texture. There are more than a hundred nematode species that are associated with the soybean. Out of these, the root-knot nematode (*Meloidogyne* spp. e.g., *Meloidogyne javanica* and *Meloidogyne incognita*), cyst nematode (*Heterodera glycines*), lesion nematode (*Pratylenchus brachyurus*), and the reniform nematode (*Rotylenchulus reniformis*) are the most important soybean parasites [5–9]. They cause injury and damage by feeding the cell contents and interfering with the soybean's normal growth and development by inserting their stylet in their feeding sites.

Surpassingly, among the above-listed nematode species, the severe problem is caused by the soybean cyst nematode (*Heterodera glycines*). It caused more than 30% of soybean yield loss even without manifesting any symptoms to us under suitable conditions [10]. In estimation, the soybean yield lost by this pest could be over 3.4 million tons (125 million bushels) in America alone between 2006 and 2014 years that worth over 1.1 billion dollars annually [11, 12].

The yield loss caused by the soybean cyst nematode is not limited to soybean because this pest has also a wide host range [13]. It is reported from 23 plant families, although the Fabaceae family is the most preferred host for soybean cyst nematode [14, 15], followed by Caryophyllaceae and Scrophulariaceae [15]. Frankly, it attacks numerous legumes crops and wide weed species. However, it highly prefers soybean.

The reasons why the cyst nematodes continue to be great problems in soybean production are because of their wide host ranges and lack of adequate management methods. Hence, the reason behind the writing of this chapter is to explore different scientific papers published concerning the soybean cyst nematode. It will also be an asset for the researchers who are working in this field. The contents of this review chapter are focused on the soybean cyst parasitic nematode's economic importance, distribution, symptoms, biology, life cycle, interaction with other pathogens, different management methods with advanced and recent approaches, and future prospects because understanding them plays a vital role in the sustainable production and cyst nematode management in soybean.

2. Overview of Soybean Cyst Nematodes

2.1. Economic Importance. Globally, 10% to 15% of soybean yield is lost because of soybean parasitic nematodes and is worth nearly $78 billion annually. Wrather and Koenning [16] reported that the soybean cyst nematode alone led to 1.9 to 3.5 million tons of yield losses per year. It is because of the fact that soybean demand has increased, whereas its production is limited by various soybean cyst nematodes worldwide, however, following the increase of the human population, a protein-rich crop like soybean production is an option less to feed and reduce food insecurity [17]. Nevertheless, the soybean yield loss is not limited to cyst nematodes alone. Occasionally, it is also attached by various soybean nematodes, such as northern root-knot, lesion, lance, dagger, stunt, pin, and spiral. The root-knot nematodes are categorized under the top 10 of the most important soybean pathogens [18]. This challenge has occurred highly following the lack of crop rotation, the intensive use of soils, monocropping, and the lack of appropriate quarantine [5]. The inefficient management of these challenging factors hindered the sustainable production of the soybean crop worldwide. Furthermore, soybean yield loss caused by the soilborne nematode varies with species, population density, the susceptibility of the cultivars, management practices, cropping systems, soil temperatures, soil texture, and the fertility status of the soil. The degree of its infection is high in mono-cropping systems, warmer soil temperatures, sand soil texture, and infertile soil. Thus, finding and applying suitable management methods of this and its associated pests in soybean production is unquestionable.

2.2. Distribution. The soybean cyst nematode is an obligate, sedentary, and devastating pest that resides in many soil types. It was reported for the first time in Japan in 1915, followed by Korea in 1936, Manchuria in 1938, the United States in 1954, and Egypt in 1968 [19]. Generally, it is distributed worldwide [5, 20]. They were reported mostly from Asia, Northern and Southern America, and European continents [15]. However, in the rest of the continents, it is less problematic and is less reported. For instance, in Africa, it is reported from Egypt only by Subbotin et al. [21]. It might be because its problem is not well-known, or it might not have been explored widely. Similarly, in Australia, its severity is not yet reported [22]. It indicated that its distribution, occurrence, severity, and prevalence are not the same and not studied well across the locations. The soybean cyst nematode distribution varies with the variation of environmental conditions, crop production practices, previous crop disease history, and varietal susceptibility of the soybean crops [10]. The damage it caused is less in fertile soil. It, likewise, survives in the soil as eggs, called cysts, within dead females, and it can survive for at least eight years even in the absence of a soybean crop.

The nematode travels long distances by irrigation water, wind, rain, animals, soil, host plants, seed harvested from infested fields, and other natural processes. However, it moves by a short distance in the soil once it establishes itself in its habitat areas. In addition, after it is dispersed to noninfested areas, it would be established itself rapidly because of the lack of natural enemies, awareness, cultural practices, short generation cycle per growing season, and high fecundity rate [15].

2.3. Symptoms. In contrast to root-knot nematodes, the soybean cyst nematodes do not form a gall on soybean roots. However, they form small white to yellow cysts andare lemon-shaped after being infected by females on the exterior of the roots. The old soybean cyst female nematodes look darker in color and cyst after they die [8]. The noticeable of its symptoms on the host plants are stunting, chlorotic foliage, yellowing, and apparent death in certain areas of a field. These symptoms usually occur in patches after six weeks of their emergence. The infected root systems of a soybean plant by this pest are developed poorly [23]. Hence, their nodules' ability to fix nitrogen is low (https://cropprotectionnetwork.org). Furthermore, the parasitic nematode symptoms imposed on soybean are stunting growth, wounding, yellowing, standing loss, early spotting, death during blooming, and pod filling. However, sometimes, it is difficult to identify the symptoms commonly associated with soybean cyst nematodes since its damage is more or less similar to that caused by manganese and potassium deficiencies, spider mite infestations, herbicide injuries, low spots, drought stresses, viral pathogens, and soil compactions. The only visible sign on the infected soybean is the presence of white or yellow female cysts on the roots.

The symptoms caused by species were identified by the symptoms of the cyst nematodes by forming stunting, wilting, yellowing, galling or swelling, and death appearance if severely infected [24, 25], while the lesion nematode infection was identified by symptoms, such as stunted patches, chlorotic (yellowish) appearance, reduced size, and number of leaves.

2.4. Biology & Life Cycle. The soybean cyst nematode has four juvenile stages. Juvenile one begins in the egg and is interposed by molting. During its second juvenile stage (J_2), it begins to migrate into the host plant`s root vascular cylinder through the soil in water films that surrounds the soil particles. At this site, it forms a permanent feeding cell called syncytium by causing the host plant's resistance to fail [26, 27]. Once it forms this site, it becomes sedentary [27]. This feeding site provides basic needs like nutrients and shelters for its growth and development. The penetration of juveniles into the soybean causes necrosis at the site of its entrance [28].

The established feeding sites look swollen, and eventually, the females burst through the root tissues [29]. It often causes the wilting of the roots and appears water deficient in the soil by forming exudates and exfoliates [20]. They result in stunting, yellowing, poor plant health, and finally, they result in yield loss.

In the third juvenile stage (J_3), sexual dimorphism usually becomes prominent before it enters the fourth stage (J_4). In the J_4-stage, it develops into an adult. The matured female adult is identified from the male by having a large body size and looks swells to lemon-shaped. The female is fertilized by a vermiform male. She might lay several hundred eggs. The eggs are deposited in an external gelatinous matrix called an egg mass [27]. When the female dies, her body becomes a cyst. This cyst is used to protect the eggs in the soil from desiccation, brokenness, and eggs encased when there are unsuitable environmental conditions [27, 30]. If there are suitable nutrients, soil temperature, and locations, its life cycle can be completed within three to four weeks [27, 31]. The optimum conditions that favor the cyst nematode growth and development are warmer soil temperature (24–32°C), adequate soil moisture, and the presence of host plant exudates [32–34], and soil pH ranging between 7.0 and 8.0. The suitable conditions for the occurrence of soybean cyst nematode includess semiarid (mostly) and temperate conditions when the environmental temperature ranges between 15°C and 33°C [15].

2.5. Interaction with Other Pathogens. The soybean damage caused by parasitic nematodes depends on the kind and number of nematodes present, suitable environmental factors (e.g., temperature, moisture, and soil type), and other organisms present (e.g., wounding the roots of soybean can lead to possible interactions with other plant diseases causing agents). Soybean parasitic nematodes interact with a lot of soybean pathogens. The intraspecific and interspecific interactions of soybean cyst nematodes with each other and other pathogens cause more damage than the sum of the damages caused by each species of pathogen. These interactions mostly occur on the feeding sites of the plant tissues that result in wounding, which may provide the entering sites to other pathogens. However, more specific associations can result in additive, synergistic, or antagonistic responses by the host plant. The soybean cyst nematode (*Heterodera glycines*) forms a complex disease in soybean with a fungus (e.g., *Fusarium solani* f. sp. glycines) that causes a sudden death syndrome [35]. Several cyst nematode species interact with *Fusarium* wilt species, causing the wilt disease to be more severe than that in the absence of the nematode, e.g., *Globodera tabacum* on tobacco, *Heterodera cajani* on pigeon pea, and *H. glycines* on soybean. In South Africa, the root-knot and lesion nematode densities were increased in the soybean fields [17, 36], and there was an increase in the disease complexes in association with other soilborne pathogens, such as *Fusarium brasiliense* (soybean sudden death syndrome) [37]. Globally, they were contributing to a substantial yield loss of soybean up to 80% under field conditions [38]. Generally, the development of diseases that occurred in these interactions is associated synergisticallyon the roots of soybean. The damage imposed by interspecific interactions of pathogens is not uniform. Besides this example, only limited examples of interactions between the cyst nematodes and root-rot fungi *(Rhizoctonia spp.)*have been documented. But, their presence is mostly found in association with other pathogens; for example, *Globodera rostochiensis* on potato, *Heterodera avenae* on wheat, *H. glycines* on soybean, and *Heterodera schachtii*on sugar beet are the typical examples.

Meloidogyne incognita has been known to form disease complexes with fungal pathogens, such as *Rhizoctonia solani* (causes seedling blight) [39–41], *Fusarium graminearum* and *Fusarium equiseti* (called the wilting fungi) [42], *Meloidogyne hapla*, and *Agrobacterium tumefaciens* [43]. Similarly, the high populations of *Pratylenchus* spp. were also found in soybean plants with *R. solani* in the USA [44]. Their infection was higher in sandy soil places than in other soil textures.

The reniform nematode is an obligatory soybean parasitic nematode that probably threatens its yield [11]. It tends to occur in sands and silt loams. However, the soybean cyst damage was greater in lighter soils [7].

Meloidogyne species infected the roots during their second juvenile stages (J_2). They are forming the galls on the roots [25] and changing the soybean nodules from pink to greenish after infected [45]. This change can interfere with the anatomical and physiological functioning of the roots, such as the translocating of water and nutrients to the upper and lower parts.

Lesion nematodes (e.g., *Pratylenchus*) are obligate biotrophic and migratory endoparasites. They form lesions and necrotic tissues (e.g., grayish, brownish, or blackish) on the surface of the infected roots of soybean [25]. Infections can occur along the entire length of the root, with damage done to the epidermis, cortex, and root endodermis [46]. However, the necrotic root tissue caused by the lesion nematodes can be confused with the damage caused by other pests.

The symptoms of *Pratylenchus* infection are highly mimicking with other soilborne diseases and insect pests damage [47]. The soybean damaged by this pest responded with stubby and discolored roots. The infection of root-knot and lesion nematodes in soybean might be complex because of their association with various phytopathogenic bacteria and fungi.

The economic effects of these interactions vary, however, their effects can be important in high value, major crops. The relationship of cyst nematodes with *mycorrhizal fungi* has focused on the arbuscular mycorrhizal fungi *(Glomus spp)* [48, 49]. The importance of this group is to enhance crop yields in nematode-infected soil by rendering nematode-susceptible plants more tolerant to these pathogens or by the suppression of nematode infections and reproduction.

Nematode communities usually contain many species that potentially interact with each other. In most instances where cyst nematodes are present, they are antagonistic to other plant-parasitic species. Its examples include *G. tabacum* and *Pratylenchus penetrans* on tobacco, *H. avenae* and *Pratylenchus neglectus* on wheat, *H. cajani and Helicotylenchus retusus* on pigeon pea, and *H. glycines* and *Meloidogyne incognita* on soybean. Very few examples of neutral or stimulatory responses between the cysts and other nematode species have been documented [50]*Glomus fasiculatum* can parasitized the eggs of *H. glycines* on soybean and *H. cajani* on cowpea [49, 50].

The potential interactions between the cyst nematodes, bacteria, insects, and other pests have received only limited study, although the cyst nematodes have a wide host range and are associated with many organisms that live in a wide range of habitats [49]. Therefore, developing effective management strategies against these pests requires rigorous evaluations of their suggested management methods in their natural habitats. Soybean cyst nematodes can cause diseases to host plants by themselves; most of them live and operate in the soil and host plant roots, where they are constantly surrounded by fungi and bacteria to cause diseases in an association. In many cases, the association between soybean cyst nematodes and other pathogens is becoming a part of an etiological complex. Their associations have resulted in combined pathogenic negative effects that appear to be far greater than the sum of the damages they caused individually.

The several nematodes–fungus disease complexes known by humans are *Fusarium wilt, Verticillium wilt, Pythium,* damping-off, *Rhizoctonia, and Phytophthora* root rots. They were increasing the incidence and severity of root-knot, lesion, sting, reniform, burrowing stunt, and cyst nematodes infections. The bacterium also produces coryne toxins, which are among the most potent toxins produced in nature, and they cause lethal neurological convulsions in most domestic animals fed with infected grasses and seeds. In these case, the role of nematodes are vectoring bacterium from plant to plant by facilitating its entry into the host plant. However, it is not well-known whether coryne toxins have any negative effects on the nematode.

Much better known are the interrelationships between the nematodes and viruses. Several plant viruses, such as grapevine fanleaf, tomato ringspot, raspberry ringspot, and tobacco rattle are transmitted through the soil using nematode as vectors. All these viruses, however, are transmitted by only one or more of the five genera of nematodes*: Xiphinema, Longidorus, and Paralongidorus* transmit only polyhedral viruses, which include most of the nematode-transmitted viruses, whereas *Trichodorus* and *Paratrichodorus* transmit two rod-shaped viruses, namely the tobacco rattle virus and pea early browning virus. These nematodes can transmit the viruses after feeding on the infected plants in 1 hour to 4 days. The nematodes remain infective for a period of 2 to 4 months and sometimes even longer. All stages of nematodes, i.e., juvenile and adult, can transmit viruses. Although nematodes can ingest and carry several plant viruses. They can only transmit certain of them to healthy plants, which suggests that there is a close biological association between the nematode vectors and the viruses they can transmit.

3. Soybean Cyst Nematode Management Strategies

3.1. Cultural Practices. Growing soybean under suitable environmental conditions can increase its healthiness by minimizing the damage caused by parasitic soybean cyst nematodes. It is achieved by proper management, such as reducing stress, maintaining optimum soil fertility, and controlling host weed and other plant pathogens in the growing farmland. However, it is impossible to eliminate parasitic nematodes from the farmland after they are established. Nematodes are soil-dwelling organisms that are categorized into entomopathogenic, free-living, and plant-parasitic nematodes [51]. Hence, it was considered to be one of the most soybean parasitic nematodes in causing yield loss [52].

It is not an easy task to control soybean cyst nematodes since they have wide host ranges [53]. Nonhost or resistant crop rotation with susceptible host crops is very important to reduce its population densities to certain entities [54]. Planting tolerant varieties in a rotational scheme would reduce the yield loss more than the nontolerant varieties [55]. For instance, Faghihi [56] reported that a one-year rotation with nonhost crops [such as alfalfa (*Medicago sativa*), maize (*Zea mays*), sorghum (*Sorghum bicolor*), barley (*Hordeum vulgare*), and oat (*Avena sativa*)] in the absence of weeds could reduce 55% of soybean cyst nematode population in Tennessee and Indiana/Illinois, USA and Ontario, Canada. In Nigeria, it has been reported that *Tagetes erecta* and *Crotalaria juncea* have the potential against the population density of *M. incognita* in soybean fields [57]. Riga et al. [33] also reported that the residues and root exudates of *Lespedeza capitata*, *Lespedeza intermedia*, *Lespedeza hirta*, *Lolium multiflorum*, *Lolium perenne*, *Lupinus perennis*, *Melilotus officinalis*, *Medicago sativa*, *Trifolium pretense*, and *Pisum sativum* have potential in the reduction of *Heterodera glycines* juveniles in the soil if they are planted before the season of soybean planting. This report finding also indicated that among the evaluated of these plants, *Lolium multiflorum* was the most effective against the juveniles of *H. glycines.* It acted by increasing the egg hatching of the nematode in the absence of host plants by depleting the reserved lipid of the juveniles and inducing them to the parasitism of nonhost plant residues. The double cropping of soybean with wheat sown in strips has the potential in reducing the SCN egg densities under field conditions [14]. It was reported that soybean with forage crops—such as *Andropogon gayanus* (genotype Planaltina), *Cajanus cajan* (genotype Caqui), and *Macrotyloma axillare* (genotype Java)—Crotalaria, and Radish oilseed reduced the population densities of *P.* brachyurus in Brazil [58, 59].

Managing the alternative species of host weed in the field of soybean reduced the cyst nematode [14]. During the movement of farm equipment, materials, and tools across the farmland, sanitation can be effective in preventing the soybean cyst nematode from spreading to uninfected fields. The application of animal waste products like poultry manure to the maize farm before sowing soybean is reported to be effective against soybean cyst nematodes [60].

The initial numbers of soybean cyst nematodes available in the soil determine the degree of damage to soybean during its growth. Preventing the spread of this pest to noninfected areas can be reduced their initial numbers in the soil. These activities are important in increasing soybean yield [52]. Thus, mechanically disturbing the infested soil by tilling and removing the infected root and other plant debris from the farmland can minimize their numbers and their dispersal to noninfested areas. It can be achieved by avoiding the utilization of the seed harvested from the infested fields and bin-run seed, reducing the wind or water transport of soil and debris from the infested to noninfested fields [61], and applying potassium fertilizer [62] could decrease the occurrence of SCN with the activation of phenylalanine ammonia lyase and polyphenol oxidase expression by releasing it to cinnamic, ferulic, and salicylic acids.

3.2. Host Plant Resistance. The resistant cultivars are the recent strategy that needs to be developed in the management of soybean cyst parasitic nematodes. It can be achieved by RNA interference (RNAi) by applying functional genomics for soybean cyst nematode management. RNAi-induced suppression of numerous genes is essential for soybean cyst nematode development, reproduction, and populations to manage the damage they imposed on soybean crops. Furthermore, suitable and effective gene targets for silencing are achieved by employing functional genome sequencing and transcriptome. The interactions between nematodes and soybean roots can be measured by microarrays to know their transcripts. In addition, laser capture microdissection is used to dissect the feeding sites (syncytia) of the cyst nematode precisely for studying gene expression, specifically in syncytia. Furthermore, the use of small RNA sequencing techniques can provide information on how to elucidate the small RNA regulatory mechanisms in host plants and specify gene silencing using artificial microRNAs for improving the potential of targeted genes as a strategy for nematode management [63].

Host plant resistance is a genetically heritable quality of a cultivar to counteract the activities of soybean parasitic nematodes by inhibiting/limiting its penetration, feeding, development, and reproduction. Host plant resistance has always been more favored choice than other management methods of soybean cyst nematoides. This method is also economically feasible and eco-safe to use. Plant varieties usually have high, moderate, low, or no levels of resistance to a target nematode species [47]. In the USA, the soybean genotype plant introduction (PI) 567516C through the breeding line was identified as being an excellent source of resistance against *M. incognita*, *H .glycines,* and *R .reniformis* nematodes [64, 65]. In addition to this, there are sources of soybean cyst nematode resistance that have been widely used, for instance, the accessions PI 88788 and Peking can be mentioned commonly. In addition, PI 90763, PI 209332, PI 437654, and Hartwig can be used as sources of soybean cyst nematode resistance [66–68]. These are used to shift resistance in the soybean cyst nematode by creating a narrow genetic base. These resistant germplasms are as follows: 1) PI 88788-type requires high-copy numbers of resistance to *Heterodera glycines* 1 (rhg1) allele (haplotype or rhg1-b), and 2) Peking-type requires both low-copy numbers of a different rhg1 resistance allele (rhg1-a) and a resistant allele at another locus, Rhg4 [31]. Liu et al. [69] showed that the gene encodes a serine hydroxymethyltransferase, an enzyme that is responsible for the interconversion of serine and glycine and cellular carbon metabolism. Hence, the alleles of *Rhg4* conferring resistance to soybean cyst nematodes by alteringa key regulatory property of enzymes in genetic polymorphisms. Genetically, it is achieved by improving the minor horizontal resistance of the soybean crops. For instance, the incorporation of the novel resistance quantitative trait loci of *Glycine soja* could increase the durability of SCN-resistance, especially if major gene resistance breaks down [70]. Liu et al. [71] demonstrated that rhg1-a Peking-type GmSNAP18 is sufficient for resistance to SCN if it was combined with Rhg4 than PI 88788-type GmSNAP18.

According to McCarville et al. [72] conducted research report between 2001 and 2015 indication, almost all SCN-resistant soybean varieties contain SCN resistance genes after the plant introduction (PI) 88788 and Peking in Iowa State, while soybean yield and virulence of SCN populations were increased.

Host plants activate their innate immune system to defend themselves by conferring basal and host-specific defense responses, depending on the plant genotype. Basal defense is dependent on the detection of pathogen-associated molecular patterns by the recognition of the available receptors. In this case, the host-specific defenses mainly rely on the activation of canonical and noncanonical genes. However, it is limited to utilize due to the cyst nematode having the capacity to develop the host genetic selection to disfavor the the emergence of the host virulence. Hence, it required the knowledge of how they were involved in getting host-specific resistance by mediating the resistance genes and quantitative trait loci against soybean cyst nematodes. But it is limited to use, due to the identified resistance traits to cyst nematodes in various crops were often unknown clearly [13].

Resistant varieties are an economical means of managing soybean cyst nematode. However, to be effective, it must be matched to the race of this nematode, and the resistant varieties are still grown in a rotation with nonhosts or susceptible varieties. Resistant cultivars limit the reproduction of soybean cyst nematodes but are not yet effective at all [60]. The accumulation of local glyceollin in soybean cultivar roots is used to resist the soybean cyst nematode after being primed for 24 hours [73]. Because they are activating a memory mechanism that leads to a faster and stronger defense after subsequent attachment to a pathogen [74]. The inhibition of syncytium formation in the susceptible and resistant soybeans that can increase their resistance ability include the features of wall perforations, increased cytoplasm density, and increased abundance of the endoplasmic reticulum [75]. The disruption of the syncytium formation in susceptible host plants can affect the maturity of nematodes. It can be achieved by disturbing the accumulation of the hypertrophy of nuclei in the rough endoplasmic reticulum during the early and late stages of infection.

Biotechnologically, researchers are also exploiting the natural resistance gene pools present in the host plant or are employing synthetic forms of resistance, such as those based on the disruption of the feeding cells that express the specific proteins or peptides of gene silencing [76]. It can be an effective resistance by transferring the natural nematode resistance genes present in the gene pools of crop species and their relatives. The important desirable resistance genes that have the potential of exploiting resistance are processed, identified, combined, and targeted by marker-assisted selection for artificial introduction or transgenic to the soybean.

3.3. Biological Control. A biological control refers to the use of predators, parasitoids, and microbial agents to reduce the population densities of target nematode pests. For instance, entomopathogenic fungi are also known as nematode-destroying fungi. It has potential against soil-dwelling nematodes in general and SCN in particular. They are promising candidates for the control of SCN and play a great role in increasing the production systems of the organic soybean [82]. Their mode of antagonizing the target soybean cyst nematodes might vary with their life cycle. Nematode-trapping fungi produce special hyphal structures to trap the vermiform nematodes found in the soil, while others, such as *Hirsutella rhosilliensis* and *Hirsutella minnesotensis* [83, 84], are endoparasites. Others are also directly parasitizing SCN embryos or juveniles in eggs within the cysts or egg masses [85, 86].

The experiment conducted on artificial media in Waseca Minnesota, USA indicated that the SCN eggs and juveniles were parasitized and inhibited by cyst mycobiome secretion metabolites that could grow quickly to make copious amounts of spores [82, 85, 87]. The fungal spores overwinter in the soil and have the capacity of parasitizing the developing juveniles in the eggs' cysts or egg masses [85, 86]. They secrete secondary nematicidal metabolites with bioactivity against nematodes. They are also considered the unexplored candidate resource for novel bio nematicides [88]. Furthermore, the natural antagonistic entomopathogenic fungi are promising candidates for the control of soybean cyst nematodes [82]. Naturally, it was widespread in soil and was antagonistic of nematodes. Environmentally, they are safe and inexpensive to purchase than nematicides [20]. These fungi can parasitize and kill nematodes at all stages of their life cycle by producing either adhesive (e.g., hyphae, branches, knobs, and nets) or nonadhesive trapping such as constricting and non-constricting rings for entering, dissolution of enzymatic eggshell, and degrading juvenile cuticle by secreting toxins to the cyst nematode body [20]. Saxena [20] reported that entomopathogenic fungi were divided into four main groups based on their mode of capture and infection mechanisms: (1) trapping nematode, (2) endoparasitic, (3) egg- and cyst-parasitic, and (4) toxin-producing fungi.

The soil fungi of the genus *Ilyonectria sp.* and *Purpureocillium sp.* significantly reduced the SCN reproduction on a susceptible soybean variety (Sturdy) after inoculated to SCN eggs when compared with untreated control [89]. These results are, in some cases, more effective than several commercially available biological control products (e.g., Melocon® WG®, DiTera®, and Poncho/VOTiVO®) under low levels of nematode infection. The *Purpureocillium* sp. isolates were indicated to be the strongest and most consistent against SCN nematode reproduction similar to Melocon® WG at 40 to 400-fold lower spore inoculum concentrations and even at higher levels of nematode infection. However, this isolate showed high degree of efficacy against SCN egg counts than Melocon® WG in the greenhouse.

Poveda et al. [90] also reported that the resistance inducers of the filamentous fungi of the genus Trichoderma—mycorrhizal and endophytic fungi—are mainly used as biological control agents against nematodes by activating hormone-mediated (e.g., salicylic and jasmonic acid, strigolactones, and among others) plant-defense mechanisms. They also have the ability of parasitism, antibiosis, paralysis, producing lytic enzymes, and minimizing competition by providing higher nutrient and water uptake to the plant by modifying the root morphology, and/or rhizosphere interactions. However, only a few nematophagous/bionematicide fungi are commercially available (e.g., DiTera, Valent BioSciences, and Libertyville, IL are obtained from the plant pathogen *Myrothecium verrucaria*) [91]). But they are being limited to use easily for biological control agents. Because their ability to sporulate, formulation, application methods, efficacy consistent, and activity retention during transport and storage.

Kang et al. [92] reported that the soybean cyst nematode had not infected the soybean roots after treated by bacteria (*Bacillus simplex*) as highly as the untreated roots. However, it consisted of lower levels of glucose, fructose, sucrose, and trehalose. Such types of sugar are important in reducing the suitability of the host crops to cyst nematodes. This sugar works by increasing the levels of melibiose, gluconic acid, lactic acid, phytosphingosine, and noradrenaline in soybean roots. The soybean treated with *Bacillus simplex* has lower levels of oxoproline, maltose, and galactose and has high resistance ability than the untreated one. It also promoted nematocidal activity. This report agrees with the report of Kang et al. [93], who indicated that *Bacillus simplex* strain Sneb545 of the rhizobacterium promotes soybean resistance to SCN by promoting plant growth. This study also confirmed that a combined metabolomic and transcriptomic could be used against SCN as a biological mechanism of defense of the Sneb545-treated soybean than nontreated soybeans under SCN infection. This is might be due to the analyzed transcriptomic was resulted in a higher accumulation of nematicidal concentration metabolites such as methionine, 4-vinyl phenol, palmitic acid, and piperine than untreated soybeans. This report also validated that the coregulation of gene expression and metabolites in soybean plants has negative impacts against the soybean cyst nematode. These substances have consisted of unsaturated fatty acid that occurred in metabolism and biosynthesis that participated in the inducing of Sneb545 soybean response against SCN.

It is a fact that rhizobacteria are used as the biocontrol agents of soilborne pathogens that colonized roots, and they serve as plant growth-promoting bacteria. It is obtained from microcolonies or biofilms and occurred in root exudation, and it enhanced the disease resistance capacity of the host plants [94].

Entomopathogenic bacteria are also effective against soybean cyst nematodes. These are achieved after they produce antibiotic toxins and enzymes that kill the nematodes. In addition to killing, they also provide systemic resistance in the host roots. They are found in the nearby rhizosphere by developing microbial antagonism. It competes for nutrients and space, and it parasitizes the nematodes. These bacteria are isolated from soil, plant tissues, infected cysts, and the eggs of nematodes. Based on their mode of parasitism, the entomopathogenic bacteria might be grouped into parasitic, nonparasitic, opportunistic parasitic, rhizobacteria, cry protein-forming, endophytic, and symbiotic bacteria [95].

The bacterial biological control agent of SCN by *Pasteuria nishizawae* in Clariva Complete seed treatment (e.g., including Syngenta, Syngenta Headquarters, Wilmington, DE), in combination with row spacing at 38 cm and seeding rate at 185,250 seeds ha^{-1}, was less effective against SCN reproduction than Cruiser Maxx Vibrance [96].

3.4. Chemical Control. Chemical control refers to the use of synthetically or naturally derived chemicals to cause death or disruption of the nematodes and their behavior [97]. Chemically, nematicides, such as carbofuran, furfural, oxamyl, organophosphates, and halogenated compounds, were used to combat plant-parasitic nematodes [17, 98–101]. In the research trials, the seed treatments by ILeVO (BASF) and BIOst (Albaugh North America) indicated the yield increment by suppressing the soybean nematodes, however, these pesticides require further investigations to explore whether they are effective under multiple locations of trials [60]. The use of nematicides can also control the soybean cyst nematode. However, it is not feasible because they are eco-unsafe [52].

3.5. Integrated Soybean Cyst Nematode Management. Crop rotation and planting resistant varieties alone are not independently effective against SCN. Commercially, seed treatments with biological agents are available to protect against yield loss from SCN. The rotation of soybean with brown mustard or camelina reduced the number of soybeans than Crambe [102]. The sowing of soybean varieties with genomic resistance to the cyst nematode by sowing in rotations is effective in reducing this pest. The alternative methods, such as no treatment, application of nematicides to the soil, resistant cultivars, and rotation to maize, can reduce the population density of cyst nematode [103]. Noel [104] findings also indicated the soybean that is genetically resistant to *Heterodera glycines* has coupled advantage over crop rotation. Thus, it is important to integrate with a biological control. Generally, *Heterodera glycines* can be tackled by increasing genetic diversity of soybean cultivars. The genetically resistant cultivars of soybean against SCN can be improved by using the molecular marker selection in breeding methods. Because the variety improved in such method might have been provided a stable novel gene for diversification and resistance cultivars of soybean against SCN [105].

4. Future Prospects

In general, the soybean cyst nematode is the production constraint of soybean. Therefore, concrete management is required particularly for resource-poor farmers. For this purpose, different management technologies have been developed in different pieces of research. This strategy's success is based on choosing resistant varieties, using appropriate cover crops, and applying antagonistic green manures and residues of crops that can contribute to the development of suppressive soybean cyst nematodes in soils and sustainable agricultural practices. Suppressive soils can keep nematode levels below the damage threshold density without the excessive use of chemicals.

At the farmers' level, the soybean cyst nematode is a serious problem in general and a poor resource in particular. Therefore, further research on its ecological distribution, species identification, information on economic importance, resistance variety identification, and crop system management will be expected to be developed to manage this pest by using various technologies, such as cultural, biological, chemical, screening the resistant soybean varieties, and IPM. Therefore, research recommendations on soybean cyst nematode management should be developed based on indigenous knowledge, breeding methods, biotechnological innovations, local conditions, and the species of soybean cyst nematode. To implement effective management options, farmers should be made aware of the importance of cooperation among themselves in a region. Local support of adequate extension services is required to create awareness among farmers about the principles and practices of management methods to minimize the damage caused by the soybean cyst nematode. Furthermore, there is a dire need on the part of the government and relevant stakeholders to design adequate soybean cyst nematode management options that are founded for subsistence farmers' needs and priorities by taking their crop production practices into account. It required giving training and awareness to overcome these devastating soybean cyst nematodes. Effective phytosanitary measures should be developed to safeguard the trade of commodities suspected to be the hosts of soybean cyst nematode. It is suggested that the screening soybean variety that is resistant to soybean cyst nematode and the time of the outbreak should be determined. Therefore, delivering different technologies developed for developing countries can effectively benefit them. To achieve improved soybean seed productivity, it is necessary to maintain the sustainable management of soybean cyst nematodes incognizant of accessing and updating appropriate management systems, particularly in developing countries and resource-poor areas. Furthermore, the areas are paradoxically faced with the challenges of soybean cyst nematodes. In such situations, the soybean cyst nematode will become increasingly prominent. I have tried to review a variety of management options possible for resource-poor farming conditions used to manage soybean cyst nematode. However, understanding the theory of the management method is not enough and requires the understanding and diagnosis of the problems practically at the right time with the right tools at the right place by experts, researchers, farmers, and other stakeholders.

5. Conclusion

Soybean is a leguminous crop that is important for various purposes. Nevertheless, its production and productivity are limited by plant-parasitic nematodes in general and soybean cyst nematodes in particular. The soybean cyst nematode is severe under suitable environmental conditions by the beginning of the second-stage juvenile (J_2). At this stage, it penetrates the soybean roots and forms a permanent feeder cell (syncytium) on the soybean root vascular tissues. Once it forms this site, it becomes sedentary and gets its basic needs through it. Hence, this review paper explores a lot of necessary information concerning soybean cyst nematodes and their management. This pest is a global pest. However, it is highly reported from Asia, North and South America, and the European continents. It indicates that its distribution, occurrence, severity, and prevalence are not uniformly studied across the world. It varies with the variation of environmental conditions, crop production practices, previous disease history, and varietal susceptibility of the soybean. It occurred in suitable conditions, such as semiarid (mostly) climate, warm temperate areas (15–33°C), and soil pH of 7.0 to 8.0. The damage it caused is less in fertile soil. The soybean infected by SCN looks wilted, appearing water deficient, stunted, yellowish, and poor in health. But the only visible sign on the infected soybean is the presence of white to yellow and the lemon-shaped female cysts on the roots. It moves, long distances through irrigation water, wind, rain, animals, soil, host plants, seeds harvested from infected fields, and other natural processes. This pest can be managed by employing different cultural practices, developing resistant varieties, biological, chemical, and integration of these methods. In the future, better research recommendations on soybean cyst nematode management should be developed based on the knowledge of indigenous, breeding, biotechnological innovations, local conditions, and species of soybean cyst nematode. To implement effective management options, farmers should be made aware of the importance of cooperation among themselves in a region. Furthermore, there is a dire need on the part of the government and relevant stakeholders to design adequate soybean cyst nematode management options. It required giving training and awareness to overcome these devastating soybean cyst nematodes. In such situations, applying the theory of the management method into practice at the right time with the right tools at the right place by considering body will have resulted in good achievements of soybean.

Data Availability

The authors have not used primary data for this review chapter.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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