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REVIEW ARTICLE

Rhizoctonia Disease of Potato: Epidemiology, Toxin Types and Management

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ABSTRACT

Potato plays an important role in food systems and its usefulness cannot be downplayed. However, the production and output of potato have been threatened by Rhizoctonia disease, caused by *Rhizoctonia solani*. Evidence of the negative effects of this fungal disease of potato is enormous in major potato growing zones in the world, particularly in temperate regions. *R. solani* produces some phytotoxins, which are detrimental to plants. It poses phytotoxic effects on the potato plants, inducing symptoms on the aerial parts and in extreme cases, on the roots as well. This review presents the overviews on Rhizoctonia disease of potato, disease cycle and its epidemiology. Data on the mycotoxins and various phytotoxins from *R. solani* and their respective chemical structures are included. It provides information on the mode of actions of the various phytotoxins produced by the *R. solani*. It also provides detailed information on the different recommended methods for the treatment of potato Rhizoctonia disease. The review seeks to make available, information about the Rhizoctonia disease and its respective pathogen, as a guide to farmers engaged in potato production, for the control of the disease and reduction of yield losses.

Key words: Epidemiology, Phytotoxins, Management, *Rhizoctonia solani*, *Solanum tuberosum*

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INTRODUCTION

Potato (*Solanum tuberosum* L.) has very great diversity and contributes to global food security (Esfahani, 2020), delivering abundant starch on hectare basis than any other edible crop. The constant failure of cereals, to meet both local and international demands, coupled with the rapid increase in food prices has increased the demand for potato, which is highly nutritious and easily grown. Gibson and Kurilich (2013) postulated that potato is very nutritious as it serves as a good source of carbohydrates, proteins, vitamins and minerals (Singh *et al*, 2019). According to Fernandes *et al*. (2005), potato has little fat, as well as phytochemicals, such as carotenoids and natural phenols. Ncobela *et al*. (2017) suggested the crop could be used in livestock feeding, fuel production, and industrial purposes. Similarly, Pedreschi *et al*. (2008), reported that 50% of the overall potato produced in the US are utilized in the manufacturing industry with over 70% of tubers used as chips and French fries. Furthermore, Friedman (2006), reported that potato tubers contain numerous secondary plant metabolites which are useful components of the human diet. Potatoes also have beneficial health characteristics and increase glucose tolerance and sensitivity to insulin. Again, it decreases plasma cholesterol and triglyceride concentrations, increasing the lipid profile and reducing the risk of infection (Carla *et al*., 2013). It is, therefore, not surprising that potato production has received much more attention in recent years.

Plant-parasitic fungi produce phytotoxins to initiate disease infection. For instance, *Rhizoctonia solani* produces a large number of hydrolytic enzymes including cellulases, and xylanases (Olivieri *et al*., 2004), resulting in maceration of tissue and death of cells (Alghisi and Favaron, 1995). These dead tissues serve as the nourishing resource of the pathogen (Aveskamp *et al*., 2008). Knowledge on the role of phytotoxins in the plant growth and development or in Rhizoctonia disease is minimal.

Management of the disease with synthetically derived pesticides has many side effects, such as pollution of underground water bodies and the environment. The indiscriminate misuse of these pesticides has also led to severe harmful effects on humans (Shoda, 2000) and plant chemical resistance. The increasingly harmful effects of synthetic pesticides and the development of chemical resistance by several plant pathogens have necessitated the development of alternative control strategies. It is also crucial for the introduction of integrated strategies to minimize the negative impact of excessive application of synthetic chemical-based products. Phytotoxins are bioactive compounds, due to this, several studies have attempted to exploit its applications. Buiatti and Ingram (1991) recommended some phytotoxins as potential markers for screening disease-resistant plants due to their role in disease development. Also, Strobel *et al*. (1991) suggested that phytotoxins could be used as potential herbicide since they are toxic not only to plant pathogens but also to weeds and herbs. Phytotoxins play an essential function in pathogens penetrating the tissues of plants. Knowledge of their mode of activity and their interactions with plant defense mechanisms will contribute to the developing of effective techniques to increase plant resistance to fungal pathogens. This review will be beneficial to crop producers as it will complement efforts to control the Rhizoctonia disease of potato, effectively.

Rhizoctonia diseases of potato:

The most destructive diseases in potato production are the black scurf and stem canker caused by the soil-borne fungus *Rhizoctonia solani* Kühn (Teleomorph: *Thanatephorus cucumeris* (Frank) Donk) (Kara and Arici, 2019). Sclerotia (dense asexual hyphal resting structures), mycelium (hyphal growth form) or basidiospores are the forms *R. Solani* used to survive as it does not produce asexual spores (Ajayi-Oyetunde and Bradley, 2018*)*. The disease is well known in potato growing regions. However, its incidence is higher in temperate climates than in the tropics. The disease causes the crop to suffer both quantitative and qualitative economic losses. Quantitatively, losses occur due to stem, stolon, and root infection, which decreases tuber size and number, whereas qualitative losses occur because the disease is frequently associated with malformed tubers and the black scurf discolorations. *Rhizoctonia solani* does not only attack potatoes but attack other plants, including rice, maize, wheat, lettuce, sugar beet, cotton, alfalfa, peanuts, soybean (Ajayi-Oyetunde and Bradley, 2018), and cowpea (Kankam *et al*., 2018). Stem canker is promoted by cool temperature as it delays emergence after planting.

Rhizoctonia disease cycle and symptoms:

Potato Rhizoctonia diseases can be divided into two stages: cankers of Rhizoctonia, which are underground lesions of plant organs which can occur at plant growth; and sclerotia deposition on the surfaces of tubers (Kara and Arici, 2019). The source of inoculum begins the life cycle of *R. solani*. Mycelia or sclerotia, found in soil or rotting plant matter in the field, or on the surfaces of seed tubers, may be the inoculum source (Johnson and Leach 2020). The pathogen may occur saprophytically during mycelial development, or may infiltrate roots of potato including; stems, stolons, and developing tubers. Brown to black sunken lesions is seen on sprouts, stolons, or roots shortly after plant emergence. These lesions may cause stem girdling, resulting in wilting and death (Wharton *et al*., 2007).

Cushions caused by infection of pathogens on the surfaces of the host plant sprouts and roots are created by the pathogen, and penetration only takes place under favorable conditions in these areas. Infection pegs then enter the vascular bundles under the infection cushions, where they develop into the symptoms of the 'canker'. The stem canker is characterized by brown and black sunken lesions on the stem and severely girdled stem (Fig. 1), which can result in reduced growth of plants, and wilting or early dying (Atkinson *et at*., 2010). Also, sprout-nipping a phenomenon whereby lesions girdle and kill young sprouts (Fig. 1) may occur and lead to poor plant emergence and sparse rooting in affected crops (Johnson and Leach, 2020). The infection process may occur, destroy or cause malformation and the 'cracking' of tubers on newly formed stolons. Dark-colored sclerotia grow on the daughter tubers which is referred to as black scurf (Fig. 1) only at the end of the growing cycle, which is the most noticeable symptom (Woodhall *et al*., 2008).

The effect of Rhizoctonia diseases on potato, depends on the strain of *R. solani* involved the potato variety, and environmental factors. It was shown that *R. solani* AG-3 dramatically reduced the overall, as well as sellable crop yields and increased potato black scurf incidence (Otrysko and Banville, 1992). It was also found by Hartill (1989) that *R. solani* infection resulted in a rise in the number of tubers attacked by the fungus and increase in the number of tubers growing on axils of leaf. These suggests that stolon cankers obstruct the transfer of photosynthetic products. Infection of tubers by *R. Solani* AG-3 was detected to be the source of dark skin spots on stored tubers prior to skin setting, due to the deposition of the waterproofing waxy material in the tuber reaction.

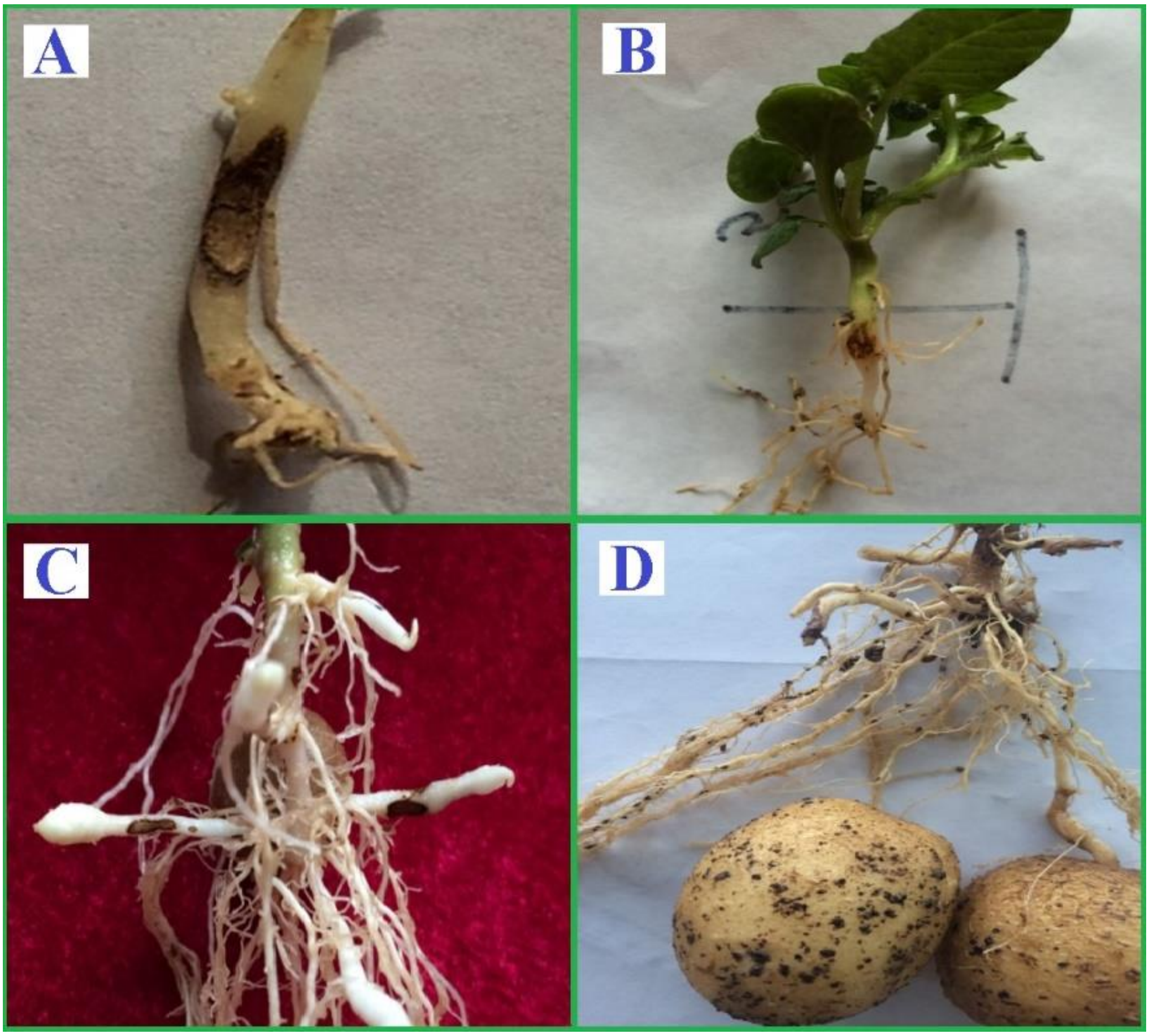

Fig. (1): Potato plants naturally infected by Rhizoctonia stem canker and black scurf disease of potato. (A: Potato buds show scab after seeding; B: Potato roots showing brown ulceration; C: Potato stolons showing scab/canker; D: *Rhizoctonia solani* sclerotia (black scurf) on the surface of tubers.

Anastomosis groups of *R. solani*.:

Based on anastomosis reactions, *R. Solani* was previously subdivided into different groups. Unknown isolates are dual-plated with tester isolates to establish their group. When there is a merger between the hyphae of the two isolates, and a 'death zone' is formed around the fusion, they are placed into the same group of anastomosis (AG) (Gondal *et al*., 2019). At present, 14 Rhizoctonia AGs have been identified, with so many subgroups (Table 1) based on a broad variety of characteristics, such as virulence, molecular features, and morphology (Samsatly *et al*., 2018; Kouzai *et al*., 2018; Picarelli *et al.*, 2019). The advent of Polymerase Chain Reaction and rDNA sequencing has thrown more light on the genetic diversity of AGs (Yang *et al*. 2017).

According to Muzhinji *et al*. (2015) strains of AGs 3, 1, 2-1, 9, 4 and 5 are economically important for potatoes in temperate climates across the globe. AG-3 is the most cosmopolitan group exhibiting disease symptoms in potato (Ito *et al*. 2017). Woodhall *et al*. (2008) documented that, the anastomosis group, AG-3, is the only members that are proven to cause an increased prevalence of black scurf on daughter tubers of potato. The AG-3 subgroup is further divided into two subgroups with non-overlapping host sets. The strains of AG 3 PT are virulent on potato, whereas AG 3 TB is virulent to tobacco (Ito *et al.*, 2017). Wibberg *et al*. (2017) postulated that sexual spores of *R. solani* cause leaf lesions on potato, even though the functioning of basidiospores in disease etiology is not well understood. Date *et al.* (1984) also documented that AG-3 of *R. solani* cause foliar blight disease in tomato in Japan. Isolates of *R. solani* strains that are transmissible in potato are non-obligate saprophytes and can consume a wide variety of substrates. Though members of AG-3 are widely reported by many researchers to be linked with potato plants, isolates seen in potato fields in Maine were of diverse anastomosis groups (Bandy *et al*., 1984).

Effective functioning, nutrient transportation, and signaling of molecules within the colony are dependent on hyphal fusions in higher fungi. The fungi must have the capacity to target and recognize other hyphae in order for this process to occur. Anastomosis reactions, however, may be caused by environmental factors, especially nutrients. *R. solani*, is known to influence anastomosis by the amount of available nutrients, particularly nitrogen (Carling, 1996).

Table (1): Anastomosis groups of *R. solani* and their subgroups

Anastomosis group	Subgroups
AG-BI	Bridging Isolate (BI)
AG-1	IA, IE, IC, ID, IF, IB
AG-2	2LP, 1, 3, Nt, 4, 2IV, t, 2IIIB
AG-3	TM, TB, PT
AG-4	HGIII, HGI, HGII
AG-5	
AG-6	GV, HG, I
AG-7	
AG-8-ZG[a]	5, 2, 1,4
AG-9	TX and TP
AG-10	
AG-11	
AG-12	
AG-13	

Source: (Ajayi-Oyetunde and Bradley, 2018)

Epidemiology of *R. solani*:

Soil-borne pathogens including *R. Solani* are popular throughout potato growing regions and have also invaded several plant species (Abdoulaye *et al*., 2019). This is due to the fact that the pathogens are distributed on seed tubers as potatoes are propagated vegetatively. Infection attributable to *R. solani* can result from inoculum, either tuber-borne or soil-borne (Abdoulaye *et al*., 2019). The primary source of infection is tuber-borne inoculum in organic potato development. Penetration and infection mode by *R. solani* is well studied by numerous scholars. The mechanisms of infection and penetration depend largely on the isolate, anastomosis classes, plant organisms, and the nature of the plant parts formation (Murray, 1982).

R. solani has reduced movement due to lack of spores and persists in harsh environments by the development of sclerotia or latent mycelia (Johnson and Leach, 2020) that can live for many years in plant residues and soil (Šišić *et al*., 2018). Peters *et al*. (2003) stated that, in the absence of host plants the inoculum levels are lower as *R. solani* population declines with time. A broad-spectrum of crops such as carrot, eggplant, radish, and oats can serve as alternative host to *R. solani* of AG-3 via the development of epiphytic connections with these crops (Carling *et al*., 1986). The development of hyphae and sclerotia on other alternative crops makes the selection of crops for rotation key in potato production. In conditions that delay the growth of new shoots, especially in cold, moist soils, and acid to neutral soils, Rhizoctonia disease is prevalent (Johnson and Leach, 2020).

Chemical structures of phytotoxins:

The chemical structure of phytotoxins in general, varies from simple to relatively complex molecules (Strobel, 1982). Liang and Zheng (2012) isolated polyketide-based lactones from the genus Rhizoctonia while Pedras et al. (2005) isolated complex cyclic peptides. These demonstrate the wide variety of chemical configurations of phytotoxins associated with *R. solani* strains. These include Phenylacetic acid, hydroxy and methoxy derivatives of PAA, benzoic acid and Nb-acetyltryptamine (Fig. 2). Plant growth regulators have been reported as essential metabolites of *R. Solani* infection processes on different plants (Hu *et al*., 2018). Several Carboxylic acids, including PAA and MeO-PAA, have been reported as some of the phytotoxins exhibiting non-specific action against rice (Liang and Zheng, 2012). Kankam *et al*. (2016a) also isolated toxic compounds such as 3-methylthiopropionic acid (3-MTPA) and 3-methylthioacrylic acid (3-MTAA) which triggered stem canker, when injected into potato plants (Kankam *et al*., 2016b).

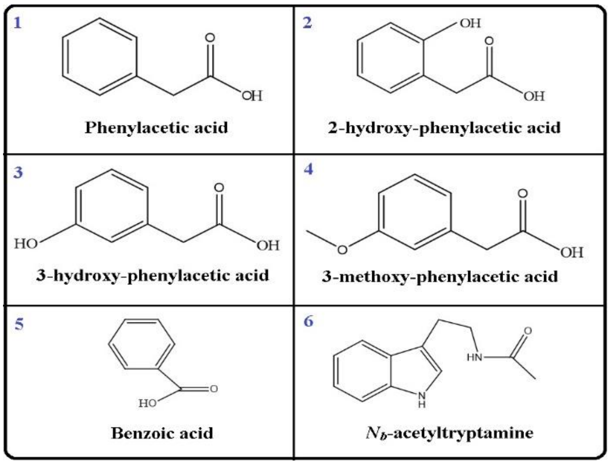

Fig. (2): Chemical structures of phytotoxins produced by the *Rhizoctonia solani*: phenylacetic acid (1), 2-hydroxy-phenylacetic acid (2), 3-hydroxy-phenylacetic acid (3), 3-methoxy-phenylacetic acid (4), benzoic acid (5), and N_b-acetyltryptamine (6).

Phytotoxins from *R. solani* and mechanism of action:

Rhizoctonia solani may enter the host through mechanical means or with the aid of enzymes or toxins (Hu *et al*., 2018). The deleterious effects of phytotoxins produced by *R. solani* on plants cannot be over emphasized. For example, Lai *et al*. (1968) found in their studies that *R. solani* produces phytotoxins which may result in changes of permeability of cell membranes and breakdown of cell wall of *Phaseolus aureus*. Yoder (1980) reported that one of the main factors involved in the growth of canker caused by *R. solani*, in seedlings of beans, is the production of phytotoxin. Similarly, Wyllie (1962) postulated that the development of symptoms in host tissue before hyphal colonization could be due to the production of phytotoxic substances by *R. solani*. Phenylacetic acid (PAA), three hydroxy (OH-) and one methoxy (MeO-) derivative of (PAA), produced by *R. solani*, are found to be crucial in the process of plant parasitism and infection (Hu *et al*., 2018). The role of PAA and its derivatives in plant growth-regulating activities and phytotoxicity on other plant species have been reported (Hu *et al*., 2018). However, in previous studies, conflicting findings and methodological limitations on the basic role of PAA in the development of Rhizoctonia disease and the optimum concentrations required to induce disease in their host are unclear (Betancourt and Ciampi, 2000). Information on the role of OH- and MeO- derivatives of PAA in the growth and development of plants or Rhizoctonia disease is lacking. PAA has also been shown to have antimicrobial properties and to inhibit the growth of *R. solani* (Hu *et al*., 2018). This is however, contradictory to Ding *et al*. (2008) observations that the fungus develops and metabolizes PAA.

Lakshman *et al*., (2006) reported that OH- and MeO- derivatives of PAA are absorbed by *R. solani* from phenylalanine via the pathway of shikimate. Hermann and Weaver (1999) indicated that, this route includes two metabolic intermediates with the carbon metabolism pathway of quinic acid (QA), which is caused by the presence of QA in the growth substrate as it is discharged from lignin in the rotting plant material. The transition between the parasitic and saprobic phases of this fungus life cycle can be regulated by the interaction of these metabolic pathways. The activation of the QA pathway has recently been shown to contribute to the sequestration of intermediates from the shikimate pathway, which reduces the development of the PAA precursor, phenylalanine in *R. solani* and other fungal filaments (Liu *et al*., 2003a). Liu *et al*. (2003b) stated that it reduces the pathogenicity of *R. solani* when the metabolic processes within the fungus are disrupted by the addition of QA-containing substrates from host crops.

Management of Rhizoctonia disease of potato:

R. solani disease management strategy is aimed at altering fungal metabolism, thereby providing an innovative idea compared to existing control practices, such as the use of fungicides, which are essentially based on reducing fungus populations (Sweetingham, 1996). An expanded awareness of *R. solani* metabolism will result in the formulation of a more successful and advanced disease suppression methods. The various control measures for Rhizoctonia potato disease include the following:

Biocontrol:

Many microorganisms have been evaluated for their possible use as biocontrol agents (Bagy *et al.*, 2019; Jiang *et al.*, 2019). Rhizoctonia antagonistic bacteria such as *Bacillus* spp. (Schreiter *et al.*, 2018) and *Pseudomonas* spp. (Yu *et al.*, 2017) were successfully used as bioagents in Rhizoctonia disease management. The plant growth-promoting rhizobacteria (PGPR) which are closely associated with root systems have beneficial effect on healthy plants and were used for disease control (Xiang *et al*. 2017b; Gouda *et al*., 2018; Abbas *et al*., 2019). Aside pathogen resistance, rhizobacteria prevent rhizoctonia diseases by inhibiting the development of pathogens in plant tissues, preventing the creation of parasite complexes, and enhancing plant defenses. Diallo *et al*. (2011) reported that potato rhizosphere has been widely colonized by *Pseudomona*s spp. in particular *P. fluorescens* and *P. putida,* which are heavily expressed in the root internal microenvironment. The combination of required physical niche and biocontrol ability makes members of the Pseudomonas genus great contenders for regulation of Rhizoctonia diseases.

Most *Bacillus* spp. including *B. subtilis*, *B. thurigiensis* and *B. cereus* have been effective to manage Rhizoctonia disease (Madhavi *et al*. 2018; Abbas *et al.*, 2019). Strains of many *Bacillus* species have proven to cause mediated systemic resistance in a number of plant species and provide defense against Rhizoctonia disease (Mekonnen and Fenta, 2020). Gururani *et al*. (2013) found that when plant growth promoters of rhizobacteria are embedded in potato field soils, they increase the resistance of abiotic stress in the crop by triggering changes in the expression of ROS-scavenging enzymes and by stimulating photosynthetic efficiency. Tomilova *et al*. (2020) found that the use of *B. bassia* for the treatment of potato tubers before planting decreased *Rhizoctonia* infection in potato stolon and stems. Commercialized biopesticides like *Botrycid*, *Sublic* and *Rhizo Plus* have been reported to be effective against *R. solani* (Abbas *et al.*, 2019). Below are some of the bioactive compounds with antimicrobial properties against *R. solani* (Fig. 3).

Fengycin	• Directly suppress fungi development • Gradual stimulation of resistance to fungi in crops
Bacillomycin D	• Directly suppress fungi development • Gradual stimulation of resistance to fungi in crops.
Bacillibactipolyketidesn	• Synthsis of siderophores
Lipopeptides Surfactin	• Synthesized biofilms • Stimulation of crop resistance to fyngi
Difficidin	• Directly suppress pathogen
Bacillaene	• Directly suppress pathogen
Macrolactin	• Directly suppress pathogen
Acetoin/2,3-butanediol	• Gradual stimulation of resistance in crops
Bacilysin Bacteriocins	• Directly suppress pathogen

Fig. (3): Bioactive compounds produced by *Bacillus* spp. (Abbas *et al*., 2019).

Cultural practices:

Cultural practices are the most widely recommended and utilized option in managing disease incidence in several places of the world (Katan, 2010). In potato fields, these methods include: (i) crop rotation (ii) flooding (iii) weed control during the first 3 weeks of potato emergence (iv) crops with antagonistic effect (v) the addition of organic amendments (Arici and Sanli, 2014).

Crop rotation is among the most efficient and less expensive management methods for farmers in developing countries (Bridge, 1996). Crop rotation has in many instances appeared to be beneficial in managing *R. solani* disease affecting potatoes worldwide as it can have overwhelming effects on crops grown in multiple consecutive years and decrease in inoculum levels due to the absence of preferred hosts (Larkin and Brewer, 2020). According to Adesiyan *et al*. (1990), susceptible crops are rotated with resistant or completely immune crops in crop rotation. Larkin *et al*. (2010) indicated that in Canada, a 2 –year cropping systems resulted in potatoes that were grown after red clover, showed less black scurf compared to potatoes grown after barley or Italian ryegrass. It is also reported that ryegrass and barley rotation significantly reduced the incidence of Rhizoctonia disease in potatoes (Larkin and Brewer, 2020). Isakeit (2011) postulated that non-infected seed tubers could be planted and potatoes could be rotated for 1-2 years in other to prevent and manage stem canker disease that causes considerable effect on potato plant. The above report indicates that these crops are appropriate choices for crop rotation in disease control and management.

Antagonistic crops produce anthelminthic compounds (Grainge and Almed, 1988) which contain toxic substances that can destroy or kill fungal pathogens after plant invasion (Karban, 2011). Certain plants produce toxic exudates that directly kill fungi, whilst in other plants; fungi fail to complete their life cycle after the invasion of the plant tissue. Plants that exhibit this type of antagonism are often known as trap crops (Agrios, 2005).

Chemical control:

Chemical control is the application of organic or in organic synthetic compounds that have a killing, inhibiting, or repulsive effect on injurious organisms threatening mankind and animals (Oudejans, 1991). There is also a published report of disease management options against stem canker and other fungal diseases with the use of fungicides (Kataria *et al*., 1991). Bains *et al.* (2002) indicated that seed treatment fungicides such as captan (Captan 50% WP), fludioxonil (Maxim @ 0.33% D and 0.50% D), iprodione (Rovral 50% WP), mancozeb (Tuberseal 16% D), thiophanatemethyl (Easout 10~ D), and thiabendazole (Mertect 45% F) were effective in controlling potato Rhizoctonia diseases.

However, there are no chemicals registered to control *R. solani* in potato, and chemical control for stem canker disease is often expensive and not stable in the field. Isakeit (2011) reported that commercial growers can also use fungicides at planting, either to treat the seed tubers or as an in-furrow soil treatment against stem canker. The use of selective fungicides has been found to increase the resistance to *R. solani*. Several chemical products are developed to combat seed-borne potato diseases as well as provide a wide range of control measures for Rhizoctonia, Silver Scurf and Fusarium Dry Rot diseases (Wharton et al., 2007). These chemical products include Quadris (a.i. azoxystrobin), Maxim 4FS (a.i. fludioxinil), Tops MZ (ai. thiophanate-methyl), and other Maxim formulations + Mancozeb (Wharton *et al*., 2007). The general effect of these seed treatments and the in-furrow fungicides applied are recognized in the crop growth and crop's energy, but intermittently, the use of treated seeds in conjunction with cold and wet soils can contribute to slowed seed growth (Wharton *et al*., 2007).

Study goals call for new methods of defense that are consistent with sustainable cultivation, thus promoting the usage of complementary methods, such as the use of bio-organic fertilizers in the management of stem cankers (Diallo *et al*., 2011). Fungicides pose problems in areas of low rainfall. For instance, in regions where planting dates must coincide with rainfall, fields are often too dry to be treated effectively before the rains come.

Over-reliance on the use of fungicides to control fungi increases production costs, exposes farmers to toxic chemicals and reduces the efficiency of the chemicals. Moreover, certain micro-organisms in the soil may develop resistance to the chemical and break it down to harmless products (Seong *et al*., 2017). Considering the numerous disadvantages of chemical control, and the limited possibility of its applications by small-scale farmers, the need for an alternative control is necessary.

Preformed defense systems:

Plants possess many attributes which allow them to either resist infection or to withstand aggressive growth and feeding of pathogens (Nürnberger and Lipka, 2005). The existence of mechanical barriers such as fur, spikes, resins and waxes on the cuticle, as well as thick cell walls on the plant surface, are the first defense barriers that pathogens must overcome in order for infection to occur (Nürnberger *et al*., 2004). These mechanical barriers prevent pathogen entry, while chemical defenses are triggered when the mechanical barriers turn out to be in-effective (Nürnberger and Lipka, 2005).

A wide variety of secondary chemical compounds that shield the host from pathogens are predominantly present in plants with good health, whether in their excited state or as inactive form ready to react when tissue safety is compromised (Morrissey and Osbourn, 1999). For instance, Osbourn (1996a) reported that plant compounds such as catechols have high inhibitory effect and protective action when it enters the host surface from the initial point of synthesis, blocking pathogen development or repulsing pathogens. However, Bennett and Wallsgrove (1994) and Osbourn, (1996b) reported that, in many instances, advanced pathogens can resist or even use these toxic chemicals. Bennett and Wallsgrove (1994) in their studies found that saponins, terpenoids, sugar-containing phenolic, phenols, sulphur-containing compounds, and glucosinolates and cyanogenic glucosides had antibiotic properties.

Biologically active secondary metabolites are abundant in *Solanaceae* family. These poisonous metabolites also shield the plant from simple diseases and pests. The two most common glycoalkaloids in potatoes are α-chaconine and α-solanidine. Symbiotically, they prevent the growth and germination of many essential pathogenic fungi, including *R. solani*, when plants are grown under controlled conditions (Fewell and Roddick, 1997).

Organic matter amendments:

Research findings have proven that organic modifications are effective for controlling soil-borne fungal plant pathogens, including *Rhizoctonia* spp. (Arici and Sanli, 2014). According to Amadioha (2003) they are quickly degraded and pollution-free. Also, they leave no hazardous traces, beside they are cheaper and not dangerous to living organisms. In all cases, the materials are added to the soil in a dry or fresh state (Sikora and Fernàndez, 2005). Several studies have shown that the incorporation of selected organic matter amendments in biocontrol treatments improved the inhibiting ability of these biocontrol agents (Scheuerell *et al*., 2005; Pugliese *et al.*, 2011). This confirms the theory that Rhizoctonia diseases are regulated by a limited number of soil microorganisms (Hoitink and Boehm, 1999). As a result, changes to organic matter can only eradicate these pathogens if they can sustain populations of suppressive species already found in soil or strains that are added simultaneously with the amendment (Arici and Sanli, 2014).

The mechanisms by which suppressive agents control diseases is through competition with pathogens for nutrients (Raviv, 2008), the production of antibiotics harmful to pathogens (Craft and Nelson, 1996), and the activation of a plant defense response (systemic acquired resistance or induced systemic resistance) in plants (Nelson and Boehm, 2002). Phytotoxic compounds can also be generated by establishing anaerobic conditions and reducing the propitiousness of soil conditions to the pathogen or by means of different salts and toxins (Hoitink *et al*., 1991; Hoitink *et al*., 1997). The use of composts has also proved to decrease population of several soil-borne pathogens including *Fusarium* spp. and *R. solani* (Bonanomi *et al*., 2020; Escuadra and Amemiya, 2008) and improves soil fertility based on the type of organic material used (Kallah and Adamu, 1998). Bonanomi *et al*. (2020) reported that pam compost, biochar, fiber of coconut, sawdust, peat, and cellulose decreased Rhizoctonia populations. The benefits of using organic soil amendments as soil additives are widely reported. However, the limited availability and the large quantities needed are the major challenges in the use of organic amendments for effective fungi control (Agrios, 2005).

CONCLUSION

This is a comprehensive review of the scientific knowledge and research works concerning *Rhizoctonia solani*, which is responsible for the Rhizoctonia disease of potato, the anastomosis groups, and the epidemiology of *R. solani*. This provided information on the overview of phytotoxins, various phytotoxins produce by *R. solani* and their chemical structures. *Rhizoctonia solani* is a known pathogenic fungus, which poses threat to the production of potato. The resulting losses associated with this fungus has been reported to be enormous. It is, therefore, important to make available, the results and knowledge generated through research about the fungus to help in the development of suitable measures to minimized the phytotoxic effects of *R. solani*.

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