

Review

White rot (*Sclerotium cepivorum* Berk) - an aggressive pest of onion and garlic in Ethiopia: An overview

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Allium crops are the most indispensable vegetable crops used as condiments in most Ethiopian cuisine. Among them, onion (*Allium cepa* L.) and garlic (*Allium sativum* L.) rightly called as “queen of kitchen”, belong to the family Alliaceae and considered as one of the most important vegetable and spice crops produced on large scale in Ethiopia, cultivated during dry and rainy seasons. The global pest, white rot, *Sclerotium cepivorum* Berk is one of the serious fungal disease reducing potential yields of onion and garlic crops in Ethiopia to a considerable degree. The development of this serious disease as depends on the environment, time and host plant, biological control; chemical and cultural practices, which are important in management of onion and garlic white rot disease. Therefore, in this paper attempts are made to collate information on pathogenicity of white rot to these two crops recorded in Ethiopia, their distribution, economic importance, damage and management options scattered over published and unpublished sources and avail them for use by researchers and development workers on white rot problem in the country. This paper is also believed to identify research gaps that need to be addressed.

Key words: *Allium cepa*, *Allium sativum*, Ethiopia, *Sclerotium cepivorum*.

INTRODUCTION

Allium crops are the most indispensable vegetable crops used as condiments in most Ethiopian cuisine. Among them, onion (*Allium cepa* L.) and garlic (*Allium sativum* L.) rightly called as “queen of kitchen”, belongs to the family Alliaceae, and considered as one of the most important vegetable and spice crops produced on large scale in Ethiopia, cultivated during dry and rainy seasons (Rubatzky and Yamaguchi, 1997). Onion and garlic played an important dietary, as well as medicinal role for centuries. Onion is used in preparation of different foods,

and in therapeutic medicine in the country. Besides, it is rich in flavonoids like quercetin and sulfur compounds, such as allylpropylsulfide, that have been perceived benefits to human health (Griffiths et al., 2002) and used as a possible cancer preventive (Krest and Keusgen, 1999). Garlic is used in the treatment of headache, bites, worms, tumors and also could be reduced risk of cancer and chest pain in Ethiopia (Giday et al., 2003; Keusgen, 2002; Fekadu and Dandena, 2006). Han et al. (1995) reported that garlic has antibiotic properties and used to

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treat wound. It can inhibit and kill the bacteria, fungi, parasites and also lower blood pressure, blood cholesterol and blood sugar, prevent blood clotting, protect the liver and contain antitumor properties (Sovova and Sova, 2004). In Ethiopia, vegetable crops holders living nearer to urban centers largely practices vegetable farming, hence, the small volume of production recorded as well evidenced by the survey results of Central Statistics Authority of Ethiopia. The production of cash crops like garlic, onion and other spices is proved to be income generating for farmers, especially for those who have cultivated in limited lands or small holder farmers (FAO, 2006). As to production of these two vegetable crops contribute 2.78% to all crops production total, conversely, of the total production of vegetables, the same crops have the lion share, that is, about 31.69 and 42.76%, in that order (CSA, 2012). These two crops is produced mainly by subsistence farmers in the mid and lowlands of the country. The best growing altitude for onion and garlic under Ethiopian condition is between 700 and 1800 masl (Getechew and Asfaw, 2000).

Onion and garlic occupy an economically important place among vegetables in the country. A total of 30,478.35 ha of land was under Onion in the country, taking up about 15.25% land area covered by all vegetable crops at country level and yielding about 328,157.42 tons of produce by the peasant holders, contributing about 19.64% to the total country level all vegetable crops production. But, now-a-days the area under the production of onion is increased by far and productivity also increased up to 80 to 120 kg/ha under optimum condition. Garlic also taking up a total of 13,278.55 ha of land was under garlic in the country, taking up about 6.64% land area covered by all vegetable crops at country level and yielding about 123,961.46 tons of produce by the peasant holders, contributing about 7.42% to the total country level all vegetable crops production. Onion is extremely important vegetable crop not only for internal consumption but also as highest foreign exchange earner among the fruits and vegetables. However, the productivity of onion and garlic is affected by many biotic and abiotic stresses accounted for the low yield of onion and garlic in Ethiopia resulting in the use of low quality seeds, imbalanced fertilizers, uneven irrigations and less storability of the crop, lack of improved variety, lack of proper disease control and insect pest management practices, improved planting material, inappropriate agronomic practices in traditional production system and marketing facilities which are the prominent ones.

Globally, there are 66 diseases attacked *Allium* crops. Among them, white rot disease caused by *Sclerotium cepivorum* Berk is one of the most destructive disease causing heavy losses in onion and garlic (Coley-Smith, 1987; Crowe et al., 1980). In Ethiopia, the main limiting factor for onion and garlic production is the white rot disease caused by breaking of floral stalks, and thus, the

bulb yield and seed production is significantly reduced. The pathogen produces a great number of poppy seed-sized sclerotia, which can survive in soil for many years. Once established in a field, it permanently renders the field unusable for garlic and onion productions in Ethiopia for up to 40 or more years (Bo Ming et al., 2010). The pathogen is particularly difficult to manage, as it can remain dormant in the soil for many years until the next crop is planted. Thus, white rot disease is considered to be a major threat to the long-term viability of onion and garlic productions in Ethiopia. However, even at substantially reduced levels, onion and garlic grown in white rot -infested fields can suffer plant losses of up to 20 to 40% (Fullerton and Stewart, 1991), making avoidance or tolerance in these fields a cheaper ideal option. The development of this serious disease as depends on the environment, time and host plant, biological control; chemical and cultural practices, which are the important in management of onion and garlic white rot disease. Therefore, in this paper attempts are made to collate information on pathogenic of white rot of these two bulbous crops recorded in Ethiopia and other countries, their distribution, economic importance, ecology and epidemiology, damage and management options scattered over published and unpublished sources and avail them for use by researchers and development workers on white rot problem in the country reviewed. This paper is also believed to identify research gaps that need to be addressed.

ONION AND GARLIC PRODUCTION AND PRODUCTION CONSTRAINTS IN ETHIOPIA

Agriculture is the backbone of economy of Ethiopia. Onion and garlic is one of the most important vegetable and spice crops in Ethiopia and mainly produced as a cash sources for the farmers. Many people's also make their living by transporting and marketing these crops. In addition, the country earns foreign currency by exporting onion flowers. The plant has a very short growing period of only three to four months, which allows it to be grown between other crops during the short rains in the dry season. The plant is grown in most areas from onset of June to the end of September or October with rain fed and from November to March or from January to May with irrigation. Even though farmer's different areas name it differently, red to grayish red onion and garlic with medium to large size is commonly practiced in the country. However, planting materials used by farmers are usually heterogeneous in size, shape, color, pungency, storability and resistance to diseases. They are also differing in their time to reach maturity.

A variety of diseases and disorders affect onion and garlic related crops in Ethiopia both at field and in the storage. Accurate disease diagnosis is an important part of an integrated disease management (IDM) program that

assists identification of onion and garlic diseases and disorders that occur in the field and sometimes in storage. But there is a shortage of information and disease diagnosis, monitoring and management guidelines in the country. It is important that onion and garlic diseases be recognized early in their development so that effective management strategies can be implemented. Careful and regular monitoring of the crop can provide this timely information. Knowledge of the field and cropping history can also provide valuable clues to the potential for diseases or disorders, because some diseases occur annually for example, onion and garlic white rot whereas others are more incidental and unpredictable.

WHITE ROT INFECTION ON ONION AND GARLIC AND THEIR SYMPTOMS

Development of sclerotia germinating stimulants is underway and may lead to their introduction into commercial garlic production. Pathogenic activity of white rot increases as the root systems develop. Mycelial growth spreads upwards from the roots to the stem plate, the bulb, and then onto the leaves above ground. Soil conditions and the pathogen population in the field will determine the extent of damage inflicted on the onion and garlic crops. In cool moist soil where disease inoculum is high in the field, the sclerotia (survival structures) will germinate in the presence of onion and garlic root and bulb exudates. The fungus then attacks the roots, developing bulb and lower plant stem. Depending on soil conditions and inoculum levels, plants may be partially or completely destroyed. In the process, new sclerotia are formed that can persist in a dormant state in the soil for many years, waiting for a susceptible host. Under conditions that are less favorable to rapid sclerotial germination, the plant may survive to harvest, although the bulb may then rot in storage as disease symptoms continue to progress.

Normally, disease symptoms appear from mid-season to harvest. The white rot problem cannot be understated. This disease attacks the crop at all the stages of growth in the field, the leaves of both partly and fully developed plants turn yellow and wilt. There are also snow white mycelia on the bulb surface or at the crown of seedlings. The small rounded shape sclerotium also develops on the mycelia. The root system of the crops is destroyed completely and the crop leaves also turn yellow and wilt. The disease is more destructive during the early spring and the autumn seasons in Ethiopia. Evidence of this dastardly disease shows up when the leaves turn yellow and die back. Plants will sometimes keel over as the roots rot. A few plants may be affected at first, but this disease often spreads to infect whole rows of plants. Upon lifting affected plants, white fluffy fungal growth, a bit like cotton wool, can be seen around the bulb with tiny black globules, like poppy seeds among the fungus.

These black globules are resting bodies or sclerotia of the white rot fungus.

DISTRIBUTION OF WHITE ROT

Fedis in Harerge; Huruta, Sire, Shirka, Bokoji, and Arsi Negelle in Arsi; Ambo, Wolliso, Godino, Kesem, and Majete in Shewa; Bure, and the vicinities of Dibre Markos in Gojam; and Warailu and Warababo in Wello are the most onion and garlic growing areas of the country (Getachew and Asfaw, 2000). In South, South-West and North-East West Showa Zone, Ambo high lands, garlic is widely cultivated using rain supplemented by irrigation. *Sclerotium cepivorum* has caused great damage in diverse regions of Ethiopia (Tamire et al., 2007). Furthermore, *S. cepivorum* is an issue of great importance for dry climate producers in Ethiopia (Zewide et al., 2007). Zeray and Yesuf (2013) reported that the distribution, incidence and prevalence of garlic white rot in major growing districts of South-East and East Tigray in Ethiopia. Ararsa and Thangavel (2013) reported the incidence, prevalence and severity of the white rot in Ambo and Toke Kutaye districts of Western Showa, Ethiopia. Tamire et al. (2007) reported white rot incidence ranging from 37.28 to 42% in cultivated fields of garlic in Northern Showa of Ethiopia. Onion and garlic white rot caused by *S. cepivorum* is a major production threat of onion and garlic in Tigray Regional State of the country (Zeray, 2011). During favorable weather conditions, and when susceptible varieties are in the production system the disease can cause 100% yield loss (Zeray, 2011). It is prevalent in many onion and garlic growing regions worldwide, but its intensity can vary with different cultural practices and environmental factors.

ECOLOGY AND EPIDEMIOLOGY OF WHITE ROT

The sclerotia that form on the decaying host will lay dormant until a host plant's root exudates stimulate germination specifically root exudates that are unique to *Allium* spp. Cool weather is also needed for germination of sclerotia and hyphal growth. The soil moisture levels optimal for host root growth are also optimal for sclerotia germination. Mycelium will grow through the soil, and once it encounters a host root the fungus will form appresoria, structures whose purpose is to aid in the attachment and penetration of the host. Mycelium can grow outwards from the roots of one plant to the roots of a neighboring plant, and it is by this method that the pathogen can move down a planted row. Sclerotia are formed on the decaying host tissue, and once the host tissue completely decays the sclerotia are free in soil. If the bulbs survive long enough to be placed into storage, the pathogen may continue to decay the bulbs if there is high humidity and low temperatures. If the bulbs are stored dry then the disease may not spread

but bulbs infected in the field will continue to decay (Crowe, 2008; Ararsa and Thangavel, 2013).

White rot originates from small hard-walled storage structures, called sclerotia, which are produced in abundance in infected plant tissue, and are 200 to 500 μm in diameter (Maude, 2006). Sclerotia rely on these volatiles to germinate, environmental conditions also influence germination, with cool weather (14 to 18°C) and moderate-to-high soil moisture favoring germination and infection (Maude, 2006), though some research has suggested sclerotial germination is fairly independent of soil moisture content. Though, each sclerotium can only grow hyphae 1 to 2 cm in length (Maude, 2006), the high density at which onions and garlic are typically planted makes infection from infested soil essentially inevitable. Once contact is made with an *Allium* plant root, the hyphae forms an appressorium, a swollen hyphal tip that presses onto the root epidermis, from whence first a fungal toxin, oxalic acid, and then degradative fungal enzymes, endopolygalacturonases and pectinases, are produced. Oxalic acid degrades tissue in concert with the degradative enzymes that follow its secretion, leading to cell death directly beneath the appressorium. The appressorium then produces an infection plug, which penetrates between the cell wall junctions and deep into the root (Maude, 2006). The advancing penetrative hyphae branch out and secrete oxalic acid ahead of the hyphal tips, followed by endopolygalacturonase and pectinase enzymes. This acid and enzyme system continues to degrade tissue allowing the pathogen to penetrate further and absorb the nutrients released from the *Allium* tissue.

The pathogen rapidly colonizes the root system and base plate, then infects the bulb tissue and extends mycelia outwards to infect the roots of neighboring onion and garlic plants. Once the bulb is infected the plant soon loses vigor, the leaves yellow and wilt, and fluffy, white mycelia fill the bulb and then produce abundant sclerotia to precipitate future infections (Maude, 2006; Mueller et al., 2006). The hard-walled sclerotia formed during infection are incredibly tough, and can remain dormant yet viable in the soil for many years (Maude, 2006), some evidence suggesting up to two decades (Mueller et al., 2006), meaning that once a field is infested with *S. cepivorum*, *Allium* cultivation may not be possible there for many years.

Enough sclerotia from an initially high population may survive 20 to 30 years or more in soil without the presence of an *Allium* host to incite unacceptable levels of disease in the next *Allium* crop. Only *Allium* spp. such as onion, leek, and shallot are attacked. Sclerotia can infect plants from 12 inches below the surface. One sclerotium can infect a group of 20 to 30 adjacent plants. Fungal activity is favored by cool soils and is restricted above 75°F. Once the disease is in a field, it is very difficult to grow *Allium* spp. successfully. Leaves decay at the base, turn yellow, wilt, and topple over. Older leaves

collapse first. Roots are rotted, and the top of the plant can be pulled out of the ground easily. Fluffy white mycelium may be on remaining roots and bulb. The affected bulb may become watery, and the outer scales crack as it dries and shrinks. Small (0.02 inch) sclerotia form in affected bulb parts and on the surface, often around the neck. Sclerotia are smaller and rounder than those of the neck rot disease.

Onion and garlic may be attacked at all stages of crop growth. Early attacks cause poor crop establishment; later infections produce yellowing and wilting, which in some cases results in the complete collapse of the plant. Affected plants have a grey-white fluffy mycelium on their stem bases, which gives the disease its name: white rot. The disease is caused by the sclerotia of *Sclerotium cepivorum*, which perennate in the soil. Sclerotia germinate producing hyphae that infect the roots and stem plates of onions. New sclerotia are formed in the stem base tissues of onions and these are released into the soil when plants die or are harvested (Entwistle and Munasinghe, 1978).

Host and soil effects are important in the epidemiology of white rot. In the first time, for plant infection to occur, the sclerotia held in check by soil fungistasis have to receive a stimulus from specific factors released as exudates by the roots of onions (Esler and Coley-Smith, 1983). When this occurs sclerotia germinate producing hyphae that may grow 1 to 2 cm through the soil to infect the roots of onions. They penetrate the root epidermis producing appressoria and infection cushions and the hyphae enter between cell wall junctions (Metcalf and Wilson, 1999). Then they invade the hypodermis and grow into the cortex of the roots. During the early stages of infection, cell death is limited to the cells penetrated by the hyphae of *S. cepivorum*; however, onion cell walls in the path of the leading infection hyphae often dissolve before the hyphal tips reach them. This was shown to be indicative of enzymic action by certain pectinases (Metcalf and Wilson, 1999). Plant-to-plant spread of infection may occur in densely-sown or closely-spaced crops.

Secondly, soil temperature is a critical factor affecting germination of sclerotia, mycelial growth and root infection of onions. Sclerotial germination is favoured by temperatures between 9 to 20°C and the disease development on onion and garlic by white rot is ranged from 6 to 24°C; outside this range, germination is slow but returns to normal when temperature is restored to 15°C (Crowe and Hall, 1980). Thus, in Ethiopia, sclerotial germination is poor during the winter but improves in spring and early summer; later in the summer, germination may be inhibited by high soil temperatures-sclerotia cannot survive temperatures of 35°C and above (Tamire et al., 2007). As a result, disease losses are high in overwintered crops in the autumn and spring, when temperatures are suitable for infection, but white rot may be of minor importance in hot summers.

Sclerotial germination is little affected by pH values varying from 4.8 to 8.5 (Entwistle and Granger, 1977); there was a decrease in germination of sclerotia as soils became drier or wetter than field capacity (-300 millibars) (Crowe and Hall, 1980). Clarkson et al. (2004) showed that over 90% of sclerotia were degraded at high water potentials where the soil was nearly saturated. This confirmed the findings of previous workers (Crowe and Hall, 1980) and those of Leggett and Rahe (1985) that used flooding to degrade sclerotia as a means of controlling the disease. Sclerotia may persist in the soil from at least 4 to 20 years (Entwistle, 1990). Attempts to forecast white rot based on assessments of the numbers of sclerotia per given weight of soil have met with variable results within and between countries (Entwistle, 1990). Newer models based on inoculum dynamics (Backhouse, 2003) have so far failed because of insufficient data to develop the relationship for the production of new sclerotia based on the size of infected bulbs. The maximum increase in numbers of sclerotia in the soil occurs at the end of the onion growing season and this will affect the following crop but only if it is an onion crop.

MANAGEMENT OF WHITE ROT

A number of chemical, biological, physical and cultural control methods have been devised or employed, as well as integrative control systems that combine methods for maximum effectiveness. On top of this, a great deal of effort has gone into the search for onion and garlic's with genetic resistance to white rot. Management of diseases caused by soil borne pathogens especially those that produce sclerotia is very difficult and need a multi-pronged management strategy. Crop rotation used for primary inoculum reduction (Banks and Edgington, 1989) but has been viewed as impractical for *Allium* white rot control due to the persistence and longevity of the sclerotia in the soil, soil solarization (Prados-Ligero et al., 2002), biological control agents (Gerlagh et al., 1996), sclerotia germination stimulants (Tyson et al., 2000) and composted onion waste (Coventry et al., 2002), host resistant, the difference in susceptibility exist among *Allium* species probably based on differences in concentration and composition of precursor to stimulatory volatiles contained in the host tissue (Brix and Zinkernagel, 1992). The management of white rot is a priority for the onion and garlic industries in Ethiopia, currently being undertaken to investigate suitable management options at both pre-planting and post-planting stages.

In Ethiopia, research effort on host resistant against onion and garlic white rot is very limited. The management methods of the diseases of onion and garlic are followed as mainly crop rotation, avoidance and sanitation to proper storage methods (Banks and Edgington, 1989). Conventional methods of control of

diseases of onion include the use of chemicals, organic means, and through integrated management efforts. As a result, attempts to manage the disease have focused on reducing the populations of sclerotia in the soil through biological control. Research on biological control of plant pathogens has received much attention in recent years, as a means of increasing crop production by avoiding a number of problems related to chemical control, and hence, developing practices compatible with sustainable agriculture (Arasa and Thangavel, 2013).

CULTURAL AND PHYSICAL CONTROL OF WHITE ROT

One of the most important forms of white rot control is simple hygiene or sanitation. It can be achieved through cleaning equipment carefully between fields and where possible leaving equipment used in white rot infested fields for use only in those fields, farmers can avoid spreading the sclerotia which introduce the disease to uncontaminated growing areas (Entwistle, 1992). Beyond simple hygiene, there are some control methods that aim to reduce the inoculum density of *S. cepivorum* sclerotia in infested soil, so as to slowly reduce the severity of disease in those fields. One of these methods is soil solarization, in which plastic sheeting; usually polyethylene is spread over or shredded into the soil to concentrate sunlight, raising the soil temperature to 36 to 50°C (Katan, 1987) during part of the day. Successive cycles of such heating throughout the hotter months, with soil temperatures above 35°C, the maximum temperature *S. cepivorum* can survive, gradually kill off most sclerotia in the soil (Katan, 1987). This method is particularly effective in hot, dry, sunny climates such as the Middle East (Satour et al., 1989), Spain (Meleró-Vara et al., 2000), and parts of Australia (Porter and Merriman, 1983), far less so in areas with high soil moisture content and less sun, such as temperate New Zealand (Stewart and McLean, 2007). In cases where the climate is appropriate, some fields have seen reductions in inoculum density of near 100% (Porter and Merriman, 1983; Satour et al., 1989), while results in wetter, cooler countries have been far more subdued (Brewster, 2008). Because the technique requires 3 to 4 months in which no other crops can be grown, as well as the expense of coating infested fields with plastic, soil solarization might only be cost-effective in countries where the climate aids the process. Many researchers have identified *S. cepivorum* sclerotia as sensitive to high soil moisture (Alexander and Stewart, 1994; Clarkson et al., 2004), as this causes cracks and weaknesses in the sclerotial rind. *S. cepivorum* sclerotia rely on moderate soil moisture to germinate.

Another form of physical control by which sclerotial density can be decreased is the use of germination stimulants and soil amendments. These amendments are artificial chemicals or organic mulches that stimulate *Sm*.

Cepivorum sclerotia to germinate by mimicking or containing the volatile chemicals in *Allium* root exudates.

The most common artificial amendment is diallyldisulphide (Stewart and McLean, 2007), a synthetic form of the volatile that stimulates sclerotial germination. If sclerotia germinate in the absence of a viable host they run out of stored nutrients and die, reducing the inoculum density of infested fields (Brewster, 2008). Similar results can be achieved using onion or garlic oil or waste compost produced in onion processing plants as an organic germination stimulant (Brewster, 2008). The application of artificial amendments or organic amendments can make a field with an otherwise prohibitive level of *S. cepivorum* sclerotia more viable for use in *Allium* cultivation. One advantage is that non-*Allium* crops can be grown during the period of amendment (Stewart and McLean, 2007).

Some work has also suggested that *Brassica* residue incorporation or intercropping may have a suppressive effect on *S. cepivorum* sclerotial germination (Ulacio-Osorio et al., 2006; Zewide et al., 2007), though this avenue has not been fully investigated yet. Soil amendment treatments, as with soil solarization, have a cost associated with application which limits its use, particularly in treating infestations that cover larger areas. As part of an integrated control program, however, germination stimulants may play an important role in protecting *Allium* cultivation from the legacy of white rot infestations.

BIOLOGICAL CONTROL OF WHITE ROT

Biological control of plant pathogens is currently accepted as the key practice in sustainable agriculture because it is based on the management of natural resources, that is, certain rhizosphere organisms that are common components of ecosystem, known to develop antagonistic activities against harmful organisms. Among microorganisms, fungi are the potential candidate for the biological control of plant pathogens and several antagonistic fungi viz., *Trichoderma*, *Gliocladium*, *Talaromyces* and Arbuscular Mycorrhizal Fungi (AMF) have shown enormous potential as bio-control agents against different soil borne and foliar diseases (Lo et al., 1996). In Egypt, research has identified *Trichoderma harzianum* as a potential biological control agent for use against white rot, providing 86% reduction in disease in one test (Abd-El-Moity, 1992). This is reinforced by work in Mexico, identifying the C4 strain of *T. harzianum* as providing protection against white rot in garlic (Miranda et al., 2006). Tasmanian researchers have achieved promising 91.2% disease suppression with *Trichoderma* isolate Td22 in one study (Metcalf and Wilson, 2001). In New Zealand, under controlled conditions, *Chaetomium globosum* and *Trichoderma* isolate C62 provided an average of about 73% suppression over two years,

though attempts to modify the agents for use in seed coats or pellets for dispersal reduced these figures to around 50%, similar to the control provided by many fungicides (Kay and Stewart, 1994).

Similar work in the United Kingdom has identified two strains of *Trichoderma viride* that provided significant protection against white rot, at levels comparable to tebuconazole (Clarkson et al., 2002). In the same country, other workers found potential in *Coniothyrium minitans* for control of white rot equal to that provided by calomel, without the phyto- and environmental toxicity associated with that chemical's use (Ahmed and Tribe, 1977). Research in Canada has also suggested *Bacillus subtilis* and *Penicillium nigricans* may provide protection from white rot up to the level shown by industry standard fungicides like iprodione and vinclozolin (Utkhede and Rahe, 1980). Clarkson et al. (2004) showed that isolates of *T. viride* effectively degraded sclerotia of *S. cepivorum* (four isolates) in four onion soil types (silty clay, sand, silt and peat) under a range of temperature and soil moisture conditions.

In Ethiopia, Ararsa and Thangavel (2013) reported that the native strains of AMF and *Trichoderma* species for plant growth promotion and biological management against white rot caused by *S. cepivorum* in onion at West shewa, Ethiopia. Five strains with 20 isolates of *Trichoderma* and 10 species of AMF were isolated from cultivated field of onion rhizosphere soils and screened for their bio-control potential against white rot pathogen. Among ten AMF species, *Glomus aggregatum* (Awaro isolate) was selected for using as a bio-control agent. The bio-control potential of bio-agents against white rot pathogen has been studied by the effect of *G. aggregatum* alone or in combination with *Trichoderma* spp. Dual inoculation with both *G. aggregatum* and *S. cepivorum* was almost comparable with control. Incidence of *S. cepivorum* was significantly reduced in bulbs and greater plant growth was observed in plants related with inoculation of both *G. aggregatum* and *T. harzianum* (ATH1). Plants inoculated with *S. cepivorum* alone showed pronounced disease symptoms with mean disease incidence of 90%. Treatments with combined inoculation of *G. gregatum* and *T. harzianum* (ATH1 isolate) significantly reduced the white rot of onion. The overall reduction in the incidence of white rot was 56.19% for *G. aggregatum* with *T. harzianum* and 56.22% for treatments with *T. harzianum*. Ararsa and Thangavel (2013) reported that the bio-control potential of seven indigenous *Trichoderma* species viz., *T. asperillum*, *T. atroviride*, *T. hamatum*, *T. harzianum*, *T. longibrachiatum*, *T. oblongisporum* and *T. viride* were evaluated by *in-vitro* and *in vivo* for their antagonistic and inhibition potential against garlic white rot disease caused by *S. cepivorum*. The overall inhibition effect of the antagonists on the pathogen's colony growth ranged from 43.9 to 59.3%. Isolate of *T. hamatum* was the highest inhibition effect (59.3%) followed by *T. harzianum* (53.3%), *T. oblongisporum*

(52.7%), *T. viride* (51.8%), *T. asperillum* (50.2%), *T. longibrachiatum* (47.2%) and *T. atroviride* (43.9%) which were not significantly different from each other. Incidence of *S. cepivorum* was significantly reduced in bulbs of garlic and also improved plant growth was observed in plants inoculated with single inoculation of *T. hamatum* alone followed by *T. harzianum* alone and in combined inoculation of *T. hamatum*, *T. harzianum*, *T. hamatum* and *T. oblongisporum* isolates. Plants inoculated with *S. cepivorum* alone showed pronounced disease symptoms with mean disease incidence of 90.5%. Treatments with combined inoculation of *T. hamatum* and *T. harzianum* isolates significantly reduced (62.22%) the white rot of garlic followed by the combined inoculation of *T. oblongisporum* and *T. harzianum* and *T. hamatum* and *T. viride*. The overall reduction in the incidence of white rot was 62.22% in the treatment of *T. hamatum* and *T. harzianum* isolates with pathogen followed by 53.72% for *T. oblongisporum* and *T. harzianum* with pathogen.

HOST RESISTANCE AND BREEDING

It was noted that resistance to white rot in onions and other *Allium* species can be correlated with the amount of volatile precursor root exudates the plant produces (Brix and Zinkernagel, 1992). *Allium* species and cultivars with lower volatile precursor levels, and those that produce mainly non-stimulatory exudates like methylcysteine sulphoxides, stimulate less germination (Esler and Coley-Smith, 1983). This may indicate that breeding for low volatile precursor-producing varieties would reduce disease incidence, but research suggests that the levels of allylcysteinesulphoxides required to stimulate germination are fairly low (Esler and Coley-Smith, 1983). In addition to these concerns, a number of variable environmental factors such as temperature and moisture levels influence stimulatory root exudates levels, making any objective comparisons between cultivars difficult to make (Brix and Zinkernagel, 1992). Brix and Zinkernagel (1992) also revealed that the size of the root mass affects disease incidence, first by affecting the likelihood of roots being close to sclerotia and secondly by affecting the spread of disease between plants. This means that *Allium* species with smaller and less spread-out root masses may incur less disease, but this characteristic is not correlated with other commercially useful traits, and is also heavily influenced by environmental conditions like water availability (Brix and Zinkernagel, 1992). With this in mind, breeding for small root masses would be unlikely to yield consistently resistant plants, and would take a prohibitively long time to achieve.

The influence of environmental variation on variation in disease incidence has plagued attempts at identifying resistance in *Allium* to white rot infection (Utkhede et al., 1982). Because the expected differences in susceptibility

between cultivars is so small, introducing even mild variation from outside makes analyzing results very difficult. While the use of carefully controlled laboratory evaluations may avoid this variation, it also introduces the problem of attempting to apply laboratory conclusions to field conditions. Without extensive evaluations for resistance under controlled conditions, and comparisons to field assessments under typical cultivation conditions, the search for resistant germplasm is flawed, and with these caveats met, it remains an expensive and time consuming process (Hunger et al., 2002). Even some of the most successful work in identifying resistance phenotypes has been painstakingly slow (Nabulsi et al., 2001), and still holds no guarantee of success. As Brix and Zinkernagel (1992) put it, "no [*Allium*] species is known which shows a consistently high degree of resistance to *S. cepivorum*."

CHEMICAL CONTROL OF WHITE ROT

Over the last 30 to 40 years chemical control of onion and garlic white rot has largely depended on the use of dicarboximide fungicides such as procymidone, iprodione and vinclozolin which can be used as seed dressings and foliar sprays. The first of these is particularly effective at reducing the severity of disease and loss of yield when growing onions or garlic in *S. cepivorum* infested fields (Stewart and Fullerton, 1991). The use of such fungicides has been important because it allows fields otherwise unusable for *Allium* cultivation to return to productive use. In addition to limited effectiveness, the phenomenon of enhanced degradation of dicarboximide fungicides by resident soil micro-organisms has been detected in fields where such fungicides have been used regularly, with some research identifying a 90% loss of dicarboximide fungicides in soils pre-treated with them within 7 days (Garcia-Cazorla and Xirau-Vayreda, 2005). With the number of sites where onions and garlic can be readily grown so small, and the proportion of those sites infested with white rot increasing, the gradual selection of soil microbes capable of enhanced degradation of dicarboximide fungicides in those soils (Athiel et al., 1995) makes the use of such fungicides ultimately a finite solution (Clarkson et al., 2002). An alternative fungicide, tebuconazole, has offered hope in the control of white rot in infested fields, showing better control than the best dicarboximide fungicide procymidone in some comparisons (Duff et al., 2001). However, tebuconazole is best suited for foliar spraying, showing phytotoxicity when applied as a seed dressing (Fullerton et al., 1995), though granular applications may avoid this (Fullerton et al., 1995). Tebuconazole and triadimenol, both triazole fungicides, may well hold the most promise for ongoing control of white rot (Tyson et al., 1999; Clarkson et al., 2002), with no evidence yet arising to suggest that enhanced degradation of these fungicides occurs in the

field (Pung et al., 2007). However, there is no reason to suppose that soil microbes in treated areas will not eventually develop the ability to degrade these fungicides at an enhanced rate, particularly if farmers become more reliant on their use, thereby selecting more heavily for soil microbes that can degrade them.

While the use of fungicides can reduce disease severity in infested fields to a point where cultivation is economically worthwhile, regular *Allium* cultivation in such fields increases sclerotial density over time, increasing disease severity in subsequent seasons (Zewide et al., 2007a). One solution to this problem is the chemical eradication of the fungal propagules, sclerotia, by fumigation with methyl bromide. By reducing the inoculum density in white rot infested fields, farmers can decrease the risk associated with *Allium* cultivation. However, there is not an absolute correlation between inoculum density and disease severity (Melero-Vara et al., 2000), and even a relatively small persisting inoculum level can result in economically significant levels of disease. Methyl bromide fumigation, while fairly effective at reducing sclerotial numbers in the field, is environmentally damaging, and is being phased out in the developed world (Avila-Miranda et al., 2006).

In addition to the above concerns, most fungicides display some kind of toxicity, and those used to control white rot are no exception. Thiram and the sclerotial germination stimulant diallyldisulphide (DADS) are both designated 'very toxic to humans' in the New Zealand Agrichemical Manual (2005). Procymidone, one of the most traditionally reliable fungicides used in white rot control is a suspected reproductive/developmental toxin, as are next generation fungicide triadimenol and soil sterilant methyl bromide. Vinclozolin, a dicarboximide fungicide like procymidone and iprodione, has been shown to cause cross-generational tumours and abnormalities in laboratory mice (Anway et al., 2006). Mercury chloride, better known as the fungicide calomel, is still used for white rot control in developing countries (Miranda et al., 2006), despite the World Health Organization (WHO) classifying it as 'extremely hazardous,' the highest hazard rating they assign (WHO, 2004).

Fungicides are among the most effective options for onion and garlic white rot disease management in Ethiopia. According to Tamire et al. (2007) reported that the systemic as well as non-systemic fungicides significantly reduced incidence of white rot, its progress rate, severity, and there by improved garlic yield. Fullerton and Stewart (1991) also found that Rocymidon reduced incidences of white rot up to 75 to 95% applied as bulb and soil treatment. According to Melero-Vara et al. (2000) and Duff et al. (2001) reported that the tebuconazole was effective in reducing the incidence and progress of the disease and in increasing the yield when applied as a clove treatment.

The control of onion and garlic white rot disease has

been almost exclusively based on the application of chemical fungicides. Several effective fungicides have been recommended for use against this pathogen, but they are not considered to be long-term solutions, due to concerns of expense, exposure risks, fungicide reused and other health and environmental hazards. In attempt to modify this condition, some alternative methods of control have been adopted. Recent efforts have focused on developing environmentally safe, long lasting and effective bio-control methods for the management of plant diseases.

INTEGRATED DISEASE MANAGEMENT OF WHITE ROT

The most effective control systems to date have involved the integration of a number of systems for managing white rot. Clarkson et al. (2004) found that high soil moisture allowed their *Trichoderma* BCAs to better degrade sclerotia, as well as speeding up degradation generally, by weakening the sclerotial rind (Alexander and Stewart, 1994). Abd-El-Moity (1992) selected a benomyl-resistant strain of *T. harzianum* for his research, as a BCA tolerant to certain fungicides would be far more useful in modern *Allium* cultivation. Under an integrated control system cultural control methods slow the spread of the disease, while physical control methods like soil solarisation, flooding and germination stimulants are used to reduce the inoculum density in fields already infested with *S. cepivorum*. Then, if previously-infested fields are planted with *Allium* species, the use of fungicidal seed coats, dips and foliar sprays reduces the incidence of disease in those fields, while biological control agents work antagonistically against the sclerotia in the soil. The use of resistant cultivars could also provide another weapon in this arsenal, but no such cultivars have been developed to a commercial standard (Clarkson et al., 2002). The use of an *Allium* cultivar specifically and directly transformed to express a gene for white rot resistance might allow these other control methods to work more effectively, or even rule out the need for some of the more economically and environmentally expensive control methods, such as soil.

CONCLUSIONS

Whit rot disease is the most pressing problem to the subsistence onion and garlic farming community more than any other category of vegetable diseases in Ethiopia. The problem is particularly acute during moist rainy season. Great attention should be rendered to creating the necessary capacity in white rot fungal disease research to effectively deal with the white rot fungal disease problem in onion and garlic areas of Ethiopia. Furthermore, the white rot problem in the

country in general and the onion and garlic growing areas in particular is growing from bad to worse. Some pathological research in the country during the past, there is still a lot remains to be done in the future. Emphasis should be given to the wealth of indigenous knowledge and build on there to develop more viable technologies that are within reach the great majority of resource poor small-scale farmers in the country.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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