DISTRIBUTION AND MANAGEMENT OF WHITE-ROT (*Sclerotium cepivorum* B.) DISEASE OF GARLIC (*Allium sativum* L.) VARIETIES IN NORTH EAST SHEWA, CENTRAL ETHIOPIA

M.Sc. Thesis Research Report

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BSc in Dry Land Crop Scince

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A Thesis Submitted to the Department of Plant Science College of Agriculture and Natural Resource Sciences, College of Graduate Studies, Debre Berhan University

In Partial Fulfillment of the Requirements for the Degree of Master of Science in Plant Protection

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COLLEGE OF GRADUATE STUDIES

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APPROVAL SHEET – I

This is to certify that the thesis entitled: **DISTRIBUTION AND MANAGEMENT OF WHITE-ROT(*Sclerotium cepivorum* B.) DISEASE OF GARLIC (*Allium sativum* L.) VARIETIES IN NORTH EAST SHEWA, CENTRAL ETHIOPIA** Submitted in partial fulfillment of the requirements for the degree of Masters of Science with specialization in Plant Protection of the Graduate Program of Plant Science, College of Agriculture and Natural Resource Sciences, Debre Berhan University and is a record of original research carried out by Mr. Yikunoamlak Yilma, under our supervision, and no parts of the thesis have been submitted for any other degree or diploma.

The assistance and help received during the course of this investigation have been duly acknowledged. Therefore, I recommend that it to be accepted as fulfilling thesis requirements.

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APPROVAL SHEET – II

We, the undersigned members of the Board of Examiners of the final open defense by Mr.Yikunoamlak Yilma have read and evaluated his thesis entitled **DISTRIBUTION AND MANAGEMENT OF WHITE-ROT (*Sclerotium cepivorum* B.) DISEASE OF GARLIC (*Allium sativum* L.) VARIETIES IN NORTH EAST SHEWA, CENTRAL ETHIOPIA** and examine the candidate. This is therefore to certify that the thesis has been accepted in partial fulfillments for the requirements of the degree of Masters of Science in Plant Protection.

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Final approval and acceptance of the thesis are contingent upon the submission of the final copy of the thesis to the Council of Graduate Studies (CGS) through the Department Graduate committee (DGC) of the candidate’s major department.

DEDICATION

This thesis is dedicated to my beloved family, wife Mrs Messeret Haile, my son Samuel, my daughters Meba and Rahel Yikunoamlak for their dedicated patience in the success of my M.Sc. study.

STATEMENT OF THE AUTHOR

I declare that this thesis is my genuine work, and that all sources of materials used for reference have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for the Master of Science degree at Debre Berhan University and is deposited at the University library to be made available to users under the rules of the library. I intensely declare that this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma or certificate.

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BIOGRAPHICAL SKETCH

The author was born in Addis Ababa, Ethiopia on February 04, 1966. He attended his elementary school at Addis Ababa (Frehiwot) and Debre Berhan (Atse Zeryakobe) Elementary Schools from 1973 - 1975 and 1976 - 1978 , respectively, and High school at Hailemariam Mamo secondary comprehensive high school from 1979 to 1984. He joined Alemaya University in September 1986 and completed in July 1988 with Diploma in Crop Production and protection Sciences and he continued his educational status by joining Mekelle University in 1999 and graduated in July 2002 by an in-service program (summer and fourth year with regular program) with a degree in Dry Land Crop Science. He had long work experience in State Farm from September 1988 to July 1995, in Agricultural Offices in Tigray and Amhara regions from August 1995 to October 2014, and Amhara Region Forest Enterprise from October 2014 to November 2017 as an expert, department head, and manager. He joined Debre Berhan University in November 2017 to continue his postgraduate study leading to M.Sc. degree in Plant Protection.

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LIST OF ABBREVIATIONS and ACRONYMS

ANOVA	Analysis of Variance
AUDPC	Area under Disease Progressive Curve
CASCAPE	Capacity bulding for Scaling up evidence-based best practices in Agricultural Production in Ethiopia
CV	Coefficient of Variation
DAP	Days After Planting
LSD	Least Significant Difference
m.a.s.l.	meter above sea level
PSI	Percentage of Severity Index
PDA	Potato Dextrose Agar
RCBD	Randomized Complete Block Design
SAS	Statistical Analysis System
SPSS	Statistical Package for the Social Science
WS	Water Soluble
WP	Wetable Powder

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ABSTRACT

Garlic production is constrained by rust, downy mildew, basal-rot, botrytis-rot, penicillium decay, white-rot and namatodes. Among these, white-rot fungal disease caused by Sclerotium cepivorum B. is a major production threat of garlic in Ethiopia. The study was conducted to assess the distribution of garlic white-rot disease and to evaluate the combined effects of fungicides and varieties on the epidemic of white-rot disease and the corresponding yield and yield components of garlic. The survey was made in four districts of the North Showa zone (Angolelanatera, Basonaworana, Tarmaber, and Mojanawodera). It was made to understand the distribution and management status of the disease; 94.78 % of the garlic producers observed the distribution of the disease on their garlic fields. The majority (57.5 %) of the garlic producers got poor productivity of garlic. Along with this, a field experiment was conducted; the treatments were laid out in a factorial arrangement with three replications using randomized complete block design (RCBD). The findings showed that varieties, fungicide types and the interaction significantly affected the disease parameters. Improved varieties increased emergence rate (Bishoftu nech by 4.12 and MM-98 by 2.11days) and prolonged maturity time by 7 days as compared to the local variety. MM-98 and Bishoftu nech varieties treated by Apron star 42 WS fungicide showed the lowest PSI, followed by the MM-98 and Bishoftu nech varieties treated by More 720 fungicide as compared with the untreated local variety. The untreated plots showed a high area under disease progress curve than the treated once. MM-98 and Bishoftu nech varieties increased the total yield by 111% (6.81 tha^{-1}) and 95% (6.28 tha^{-1}) as compared to the local variety (3.22 tha^{-1}), respectively; and also Apron star 42 WS treated increased the total yield by 85.85 % (7.88 tha^{-1}) as compared to untreated (4.24 tha^{-1}). The application of fungicides along improved varieties for the disease management was found profitable. Hence, it could be concluded the field survey indicated that the occurrence of white-rot disease in the garlic field and productivity were different among districts and Apron star 42 WS treated and MM-98 and Bishoftu nech varieties had resulted in a lower disease incidence at 90 DAP, severity at 90 and 97 DAP and AUDPC with highest bulb weight, total dry biomass and yield per hectare.

Keywords*:* Fungicides, Garlic Varieties, Sclerotium cepivorum, white -rot

1. INTRODUCTION

Garlic (*Allium sativum L.*) belongs to the family Alliaceae and considered as one of the most important vegetable and spice crops produced in Ethiopia (Mohammed Amin *et al*., 2014). It is the second most widely cultivated Allium after onion and has been used for culinary and medicinal purposes such as antibacterial, antifungal, antiviral, antitumor and antiseptic properties (Pandey, 2012) and an excellent source of several minerals and vitamins that are essential for health (Dresse Deka, 2010). It has been cultivated worldwide to use as fresh bulb, dried bulb, and the oil extracted used as a flavoring agent of a traditional medicine (Satyal *et al*., 2017) and has a wide range of climatic and soil adaptation (Yemane Gebre Meskel *et al*., 2017).

The total world production of garlic crop was 26,573,001 metric tons and China was by far the largest producers, 80% of the world production (21,197,131 metric tons) was from China. Ethiopia was 13th country in the world and 2nd from Africa countries, and the total production was138, 664 metric tons (FAO, 2017). The yield produced in China (23.08 tha^{-1}) was more than four times higher than the yield observed in India (5.27 tha^{-1}) and higher than theworld means (16.71 tha^{-1}) (FAO, 2011). In Ethiopia , according to CSA report, in 2017/18; 19,412.49 ha with a total production of 178,222.00 tons of bulbs with the productivity of 9.18 t ha^{-1}.

The low productivity of garlic in Ethiopia is due to rust, downy mildew, basal-rot, botrytis-rot, penicillium decay, white-rot and namatodes. Among these, white-rot fungal disease caused by *Sclerotium cepivorum* B. is a major production threat of garlic and by far the most destructive and widely spread disease of allium species (Fuga *et al.*, 2012). It is a devastating soil-born fungal disease in several parts of the world (Valdir *et al*., 2018) and causing tremendous yield losses in the major production area of garlic (Pinto, 2000). Worldwide distribution of white-rot disease has been reported in many countries including: Argentina, Australia, Iran, Mexico, New Zealand, Netherlands, Spain, Switzerland, United Kingdom, and USA (Camiletti *et al*., 2016, Villalta *et al*., 2012, Saremi *et al*., 2010, Ponce-Herrera *et al*., 2008, Davis *et al.*, 2007, Tyson *et al.*, 2002, and Earnshaw and Boland, 1997). White-rot disease is prevalent in many Allium growing regions worldwide and causes serious economic losses in garlic crops (Earnshaw *et.al.*, 2000). In Ethiopia, the disease has become a major production threat of garlic in the main growing season (Getachew Tabor and Asfaw Zeleke, 2000). Besides, the farmers shifted their production to other vegetables due to this disease (Fekadu Mariame and Dandena Gelmesa, 2006). In the absence of host plant sclerotia as small and dormant structures, it can survive for long years in the soil (Mohammed Amin *et al.*, 2014). Once white-rot appears in cool soils of garlic fields, it spreads rapidly and would become very difficult to cultivate garlic (Crowe *et al.*, 1980b). Intensive cropping of allium species for a long time would build-up of sclerotial inoculums which plays an important role in the distribution of the fungus (Fuga *et al*, 2012). In Ethiopia white-rot problem in general and the onion and garlic growing areas in particular is creating great challenges (Mohammed Amin *et al*., 2014).

The garlic crop is challenged with several problems, that caused low productivity and poor quality largely attribute able to the use of unimproved local varieties with poor productivity (Yebirzaf Yeshiwas *et al* 2017). Several efforts have been made to combat white- rot worldwide. This includes the use of resistant garlic varieties, fungicidal control and different cultural practices (Agrios, 2005).

The profound ability of the disease to reach an epidemic level with short periods, the inadequate efficiency of cultural practice to reduce the high level of disease severity, the rapid development of resistance to fungicides and breakage of plant resistance in garlic varieties with in short period of time have made integrated use of different disease management strategies very essential in white-rot management. Apron star 42 WS is in controlling the white-rot disease reported in Ethiopia for while it is not common elsewhere (Chemeda Dilbo *et al.*, 2015). Besides, no single management practice will result in complete control of Allium white rot, and generally combining different approaches enhances control (Clarkson *et al.*, 2016). Hence, fungicides with varieties have been commonly practiced for sustainable production of garlic in the most developed world and were found to reduce the disease incidence from 75 to 95 % when applied as seed and soil treatment (Melero *et al.*, 2000). However, In Ethiopia, research efforts on fungicides with varieties combination against onion and garlic white rot is very limited, moreover, there is a shortage of information, no guide line in disease diagnosis, monitoring, and management (Mohammed Amin *et al.*, 2014). When there are susceptible varieties, moist soils and cool temperature in garlic fields the white-rot disease can cause a 100 % loss (Zeray Siyoum, 2011). In the highlands of Ethiopia, the disease can cause 20.70 % to 53.40 % garlic yield loss, and 37.28 % to 42.00 % incidence of white-rot on garlic crops in farmers' fields in north Shewa (Tamire Zewde *et al.*, 2007). Therefore, the objectives of this study were:

- General objective: To assess the distribution and management stats of garlic white-rot disease in North East Shewa, central Ethiopia.

Specific objectives:

- To assess the distribution of garlic white-rot diseases on four districts of North East Shewa, central Ethiopia.
- To evaluate and determine the effects of fungicide types and varieties on the epidemics of garlic white-rot and yield and yield components.

2. LITERATURE REVIEW

2.1. Origin and Botany of Garlic

The origin of garlic(*Allium sativum* L.) is on the north-western side of the Tien-Shan Mountains of Kirgizia in the arid and semi arid areas of Kazakhstan, central Asia and being the center of domestication and variability (Etoh and Simon, 2002; Brewster, 2008). China to India; Egypt to Ukraine is the larger area wild garlic may grow. Depictions more than 5000 years old onion bulbs and models of garlic bulbs have been found in Egypt. Even if garlic found before long years in Egypt how and when introduced in Africa was not documented. However, some evidence indicated that garlic introduced in Ethiopia by foreigners and now a days the crop cultivated in high land areas of the country (Tadesse Adgo, 2008).

Garlic can be grown as annual and perennial with height of two feet high or more may grow to be 30-90 cm tall. The bulb is the main part of the plant and is divided into segments called cloves, depending on the size of the bulb containing 6 to 12 cloves per bulb. The clove is an important product which harvests from garlic crop and found under the surface soil (Davies, 2012). The roots reach up to 50 cm depth or little more, the stems snipped or braided and leaves are thin tape-shaped about 30 cm long (Pretorius, 2006). Garlic flowers are sterile and propagate by using the cloves or bulbs as seeds (Mann, 1952).

Garlic capsule found at the top of the flower small, greenish-white, purple, or pink and the number of flowers that can vary, in some flowers may not present. There are estimated to be about 780 species in the genus Allium.

2.2. Ecological Requirements of Garlic

Garlic is the mid and high land crop which grows on average from 1800 - 2500 m.a.s.l. (EFDRMANR, 2017). It requires reasonably mild winter with an average rainfall of 600mm to 700 mm (Yemane Gebre Meskel *et al*., 2017). It requires plenty of sunshine and does particularly well in Mediterranean countries where the big, juicy cloves have an excellent flavor (Innvista, 2005). The areas which have an average temperature of 12 - 24 ℃ are appropriate for garlic production. Garlic plants can tolerate cold temperatures (Rubatzky and Yamaguchi, 1997). It likes well-drained soil. Garlic is quite tolerant when it comes to soil types and textures, but it appreciates sandy-clay-loam that is easily crumbled in the hand and has high organic matter content. It does best when the PH in the range of 6.5-7.5 as it is sensitive to higher acidity (Bachmann, 2001; Potgieter, 2006).

2.3. Production Constraints of Garlic

Due to different factors like genetic and environmental garlic productivity is very low, insects and fungi are the major pests of the crop in different parts of the world (Janet and Tammy, 2008). In addition, diverse crop management problems and the nature of propagation limit the supply of production too. In Ethiopia, major production constraints of garlic include lack of improved varieties, garlic rust (*Puccinia allii* Rudolphi*)*, downy mildew (*Peronospora destructor* Berk.), basal rot (*Sclerotium rolfsii* Sacc.), white rot (*Sclerotium cepivorum* Berk.) and onion thrips (*Thrips tabaci* Lind.) (Getachew and Asfaw, 2000).

2.4. White-rot of Garlic

2.4.1. Taxonomic Position of the Pathogen

White-rot is caused by the fungus *Sclerotium cepivorum* B. The white-rot disease is belonged in the kingdom fungi an ascomycete (subphylum Pezizomycotina, class Leotiomycetes, order Helotiales, and family Sclerotiniaceae) and grows in soil from an infected food base (Scott, 1956 and Fuga *et al*., 2012). The pathogenic activity of white-rot increases as the root system develop**s,** under natural conditions are restricted to Allium species. The fungus produces micro conidia in nature and culture (Coley, 1986**).**

2.4.2. Biology, Epidemiology, and Ecology of the Disease

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). Host plant exudates stimulate to germinate sclerotia that form on the decaying host plant until it got unique Allium species root exudates to stay dormant. To germinate sclerotia and to grow the cool weather is an important factor. The soil moisture level which is suitable for host plant early-stage growth is similarly appropriate for sclerotia germination. Mycelium will grow through the soil and once it encounters a host root the fungus will form appressoria, structures whose purpose is to aid in the attachment and penetration of the host (Crowe, 2008; Ararsa Lema and Thangavel, 2013).

Mycelial growth spreads upwords from the root 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 the damage. In cool moist soil where disease inoculums are high in the field, the causative agent sclerotia (survival structures) will germinate in the presence of onion and garlic root and bulb exudates (Mohammed Amin *et al*., 2014).

Mycelium can grow outwards from the roots of one plant to the roots of the neighboring plant and by this method that the pathogen can move down a planted row. Once the host tissue completely decays the sclerotia are free in the soil. If the bulbs survive long enough to be placed into storage, the pathogen may continue to decay the bulbs if there are 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 Lema and Thangavel, 2013).

2.4.3. Geographic Distribution of the Disease

The white-rot disease in the world is the main problem in a large number of Allium growing areas (Crowe *et al*.,1980; Perez *et al.,* 1994 and Pinto *et al.,* 1998). The disease first reported on garlic in Italy (Walker, 1924). White-rot disease is distributed worldwide and causes serious economic losses in garlic production. In Mexico and Brazil, 100% loss were reported (Ernshew *et al.,*2000). In garlic production, because of white-rot disease there is a great yield loss and a wide range of land became out of use all over the world (Crowe *et al.*, 1980b and Coley *et al.*, 1987). The distribution of white-rot disease in Ethiopia cover a wide range of areas, like Northern part of the country is a major production threat of garlic in the Tigray regional state of Ethiopia. During favorable weather conditions and when susceptible varieties are in the production system, the disease can cause 100% yield loss (Zeray Siyoum, 2011). In Western Shewa (Ararsa Lema and Thangavel, 2013), and in whole, Harerge, Arsi, East Gojam, in Shewa and in South Wello where garlic is planted in a wide coverage of land white-rot is a problem (Getachew Tabor and Asfaw Zeleke, 2000). In South, southwestern, North East Shewa and in a different region of Ethiopia *Sclerotium cepivorium* causes great damage in garlic crops; around North Shewa white-rot incidence was reported at a level ranging from 37.28% to 42% in farmers field (Tamire Zewde *et al*., 2007).

Even if currently designed the strategy to prevent the introduction and distribution of the fungus into farms, and disease spread within farms, includes restricting the movement of equipment, infected plant materials, and grazing animals, many growers do not adopt these measures and many often acquire contaminated garlic bulb seeds.

2.4.4. Host Range and Survival of the Pathogen

The causes of White-rot disease are *Sclerotium cepivorum* (Coley *et al.*,1987; Entwistle, 1986, 1990a). *Allium* plants may be infected at any stage of growth when sclerotial germination is triggered by volatile sulfur compounds associated with host plant root exudates and environmental conditions are favorable for infection: damp soil and temperature at the range of 13-18 °C (Crowe & Hall, 1980a; Fuga *et al*., 2012). Sclerotia are the only reproductive structures of *Sclerotium cepivorum* (Mohammed Amin *et al*., 2014). There is no report of sexual reproduction in the population of *Sclerotium cepivorum,* it reproduces by clone (clonal) genetic difference is not clear (Xu *et al.*, 2010). White-rot is a soil-borne fungus *Sclerotium cepivorum*, and a very destructive disease that begins in the field and possibly carry-over into storage (Chaput, 1995). The cooler environment is favorable for white-rot. To germinate Sclerotia favorable temperature is 9 to 24 ^{0}C and to continue disease development 6 to 24 ^{0}C (Crowe and Hall, 1980). Host and soil effects are important in the survival of white-rot (Tamire Zewde *et al*., 2007).

2.4.5. Symptoms and Signs of the Disease

The white-rot disease can be identified by observing symptoms on garlic plant parts. It includes destruction of the root system, premature yellowing and dying of older leaves, stunting, and leaf tip burn, followed by the leaf dieback, wilting, snow white mycelia on the bulb surface or at the crown of seedlings, and rotting of the bulb (Mahmoud, 2018). However, unless care is taken, these symptoms alone may be confusing with other types of damage (i.e., onion maggot). When the bulbs and roots are examined, white, fluffy mold and soft rot will be observed. Masses of tiny black sclerotia can also be seen within this mold. These sclerotia remain in the soil for many years. Infected bulbs can rot in storage boxes and stain other bulbs. White-rot typically develops in patches in the field and is less of a problem when soils are warm (higher than 24 °C) and dry. The organism is most active when the temperature is cool(Chaput, 1995).

2.5. Economic Importance of the White-rot Disease

In Ethiopia, white-rot causes important economic losses in garlic production, caused by breaking of floral stalks, and thus, the bulb yield and are significantly reduced (Mohammed Amin *et al*., 2014**).** In Ethiopia, around northern Shewa white rot incidence was reported at a level ranging from 37.28 % to 42 % in farmers' fields and yield loss due to white rot has been found to range between 20.7 % and 53.4 % (Tamire Zewde *et al*., 2007). One of the minimum requirements to export garlic in the world market is the quality of bulb, however, due to the white-rot disease , it is affected by rotting or deterioration (FAO, 2007). Currently, the economic loss due to the disease is very high (Valdir *et al.*, 2018). If the weather is cool and moist, with poor management practice and susceptible variety, the white-rot infestation, can result in 100 % yield loss (Zeray Siyoum and Yesuf Mohammed, 2013). The disease can be recognized early in its development stage so that effective management strategies can be implemented. Careful and regular monitoring of the crop can provide this timely information that can help to minimize the unpredictable economic loss (Chaput, 1995).

2.6. Management of White-rot Disease

2.6.1. Cultural and Physical Control

Hygiene and sanitation are some of the most effective methods to control white-rot. Cleaning equipment and farm fields can avoid the spreading of sclerotia (Entwistle, 1990). Increasing soil temperature by using plastic sheet usually polyethylene is spread over or shredded in to the soil to concentrate sunlight, raising soil temperature to 36 ^{o}C to 50 ^{o}C that is called solarization (Katan, 1987). Many researchers have identified *Sclerotium cepivorium* sensitive to high soil moisture (Alexander and Stewart, 1994; Clarkson *et al.*, 2004).The use of germination stimulants like Allium species root exudates (diallyl disulfide), soil amendments and using mulches that mimicking the sclerotia as a physical control to minimize sclerotial density (Stewart and Mclean, 2007). Crop rotation, planting date, bio-fumigation and deep cultivation are cultural practices and solarization and flooding are physical methods of control that have been effective in reducing the population of sclerotia in soils and disease incidence (Valdir *et al.*, 2018).

2.6.2. Biological Control

In sustainable agriculture, the biological control of pathogen is currently accepted. Certain rhizosphere organisms that are common components of an ecosystem known to develop antagonistic activities against harmful organisms. Among these, Fungi viz., Trichoderma, Gliocladium, Talaromyces and Arbuscular Mycorrhizal Fungi (AMF) have shown enormous potential as biocontrol agents against different soil borne and foliar diseases (Lo *et al*., 1996). *Trichoderma harzianum* as a potential biological control agent to use against white-rot, provide an 86 % reduction in disease on the test (Abd, 1992). The C4 strain of *Trichoderma harzianum* as provide protection against white-rot (Miranda *et al*., 2006). AMF and Trichoderma species are native strains used for plant growth promotion and biological management against white-rot. Some work has suggested that Brassica residue incorporation or intercropping may have a suppressive effect on sclerotia germination (Ulacio *et al.*, 2006).

2.6.3. Fungicidal Control

The use of chemical fungicides is the most common control method for the disease at the present time. This control measure is costly, contaminates the environment, and harms non-target organisms. Moreover, since the pathogen is soil-borne, the chemical control strategy is not quite effective against the disease (Razak *et al*., 2015). Now days, in the world there are only a few effective fungicides for white-rot control (Valdir *et al.*, 2018). Tebuconazole and captan generally gave a significant reduction in white-rot and increase in total as well as marketable yield over the control (Tamire Zewde *et al*.,2007).

The use of fungicides depends on dicarboximides such as procymidone, iprodione, and vinclozolin which can be used as a seed dressing and foliar sprays; particularly effective at reducing garlic *Sclerotium cepivorium* infested fields (Stewart and Fullerton, 1991). In addition to limited effectiveness, the phenomenon of enhanced degradation of dicarboximide fungicides by resident soil microorganisms has been detected in fields where such fungicides have been used regularly, with some research identifying a 90% loss of dicarboximide fungicides in soil pretreated with them within 7 days (Garcia, and Xirau, 2002).

Instead of pre-plant treatments it is better to use garlic clove treatments, post-planting as foliar sprays and as a combination of seed and foliar sprays to control the white-rot disease. It is difficult to control the disease by pre-plant treatments because the fungicides might degrade and below the zone of protection, the fungus may spread through the soil among roots, it must remain effective throughout the season. When the fungicide begins to diminish, the fungus may infect and/or kill plants if fungicide protection is not present (Crowe *et al.,*1980b). Fungicide not only protected plants against infection in early and late stages of growth, but also reduce the formation of sclerotia at harvest period (Valdir *et al.,* 2018).

2.6.4. Host Resistance

In garlic production the use of resistant varieties is cheaper, environment-friendly and easily practicable in disease control method (Shah *et al*., 2006). In the world, in different agro-climatic zones about 300 varieties of garlic are cultivated, (Innvista, 2005). Most of the garlic producers in Ethiopia have obtained the garlic seed from local markets for production purposes. However, using of different improved cultivars from the known source and integrating with different diseases management practices could be guaranty for better productivity of garlic seed (Acquaah, 2015).

For white-rot disease, susceptible host are important in the survival of white rot (Tamire Zewde *et al*., 2007). Allium-specific root exudates (alkyl cysteine sulphoxides) stimulate *Sclerotium cepivorum* sclerotia to germinate, indicating that the host range is limited to Allium species (Mohammed Amin *et al*., 2014). In Ethiopia, there is a great limitation on research effort on host resistance against garlic white-rot. Onion and other Allium species including garlic resistance to white-rot can be correlated with the amount of volatile precursor root exudates the plant produces (Brix and Zinkernagel, 1992). Despite to its production potential at the different agro ecology of the country, till now there is no an authorized companies that produce the variety of vegetable crops in general to meet the growers demand (Nikus Olani and Mulugeta Fikre, 2010). Those Allium species having 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 and also no Allium species is known which shows a consistently high degree of resistance to *Sclerotium cepivorum* (Brix and Zinkernagel, 1992). In white-rot disease control, the use of resistant cultivars could provide weapon in disease protection, but no such cultivars have been developed to a commercial standard (Clarkson *et al.*, 2006).

2.6.5. Integrated Disease Management

Integrated disease management (IDM) is a combination of different disease control methods such as resistant varieties, biological, chemical, cultural and physical that is acceptable to reduce damage caused by disease to tolerable levels(Agrios, 2005). Currently, integrated use of fungicides types and bio control agents helps to protect the crop against infection and by using stimulant agents mimic the sclerotia and soil fumigation to reduce sclerotia density in soils (Valdir *et al.*, 2018). No single management practice will result in complete control of Allium white-rot, so combining different approaches make effective control method (Clarkson *et al.*, 2016).

The disease minimizes its expansion by using the cultural method with the integrated control system, while physical control methods like heating soil by the sun, flooding, and germination stimulants are used to reduce the density of the inoculum in fields already infested with *Sclerotium cepivorum* (Chemeda *et al,* 2015). To manage white-rot disease, using of fungicides coated seed, biological control agents and resistant cultivars were the most effective method (Clarkson *et al*., 2004).

3. MATERIALS AND METHODS

The topics includes three components, such as field survey on status of white-rot disease and field experiment to determine and evaluate effect of varieties and fungicide types on white-rot disease development and its effect on yield and yiel components of garlic and includes also laboratory activities done in North East Shewa, Central Ethiopia.

3.1. Survey of Garlic White-rot

3.1.1. Description of the Study Area

Field survey was conducted in North East Shewa, Central Ethiopia, four districts namely Angolelanatera, Basonaworana, Tarmaber and Mojanawodera districts during 2019/2020 cropping season. Each districts lies at altitude of 937 – 4326 m.a.s.l. Each districts, the mean minimum and maximum temperature ranges from 6 to 30 ^{O}C and the mean minimum and maximum rain fall ranges from 800 to 2200 mm per annum. The major soil types in each districts Black, Loam and Sandy loam. Major crops grown in each districts irrigation sites are garlic, onion, carrot, potato and lentil. (Figure 1 and Table 1).

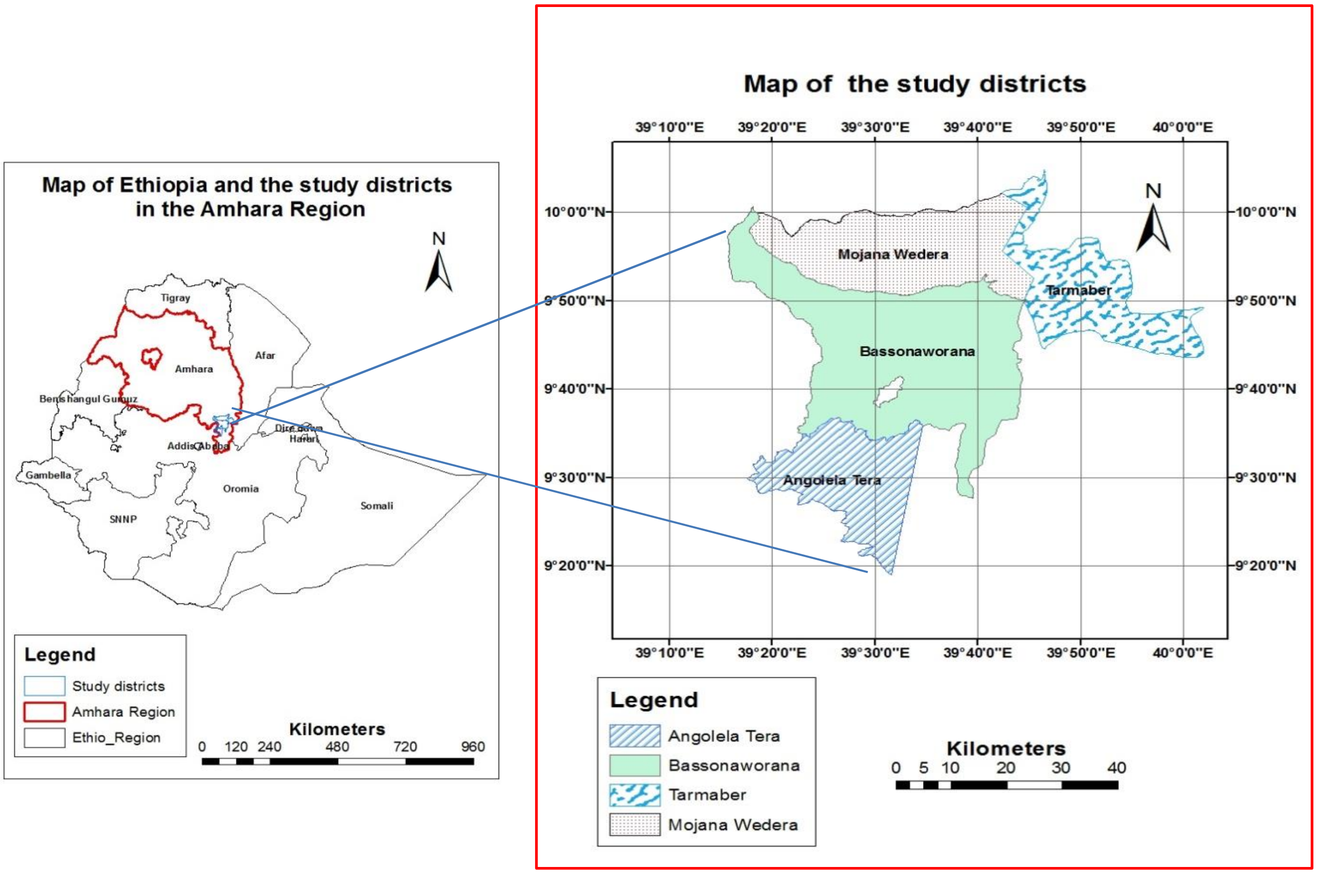

Figure1. Location Map for the Study Districts

Table1. Districts geographical location, rainfall and temperature

Districts	Latitude	Longitude	Altitude m.a.s.l.	Rainfall (mm)	Temperature (^oC)
Angolelanatera	9^0 19' 30'' N- 9^0 37'20'' N	39^0 18' 36'' E- 39^0 34' 19''E	2756-4326	800-1500	6-30
Basonaworana	9^0 28' 40''N- 10^0 2' 20'' N	39^0 17' 28'' E- 39^0 44' 10'' E	1500-3450	900 -1050	19-25
Tarmaber	9^0 44' 12''N- 10^0 5' 20'' N	39^0 43' 11'' E - 40^0 3' 28'' E	937 -3700	1100-1400	15-25
Mojanawodera	9^0 50' 12''N- 10^0 1' 10'' N	39^0 18' 50'' E- 39^0 46' 20'' E	1600-3054	1200-2200	12-22

3.1.2. Farmer Sampling Procedures

A survey was conducted by using multistage sampling technique. Four potential garlic production districts of North East Shewa,Central Ethiopia, namely Angolelanatera, Basonaworana, Tarmaber and Mojanawodera were selected with the consultation of zonal agricultural staff members. Number of peasant associations and sampled garlic producers selected based on garlic production and number of garlic producers in the districts. Eight peasant associations (PAs), three from Angolelanatera district, three from Basonaworana, one from Tarmaber and one from Mojanawodera districts were chosen purposively. The farm households in each potential garlic producing PAs were stratified into garlic producers and non-producers using irrigation. Generally, a total of 120 garlic producers using irrigation were randomly selected from each districts; i.e. 40, 40, 20 and 20 garlic producers from Angolelanatera, Basonaworana, Tarmaber and Mojanawodera, respectively. The data necessary for the study were collected from those sampled garlic producers by conducting a survey using a structured interview, which is found in appendix.

3.2. Field Experiment

3.2.1. Description of Experimental Site

The field experiment was conducted under irrigation condition at Chefanen peasant association at Bura irrigation site in Angolelanatera district, North East Shewa, Central Ethiopia, during 2019/2020 cropping season. The site is located at about 111 km North East of Addis Ababa and geographically at 9°32'19''N latitude and 39°27'10'' E longitude. The area has an altitude of 2800 m.a.s.l. The area has an average annual rainfall of 897.8 mm and the annual mean minimum and maximum temperature 6.1ºC and 19.67ºC respectively with loam soil type.

3.2.2. Treatments and Experimental Design

The treatments were consisted of 3 × 3 factorial combinations of three fungicides (Control, Apron star 42 WS, More 720 WP) and three garlic varieties (MM-98, Bishoftu nech and

Local). The treatments were arranged in a randomized complete block design (RCBD) with three replications. The required amount of cloves to be treated was weighed at a rate of 600 kg/ha and immersed in the recommended rate. At the time of planting the garlic clove was treated by Apron star 42 WS fungicide with a rate of 1.5 kg/ha in 600 lt. of water (Abraham *et al.*, 2015) and 2 kg/ha of More 720 WP with 900 lt of water was applied by foliar spray after the onset of the disease.

Table 2. Treatment combination (fungicide types x varieties)

Treatments	Varieties	Fungicide types
1	MM-98	Untreated
2	>>	Apron Star
3	>>	More 720 WP
4	Bishoftu nech	Untreated
5	>>	Apron Star
6	>>	More 720 WP
7	Local	Untreated
8	>>	Apron Star
9	>>	More 720 WP

3.2.3. Experimental Procedures

The land was ploughed with a depth of 25 - 30 cm, pulverized and leveled. The seed beds were prepared with ridges and furrows in an appropriate way for furrow irrigation. Improved seed varieties of Bishoftu nech and MM-98 of garlic were collected from Debre Zeit and Debre Berhan Agricultural Research Centers respectively. The experimental field plots size was 3.6 m^2 (2m * 1.8m) with a total of six rows and 120 plants per plot with 1m spacing between blocks and 0.5m between plots. The treated and untreated cloves were planted in the experimental field according to the standard planting density of (30*10) cm with 20 plants per row. UREA and NPKS were applied at the rate of 150 kg ha^{-1} and 200 kg ha^{-1}, respectively. All NPKS were applied at the planting time, whereas the half rate of nitrogen fertilizer was applied at the emergence of the seedlings and the remaining half after a month of the first urea application (EFDRMANR,2017). Irrigation and other cultural practices such as weeding and cultivation were conducted repeatedly as necessary based on Amhara region agricultural office recommendation (irrigate the land before planting and continue in seven days interval; weeding starting at early emergence) in the study area.

Data Collection-:

Both disease and crop data were collected as required. Disease data was recorded since disease on set observed on the field and continued every seven days until the crop maturity.

3.2.4. Disease Parameters

Disease Incidence (%)*:*

Disease incidence is the percentage of plants which show symptoms of infection from the total plants considered. Both diseased and healthy plants were counted. The assessment was done, when the symptoms appear for the first time and it was calculated with the following formula;

$$\textbf{Disease Incidence} = \frac{\textit{No.of infected plants from the samples taken}}{\textbf{Total No.of plants assessed}} * 100$$

Disease Severity (%): was recorded 4 times with the interval of seven days from the first appearance of the disease in the plots using ten randomly selected garlic plants in the four central rows. It was recorded by estimating the percentage of leaf and stem area diseased using a scale from 0-5 (Chemeda Dilbo *et al* 2015 and Rengwalska, 1986). The severity grades were then converted into percentage severity index (PSI) for ease of analysis according to the formula byWheeler (1969).

Scales-: Foliar symptoms (0 for healthy leaves, 1 for one to two leaves infected, 2 for 2 to 3 leaves infected, 3 for 3 to 4 leaves infected, 4 for 4 to 5 leaves infected and 5 for 5 and above leaves infected)

$$\textbf{PSI} = \frac{Snr}{Npr \times Msc} \times 100$$

Where Snr is the sum of numerical ratings, Npr is number of plant rated; Msc is the maximum score of the scale. Means of the severity of each plot was used in data analysis.

The Area under the Disease Progress Curve (%-day*):* it was calculated for each treatment from the assessment of disease severity using the following formula (Campbell and Madden, 1990).

$$\text{AUDPC} = \sum_{i=1}^{n-1} 0.5[(X_{i+1} + X_i)(t_{i+1} - t_i)]$$

Where: xi = the cumulative disease severity percentage of infected plants at the i^{th} observation (day i), ti = time (days) at the i^{th} observation, n = total number of symptom observations. AUDPC was expressed in percent-days, because severity (x) was expressed in percent and time (t) in days (Shaner and Finney, 1977). AUDPC values were used in the analysis of variance to compare the amount of disease among plots with different treatments.

3.2.5. Phenological Parameter

Days to Emergence: The number of days required for emergence was determined as the number of days from planting to when 50% of garlic seedlings emerge.

Days to Maturity: The number of days required for maturity was determined as the number of days from planting to when 75% of leaves fall over.

3.2.6. Growth Parameters

Plant height (cm): the length of the plant in cm was measured from 10 randomly selected plants in each plot from the soil surface to the tip of the plant at physiological maturity and the average was considered for statistical analysis.

Leaf diameter: the average diameter of leaves was considered from 10 randomly selected plants in the four central rows. One leaf from each sample plant was measured at the widest part at the time of physiological maturity.

Leaf length: the average length of the longest leaf, at physiological maturity was measured in cm from 10 randomly selected plants in the four central rows.

Leaf number per plant: the total number of healthy leaves was counted from 10 randomly selected plants in the four central rows at physiological maturity.

Neck diameter (cm): Thickness of neck was determined from ten randomly selected plants of the four central rows. It was measured by using caliper after curing.

Shoot dry weight (gm): The shoot fresh mass was oven-dried at the temperature of 65 ^{0}C to a constant weight and its dry matter yield was determined.

3.2.7. Yield and Yield Components

Bulb diameter (cm): bulb diameter was determined from10 randomly selected plants of the four central rows. It was measured at the middle cross section of the bulb by using caliper after curing.

Bulb length (cm): the length of the bulb was determined from 10 randomly selected plants of the four central rows. It was measured longitudinally by using caliper after curing.

Average bulb weight (gm): the average mature bulb weight per plant was registered after the weighing of all cured bulbs produced in the four central rows and divided by the number of bulbs.

Clove length (cm): the average clove length was measured in caliper from 10 randomly selected plants.

Clove diameter (cm): diameter of the cloves was measured in caliper from 10 randomly selected plants.

Average clove weight (g): clove weight of 10 randomly selected plants from the four central rows was measured after curing and divided by the number of cloves.

Clove number per bulb: the number of cloves produced from 10 randomly selected plants as counted and divided by the number of bulbs.

Bulb dry matter content (%): Cloves from five randomly selected bulbs were chopped into small pieces with the help of stainless steel knife, mixed thoroughly, and the exact weight of each sample was measured and recorded as fresh weight . The samples were placed in paper bags and dried in an oven at 65^{o}C until a constant weight is obtained. Each sample was immediately weighed using a digital sensitive balance and recorded as dry weight. Percent dry matter content for each sample was calculated by the following formula:

$$DW = \frac{[(DW + CW) - CW]}{[(FW + CW) - CW]} X100$$

Where: DW= dry weight, CW=container weight, FW= fresh weight

Yield per plot (t ha^{-1}): the bulb weight of plants harvested from four central rows was weighted after curing for 10 days under shade in ambient condition and converted to tons per hectare.

Total dry biomass (gm): this was determined by taking the total biomass weight which included dried bulbs, leaves, stems and roots after curing and sun drying until a constant weight was attained.

3.3. Laboratory Activities

Isolation and Identification of *Sclerotium cepivorum* of Garlic -:

Infected garlic bulbs showing symptoms of the disease and healthy bulbs were obtained from the experimental field and taken to the laboratory. Cloves from healthy bulbs were chopped with clean mortar and pistil. Sclerotia have stromatic mantles which contain Melanin composed of layers of pigmented and thickened cells made of polysaccharide hyphae and protein bodies (Backhouse & Stewart, 1987). Melanin is responsible for the dark color acting as a defense to desiccation (Willets & Bullock, 1992). Sclerotia are easily produced around 10 days in potato dextrose agar (PDA) at 18 °C (Backhouse & Stewart, 1987). For this study in the laboratory every step of material preparation, sterilization, and incubation taken place according to the lab procedure. Several single sclerotia from infected bulbs was placed on potato dextrose agar (PDA) medium and incubated at 20^{0}C in the dark for seven days. Similar sclerotia were cultured without PDA using chopped healthy cloves as a media in a petridish and incubated at 20^{0}C in the dark for seven days (Bakonyi *et al*., 2011). Then, the pathogen was identified by comparing with the morphological characters of white-rot (*Sclerotium cepivorum* Berk) described by Bakonyi *et al*. (2011).

3.4. Data Analysis

3.4.1. Survey Data Analysis

Data collected through questionaire were organized and summerized for analysis. Data were analyzed using descriptive statistics with SPSS (SPSS, 23). Pearson's chi-square (X^2) test was used for categorized variables to assess a statistical significance of a particular comparison.

3.4.2. Experimental Data Analysis

Data were subjected to Analysis of variance (ANOVA) using the General Linear Model (GLM) of the SAS statistical package (SAS, 2007) version 9.1. Least significant difference (LSD) at 0.05 probability levels was used to separate treatment means and correlation between disease parameters and garlic growth parameters, yield components and yield were calculated.

3.4.3. Economic Analysis

To understand the profitability, price of improved or locally selected garlic seed was considered (the price of improved and locally selected garlic seeds was similar). Besides, the cost of fungicides and cost of application was calculated by the following equation (Wegulo *et al*., 2011).

$$\mathrm{RN} = \mathrm{YiP} - (\mathrm{Fc} + \mathrm{Ac})$$

Where, Rn = the net return from fungicide application (birr ha^{-1}); Yi = is yield increase from fungicide application (kg ha^{-1}) obtained by subtracting the yield in the control treatment from the yield in the fungicide treatment, P = is the garlic prices (birr kg^{-1}); Fc = is the fungicide cost (birr ha^{-1}); and Ac = the fungicide application cost (birr ha^{-1}).

4. RESULTS AND DISCUSSION

4.1. Distribution of White-rot Disease

4.1.1 Distribution of Garlic White-rot

The survey was done in four districts of North East Shewa, Central Ethiopia namely, Basonaworana, Angolelanatera, Tarmaber and Mojanawodera. The results revealed that hectares of lands used for garlic production were very small in the four districts. In this study, from the 120 sampled garlic producers, the average cultivated land was 1.45 hectare out of which 0.53 and 0.16 hectare were irrigable and garlic cultivated land, respectively (Table 3). Even if the demand factors create a wide range of interest to produce and to consume garlic as an important vegetable (Agricultural outlook, 2000), in Basonaworana district (28.88%) and in Angolelanatera district (22.87%) of their irrigable land was used to produce garlic. This poor coverage might be associated with the fear of risk of white-rot disease; which has been a challenge for long time (Table 3). Agrobolivia,(2006) reported that due to the production units of 0.25 hectares per family, producers usually have limited resources to afford the extra expense to protect their land from the diseases. However, in the study area the average for garlic cultivated land was 0.16 hectares which less is than 0.25 hectares.

Table 3. Garlic cultivated land (in hectare) and yield (ton- ha-1) across the districts

Districts	Cultivated land (ha)		Irrigable land (ha)		Average Garlic cultivate land (ha)		Garlic land out of Irrigable%	Garlic average yield (ton-ha^{-1})
	Total	Average	Total	Average	Total	Average		
Basonaworana	59.63	1.49	24.00	0.60	6.69	0.17	28.88	2.95
Angolelanatera	74.75	1.87	29.91	0.75	6.84	0.17	22.87	3.79
Tarmaber	19.31	0.97	3.69	0.18	3.50	0.18	94.85	1.77
Mojanawodera	20.63	1.03	5.41	0.27	2.28	0.11	42.14	7.23
Sum	174.32	1.45	63.01	0.53	19.31	0.16	30.65	3.54

In the study areas, white-rot disease was distributed and occurred in garlic fields. About 37.72 % of the respondents described white-rot as a sole disease while 57.02% of them explained the association of white-rot with other diseases such as Black mold, Rust, and Downy mildew (Table 4). This destructive disease become out of their control and resulted in the shifting of garlic production in to other crops, so garlic production area remains small 30.65 % out of the total irrigable land of sampled farmers (Table 3). Similarly, Alemayehu Hailu (2016) reported that the major problem for garlic production was white-rot. On the other hands, Tamire Zewde *et al*. (2007) also reported that there was a great yield loss of garlic at North Shewa due to white-rot disease.

Table 4 . Types of diseases observed by producers across the districts

Districts	White-rot (1)	Black mold(2)	Rust (3)	Downy mildew (4)	1&2	1&3	1&4	Total
Bassonaworan	12	3	0	2	8	6	7	38
Angolelanatera	20	0	0	0	4	16	0	40
Tarmaber	6	0	1	0	1	10	1	19
Mojanawodera	5	0	0	0	0	11	1	17
Total sum	43	3	1	2	13	43	9	114
%	37.72	2.63	0.88	1.75	11.40	37.72	7.89 (57.02%)	

4.1.2 Sampled Farmers Experience to Identify the Distribution of Garlic White-rot

Sample respondents were experienced for 2 to 38 years in garlic production and aware its constraints (Table 5). Even if there were long experiences in the two districts Basonaworana and Angolelanatera as compared to Tarmaber and Mojanawodera districts, they did not show the expansion of garlic production land that might be due to the risk of white-rot disease. The majority of the garlic producers were new entrances (2 to 6 years), this might be, if the land continued to produce garlic for long years because of the white-rot disease infestation, it became out of production. In line with this, 1 to 5 years experienced farmers were found in garlic production (Halimatun *et al*., 2016).

Table 5. Producers experience (in year) in garlic production

Districts	2- 6 years	7-12 years	13-38 years	Total
Bassonaworan	30	8	2	40
Angolelanatera	34	3	3	40
Tarmaber	20	0	0	20
Mojanawodera	18	2	0	20
Total	102	13	5	120

The result indicated that 94.78 % of the sampled farmers of the four districts faced with the occurrence of white-rot disease (Table 6). This is in conformity with of Zeray Siyoum (2011) who reported that white-rot is a major production threat of garlic.

Table 6. White-rot disease occurrence described by sampled farmers across the districts

Districts	Yes	%	No	Total
Bassonaworana	38	95	2	40
Angolelanatera	40	100	0	40
Tarmaber	19	95	1	20
Mojanawodera	17	85	3	20
Total	114	94.78	6	120

4.1.3 Cropping System in Controlling the Distribution of White-rot

The cropping system showed a significant difference ($P \leq 0.01$) on garlic productivity. It includes garlic crop rotation with other crops (Carrot, Lentil, and Barley), crop rotation with onion, and mono-cropping. Out of 14 mono-cropping users, 21.4 % and 78.6 % recorded good and poor garlic productivity, respectively. The sampled farmers that have used crop rotation of garlic with onion were 22 in numbers, 22.7% and 77.3 % recorded good and poor productivity, respectively and the remaining 84 sampled garlic producers used crop rotation of garlic with other crops and recorded 51.2 % good productivity and 48.8% poor productivity and it was better than the previous two cropping systems (Table 7). This might be due to planting of garlic following any member of the onion family or other alternate disease hosts increase the distribution of white-rot disease and reduce disease control effectiveness in mono-cropping and crop rotation with onion cropping system (FAO, 2007).

Similarly, crop rotation with other crops was one of the proper agronomic practices like land preparation, planting at the right time, weeding, hoeing, use of disease-free planting materials, keeping optimum irrigation interval that promotes the effectiveness and productivity of the recommended technology (Abrha Harnet *et al.*, 2015).

Table 7. Association between cropping system and productivity of garlic in the study areas

Cropping System	Productivity N (%)		Df	X^2	P- Value
	Good	Poor			
Mono-cropping	3 (21.4)	11 (78.6)			
Crop rotation(garlic with onion)	5 (22.7)	17 (77.3)	2	8.66	$\leq 0.01^{**}$
Crop rotation(garlic with other crops)	43 (51.2)	41(48.8)			
Total	51 (42.5)	69 (57.5)			

**Highly significant (P < 0.01), N= number of sampled farmers, df= degree of freedom

4.1.4 Garlic productivity Difference among Districts

The garlic productivity among the districts showed a significant (P≤0.001) differences (Table 8). The range of garlic productivity among garlic producers showed very wide variation, (Basonaworana 2.95, Angolelanatera 3.79, Tarmaber 1.77 and Mojanawodera 7.23 t ha^{-1}). Based on the sampled garlic producers, the productivity which was less than the average productivity (3.54t ha^{-1}) is considered as poor productivity and greater than this average as good productivity (Table 3); the majority of the respondents claimed poor productivity was at Basonaworana district. Out of 40 sampled garlic producers 22.5 % and 77.5 % described good and poor productivity, respectively. The majority of the respondents claimed good productivity was at Mojanawodera district. Out of 20 sampled garlic producers 80.00 % and 20.00 % replied good and poor productivity, respectively (Table 8 and Figure 2). The existed variation might be due to the variation of the effectiveness of white-rot disease control measures and in Tarmaber and Mojanawodera districts, the irrigation sites were newly established and the grazing lands were shifted to garlic production fields, and the farmers experience in garlic production were few years (Table 5). The average garlic productivity of the districts, summarized from the respondents was 3.54 t ha^{-1}, which is explained as very low productivity (Table 3), when, it compared with the country's average 9.18 t ha^{-1}(CSA,2017/18) and also with the mean productivity of the field experiment result of this study (5.44 t ha^{-1}). In conformity with this, the maximum 5.54 t ha^{-1} and the minimum 1.61 t ha^{-1} yield were recorded at South Gonder (Dessie Getahun and Mulat Getaneh, 2019). However, the productivity of Mojanawodera district was the best as compared to the other three districts. It might be due to the experience in using integrated disease management (Table 9). Similarly, Clarkson *et al.* (2016) reported that integrated disease control approach minimized the white-rot infestation and improved the yielding capacity of garlic.

Table 8. Garlic productivity difference among districts

Districts	Productivity N (%)		df	X^2	P- Value
	Good	Poor			
Bassonaworana	9 (22.5)	31 (77.5)			
Angolelanatera	18 (45.0)	22 (55.0)	3	18.21	$\leq$0.001***
Tarmaber	8 (40)	12(60)			
Mojanawodera	16(80.0)	4 (20)			
Total	51 (42.5)	69 (57.5)			

*** Very highly significant ($P \leq 0.001$), N= number of sampled farmers, df= degree of freed
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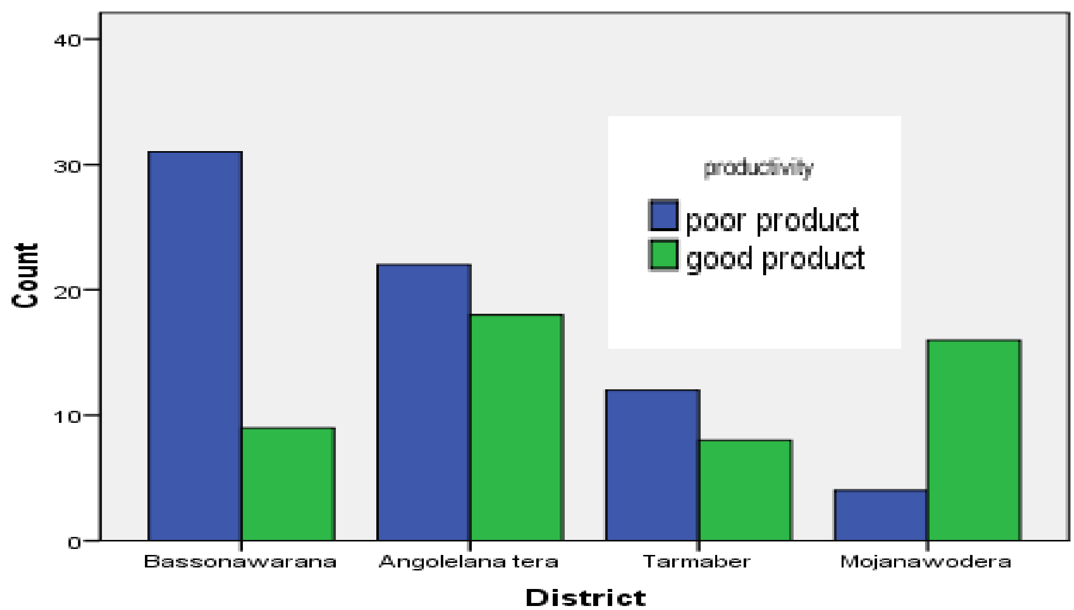

Figure 2. Garlic Productivity in the Study Area

The majority of Mojanawodera district garlic producer using integrated disease management. Especially chemical control measures with cultural that might be make them effective in controlling the disease for geting good productivity as compared to other districts (Table 9). In line with this, integrated disease control system can achieve different level of disease control result (Clarkson *et al*., 2004).

Table 9. Users of integrated disease management across the districts

District	No	Cultural & Chemical	Total
Bassonaworan	38	2	40
Angolelanatera	38	2	40
Tarmaber	20	0	20
Mojanawodera	8	12	20
Total	104	16	120

4.1.5 Disease Control Methods and Garlic Productivity

The white-rot control methods used by the garlic producers showed a significant difference ($P \leq 0.01$). Out of 13 respondents which did not use any control methods, 38.5 % and 61.5 % recorded good productivity and poor productivity, respectively. The sampled farmers who have used cultural and physical control methods were 52 in numbers; 30.00 % and 70.00 % recorded good productivity and poor productivity, respectively. Biological control methods using farmer was one in number and recorded good productivity. Chemical control methods using farmers were 38 in numbers; 50.00 % and 50.00 % recorded good productivity and poor productivity but the remaining 16 sampled garlic producers used integrated disease management method and recorded 81.20 % good productivity and 18.80% poor productivity, (Table 10). The integrated disease management might be most effective due to instead of single disease management integrated different control system reduce the amount of sclerotia in different level in the soil. In line with this, the most effective control systems to date have involved the integration of a number of systems for managing white-rot (Clarkson, 2004). Similarly, Clarkson *et al*., (2016) reported that an integrated control method based on individual treatments identified as having some efficacy against white-rot.

Table 10. Association between Disease Control Methods and Productivity of Garlic

Disease control measures	Productivity N (%) Good	Poor	df	X^2	P- Value
No control methods	5 (38.5)	8 (61.5)			
Cultural and physical	13(30.0)	39 (70.0)	4	17.26	≤0.01**
Biological control	1 (100.0)	0(00.0)			
Chemical control	19(50.0)	19 (50)			
Integrated disease management	13(81.2)	3 (18.8)			
Total	51 (42.5)	69 (57.5)			

**Highly significant (P ≤ 0.01), N= number of sampled farmers, df= degree of freedom

4.1.6 Farmers Perception on the Effectiveness of Control Methods

The effectiveness of control methods was significant (P≤0.001). Garlic producers who responded the control methods as ineffective were 94 in number (34 % of them claimed good productivity and 66 % poor productivity) and others who responded the control methods as effective were 26 in number 73.1 % and 26.9% of them claimed good productivity, and poor productivity, respectively (Table 11). Garlic producers who have recorded good productivity mentioned that by integrating of practices, like cultural practices, resistant varieties, and chemicals reduced the disease infestation. In conformity with this, incomplete control of white-rot diseases was due to the single management practice. However, the combined or integrated use of different control systems improved the disease control (Clarkson *et al*., 2016). Garlic producers who have recorded poor productivity were hope-less to grow garlic because of the white-rot disease. It coincides with the study result in Brazil in which some growers were forced to lack the interest to produce garlic in their traditional growing regions due to high levels of sclerotia of *Sclerotium cepivorum* in soils (Pinto *et al*., 1998 and Fuga *et al*., 2012).

Table 11. Association of effectiveness of control method and productivity of garlic

Control Method	Productivity N (%)		df	X^2	P- Value
	Good	Poor			
1.Effectiveness of control method					
No	32(34.0)	62 (66.0)	1	12.7	
Yes	19 (73.1)	7(26.9)			$\leq 0.001^{***}$
Total	51 (42.5)	69 (57.5)			

*** Very Highly significant (P < 0.001), N= number of sampled farmers, df= degree of freedom

4.1.7 Status of Input Provision to Control the White-rot Disease

In this study, the result revealed that 67.5 % of the farmers from all districts did not have access to credit despite its crucial importance for input provision like improved varieties seed and fungicides to produce high yield and good quality garlic (Table 12). In conformity with this, ensuring access of farmers to credit services is important to improve the use of required inputs by farmers (Yemane Gebre Meskel *et al*., 2017).

Table 12. Source of credit for inputs across districts

Districts	No	%	Yes	%	Total
Bassonaworan	25	62.50	15	37.5	40
Angolelanatera	30	75.00	10	25	40
Tarmaber	12	60.00	8	40	20
Mojanawodera	14	70.00	6	30	20
Total	81	67.50	39	32.5	120

From the sampled garlic producers, 55.83 % had no access for chemical provision; while, 10.00 %, 28.33 %, and 5.83 % of the respondents had chemical access from cooperatives, traders and from both, respectively (Table 13). Graffham and Macgregor, (2007) reported that there were different problems in supplying high- quality seed and chemicals.

Table 13. Source of chemicals across districts

Districts	No provider	Cooperatives (1)	Traders (2)	1&2	Total
Bassonaworan	39	0	0	1	40
Angolelanatera	11	4	25	0	40
Tarmaber	15	0	5	0	20
Mojanawodera	2	8	4	6	20
Total	67(55.83)	12 (10)	34(28.33)	7(5.83)	120

The initial source of garlic seed was majorly collected from the local market, 12.50 % from farmers and 1.67 % from home or 'NGOs' (Table 14). Since most of the garlic seed sources were from the market, so it was difficult to ensure whether the garlic seeds are disease-free or not. Even though some trials were made to get improved garlic seed in Basonaworana (5%) and Mojanawodera (30%) districts, 93.33% of the garlic producers from all the districts were not able to access the improved varieties (Table 15). Hence, the producers were obligated to use local seed and with this situation they were difficult to get white-rot disease-free or resistant seed. In line with this, the source of planting materials was not specified and it did not address most farmers (Alemayehu Hailu, 2016).

Table 14. Initial sources of garlic seed across districts

Districts	Market	%	Farmers	Others (from home, NGOS')	Total
Bassonaworana	35	87.50	5	0	40
Angolelanatera	35	87.50	3	2	40
Tarmaber	15	75.00	5	0	20
Mojanawodera	18	90.00	2	0	20
Total	103	85.83	15 (12.5)	2(1.67)	120

Quality inputs and their timely availability are, among other things, the most important conditions that needs due attention. Especially supply of improved varieties was very crucial problem in the study areas that 93.33 % of sampled garlic producers did not have access for improved varieties (Tabel 15). In line with this, it is important to link farmers with input providers (Yemane Gebre Meskel *et al*., 2017).

Table 15. Users of improved garlic varieties across districts

Districts	No	%	Yes	Total
Bassonaworan	38	95.00	2	40
Angolelanatera	40	100.00	0	40
Tarmaber	20	100.00	0	20
Mojanawodera	14	70.00	6	20
Total	112	93.33	8	120

4.1.8 Criteria Used for Seed Selection

The criteria used for the selection of best performing improved or local varieties were mainly disease tolerance (54.17 %) followed bulb size or yield capacity (38.33 %) and to some extent the germination capacity and marketability (7.50%). The result depicted that the main focused criteria by farmers was the disease tolerant characteristics of the garlic seed (Table 16).

Table 16. Criteria for Garlic Seed Selection across districts

Districts	Disease tolerance		Bulb size (Yield)	Others (market, germination…)	Total
	N	%	N		N
Bassonaworan	23	57.50	11	6	40
Angolelanatera	20	50.00	19	1	40
Tarmaber	10	50.00	8	2	20
Mojanawodera	12	60.00	8	0	20
Total	65	(54.17)	46(38.33%)	9(7.5%)	120

4.1.9 Garlic Producers Wealth Category and its Impact on Disease Control

The wealth category of the garlic producers, it was shown that the majority were categorized under rich (11.67%) and average (81.67%) wealth category (Table 17). Hence, the study confirmed that most of the farmers can afford the cost of fungicide, despite the absence of proper fungicide supply and effective controlling system. Similarly, CASCAPE project (2012) reported that in garlic producers area majority of the farmers wealth category was average.

Table 17. Sampled farmers wealth category across districts

Districts	Rich	Average	Poor	%	Total
Bassonaworan	6	31	3	7.50	40
Angolelanatera	6	30	4	10.00	40
Tarmaber	0	19	1	5.00	20
Mojanawodera	2	18	0	0.00	20
Total	14 (11.67%)	98(81.67%)	8	6.67	120

4.2 Management of White-rot Disease

4.2.1 Effect of Varieties and Fungicide types on Phenological Parameters

Days to Emergence

The main effects of varieties and fungicide types significantly affected days to emergence while the interaction effect did not show a significant difference on this parameter (Appendix Table II). Bishoftu nech variety established first in the field by 4.12 days and MM-98 variety by 2.11 days prior to the local variety. It might be due to the genetic difference among different garlic varieties that showed variation in days to emergence. Similar with this, Yebirzaf Yeshiwas *et al.* (2017) reported that there was variation for emergence due to germplasm difference. Inconformity with this, Saye et al. (2016) reported that there were strong genotypic and treatment differences with respect to germination mean. Apron Star 42 WS treated plots showed a delayed emergence by 2.66 days than the untreated plots (Table 18). In line with this, Villalta *et al*.(2004) reported that fungicide application to protect white-rot was effective but it showed a negative effect on seedling emergence. In conformity with this, Clarkson (2016) also reported that there was some reduction in seedling emergence due to tebuconazole fungicide application.

Table 18. The main effect of varieties and fungicide types on days to emergence and days to maturity

Varieties	DE	DM
MM-98	18.67[b]	134.11[a]
Bishoftu nech	16.66[c]	134.33[a]
Local	20.78[a]	127.11[b]
LSD 5%	2.26	10.00
Fungicide Types		
Apron Star 42 WS	20.44[a]	136.11[a]
More 720 WP	17.89[b]	135.00[a]
Untreated	17.78[b]	124.42[b]
LSD 5%	2.26	10.00
CV (%)	6.98	4.39

*****DE= day to emergence, DM= day to maturity and mean values connected by different letter across a column are significantly different at 5% significant level.

Days to Maturity

The main effects of varieties ($P \leq 0.05$) and fungicide types ($P \leq 0.001$) significantly affected days to maturity while the interaction effect did not show a significant difference (Appendix Table II). The maturity time by MM -98 and Bishoftu nech varieties was prolonged by 7.00 and 7.22 days, respectively as compared to the local variety (Table 18). This might be due to the vigor's vegetative growth of improved varieties as compared to the local variety (Table 19). Messeret Tadess (2014) also reported that the favoring of vegetative growth resulted in prolonged days to maturity. In agreement with this, different garlic germplasms collected from different areas showed variation in days to maturity (Yebrzaf Yeshiwas, 2017). Apron star 42 WS and More 720 WP fungicides treatment delayed days to maturity by 11.69 and 10.58 days, respectively as compared to the untreated plots. In line with this, Zenebu

Shewakena (2018) reported that Apron star 42 WS and More 720 WP fungicides treatment prolonged days to maturity as compared to the other treatments.

4.2.2 Effect of Varieties and Fungicide Types on Growth Parameters

Plant height (cm)-: It was not significantly affected by the main effect of fungicide types and the interaction effect of fungicide types and varieties. However, varieties showed a significant effect ($P \leq 0.001$) (Appendix Table II). The highest plant height was recorded by MM-98 followed by Bishoftu nech. The increases in plant height by these varieties were 15.64 % and 11.79 %, respectively as compared to the local variety (Table 19). This might be due to the improved genetic characteristics of improved varieties that have a vigorous stand. In agreement with this, Yebrzaf Yeshiwas (2017) reported that the difference of germplasm for plant height was due to the genetic difference.

Leaf number and diameter-: Varieties Showed a significant effect on leaf diameter and number while fungicide types and the interaction effect of varieties and fungicide types showed a non-significant effect (Appendix table III). MM-98 variety showed the highest leaf diameter 1.72 cm which was statistically similar with Bishoftu nech variety while the local variety recorded the lowest leaf diameter. The highest leaf number was recorded by Bishoftu nech as compared to to the other varieties. The increase in leaf number by this variety was by 21.6 % higher as compared to the local variety (Table 19). This might be due to the difference in genetic characteristics. In agreement with this, Yebirzaf Yeshiwas (2017) reported that among different garlic germplasm there were difference in leaf number and diameter.

Neck diameter -: Fungicide types showed a significant effect ($P \leq 0.05$) on neck diameter while varieties and the interaction effect of varieties and fungicide types showed a non-significant effect (Appendix Table III). Apron star 42 WS treated plants increase the neck diameter by 6.9 % and 5.08% as compared to untreated and More 720 WP treated plants, respectively. It might be due to the plant which is treated by Apron star 42 WS protected from white-rot infection having large size bulb (in bulb diameter and length) (Table 22) resulted in highest neck diameter. More 720 WP treated and untreated plants statistically similar (Table 19). It might be due to the nature of the disease the foliar application of More

720 WP showed lower effectiveness. Similarly, Razak *et al*. (2015) reported that fungicides are not usually effective due to the soil-born nature of the causal agent.

Leaf length (cm)-: The main effects of varieties and fungicide types significantly affected the leaf length. However, the interaction effect of varieties and fungicides did not significantly affect this parameter (Appendix Table II). The longest leaf length was recorded by MM-98 followed by Bishoftu nech. The increase in leaf length by these varieties were 15.52 % and 7.78 % respectively as compared to the local variety. This might be due to the difference in genetic characteristics. The application of Apron Star 42 WS resulted in the longest leaf length (47.57) but statistically similar with the application of More 720 WP. However, the untreated plots recorded the shortest leaf length (45.26) (Table 19). This could be due to the Apron Star 42 WS fungicide dressed cloves starting from the germination time, protected the cloves from white rot disease and More 720 WP fungicide foliar spraying after the incidence of the white-rot controlled the disease. Inconformity to this, Tamire Zewde *et al*. (2007) reported that the rate of disease development was double on untreated plot.

Shoot dry weight-: Varieties and fungicide types showed a significant effect ($P \leq 0.001$) on shoot dry weight but the interaction effect of varieties and fungicide types did not significantly affect this parameter (Appendix Table III). MM-98 variety resulted in the highest shoot dry weight but statistically similar with Bishoftu nech variety. The shoot dry weight of MM-98 and Bishoftu nech increased by 46.36% and 42.97 %, respectively as compared to the local variety.The increase in shoot dry weight might be due to the effectiveness of the genetic material of improved varieties to resist the white rot disease. In line with this, Yebrzaf Yeshiwas (2017) described that the difference of germ plasm for plant physiological (height, leaf length) growth was due to the genetic difference. The Application of Apron star 42 WS had increased shoot dry weight by 31.28 % as compared to the untreated plots. The increase in shoot dry weight might be due to the higher effectiveness of treating of cloves with Apron star 42 WS fungicides before planting that led to the control of early stage infestation of the disease and resulted in vigorous vegetative growth. Similarly, Zenebu Shewakena (2018) described that the higher shoot dry weight due to clove dressing of fungicides might be resulted from the effective reduction of disease infestation. However More 720 WP fungicides were poorly responded and gave the lowest result as compared to the untreated plots and Apron star 42 WS treated plots (Table 19). In line with this, Razak *et al*.(2015) reported that fungicide are not usually effective due to the soil-borne nature of the causal agent.

Table 19. The Main Effect of Varieties on ND, PH, LL, LD, LN and SDW

Varieties	ND	PH	LL	LD	LN	SDW
MM-98	1.15^{ab}	67.00^{a}	49.86^{a}	1.72^{a}	11.24^{b}	53.23^{a}
Bishoftu nech	1.23^{a}	64.77^{b}	46.52^{b}	1.69^{ab}	13.14^{a}	52.00^{a}
Local	1.16^{ab}	57.94^{c}	43.16^{c}	1.48^{c}	10.81^{b}	36.37^{b}
LSD 5%	0.68	4.26	2.89	2.24	3.59	2.78
Fungicide Types						
Apron Star 42 WS	1.24^{a}	64.35^{a}	47.57^{a}	1.62^{a}	12.32^{a}	57.41^{a}
More 720 WP	1.18^{b}	63.10^{a}	46.71^{ab}	1.64^{a}	11.54^{ab}	40.45^{c}
Untreated	1.16^{bc}	62.25^{a}	45.26^{b}	1.63^{a}	11.33^{ab}	43.73^{b}
LSD 5%	1.46	0.74	1.82	0.16	1.46	7.48
CV (%)	7.16	4.26	3.59	5.62	10.21	9.15

*ND= Neck Diameter, PH= Plant Height, LL= Leaf Length, LD= Leaf Diameter, LN=Leaf Number and SDW=Shoot Dry Weight mean values connected by different letter across a column are significantly different at 5% significant level.

4.2.3 Effect of Varieties and Fungicide Types on Disease Parameters

Disease incidence-: The main effects varieties, fungicides and the interaction effect of varieties and fungicide types significantly affected disease incidence (P≤0.001) (Appendix Table V). The untreated local variety was the most affected and recorded 46.67 % incidence. However, MM-98 Apron star 42 WS and Bishoftu nech Apron star 42 WS treated plots are the least affected and recorded 6.67 % incidence (Table 20). MM-98 and Bishoftu nech varieties and even the local variety which were treated by Apron star 42 WS were able to minimize or resist early infections by the white-rot disease. This might be due to pre planting seed dressing control the early infestation of the white-rot disease and continue its toxicity for the pathogen for longer time. In line with this Zenebu Shewakena (2018) reported that Apron star reduced the disease incidence, which might be due to its persistance at toxic levels longer than Mancozeb for the pathogen .

Table 20. Interaction Effects of Varieties and Fungicide Types on Incidence of Garlic White-rot at 90, PSI at 90 and 97 DAP.

Treatments	Incidence % at 90	PSI at 90	PSI at 97	AUDPC (%-day)
MM – 98 Untreated	16.67^{c}	24.00^{bc}	27.33^{bc}	975.33^{b-d}
MM – 98 Apron star 42 WS	6.67^{d}	21.33^{cd}	24.67^{cd}	847.00^{e}
MM - 98 More 720 WP	20.00^{b}	24.00^{bc}	26.67^{c}	942.67^{c-e}
Bihoftu nech Untreated	20.00^{b}	24.00^{bc}	30.00^{b}	1038.33^{bc}
Bishoftu nech Apron star 42 WS	6.67^{d}	21.33^{cd}	24.67^{cd}	849.33^{e}
Bishoftu nech More 720 WP	20.00^{b}	24.00^{bc}	26.67^{c}	935.67^{de}
Local Untreated	46.67^{a}	31.33^{a}	38.67^{a}	1320.67^{a}
Local Apron star 42 WS	13.33^{c}	22.67^{c}	27.33^{bc}	1024.33^{bc}
Local More 720 WP	23.33^{b}	26.00^{b}	28.67^{bc}	1061.67^{b}
CV (%)	22.63	4.91	6.54	5.56
P- value	***	***	***	***
LSD (5%)	7.54	2.07	3.20	96.22

* PSI = Percentage of severity index, DAP =Days after planting and mean values connected by different letter across a column are significantly different at 5% significant level.

Percentage of disease severity index-: The analysis of variance revealed that the fungicide types and the varieties showed significant effect on PSI at all the interval days after planting (90, 97,104 and 111). The interaction of varieties and fungicide types also showed significant effect on disease severity index at 90 and 97 DAP while it did not affect this parameter at 104 and 111 days after DAP (Appendix Table IV).

Apron star 42 WS treated MM-98 and Bishoftu nech improved varieties recorded similar result that reduced the disease severity index by 31.92 % as compared to the untreated local variety at 90 days after planting. The maximum severity (31.33 %) and (38.67 %) was recorded on untreated local variety at 90 and 97 days after planting, respectively. The disease severity index on untreated local variety increased by 46.88 % and 56.75 % at 90 and 97 days after planting, respectively as compared to Apron star 42 WS treated MM-98 and Bishoftu nech varieties (Table 20). This might be due to clove treatment of Apron star 42 WS fungicides that reduced the initial disease severity of white rot by in activating the pathogen in infected cloves and due to vigor's growth of MM-98 and Bishoftu nech varieties increase the capacity to resist the white-rot disease. Inconformity with this, Abrha Harnet *et al.* (2015) reported that Apron star 42 WS treated plots registered the lowest disease severity.

At 104 days after planting, the MM-98 and Bishoftu nech varieties statistically recorded similar PSI and reduced the disease severity by 18.05 % and 16.92 %, respectively as compared to the local variety. At the final (111) date of disease assessment, Bishoftu nech and MM-98 varieties reduced the PSI by 24.90 % and 17.90 %, respectively as compared to the local variety (Table 21). Such resistance of improved varieties could be due to the genetic improvement and the vigorous growth of the varieties. At 104 date of disease assessment, Apron star 42 WS and MORE 720 WP reduced the PSI by 12.43 % and 13.55 %, respectively as compared to the untreated plots. At the final (111) date of disease assessment, Apron star 42 WS and MORE 720 WP reduced the PSI by 18.11 % and 11.94 %, respectively as compared to the untreated plots. Such resistance of fungicides could be due to the effectiveness at initial stage and later on control of the infestation of the disease. Similarly, Zenebu Shewakena (2018) reported that clove treatment of fungicides reduced the initial disease severity of white rot by inactivating the pathogen in infected cloves.

Table 21. Main Effect of Varieties and Fungicide Types on PSI at 104 and 111 DAP

Varieties	PSI1O4	PSI111
MM-98	33.32[b]	46.89[b]
Bishoftu nech	33.78[b]	42.89[bc]
Local	40.66[a]	57.11[a]
LSD 5%	2.45	4.13
Fungicide Types		
Apron Star 42 WS	34.44[b]	44.22[bc]
More 720 WP	34.00[b]	47.55[b]
Untreated	39.33[a]	54.00[a]
LSD 5%	5.74	7.16
CV (%)	9.36	8.54

Area under disease progress curve (AUDPC): The analysis of variance revealed that fungicide types, varieties and their interaction showed a significant effect on AUDPC (Appendix Table V). The untreated treatments showed a high disease progress curve than treated once. MM-98 and Bishoftu nech varieties showed lower disease progress curve as compared to the local variety (Figure 3).

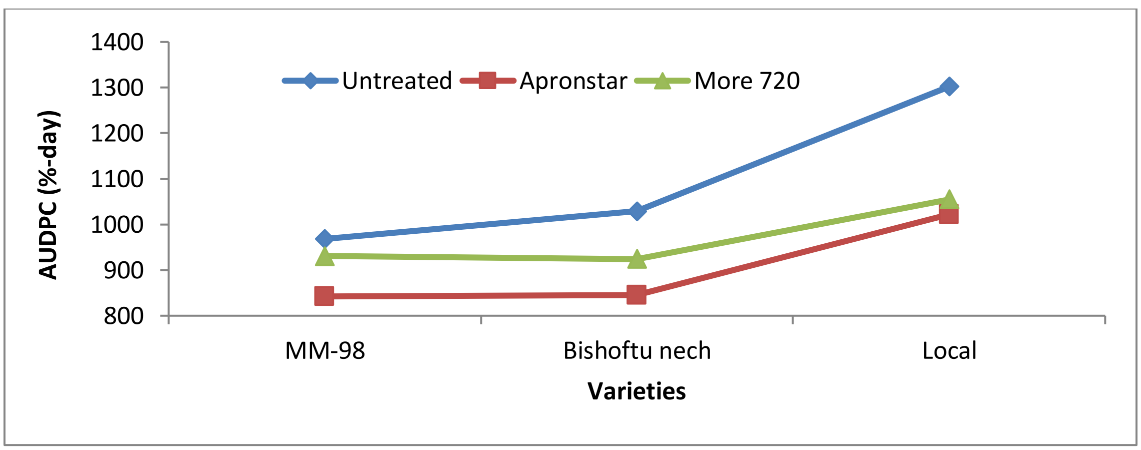

Figure 3. Interaction Effect of Varieties and Fungicide Types on AUDPC

Apron star 42 WS treated MM-98 and Bishoftu nech varieties exhibit the lowest area under disease progress curve but statistically similar with More 720 WP treated MM-98 and Bishoftu nech varieties (Table 20). The result indicated that the improved varieties treated by the fungicides showed a resistance to white-rot disease. The local untreated plots recorded the highest disease progressive curve as compared to the other treatments. Similarly, Zenebu Shewakena (2018) reported that Apron star 42 WS and MORE 720 fungicides treatment had ability for the reduction of pathogen development.

4.2.4 Effect of Varieties and Fungicide Types on Yield and Yield Components

Clove length and Diameter (cm)-: The main effect of varieties showed a significant effect on clove length ($p \leq 0.05$) and diameter ($p \leq 0.001$) whereas fungicide types and the interaction effect of varieties and fungicide types are non-significant (Appendix Table VI). MM-98 variety had the highest clove length and diameter as compared to the other varieties. The increase in clove length and diameter of MM-98 variety was 11.69 % and 29.51 %, respectively as compared to the local variety. On the other hand the local variety recorded the lowest clove length and diameter (Table 22). The difference in clove length and diameter among varieties might be due to the genetic differences that in turn result in the capability to resist the disease. Similar with this, Maude (2006) reported that the white-rot infected plant loss its size in clove length and diameter.

Average Clove weight-: Varieties and fungicide types showed a significant effect on average clove weight whereas the interaction effect of varieties and fungicide types was non-significant (Appendix table Table VI). The highest clove weight was recorded by MM-98 followed by Bishoftu nech variety. The increase in clove weight by these varieties was 40 % and 25.33 %, respectively as compared to the local variety. This might be due to the increase in size of cloves (clove length and diameter). Inconformity with this, Yebrzaf Yeshiwas (2017) reported that a good genetic potential having large size of cloves resulting better clove weight. Apron Star 42 WS fungicide resulted in the highest clove weight followed by More 720 WP fungicide. However, the untreated recorded the lowest clove weight (Table 22). This could be due to the effective control of the disease by fungicides. Similarly, Zenebu Shewakena (2018) described that the white-rot disease infection of the untreated plot resulted in average clove weight reduction.

Clove number-: Varieties (P≤0.001) and fungicide types (P≤0.01) showed a significant effect on clove number. However, the interaction effect of varieties and fungicide types did not affect this parameter (Appendix Table VI). In MM-98 and Bishoftu nech variety, the number of cloves increased by 38.82 % and 23.10%, respectively as compared to the local variety. It might be due to the vigor's stand of MM-98 and Bishoftu nech varieties. The application of Apron star 42 WS and More 720 WP fungicides recorded statistically similar result. The increase in clove number by Apron star 42 WS and More 720 fungicide treatment was 35.64 % and 30.15 %, respectively as compared to the untreated plots. It might be due to the effectiveness of the Apron star 42 WS in protection of the white-rot disease at early stage of the growth and the More 720 WP control the white- rot disease after the incidence of the disease (Table 22). In agreement with this, Zenebu Shewakena (2018) described that Apron star 42 WS and More 720 WP fungicide treated plots recorded high number of clove numbers as compared to the untreated plots.

Bulb Length and Diameter -: The main effects of varieties and fungicide types showed a significant effect on bulb length (P≤0.01) and diameter (P≤0.001), However, the interaction effect of varieties and fungicide types was non- significant (Appendix table VI). Bishoftu nech variety and MM-98 variety increased the bulb length by 3.33 % and diameter by 5.52 % and 6.47%, respectively as compared to the local variety. This might be due to genetic difference. The application of Apron star 42 WS fungicide increased the bulb length and diameter by 3.33 % and 5.41%, respectively as compared to untreated plots (Table 22). The clove dressing by Apron star 42 WS protect the early stage infestation of the white rot disease and keep the healthy growth which resulted in proper bulb size development. In agreement with this, Zenebu Shewakena (2018) explained that clove dressing of fungicides increased the bulb length and diameter. Inconformity with this, Tedros Bezu *et al.*, (2014) described that the variety exhibited deep green foliage with vigorous growth, moderately susceptible to disease; has large-sized bulbs and cloves. However, More 720 WP fungicide recorded statistically similar result with the untreated plots. It might be due to the foliar application of this fungicide after the disease incidence resulted in less effectiveness for soil born white-rot disease. In agreement with this, Razak *etal*. (2015) reported that the fungicides are not usually effective due to the soil-borne nature of the causal agent.

Average bulb weight-: Varieties and fungicide types showed a significant ($P \leq 0.001$) effect on average bulb weight. However, the interaction effect of varieties and fungicide types was non -significant (Appendix Table VII). The highest average bulb weight was recorded by MM-98 variety. In MM-98 and Bishoftu nech varieties average bulb weight was increased by 44.98 % and 35.99 %, respectively as compared to the local variety (Table 22). The difference in average bulb weight might be related with its bulb length and diameter. The application of Apron star 42 WS fungicide increased the average bulb weight 44.75 % as compared to the untreated plots. This could be due to the Apron star 42 fungicides that might protect the white-rot disease starting from the early stage of the garlic plant and in turn resulted in well developed healthy bulbs. In agreement with this, Zeray Siyoum *et al*. (2013) reported that different fungicides by reducing the white-rot disease infestation increased the average bulb weight. However, More 720 WP and untreated plots recorded statistically similar results (Table 22).

Bulb dry matter content -: Varieties and fungicide types ($P \leq 0.01$) showed a significant effect on bulb dry matter content. However, the interaction effect of varieties and fungicide types was non-significant (Appendix Table VII). MM-98 and Bishoftu nech varieties exhibited 26.17 % and 22.77 % increment on bulb dry matter content, respectively as compared to the local variety. The well developed size of garlic bulb related to its average bulb weight might led to increased to he bulb dry matter content. In agreement with this, Malashri and Shashidhar (2018) reported that the change in bulb weight and bulb diameter had direct impact on accumulation of dry matter content. The application of Apron star 42 WS fungicide increased the bulb dry matter content by 19.58 % as compared to untreated plots (Table 22). This might be due to the fungicide that controled and reduced disease severity and resulted in a higher average bulb weight and in then a higher dry matter content. Inconformity with this, Zenbu Shewakena (2018) reported that Apron star 42 WS clove dressing was effective by reducing the disease infection and gave well-developed bulbs that resulted in a higher dry matter content. On the contrary to this, the More 720 WP fungicide application showed statistically similar result with the untreated plots. In agreement with this, Razak *et al*. (2015) described that fungicides are not usually effective due to the soil born nature of the causal agent.

Total dry biomass-: The main effects varieties and fungicide types (P≤0.001) showed a significant effect on total dry biomass. However, the interaction effect of varieties and fungicide types did not affect this parameter (Appendix Table VII).MM-98 variety recorded the highest total dry biomass as compared to the other varieties. MM-98 and Bishoftu nech varieties showed 48.61 % and 37.04 % increment on total dry biomass, respectively as compared to the local variety. It might be due to the vigorous growth and larger bulb size. Similarly, Malashri and Shashidhar (2018) reported that the well-developed growth of garlic has ultimately led to higher total dry biomass.

The application of Apron star 42 WS increased total dry biomass by 48.56% as compared to the untreated plots and also it exceeded by 43.32% as compared to More 720 WP fungicides treated plots (Table 22). Apron star 42 WS clove dressing was effective that might be due to the early protection of the disease which resulted in vigorous plant stand and a higher average bulb weight thus had direct impact on total dry biomass. Similarly, Zenbu Shewakena (2018) reported that clove dressing by Apron star 42 WS fungicide resulted in the highest dry biomass of garlic. The application of More 720 WP fungicide did not show a remarkable difference from untreated plots. It might be due to less effectiveness of the fungicide. In line with this, Cooley and Autio (1997) described that the efficacy of fungicides depends on different factors.

Total yield (tha^{-1})-: The main effects varieties and fungicide types (P≤0.001) showed a significant effect on total yield. However, the interaction effect of varieties and fungicide types was non-significant (Appendix Table VII). MM-98 variety and Bishoftu nech had shown 111.49 % and 95.03 % yield increment over local variety, respectively (Table 22). It might be due to the genetic characteristics that had vigorous stand of the plant and disease resistant capability. In line with this, Yebirzaf Yeshiwas (2017) reported that good genetic potential resulted in a higher yield. The application of Apron star 42 WS fungicide had exhibited 85.85 % yield increment as compared to the untreated plots. It could be due to Apron star 42 WS fungicide clove dressing help to protect the white-rot disease starting from the early stage of the plant growth and continue in the later stage and exhibited better results on shoot dry weight and average bulb weight those have direct impact on total yield. Similarly, Zenbu Shewakena (2018) described that clove dressing of Apron star has shown better yield increment over untreated. More 720 WP fungicide showed poor performance. This could be due to the infection might start before the appearance of the symptom. Inconformity with this, Razak *et al*. (2015) reported that fungicides are not usually effective due to the soil-borne nature of the sclerotia

Table 22. The Main Effect of Varieties on CL, CD, ACW, CN, BL, BD, ABW, BDM, TDB AND TY

Varieties	CL	CD	ACW	CN	BL	BD	ABW	BDM	TDB	TY
MM-98	2.58^{a}	1.58^{a}	2.10^{a}	20.67^{a}	2.48^{a}	4.44^{a}	35.26^{a}	11.86^{a}	119.45^{a}	6.81^{a}
Bishoftu nech	2.52^{b}	1.38^{b}	1.88^{b}	18.33^{a}	2.48^{a}	4.40^{a}	33.07^{b}	11.54^{a}	110.15^{b}	6.28^{a}
Local	2.31^{c}	1.22^{c}	1.50^{c}	14.89^{b}	2.40^{b}	4.17^{b}	24.32^{c}	9.40^{b}	80.38^{c}	3.22^{b}
LSD (5%)	3.38	2.58	0.46	5.17	0.86	1.60	5.56	1.98	56.75	0.72
Fungicide Types										
Apron Star 42 WS	2.51^{a}	1.45^{a}	2.03^{a}	22.00^{a}	2.51^{a}	4.48^{a}	39.01^{a}	12.46^{a}	128.98^{a}	7.88^{a}
More 720 WP	2.44^{a}	1.43^{a}	1.91^{b}	21.11^{a}	2.42^{b}	4.28^{b}	26.69^{b}	9.92^{b}	89.99^{b}	4.19^{b}
Untreated	2.42^{a}	1.29^{ab}	1.65^{c}	16.22^{b}	2.43^{b}	4.25^{b}	26.95^{b}	10.42^{b}	86.82	4.24^{b}
LSD(5%)	1.33	0.86	1.75	7.36	2.38	3.58	7.59	2.13	69.85	1.28
CV (%)	7.94	10.69	15.07	15.06	2.03	2.13	14.21	11.26	11.16	13.58

*CL= Clove Length and CD= Clove Diameter, ACW= Average Clove Weight, CN= Clove Number, Bulb Length and Bulb Diameter, ABW= Average Bulb Weight, BDM= Bulb Dry Matter, TDB=Total Dry Biomass and TY= Total Yield; mean values connected by different letter across a column are significantly different at 5% significant level.

4.2.5 Isolation and Identification of Sclerotium cepivorum of Garlic

White-rot infested garlic bulbs were isolated by observing the physical symptoms like yellowing, wilting and leaf die back from the experiment fields. When the bulbs checked, they have showed white- rot disease symptoms, like white fungus structures were observed, root part was dried and almost absent; the bulb rotten, and turn in to black. Besides, the infestation of white-rot disease was high in the adjacent garlic cultivated lands. In line with this, Entwistle (1990a) reported that when the plant seriously attaked by the disease,, the death of the roots obvious and the diseased plant was easily detached from the soil. When checked the underground parts, the fungus itself is visible as superficial and fluffy white mycelium. It was confirmed by the report that the result of the presence of sclerotia giving a blackened appearance to the bulbs, soft rot and white mycelial growth was observed at the base of the plant. When digging up an infected plant, it will be free from the soil easily, and tiny black growth like poppy seeds (Ann, 2016). The symptoms like yellowing, leaf die back, and wilting were observed on a number of garlic plants having specific white- rot diseases (Mahmoud, 2018).

In the laboratory, after six days of incubation, sclerotia cultured in potato dextrose agar (PDA) media was started to germinate and grow its mycelium at the fifth date after incubation (Appendix figure 2) and the colour changed to black at the seventh date. However, sclerotia cultured in a Petri dish with a healthy garlic bulb was not started to grow within a similar incubation period (Appendix figure 1).

4.2.6 Regression of Disease Parameters with Garlic growth, Yield and Yield components

Regression analysis was done to evaluate the association of disease parameters with growth and yield parameters. Days to maturity showed the existence of significant and negative association with PSI, incidence and AUDPC, this could be due to the increase in disease severity had negative impact on growth parameters and in then it tends to shorten the maturity days. Similarly, Zenbu Shewakena (2018) reported that garlic white rot severity and incidence were very important in determining the extent of reduction in physiological growth of garlic. Shoot dry weight showed Regression with PSI, incidence and AUDPC. The shoot dry weight strongly influenced by PSI, incidence and AUDPC that might be due to the disease directly affected the plant height, leaf length, and leaf diameter. Similar report was revealed by Zenbu Shewakena (2018) that showed Regression of shoot dry weight with disease parameters. Exceptionally, leaf number, neck diameter and average clove weight showed regression with severity, incidence and AUDPC. This might be due to the disease infestation not affected directly these plant parts. Almost all other yield components, such as clove length, clove diameter, bulb length, bulb diameter, bulb weight, bulb dry matter, total dry biomass and total yield showed a strong negative correlation with PSI, incidence and AUDPC. This might be due to the white-rot disease directly affected growth parameters and resulted in related impact on yield and yield components. In agreement with this, Yonas Worku (2018) reported that there was a negative relationship between garlic disease and yield and yield components. Similarly, Zenebu Shewakena (2018) reported that there was a strong negative correlation between white-rot disease parameters and yield parameters.

Table 23. Regression of disease parameters with growth and yield parameters.

parameters	PSI 90 DAP	PSI 97 DAP	PSI 104 DAP	PSI 111 DAP	Incidence	AUDPC
DM	-0.527^{**}	-0.846^{**}	-0794^{*}	-0.717^{*}	-0.524^{**}	-0.727^{**}
PH	-0.588^{**}	-0.698^{*}	-0.816^{**}	-0.860^{**}	-0.554^{**}	-0.692^{**}
LL	-0.550^{**}	-0.626^{ns}	-0.691^{*}	-0.900^{**}	-0.515^{**}	-0.632^{**}
LD	-0.528^{**}	-0.595^{ns}	-0.706^{*}	-0.780^{*}	-0.499^{**}	-0.677^{**}
LN	-0.299^{ns}	-0.391^{ns}	-0.395^{ns}	-0.732^{*}	-0.220^{ns}	-0.240^{ns}
ND	-0.233^{ns}	-0.451^{ns}	-0.360^{ns}	-0.615^{ns}	-0.179^{ns}	-0.100^{ns}
SDW	-0.815^{**}	-0.658^{ns}	-0.778^{*}	-0.813^{**}	-0.811^{**}	-0.725^{**}
CL	-0.504^{**}	-0.796^{*}	-0.905^{**}	-0.811^{**}	-0.526^{**}	-0.705^{**}
CD	-0.530^{**}	-0.578^{**}	-0.621^{**}	-0.510^{**}	-0.543^{**}	-0.640^{**}
ACW	0.005^{ns}	-0.264^{ns}	-0.142^{ns}	-0.433^{ns}	0.071^{ns}	0.023^{ns}
CN	-0.547^{**}	-0.595^{ns}	-0.615^{ns}	-0.867^{**}	-0.499^{**}	-0.654^{**}
BL	-0.700^{**}	-0.679^{*}	-0.740^{*}	-0.717^{*}	-0.707^{**}	-0.665^{**}
BD	-0.899^{**}	-0.810^{**}	-0.852^{**}	-0.931^{*}	-0.899^{**}	-0.850^{**}
ABW	-0.852^{**}	-0.651^{ns}	-0.752^{*}	-0.812^{**}	-0.862^{**}	-0.805^{**}
BDM	-0.731^{**}	-0.612^{ns}	-0.698^{*}	-0.827^{**}	-0.749^{**}	-0.719^{**}
TDB	-0.831^{**}	-0.677*	-0.752^{*}	-0.821^{**}	-0.832^{**}	-0.713^{**}
$TYha^{-1}$	-0.871^{**}	-0.699^{**}	-0.781^{*}	-0.848^{**}	-0.873^{**}	-0.794^{**}

where, PSI=percentage of severity index, AUDPC=area under disease progress curve, DM= days to maturity, PH= plant height, LL = leaf length , LD= leaf diameter , LN= leaf number, ND= neck diameter, SDW= shoot dry weight, CL= clove length, CD=clove diameter, ACW= Average clove weight, CN =clove number, BL=bulb length, BD=bulb diameter, ABW=Average bulb weight, BDM=bulb dry matter content,and $TYha^{-1}$= total yield per hectare.

4.3 Economic Analysis

The purchasing price of improved varieties of garlic seeds was almost similar to local garlic seeds which were more preferred by the producers based on their experience. The garlic price difference in the market was only between for seed and consumption. To estimate the profitability of fungicide costs, fungicide application cost and garlic prices were considered. The price of the garlic was estimated based on the survey study from four garlic producer districts and net return from fungicide cost was calculated by using the formula (Wegulo *et al*., 2011). The profitability of fungicide costs was assessed to estimate the economic returns. Results indicated that fungicide application and using improved garlic seeds for garlic white-rot management in garlic production was profitable. Computing its profitability is very important. The highest net return (252,203 birr ha^{-1}) was obtained from Apron star 42 WS treated MM-98 variety. The second (240,070 birr ha^{-1}) was obtained from Apron star 42 WS treated Bishoftu nech variety and the third (122,108 birr ha^{-1}) was obtained from More 720 WP treated MM-98 variety. The good economic return found from the combination of fungicide types and improved garlic varieties indicated that the fungicides play a great role in controlling the white-rot and also the improved varieties were resistant to the disease, Besides, the management of white-rot by a combination of fungicide types and improved varieties were satisfactory and performed better on the yield parameters. In conformity with this, Robert W.*et al.* (2018) reported that cost effective fungicide types increased crop revenue by hundreds of dollars. Similarly Zenebu Shewakena (2018) reported that Apron star 42 WS treated plots recorded the highest net return. The lowest and negative net return (-22,383 birr ha^{-1}) was exhibited from the application of More 720WP on a local variety of garlic seed plots. It might be due to low effectivness of More 720 WP and disease susceptibility of local varieties (Table 30). Similarly, Meseret Tadesse (2014) reported that variation in net benefit was seen among the fungicide treatments. In conformity with this, reported that the cost of fungicides must not comprises the effective control of the disease, rather, to optimize the application of fungicide was necessary.

Table 24. Net returns of garlic white-rot management with fungicides types

Treatments	TY (kg/ha)	Yi (kg/ha)	P (birr)	Fc (birr/ha)	Ac (birr)	RN(birr/ha)
MM 98- Untreated	5318.3	2828.6	38	0	0	107486.8
MM 98-Apronstar 42 WS	9374	6884.3	38	9000	400	252203.4
MM 98- More 720 WP	5755.7	3266	38	1600	400	122108
Bishfotu untreated	4906.7	2417	38	0	0	91846
Bishoftu Apronstar 42 WS	9054.7	6565	38	9000	400	240070
Bishoftu More 720 WP	4873.3	2383.6	38	1600	400	88576.8
Local Untreated	2489.7	0	38	0	0	0
Local ApronStar 42 WS	5215.7	2726	38	9000	400	94188
Local More 720 WP	1953.3	-536.4	38	1600	400	-22383.2

* Rn = the net return from fungicide application (birr ha^{-1}); Yi = is yield increase from fungicide application (kg ha^{-1}) obtained by subtracting the yield in the control treatment from the yield in the fungicide treatment, P = is the garlic prices (birr kg^{-1}); Fc = is the fungicide cost (birr ha^{-1}); and Ac = the fungicide application cost (birr ha^{-1}

5. CONCLUSION AND RECOMMENDATION

Garlic is one of the most popular spices in the world and the second widely cultivated Allium species next to onion. Garlic yield is reduced due to many factors (biotic and physical) of which diseases are economically important problems. White-rot fungal disease caused by *Sclerotium cepivorium* can result in sever garlic production losses in Ethiopia. The study was conducted to assess the distribution of white-rot diseases on selected districts of North East Shewa, Central Ethiopia and to evaluate the combined effects of fungicides and varieties on the epidemic of white-rot disease and the corresponding yield and yield components of garlic. The survey was made in four districts of the North East Shewa, Central Ethiopia (Angolelanatera, Basonaworana, Tarmaber, and Mojanawodera). The assessment was made to understand the distribution and status of the disease, a multistage sampling technique was used to select the respondents. Along with this, the field experiment was conducted and the treatments were laid out in a factorial arrangement with three replications using randomized complete block design (RCBD).

In the sampled districts, the land cultivated for garlic had lower coverage of hectare (30.65%) as compared to the other crops. This poor coverage was associated with the risk of white-rot disease. 94.78 % of the respondents in the study districts were engaged on garlic production for 2-38 years. They have observed the distribution of the damaging white-rot disease symptoms in their garlic fields. 57.5 % and 42.5 % of garlic producers them were grouped in poor and good productivity range respectively, so the majority of the garlic producers were got poor productivity of garlic. 67.5 % of garlic producers did not have access for credit and 85.83 % got the garlic seed from the local market so they had not guaranty for white-rot free seed.

The application of Apron star 42 WS resulted in a delayed emergence as compared to other treatments. MM-98 and Bishoftu nech varieties were fast in emergence as compared to local variety. The application of Apron star 42 WS and More 720 WP fungicides resulted in long maturity days as compared to the untreated plots, MM-98 and Bishoftu nech varieties also took long period of maturity time as compared to local variety. Besides this, the application of Apron star 42 WS fungicide also recorded best results on shoot dry weight, average clove weight, average bulb weight, bulb dry matter content, total dry biomass and total yield as compared to More 720 WP fungicide treated and untreated plots. Along this MM-98 and Bishoftu nech varieties exhibited better results on plant height, leaf diameter, leaf number, leaf length, shoot dry weight, clove length, clove diameter, average clove weight, average bulb weight, bulb dry matter, total dry biomass and total yield parameters.

The application of Apron star 42 WS on improved and local varieties reduced the white-rot disease infestation as compared to the untreated local variety and More 720 WP treated plots. Applying fungicide types, planting improved varieties, and the different combinations of improved varieties and fungicide types showed a positive net return. The significant effect and the regression of days to maturity, growth parameters, yield, and yield components with disease parameters indicated that the white-rot disease had a very crucial influence for poor garlic production.

In general, the majority of garlic production fields are infested by the white-rot disease with no or less effective protection and control methods. So planting of the improved varieties of MM-98 and Bishoftu nech garlic seed treated by Apron star 42 WS fungicide are recommended to be used in garlic production to reduce the white-rot infestation. The combined effect of Apron star 42 WS fungicide and improved varieties and even the local garlic variety are recommended to reduce white-rot disease incidence and severity. Future studies need to search more alternative fungicide types, improved varieties and integrated disease management options for sustainable garlic production.

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7. APPENDICES

I. Types of Disease Control

District	No	Cultural (1)	Biological (2)	Chemical (3)	1&2	1&3	Total
Bassonaworan	4	34	0	0	2	0	40
Angolelanatera	3	8	0	27	0	2	40
Tarmaber	4	10	1	5	0	0	20
Mojanawodera	2	0	0	6	0	12	20
Total	13	52	1	38	2	14	120

II. Mean square for analysis of variance on DE, DM, PH and LL

Sources	df	DE	DM	PH	LL
Rep	2	11.37**	134.48*	39.52*	21.36**
Fungicide	2	20.48***	373.15***	10.05ns	12.39*
Variety	2	38.04**	151.81*	200.30***	101.34***
Variety*Fungicide	4	4.15ns	99.87ns	6.87ns	1.75ns
Error	16	1.70	33.44	7.27	2.78
CV (%)		6.98	4.39	4.26	3.59
LSD (5%)		2.26	10.00	4.67	2.89

***Very highly significant (P < 0.001), **Highly significant (P < 0.01), Significant (P < 0.05), and ns = non-significant; DE= Days to Emergence, DM= Days to Maturity,PH= Plant Height and Leaf Length

III. Mean square for analysis of variance on LD, LN, ND and SDW

Sources	df	LD	LN	ND	SDW
Rep	2	0.05*	0.03ns	2.10ns	220.97***
Fungicide	2	0.01ns	2.44ns	3.74*	727.91***
Variety	2	0.16***	13.86**	1.42ns	794.79***
Variety*Fungicide	4	0.03ns	2.34ns	1.21ns	34.79ns
Error	16	0.08	1.44	0.71	18.66
CV		5.62	10.21	7.16	9.15
LSD (5%)		0.16	2.07	1.46	7.48

***Very highly significant (P < 0.001), **Highly significant (P < 0.01), Significant (P < 0.05), and ns = non-significant; LD= Leaf Diameter, LN= Leaf Number, ND=Neck Diameter and SDW= Shoot Dry Weight.

IV. Mean square for analysis of variance on PSI at 90, 97, 104 and 111 DAP

Sources	df	PSI90 DAP	PSI97DAP	PSI104 DAP	PSI111 DAP
Rep	2	21.93^{***}	55.26^{***}	165.48^{***}	140.44^{**}
Fungicide	2	49.93^{***}	99.70^{***}	117.48^{***}	240.44^{***}
Variety	2	37.93^{***}	73.48^{***}	195.70^{***}	520.44***
Variety*Fungicide	4	10.81^{**}	21.48^{**}	24.37^{ns}	15.56^{ns}
Error	16	1.43	3.43	10.98	17.11
CV		4.91	6.54	9.36	8.54
LSD (5%)		2.07	3.20	5.74	7.16

***Very highly significant (P < 0.001), **highly significant (P < 0.01), Significant (P < 0.05), and ns = non-significant

V. Mean square from analysis of variance for incidence and AUDPC

Sources	df	Incidence	AUDPC
Rep	2	548.15^{***}	76347.44^{***}
Fungicide	2	825.93^{***}	96698.78^{***}
Variety	2	492.59^{***}	125902.78^{***}
Variety *Fungicide	4	187.04^{***}	10823.56*
Error	16	18.98	3090.40
CV		22.62	5.56
LSD (5%)		7.54	96.22

***Very highly significant (P < 0.001), **highly significant (P < 0.01), Significant (P < 0.05), and ns = non-significant

VI. Mean square for analysis of variance on CL, CD, ACW, and CN, BL and BD

Sources	df	CL	CD	ACW	CN	BL	BD
Rep	2	6.48^{ns}	14.92^{**}	0.26^{*}	43.81^{*}	0.25^{ns}	9.54^{***}
Fungicide	2	1.93^{ns}	7.37^{ns}	0.37^{*}	91.70^{**}	2.08^{**}	16.79***
Variety	2	16.59*	28.59^{***}	1.09^{***}	287.26^{***}	1.79^{**}	17.22***
Variety *Fungicide	4	0.37^{ns}	1.65^{ns}	0.10^{ns}	3.70^{ns}	0.68^{ns}	1.01ns
Error	16	3.81	2.22	0.07	8.94	0.25	0.85
CV (%)		7.94	10.69	15.07	15.06	2.03	2.13
LSD (5%)		3.38	2.58	0.46	5.17	0.86	1.60

***Very highly significant (P < 0.001), **Highly significant (P < 0.01), Significant (P < 0.05), and ns = non-significant; CL= Clove Length, CD= Clove Diameter, ACW= Aerage Clove Weight, CN=Clove Number, BL=Bulb Length and Bulb Diameter.

VII. Mean square for analysis of variance on ABW, BDM, TDB,TY and MY

Sources	df	ABW	BDM	TDB	TY	MY
Rep	2	166.60**	26.00***	37881.06***	24.02***	1.37ns
Fungicide	2	445.66***	16.35**	54442***	40.29***	2.81ns
Variety	2	301.54***	16.15**	45918***	33.86***	0.06ns
Variety* Fungicide	4	21.65ns	0.84ns	1030.43ns	0.54ns	1.04ns
Error	16	19.25	1.52	1628.52	0.55	2.37
CV (%)		14.21	11.26	11.16	13.59	18.31
LSD (5%)		7.59	2.13	69.85	1.28	2.66

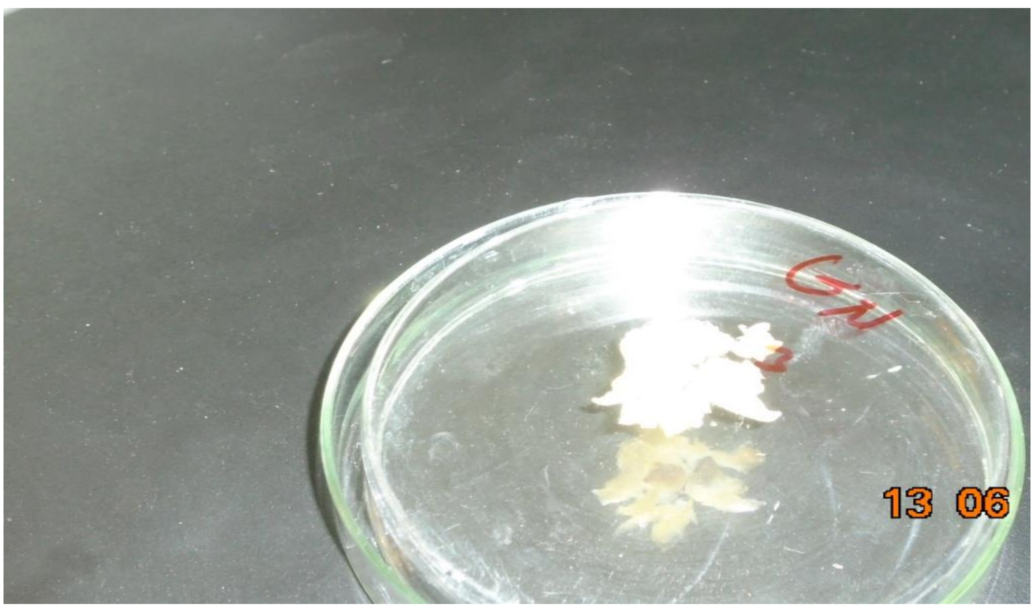
***Very highly significant (P < 0.001), **Highly significant (P < 0.01), Significant (P < 0.05), and ns = non-significant; ABW= Average Bulb Weight, BDM= Bulb Dry Matter, TDB= Total Drey Biomass, TY= Total Yield and MY= Marketable Yield.

VIII. Main effect of varieties and fungicide types on disease parameters of garlic

Varieties	IN	PSI90	PSI97	AUDPC
MM-98	14.45b	23.11b	26.22b	921.67b
Bishoftu nech	15.56b	23.11b	27.15b	941.11b
Local	27.78a	26.67a	31.26a	1135.56a
LSD 5%	7.54	2.07	3.20	96.22
Fungicide Types				
Apron star 42 WS	8.89b	23.33b	25.56b	906.89bc
More 720 WP	21.11a	23.11b	26.89b	980.00b
Untreated	20.00a	26.44a	32.00a	1111.44a
LSD 5%	1.28	3.48	4.99	9.54
CV (%)	22.63	4.91	6.54	5.56

8. Appendix Figures

1. White-rot infected garlic bulb from field plots



2. Culture Media Prepared from Pieces of Healthy Garlic Bulb for Growing White-rot Out of a piece of Infected Garlic Tissue

3. Culture Media Prepared from PDA for Growing White-rot Out of a Piece of Infected Garlic Tissue

Appendix Questioner

SURVEY INTERVIEW

Distribution of garlic white rot study formal survey of farm households in four districts of North Shewa, Ethiopia

PART ONE: IDENTIFICATION

1.1. Zone: ______________________

1.2. Woreda: _____________________

1.3. Peasant Association: ____________

1.4. Village: ______________________

1.5. Date of the interview:___________

1.6. Farmer name: _________________

1.7. Serial number: ________________

1.8. Name of the enumerator:_____________
Signature:___________________

PART TWO: HOUSEHOLD RESOURCES

2.1. Of the land you cultivated in 2010:

1. Own land: _____(timad) 2. Rented in_______ (timad) 3. Rented out________(timad) 4. Shared in ______(timad) 5. Shared out_______(timad)

2.2. Livestock ownership

Sr.no.	Type of livestock	No. of livestock	Sr.no.	Type of livestock	No. of livestock
1	Ox		5	Goat	
2	Cow		6	Donkey	
3	Heifer		7	Mule	
4	Sheep		8	Horse	

2.3 Total cultivated land (in timad)

2.4 Total crop land you allocated for the following crops in the last crop season (in timad)?

Crops	area (in timad)	Crops	area (in timad)
1. Bean		5. Pea	
2.Garlic		6. Lentil	
3.Wheat		7. Barley	
4.Onion		8. 0thers specify	

2.5. Did you get access to credit for agric. inputs (fertilizer and improved garlic var.)? 1.Yes 2. No

PART THREE: VARIETEIS GROWN

3.1. For how long did you involve in garlic production?____year.

3.2. What was the amount of garlic yield obtained in 2010?__kg

3.3. Have you grown local garlic cultivar last year on your farm? 1. Yes 2. No

3.4. If yes, what was the area coverage?_________ (in timad)

3.5. Have you grown improved garlic variety last year on your farm? 1. Yes 2. No

3.6. What criteria have you used for adopting the improved varieties?

Criteria for selection/Famers' perception (√)	Varieties adopted and grown in the area		
High bulb yield			
Large bulb size			
Good food quality			
Marketability			
Early maturity			
Uniform maturity			
Higher germination rate			
Pest tolerance			
Disease tolerance			
Frost tolerance			
Low soil fertility tolerance			
Others (specify)			

PART FOUR: SEED SOURCES

4.1. What was your initial source of seed?_________________

4.2. Where did you get garlic seed in the last three years?

SOURCE	(√) 2007	(√) 2008	(√) 2009
1.Own stock			
2. Farmer			
3. Market			
4. BoA			
5. NGOs			
6. University/Research			
7.Others (specify)			

Market=traders, shops, stores; Farmer=purchase, gift, loan etc.

PART FIVE: AGRONOMIC PACKAGES

5.1. Did you plant local garlic cultivars or improved ones in the past three consecutive years?

5.2. What type of production system did you adopt for garlic?

1. Mono-cropping 2. Crop rotation (garlic with onion)

3. Crop rotation (garlic with other crops) 4. Others (specify)_______

5.3. Disease and insect pest control.

5.3.1. Have you observed diseases and pests in garlics?1. Yes 2. No

5.3.2. If yes, what type of diseases and pests? (name)________

5.3.3. What type of disease control did you exercise for garlic?

1. Cultural and physical control 2. Biological control 3. Chemical control 4. Using resistant variety 5. Integrated disease management

5.3.4. If you have used integrated disease management, what were the methods? ___

How many times did you apply? ______________________________

5.3.5. If you have used 1 or 2 or more of the above methods, which one was the most effective? _

5.3.6. Did you apply chemicals/fungicides and insecticides for garlic? 1. Yes 2. No

5.3.7. Where did you get the chemicals?

1. Bureau of Agriculture 2. Rural cooperatives 3. Traders in nearby towns 4. Other (specify)____

5.3.8. Did you think the control methods for white rot are effective? 1. Yes 2. No

If yes, why ______________________

If no, why _______________________

5.4. Irrigation Management

5.4.1. Did you use irrigation for garlic production? 1. Yes 2. No

5.5. Garlic plant Population density

5.5.1. Did you use recommended population density of garlics? 1. Yes 2. No

5.5.2. If the answer is yes, what was the density (spacing b/n row and b/n plant)?

5.6. What was the price of garlic/kg?

If sold fresh___ 2. If sold stored (dry)___

5.7. Rank the observed garlic diseases in descending order.

Type of diseases	Rank (1-6)
Rust	
White rot	
Purple blotch	
Black mould	
Downy mildew	
Damping off	
Other(specify)__________________	

FOR INTERVIEWER ONLY.

In which wealth category (relative to other households, look at the land size, house type, other assets etc) will you group this household?

Interviewers' comment: ________________________________