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Integrated Management of Chickpea Fusarium Wilt: Insights from Epidemiology, Farmers Practices, and Pathogen Characterization in West Amhara, Ethiopia

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**COLLEGE OF AGRICULTURE AND ENVIRONMENTAL SCIENCES,
DEPARTMENT OF PLANT SCIENCES**

**INTEGRATED MANAGEMENT OF CHICKPEA
FUSARIUM WILT: INSIGHTS FROM EPIDEMIOLOGY,
FARMERS PRACTICES, AND PATHOGEN
CHARACTERIZATION IN WEST AMHARA, ETHIOPIA**

PhD Dissertation

By

Abebe Yilma Tasew

May 2026

BAHIR DAR, ETHIOPIA

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COLLEGE OF AGRICULTURE AND ENVIRONMENTAL SCIENCES,
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Ph.D. IN PLANT PATHOLOGY

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FUSARIUM WILT: INSIGHTS FROM EPIDEMIOLOGY,
FARMERS PRACTICES, AND PATHOGEN
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A PhD Dissertation

**Submitted to the Department of Plant Sciences, Bahir Dar University in Partial
Fulfilment of the Requirements for the Degree of Doctor of Philosophy (PhD) in
Plant Pathology**

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May 2026

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PhD DISSERTATION APPROVAL SHEET

As member of the Board of Examiners of the Doctor of Philosophy (Ph.D.) Dissertation open defense examination, we have read, and evaluated this dissertation prepared by Mr. Abebe Yilma Tasew, and examined the candidate entitled "**Integrated Management of Chickpea Fusarium Wilt: Insights From Epidemiology, Farmers Practices, and Pathogen Characterization in West Amhara, Ethiopia**". We hereby certify that; the Dissertation is accepted for fulfilling the requirements for the award of the degree of Doctor of Philosophy (Ph.D.) in Plant Pathology.

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DECLARATION

This is to certify that this "**Integrated Management of Chickpea Fusarium Wilt: Insights From Epidemiology, Farmers Practices, and Pathogen Characterization in West Amhara, Ethiopia**" submitted in fulfillment of the requirements for the award of the degree of Doctor of Philosophy in "Plant Pathology" to the Department of Plant Sciences, Graduate Program of College of Agriculture and Environmental Sciences, Bahir Dar University by Mr. Abebe Yilma (ID No.= BDU 1301223) is an authentic work carried out by him under our supervision. The matter embodied in this dissertation work has not been submitted earlier for an award of any degree to the best of our knowledge and belief. The materials obtained from other sources are duly acknowledged in the dissertation.

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DEDICATION

To my beloved mothers Mrs. Aseged Mengistu and my betterhalf Mrs. Weletehana Weldeamanuel, as well as, my son Mickeyas Abebe.

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Integrated Management of Chickpea Fusarium Wilt: Insights from Epidemiology, Farmers Practices, and Pathogen Characterization in West Amhara, Ethiopia

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GENERAL ABSTRACT

Chickpea (*Cicer arietinum* L.), a legume of immense nutritional and economic significance has a unique niche in Ethiopian agriculture. However, Ethiopia's current productivity, which is about 2 tons per hectare, is incredibly low compared to its attainable yield of 5 tons per hectare. This could partially be attributed to chickpea Fusarium wilt; one of the most devastating diseases that gave rise to considerable grain yield loss. This study employed a multi-dimensional approach integrating socio-economic assessments, epidemiological surveys, lab-based identification, pathogenicity test and pathogenic potential studies, and field-validated management trials to establish sustainable management options for chickpea Fusarium wilt in West Amhara, Ethiopia. A socio-economic survey of 246 farmers across four districts revealed a significant knowledge and disease management practice associated with socioeconomic variables. Thus, age, farming experience and farm holding size were significantly associated with disease related knowledge. A two-year epidemiological disease survey (2022–2024) across six districts demonstrated that chickpea Fusarium wilt is ubiquitous, with its intensity significantly influenced by biophysical factors. The minimum wilt incidence (8.63%) and percent severity index (8.78%) were noted from chickpea fields planted late in the season after four or more consecutive years of crop rotation practice. Conversely, the maximum wilt incidence (43.74%) and percent severity index (39.58%) were obtained from fields owning early planted chickpeas after one year of crop rotation

practices. Pathogenicity tests revealed that all isolates obtained from infected roots of chickpea were found to be pathogenic; inducing yellowing and wilting symptoms with a mean incidence percentage ranging from 7.9 to 63%. Thus, about 61% of the isolates were moderately pathogenic causing a wilt incidence of 30-50%. The rest 22.2 and 16.7% of the isolates were highly pathogenic and less pathogenic by inducing above 50% and less than 30% mean wilt incidences respectively. Integrated laboratory and greenhouse studies confirmed that while *Fusarium oxysporum* f.sp. *ciceri* is a well-established soil-borne pathogen, it also possesses seed-borne nature. Thus, this study demonstrated that about 62% of the isolates sourced from infected chickpea seeds were able to induce wilt and yellowing symptoms. Delayed planting, long-term crop rotation practices and proper weed management is pivotal for effective management of chickpea Fusarium wilt. Moreover, field experiments conducted in two districts showed significant synergistic interaction among seed dressing fungicides, chickpea varieties and vermi-compost application and an impact on wilt intensity, yield, and yield components of chickpea. Thus, the Natoli variety treated with Goldazim 500SC seed dressing fungicide and supplemented with vermi-compost showed the lowest wilt incidence and severity in both study sites. However, untreated Dhera variety retained the highest mean incidence and disease severity of 26.83% and 30.67% respectively at Bahir Dar Zuria which is also consistently highest at Fogera site. The maximum grain yield recorded was 2953.8kg ha⁻¹ achieved by the Natoli treated with Goldazim 500SC and receiving Vermicompost application. The study also noted that the highest grain yield loss due to Fusarium wilt were 27.8% at Bahir Dar Zuria and 23.96% in Fogera district correlating with increased disease incidence and severity. Chickpea producers should focus on an integrated package consisting of the Natoli variety, Goldazim 500SC seed treatment, and vermi-compost application, supplemented by use of healthy planting seed, delayed planting and extended crop rotation practices.

Keywords: Incidence, pathogenic potential, pathogenicity test, severity, yield, yield components

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LIST OF ABBREVIATIONS AND ACRONYMS

ai	Active Ingredient
AUDPC	Area Under Disease Progress Curve
BC	Before Christ
BNF	Biological Nitrogen Fixation
BZDOA	Bahir Dar Zuria District Office of Agriculture
CFW	Chickpea Fusarium Wilt
CIMMYT	Centro Internacional de Mejoramiento de Maíz y Trigo /International Maize and Wheat Improvement Center/
CRD	Completely Randomized Design
CSA	Central Statistical Agency
DAE	Days After Emergence
DAI	Days After Inoculation
DARC	Debre Zeith Agricultural Research Center
DNA	Deoxy Ribonucleic Acid
EC	Emulsifiable Concentrates
EDOA	Enemay District Office of Agriculture
EEDO A	Enarj Enawga District Office of Agriculture
ETB	Ethiopian Birr
FDOA	Fogera District Office of Agriculture
FOC	<i>Fusarium oxysporum</i> f.sp. <i>ciceris</i>
GDP	Gross Domestic product
GPS	Global positioning system
IDM	Integrated Disease Management
ISTA	International Seed Testing Association
KA	Kebele Administration
LKDOA	Libo Kemkem District Office Agriculture

NaOCl	Sodium hypochlorite
NMA	National Meteorological Agency
PDA	Potato Dextrose Agar
PSI	Percent Severity Index
RCBD	Randomized Complete Block Design
SC	Suspension Concentrate
SNNPR	Southern Nations, Nationalities and Peoples Region
SSA	Sub Saharan Africa
USAID	United States Agency for International Development
USD	United States Dollar
YDDOA	Yilmana Densa District Office of Agriculture

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CHAPTER 1: General Introduction

1.1. Background and Justification

Chickpea is an ancient self-pollinated legume crop supposed to have originated in south-eastern Turkey and the adjoining part of Syria (Singh, 1997). The crop distributed with the cluster of founder crops from the Fertile Crescent into Europe and west-central Asia from the 5500 BC onwards. Currently, it is the third most important cool season food legume crop in production, next to common bean (*Phaseolus vulgaris* L.) and peas (*Pisum sativum* L.) in the world (Bulti Merga and Jema Haji, 2019) with annual production over 16.8 million tons (FAOSTAT, 2024). It is cultivated on about 11.5 million hectares of land, and occupies more than 20% of the world's pulse production exceeded only by the dry bean and pea (Patra and Kumar Biswas, 2017). India is the leading producer, accounting for 65% of global production (FAOSTAT, 2024). Ethiopia stands at the third largest producer contributing 4% to the global output and 90% production in Sub-Saharan Africa (Verkaart *et al.*, 2017) with production exceeding 443,950 tons and over 207,377 hectares of land during 2024 cropping season (FAOSTAT, 2024).

Chickpea holds a pivotal place in Ethiopia's agricultural landscape, serving both as a vital food source and a key export commodity. Ethiopia is the largest exporter in Africa, where it is the eighth top chickpea exporter in the world accounting for an average of approximately 3.5% of the global chickpea export market for the last 2 decades, followed by Tanzania with 1.7% (FAOSTAT, 2020). The total cultivated area and production contribution of Ethiopia to African market is about 43 and 63%, respectively (Laxmipathi Gowda, 2016). In the country, over one million farmers are engaged in chickpea production (CSA, 2021). In the country, where 90% of chickpea production is achieved in Sub-Saharan Africa; it is an economically valuable pulse crop grown by about one million smallholder farmers (Lijalem Korbu *et al.* 2022) and the chickpea sector has the potential to be a key driver of the country's agricultural development and economic growth (Asrat Mulat, Almaz Giziew and Dereje Ayalew, 2022).

Importantly, chickpea is among the principal legumes in the highland vertisols mainly in the tef, wheat, and sorghum- based cropping systems (Lijalem Korbu *et al.*, 2020). Chickpea can grow well in elevation ranging from 1500 to 2700 meters above sea level (m.a.s.l.). The crop is largely confined to the central and northern high lands of the country (Lijalem Korbu *et al.*, 2020). Although chickpea is cultivated in most regions of the country; Amhara, Oromiya, Southern Nations, Nationalities and People's Region (SNNPR) and Tigray, in decreasing order, are the major producers (Tarekegn Fite *et al.*, 2018). Amhara and Oromiya regions alone produce over 93% of total chickpea production in Ethiopia, while SNNPR and Tigray produce 3.5 and 3%, respectively (Wasihun Yaregal, 2016). In Amhara region, the major producing zones are South Gondar (Fogera, Smada, Misrak Estie and Ebinat), North Gondar (Chilga, Takusa, Dembia), South Wello (Wegidi), North Shewa (Ensaro, Mojana Wedera and Minjar Shenkora), East Gojam (Enarj Enawga) and North Gojam (North Achefer) (Warner, Stehulak and Kasa, 2015; CSA, 2021).

Chickpea can be put in to diverse uses for food, feed, nutrition, market, homemade processing, and healthy food (Ebisa Olika, Solomon Abera and Asnake Fikre, 2019). It is a smallholder farmer and gender-friendly crop in that chickpea can be a backyard crop handled by women for home consumption, medium-sized fields for market and home consumption or at the commercial scale for a wider market and agro-processing (Tabe-Ojong and Mausch, 2017; Asnake Fikre, Haile Desmae and Seid Ahmed, 2020). Chickpea is multipurpose legume crop for integrating with different cereals, maize, millet, rice, sorghum, maize, wheat and tef in diverse cropping systems of double cropping, relay cropping and rotational cropping (Birhanu Gizaw *et al.*, 2018).

In areas where double cropping per season is designed, chickpea is suitably designed survive its reproductive phase using the residual moisture of progressive depletion (Birhanu Gizaw *et al.*, 2018; Kumar *et al.*, 2023). The deep root system of the crop enabling efficient utilization of the untapped moisture resource by the previous crop and the chickpea crop breaks and disrupts the circuit of regular pest and ameliorates soil fertility by natural nitrogen replenishment of the soil for use by cereals planted after

(Asnake Fikre, Haile Desmae and Seid Ahmed, 2020). Chickpea fixes about 140 kg ha⁻¹ atmospheric nitrogen through rhizobium bacteria present in its root improves the soil fertility (Laxmipathi Gowda, 2016). Chickpea contributes to at least one-third of the N fertilizer needs of the following cereal crop. This natural fixation of nitrogen from the air can save up to USD 20 per hectare (Asnake Fikre *et al.*, 2020), which otherwise should be supplied by the application of chemical fertilizer. This, in turn, is also environmentally friendly and safe with almost zero pollution.

The integration of chickpea into cropping systems would contribute to increasing total production, mitigating crop failure, sustaining the systems, improving benefits, and optimizing resource use (Asnake Fikre, Haile Desmae and Seid Ahmed, 2020). The different cropping systems to which chickpea is an important component creates accumulative intensification (Birhanu Gizaw *et al.*, 2018). Conservation agriculture based crop production practices coupled with the recommended fertilization could enhance the yields, farm profits, and soil properties of the maize–chickpea rotation, enabling sustainable production in the long run (Prakash *et al.*, 2019). Apart from being an important source of dietary protein for human consumption, this leguminous crop is also important for management of soil fertility due to its nitrogen-fixing ability through nodulation by *Rhizobium* spp. The use of chickpea into cropping systems, as integral component would contribute to increasing total production, mitigating crop failure, sustaining the agricultural productivity, improving benefits, and optimizing resource use efficiency (Asnake Fikre, Haile Desmae and Seid Ahmed, 2020; Richards, Maphosa and Preston, 2022).

Despite its significance for soil fertility management, economic stability, food and nutritional security in Ethiopia, the crop experiences alarmingly low average productivity levels, currently about 2 tons per hectare (FAOSTAT, 2024). This productivity falls far short of its potential of 5 tons per hectare (Gemechu Keneni *et al.*, 2012; Verkaart *et al.*, 2017). This lower productivity of chickpea in Ethiopia is mainly attributed to a shortage of improved and good quality healthy seeds, various diseases, and insect pests (Mulat *et*

al., 2022). Chickpea experienced significant biotic stresses, with diseases proving to be the most significant yield-limiting constraints (Venkataramanamma *et al.*, 2023).

Chickpea Fusarium wilt, incited by the fungal pathogen *Fusarium oxysporum* f.sp.*ciceri*, is a widespread, and leads to reduced chickpea yield harvest in many chickpea growing regions in Ethiopia mainly in West Amhara Ethiopia (Sultan Mohammed *et al.*, 2018; Dagnachew Bekele *et al.*, 2021; Awoke Yemataw *et al.*, 2025). Further to this, Yigerem Mengist *et al.* (2018) reported the devastating impact of chickpea Fusarium wilt, recording a grain yield losses as high as 95.4% in untreated local varieties as compared to treated plots under sick plot condition in Yilmana Densa, West Amhara Ethiopia. It is described as one of the most destructive disease inducing an estimated mean annual yield loss ranging from 10 to 90% under Ethiopian conditions based on favorable biophysical factors like atmospheric humidity and temperature (Yigerem Mengist *et al.*, 2018; Zemenu Endalew *et al.*, 2022;).

Chickpea Fusarium wilt is a vascular disease with monocyclic characteristics, in which management of the disease should be targeted to exclusion of the pathogen and reducing the amount and efficiency of the initial inoculum. Cultural management practices like, manure application; delayed planting; intercropping; proper weed management, raised seed bed and optimum spacing can be employed to manage the disease and resulted in partial management of the disease. Merkuz Abera and Getachew Alemayehu (2012) reported that tolerant chickpea variety planted on raised seed bed planted during the optimum time managed the wilt incidence and reduced plant mortality due to wilt. Delayed planting and proper weed management are the key agronomic practices to manage chickpea Fusarium wilt and associated wilt root complex (Sultan Mohamed *et al.*, 2018; Bereket Ali and Habtamu Terefe, 2021; Dagnachew Bekele *et al.*, 2021). According to Merkuz Abera *et al.* (2011), Fusarium wilt incidence was reduced with application of green manure and dried plant residue. According to Kaulage, Raghuwanshi and Pawar (2018), organic amendment in the form of vermicompost significantly reduced incidence of chickpea Fusarium wilt at different growth stage. Vermicompost treatment showed significant reduction in the incidence of Fusarium wilt and increased plant height, stem

diameter, leaf area and ultimately increased yield (Zhang *et al.*, 2020). From agronomic view, application of vermicompost at the rate of 5 tons per hectare gave the maximum resulted in yield advantage of 27.4% over the control (Kaur, Kumar and Singh, 2023).

The application of fungicides in the form of seed treatment alone or in combination with other management options are the most effective approach. Seed dressing fungicides, like Thiram and Apron star offers a good protection against chickpea Fusarium wilt (Yigerem Mengist *et al.* 2018; Zemenu Endalew, Gizachew Haylemariam and Ahmed Mohamed, 2022). Furthermore, Bhimani (2020) reported that Carbendazim 50% WP resulted in the least (23.3%) disease incidence and 76.7% yield increase compared to the control which retained incidence of 100%.

Integration application of effective microorganisms and resistant varieties significantly reduced wilt incidence and affect yield and yield components of chickpea. Application of Trichoderma species integrated with moderately susceptible or resistant cultivars is a more effective method in reducing chickpea Fusarium wilt by 30–46% (Meki Shehabu *et al.*, 2011). Chickpea seed treated with Mancozeb 63% @ 2 g kg⁻¹ of seeds combined with carbendazim 12% resulted in a yield advantage of 34.4% as compared to the control (Kl and Huilgol, 2021). According to Sahni (2021), the combined treatment with 15% vermicompost, seed bacterization, and pre-inoculation with salicylic acid foliar spray resulted in complete suppression against *Fusarium oxysporum* f.sp. *ciceris*. Late planting of Mastewal chickpea variety expressed the minimum (10.2%) wilt incidence, however the early planted Arerti variety showed a maximum (50.6%) mean wilt incidence at Alem Ketema, North Shewa Zone of Amhara regional state, reflecting the significant contribution of combining sowing date and varieties for chickpea Fusarium wilt management (Bereket Ali and Habtamu Terefe, 2023).

1.2. Statement of the Problem

Above 172 pathogens, among which over 67 are reported as fungi, have been reported to infect chickpea (*Cicer arietinum* L) reported from 55 countries until the year 1995. The persistent chickpea diseases in the world with wide geographic areas include *Ascochyta rabiei* (35 countries), *Fusarium oxysporum* f.sp. *ciceris* (32 countries), *Uromyces ciceris-arietini* (25 countries), bean (pea) leaf roll virus (23 countries), and *Macrophomina phaseolina* (21 countries) (Nene, 1996). In Ethiopia, the major diseases of chickpea include Fusarium wilt (*Fusarium oxysporum* f.sp. *ciceris*), Ascochyta blight (*Ascochyta rabiei*), dry root rot (*Rhizoctonia bataticola*), black root rot (*Fusarium solani*), wet root rot (*Rhizoctonia solani*) and collar rot (*Sclerotium rolfsii*) (Tebkew Damte and Ojiewo, 2016; Sultan Mohamed *et al.*, 2018).

The vulnerability of chickpea to biotic and abiotic stresses is a major constraint for reduced yields (Tarafdar *et al.*, 2018). The productivity of chickpea is severely compromised by the aggressive soil-borne and seed-borne disease; chickpea Fusarium wilt caused by the fungal pathogen, *Fusarium oxysporum* f. sp. *ciceris*. Chickpea Fusarium wilt, caused by *Fusarium oxysporum* f.sp. *ciceri* is one of the most widely distributed and leads to 80-100% yield losses (Dhawale and Dhale 2021) in many chickpea growing countries globally including Ethiopia (Dubey, Singh and Singh, 2010; Venkataramanamma *et al.*, 2023). The disease is distributed to all chickpea growing districts of Ethiopia resulting about 30% yield loss and lower productivity of chickpea (Asrat Zewdie, 2017; Sultan Mohamed *et al.*, 2018; Bereket Ali and Habtamu Terefe, 2021; Dagnachew Bekele *et al.*, 2021). It is the most widely distributed disease of economic importance reported in major and minor chickpea growing districts in Amhara, Oromia, Tigray and Southern Nations, Nationalities and People's Region. Amhara region is the primary hotspot, where incidence rates in areas like Gonji Kolela escalate to 58% (Sultan Mohamed *et al.*, 2018; Bereket Ali and Habtamu Terefe, 2021). Several studies demonstrated that CFW is the most predominant challenge adversely affecting chickpea disease in Ethiopia including West Amhara part causing 30-100 % yield loss in different parts of the country (Meki Shehabu *et al.*, 2008; Awoke Yemataw *et al.*, 2025).

Current interventions often rely on cultural methods that fail to address the systemic nature of the disease, allowing the persistent yield gap. This critical management failure is rooted in a significant, multifaceted knowledge deficit concerning the pathogen's current state and transmission pathways among chickpea producers. The implementation failure is compounded by a socio-economic gap: there is no effective assessment of farmers' current knowledge and CFW management practices. Without understanding local constraints, perceptions, and their indigenous knowledge, any proposed solution risks being technically sound but socially irrelevant, leading to low adoption rates and continued disease pressure. This convergence of complex, underestimated and unstudied pathogen dynamics and unaddressed socio-economic barriers highlights that the current problem is not a lack of effort, but a lack of integrated and current scientific intelligence.

Besides, the virulence and pathogenic potential of local FOC isolates, particularly those originating from seed-borne inoculum are not well studied in Ethiopia. Gezahegn Getaneh, *et al.* (2020) reported that *Fusarium oxysporum* is the most frequently detected fungi associated with seeds of chickpea. However, information is lacking on the fungal virulence, pathogenic potential and its seed borne nature. Moreover, lack of information on biophysical factors influencing the disease epidemics hinders effective management practices. Rapid shifts in climate patterns, production systems, and cropping rotations mean the pathogen's geographical distribution and the environmental triggers of infection needs to be studied. The on-going changes in climatic conditions such as unpredicted rainfall patterns, temperature rise, relative humidity fluctuations, and low soil moisture stress (Zhao and Running, 2010) are likely to influence the establishment plant disease, its distribution and epidemiology (Zhang, Wong and Chow, 2003). Although, integrated disease management is the most effective and sustainable approach, reports are too limited under Ethiopian conditions on compatibility and synergistic interaction study among the different single management tactics.

Thus, a comprehensive disease status survey and identification of biophysical factors influencing CFW spread are valuable variable and are directly associated with management practices. Addressing this challenge is crucial, which relies heavily on

integrated management approach mainly relaying on seed dressing fungicides, host plant resistance and soil amendment along with cultural methods used by the producers. The purpose of this research is to develop, validate, and promote a realistic integrated CFW management under field conditions that synthesizes the underestimated epidemiological, environmental, and socio-economic realities. By providing this integrated, site-specific solution, this study will equip extension services and farmers with the decisive tool needed to secure sustained chickpea production and enhance long-term food system resilience in North West Ethiopia.

1.3. Significance of the Study

Chickpea is a cornerstone of nutritional intake, yet national productivity remains drastically below potential, a shortfall primarily driven by Fusarium wilt (*Fusarium oxysporum* f.sp. *ciceris*). Success in mitigating this loss is a paramount importance to stabilizing the national chickpea supply and reduction of the yield loss caused by the pathogen. This study's holistic approach begins by confronting the earliest infection source through the analysis of seed-borne inoculum and its pathogenic potential, which informs the design and validation of the full-scale integrated disease management protocol under field conditions. By tackling the problem from the very start, this research provides the essential, evidence-based strategy required to substantially reduce disease incidence and secure a vital food source for millions.

Crucially, the significance of this work extends beyond domestic nutrition to impact national economic viability. As a major pulse exporter, Ethiopia's foreign exchange earnings are highly sensitive to the quality of its chickpea harvests. To ensure quality harvest the resulting IDM package is adopted and translates into real economic gain, the research includes a vital assessment of farmers' current knowledge and disease management practices. This socio-economic baseline ensures the final recommendations are locally appropriate, cost-effective, and practical, guaranteeing the high adoption rates necessary to enhance the consistency of high-quality production. This improved market stability and higher revenue generation will serve as a critical catalyst for broader

agricultural development and uplift the livelihoods of smallholder farmers who are dependent on this cash crop.

Furthermore, the study provides appropriate answers rooted in scientific precision and environmental sustainability. To determine the genetic variability of *Fusarium oxysporum* f.sp. *ciceris* and move beyond unsustainable single control-tactic, the IDM strategy must be based on localized data. The systematic disease status survey and identification of biophysical factors influencing CFW are indispensable for this purpose. This site-specific environmental profiling moves the study beyond general recommendations, allowing the integrated strategy to be precisely tailored against the regional distribution and environmental triggers of the pathogen. This scientific approach ensures long-term disease management, minimizes reliance on heavy chemical inputs and applications, and directly aligns agricultural practices with contemporary conservation and environmental stewardship initiatives.

In direct terms, this study is indispensable for enhancing the resilience and profitability of smallholder farming systems. The chickpea crop provides dual benefits as a source of income and crucial soil improvement via nitrogen fixation. By integrating the field-validated CFW management strategies, the farmer knowledge baseline, and the site-specific biophysical data, this research directly empowers farmers with a comprehensive, validated, and cost-effective management system. This collective effort ensures to mitigate crop loss effectively, secure reliably higher yields, and fully leverage the economic and environmental advantages of including chickpea in their farming plans, contributing decisively to poverty alleviation and sustainable household food security.

1.4. Research Objective

1.4.1. General objectives

To develop multi-dimensional integrated chickpea *Fusarium* wilt management for reducing disease impact and improving chickpea productivity in West Amhara, Ethiopia

1.4.2. Specific objectives

The study was undertaken with the following specific objectives

- I. To explore the Farmers' knowledge and their practices of chickpea *Fusarium* wilt management in West Amhara, Ethiopia;
- II. To assess the status of chickpea *Fusarium* wilt and its association with diverse biophysical factors influencing its epidemics in West Amhara;
- III. To evaluate pathogenic potential and virulence of *Fusarium oxysporium* f.sp. *ciceris* isolates associated with chickpea seeds;
- IV. To determine the synergistic effects of seed dressing fungicides, Vermicompost applications and varieties on chickpea *Fusarium* wilt incidence, severity, yield and yield components of chickpea.

CHAPTER 2: Literature Review

2.1. Taxonomy, Origin and Distribution of Chickpea

Chickpea (*Cicer arietinum* L.) was domesticated in association with other crops of barley, flax, lentil, peas, rye, vetch and wheat and with goats, pigs and sheep and cattle as part of the evolution of agriculture in the Fertile Crescent 10,000-12,000 years ago (Berger, 2007). Chickpea is an ancient self-pollinated legume crop believed to have originated in south-eastern Turkey and the adjoining part of Syria (Singh, 1997). However, it is developed as a post-rainy season, spring-sown crop, early in its evolution and spread into sub-tropical regions, in contrast to its wild relatives that have remained as winter annuals in the West and Central Asia (Berger, 2007). The crop spread with the cluster of founder crops from the Fertile Crescent into Europe and west-central Asia from the 5500 BC onwards.

2.2. Importance and expansion potential of Chickpea

Chickpea is a highly versatile crop serving various purposes spanning from human food and animal feed to nutritional enhancements, market commodities, homemade preparations and healthy focused diets (Ebisa Olika, Solomon Abera and Asnake Fikre, 2019). It is uniquely suited to small-scale farming and promotes gender inclusivity, as it can be cultivated in backyard gardens for household use to medium-sized production for both family consumption and market sales, and even at large commercial production and broader market distribution (Tabe-Ojong and Mausch, 2017; Asnake Fikre, Haile Desmae and Seid Ahmed, 2020). Chickpea can be categorized into diverse uses for food, feed, nutrition, market, homemade processing, and healthy food diets (Ebisa Olika, Solomon Abera and Asnake Fikre, 2019).

Chickpea is a multipurpose legume crop for integrating with different cereals, like maize, millet, rice, sorghum, tef, and wheat in diverse cropping systems of double cropping, relay cropping and rotational cropping (Tsedalu Jemberu *et al.*, 2018). In areas where double cropping per season is desired, chickpea is suitably designed coincide its reproductive phase with the residual moisture of progressive depletion (Tsedalu Jemberu *et al.*, 2018; Lijalem Korbu *et al.*, 2020). The deep root system of the crop enabling

efficient utilization of the untapped moisture resource by the previous crop and the chickpea crop breaks and disrupts the circuit of regular pest and ameliorates soil fertility by natural nitrogen replenishment of the soil for use by cereals planted after it (Asnake Fikre, Haile Desmae and Seid Ahmed, 2020). Chickpea fixes about 140 kg ha⁻¹ atmospheric nitrogen per cropping season through rhizobium bacteria present in the roots and improves the soil fertility (Laxmipathi Gowda, 2016). Chickpea contributes to at least one-third of the N fertilizer needs of the following cereal crop. This natural fixation of nitrogen from the atmospheric air can save up to USD 20 per hectare, which otherwise should be supplied by the application of organic or synthetic chemical fertilizer. This natural nitrogen fixation, in turn, is also environmentally friendly and safe with almost zero pollution.

The integration of chickpea into cropping systems would contribute to increasing total production, mitigating crop failure, sustaining the systems, improving benefits, and optimizing resource use (Asnake Fikre, Haile Desmae and Seid Ahmed, 2020). The different cropping systems to which chickpea is an important component creates accumulative intensification (Birhanu Gizaw *et al.*, 2018). Conservation agriculture based crop production practices coupled with the recommended fertilization could enhance the yields, farm profits, and soil properties of the maize–chickpea rotation, enabling sustainable production in the long run (Pooniya *et al.*, 2021).

In Ethiopia, double cropping of wheat with chickpea provided the highest grain yield of 2.7 tons per hectare for the wheat and 2.6 tons per hectare for the chickpea in just one growing season. This combination demonstrated double-cropping rewards to a maximum land equivalent ratio of 1.99, implying the yield and benefit maximization per unit area per season (Tsedalu Jemberu *et al.*, 2018). Similarly, research results proved the advantage of chickpea by tef rotational (1:3) production, where high productivity of both crops was sustainably realized (Birhanu Gizaw *et al.*, 2018). Chickpea is also a suitable crop for an irrigated production system. Multiple generations of chickpea up to six per year were reported by (Asnake Fikre and Tulu Degefu, 2019) under field experimental conditions, which demonstrated the possibility to obtain high gains per unit area per unit

time in production using irrigation during the dry season. Irrigation based production of chickpea enhances productivity as can be observed from Sudan with productivity of above 3 tons ha⁻¹ (FAOSTAT, 2020). Under Ethiopian condition, irrigated chickpea productivity is about 3.2 tons per hectare (Nigusie Girma, Asnake Fikre and Ojiewo, 2017).

2.3. Ecological Requirements of Chickpea

Chickpea is highland pulse crop that is best grown in the northern hemisphere, mostly at relatively high elevations. It is grown between 20–40°N in the northern hemisphere and 27–38°S in the southern hemisphere (Imtiaz, Malhotra and Yadav, 2011). Growing regions of chickpea can be broadly divided into two, non-tropical dry areas and semi-arid tropics (Imtiaz, Malhotra and Yadav, 2011). In Ethiopia, chickpea is mainly grown in the central, northern, and eastern highland areas of the country at an altitude of 1400-2300 meters above sea level, where annual rainfall ranges between 500 and 2000 mm. However, when the rainfall is heavier in the seasons it shows reduced yields due to disease outbreaks and stem lodging problems from the excessive vegetative growth. Areas with lighter, well-distributed rainfall patterns have produced the highest yield and quality chickpea seed.

Chickpea becomes one of the promising rain fed crop on black soils during the winter season in India. Chickpea cultivation is solely dependent on the soil moisture reserve where planting is late during the recession of the main rainy season to escape the water logging conditions. Shorter cool and dry weather period prevailed between November to February favor the crop growth and development in this region. Delayed sowings force the crop to pass through warmer temperatures during the reproductive phase which is one of the major hindrances to optimum productivity (Martin Luther, Narasimha Rao and Prasad, 2020). Both temperature situation and moisture supply during the growing period had a strong influence on chickpea production and productivity. The start of flowering in chickpea is dependent on photothermal conditions which is the main determinant for growth and development (Basu, Masood Ali and Chaturvedi 2009).

Chickpea is a drought-tolerant legume and is grown as a summer crop in temperate environments (Devasirvatham and Tan, 2018; Korbu *et al.*, 2020). Genetic variability exists in chickpea germplasm for the response to variation in day length (photoperiod sensitivity) and response to variation in temperature (thermal sensitivity) and has been exploited in the development of short-duration cultivars (Tejaswini *et al.*, 2025). Globally, chickpea is adapted to black soils in the cool semi-arid areas of the tropics, subtropics as well as temperate areas (Rani *et al.*, 2020). It does best on fertile sandy, loam soils with good internal drainage. Good drainage is necessary because even short periods of flooded or waterlogged fields reduce growth and increase susceptibility to root and stem rots.

Chickpea, like other pulse crops, requires phosphorus, potassium, and micronutrients for its growth and development. It significantly responds to a combined application of phosphorus and bio-fertilizers (Rhizobium and phosphobacterin) and seed inoculated with Rhizobium and phosphobacterin gave significantly higher number of pods per plant and seeds per pod compared to no inoculation (Dutta and Bandyopadhyay, 2009). Nitrogen is known to be an essential nutrient for plant growth and development due to its role in biochemical, physiological, and morphological processes of plant production. Next to nitrogen, phosphorus is the most important and decisive element for adequate grain production. Application of phosphorus fertilizer enhanced mid-season dry matter accumulation and tissue phosphorus accumulation of both desi and kabuli chickpea, but grain yield was increased only moderately for desi chickpea, while the yield of kabuli chickpea was not affected by the application of phosphorus (Parashar and Jaidev Sharma, 2024).

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2.4. Chickpea production trend in Ethiopia

Chickpea holds a pivotal place in Ethiopia's agricultural landscape, serving both as a vital food source and a key export commodity. The crop's status as an export commodity has undeniably driven this growth, as Ethiopian farmers, responding to market incentives, have gradually shifted towards chickpea cultivation. The upward trajectory in production

has also been bolstered by an increasing knowledge and information on the crop's environmental resilience, particularly in arid and semi-arid regions.

Ethiopia is the largest exporter in Africa, whereas it is the eighth top chickpea exporter in the world accounting for an average of approximately 3.5% of the global chickpea export market for the last two decades, followed by Tanzania with 1.7% (FAOSTAT, 2024). The export volume and export earnings from the crop have recently shown a moderate increase over the years in both Ethiopia and Tanzania. However, approximately 94% of the export from Ethiopia still goes to low-value markets. The total cultivated area and production contribution of Ethiopia to African market is about 43% and 63%, respectively (Laxmipathi Gowda, 2016). Chickpea has the potential to be a key driver of the country's agricultural sector and economic contribution (Asrat Mulat, Almaz Giziew and Dereje Ayalew, 2022). Kabuli types fetch higher market prices than desi types with price differences ranging from 15% to 36% (Setotaw Ferede, Nigusie Girma and Sherif Aliy, 2019).

In Ethiopia, about 75% of the produce is used for home consumption while the remaining 25% is supplied to the market (CSA, 2021). The trend is reversed for improved technology intervention areas, where 82% of the product is supplied to the market (Setotaw Ferede, Nigusie Girma and Sherif Aliy, 2019). This transformational process for improved technology intervention areas from subsistence farming to market oriented production system was facilitated by scaling-up of technologies through projects such as the Tropical Legumes projects (Rubyogo *et al.*, 2019). The projects promoted improved varieties with market competitive traits and high yield that stimulated producers to a shift from subsistence to market-oriented farming. Chickpea could be one important source of hard currency for countries from the international trade of grain and value-added products (Bulti Merga and Jema Haji, 2019; Afzal, 2021).

The trajectory of chickpea production in Ethiopia has witnessed a series of fluctuations, marked by periods of growth as well as setbacks, shaped largely by environmental, economic, and technological factors. As one of the preeminent producers of chickpeas in

sub-Saharan Africa (SSA), Ethiopia consistently ranks among the top global producers, with its chickpeas forming an integral part of international markets, particularly in South Asia and the Middle East (Jendoubi *et al.*, 2017; Rubyogo *et al.*, 2019). Understanding the nuances of Ethiopia's chickpea production trends provides invaluable insights into the future of this critical crop, as well as its broader implications for the country's agricultural development.

In the past two decades, Ethiopia has experienced a noticeable upward trend in the hectareage dedicated to chickpea cultivation. According to FAOSTAT (2024), over 207,377 hectares of land during 2024 cropping season were allocated to chickpeas, reflecting both increased domestic consumption and burgeoning export demand. As Ethiopia continues to capitalize on the rising global demand for pulses, particularly from countries such as India, the area under chickpea cultivation has expanded, especially in key agricultural regions like Oromia, Amhara, and Tigray. However, its productivity is becoming diminishing due to many biophysical constraints; being diseases being responsible for the lions share (Asrat Mulat, Almaz Giziew and Dereje Ayalew, 2022).

2.5. Constraints of Chickpea Production in Ethiopia

The production of chickpeas has been subject to considerable volatility, largely owing to the vagaries of Ethiopia's climate. Ethiopia's reliance on rain-fed agriculture places chickpea farming at the mercy of unpredictable weather patterns, with droughts being a recurring challenge. In particularly dry years, such as 2015 and 2016, the crop's yields were significantly diminished, revealing the fragility of the farming system in the face of climate change.

2.5.1. Major abiotic constraints to chickpea production

The growing frequency of erratic rainfall patterns underscores the urgent need for adaptation strategies. In response to these climatic challenges, researchers and agricultural policymakers have prioritized developing drought-tolerant chickpea varieties. Despite these innovations, however, access to these chickpea varieties remains uneven, due to logistical and financial barriers with many smallholder farmers still struggling to obtain

high-quality seeds. In Ethiopia, several abiotic, biotic and socio economic constraints are causing to the low production and productivity of chickpea (Asrat Mulat, Almaz Giziew and Dereje Ayalew, 2022). Unpredictable rainfall, poor soil and nutrient management, and agro-ecological adaptations are among abiotic factors. However, of biotic factors, which lead to an overall reduction in chickpea productivity, fungal diseases take the lions share, followed by viral and bacterial diseases, which affect all parts of the plant at all growth stages.

2.5.2. Biotic constraints to chickpea production

The persistent challenges of pest and disease management have further compounded the difficulties of chickpea production. Insect pests, particularly the chickpea pod borer, along with the prevalent fungal diseases of wilt/root rot complex and Ascochyta blight, pose significant threats to the crop's health. These pests and pathogens can wreak havoc on chickpea yields, lowering both quality and quantity. Additionally, the lack of efficient disease management further exacerbates the vulnerability of chickpeas to crop failure. As a result, these recurring pest and disease outbreaks not only undermine farmers' productivity but also hinder the overall stability of chickpea production in Ethiopia (Alemu Nega, 2025).

In Ethiopia, 16 economically important diseases were reported on chickpea, of which about 50% are caused by fungal species and 38% are caused by viral pathogens. The major chickpea diseases reported in Ethiopia are; Fusarium wilt (*Fusarium oxysporum* f.sp. *ciceris*), Ascochyta blight (*Didymella rabiei*), dry root rot (*Rhizoctonia bataticola*), black root rot (*Fusarium solani*), wet root rot (*Rhizoctonia solani*), collar rot (*Sclerotium rolfsii*), root knot nematode (*Meloidogyne spp*), powdery mildew (*Leveillulatauricacv.* Arn), and rust (*Uromyces ciceri-arietinum*). Chickpea wilt caused by the pathogen *Fusarium oxysporum* f.sp. *ciceris* is one of the most important yield-limiting biotic constraints to chickpea production worldwide (Sharma *et al.*, 2012) and also the most production-bottleneck to chickpea farming in Ethiopia (Sultan Muhamed *et al.*, 2018).

2.6. Chickpea *Fusarium* Wilt

2.6.1. Symptoms and damage

Chickpea *Fusarium* wilt exhibits various symptoms, with the most common visible symptoms being wilting, yellowing and discoloration of vascular tissue (Jendoubiet *et al.*, 2017; Bereket Ali and Habtamu Terefe, 2021; Younesi *et al.*, 2021). Within *Fusarium oxysporum* f.sp.*ciceris*, two pathotypes have been identified based on the distinct above-ground symptoms: one induces yellowing and the other induces wilting symptoms in chickpea (Trapero-Casas and Jimenez-Diaz, 1985). The yellowing pathotype induces progressive foliar yellowing accompanied by vascular discoloration and late death, while the wilting patho-type induces severe and fast chlorosis, flaccidity, vascular discoloration and early plant death (Singh and Vyas, 2021; Younesi *et al.*, 2021). Symptoms of chickpea *Fusarium* wilt can develop at any stage of plant growth, and affected plants often be grouped in patches or appear spread across a field (Jiménez-Díaz *et al.*, 2015). The wilt symptom can be observed within 25 days after sowing in susceptible cultivars termed as early wilt (Al-Taae and Al-Jobory, 2013; Jiménez-Díaz *et al.*, 2015). However, symptoms are usually more pronounced in the early stages of flowering, about 42 to 54 days after sowing and can also appear up to pod setting stage.

Initial yellowing symptoms are observed in the lower parts of the chickpea plants about 2 weeks after sowing and then gradually progressing top wards. About 40 days after sowing, these yellowing symptoms intensify, and all chickpea plants died at 60 days after planting as a result of being infected by highly virulent isolates (Younesi *et al.*, 2021). However, symptoms are usually more visible in the early stages of flowering, 42 to 54 days after sowing and can also appear up to the pod setting stage termed as late wilt (Jendoubi *et al.*, 2017). Late wilted plants exhibit drooping of the petioles, rachis and leaflets, followed by yellowing and necrosis of foliage (Jiménez-Díaz *et al.*, 2015). Early wilting causes greater loss than late wilting (Jendoubi *et al.*, 2017). Roots and stems of affected plants develop a dark-brown discoloration of xylem tissues visible upon vertical split or when cross-sectioned. Moreover, seeds harvested from late-wilted chickpea plants are often lighter, rougher and duller than those sourced from healthy plants (Navas-Cortes, Hau and Jimenez-Diaz, 2000).

2.6.2. Pathogen biology and host range

Fusarium oxysporum f. sp. *ciceris* is an ascomycete fungus that causes Fusarium wilt in chickpea. It is an asexually-reproducing root inhabiting fungus (Garret, 1956), which survive inactive in soil by means of chlamydospores free or embedded in plant tissues. The fungus can survive in soil and chickpea debris by means of chlamydospores for at least 6 years (Haware, Nene and Natarajan, 1996) and infection of symptomless dicotyledonous weeds can enhance survival of the pathogen. Thus, infested soil is a main source of primary inoculum for the development of Fusarium wilt epidemics in chickpea. Infected seeds are also a source of primary inoculum of the disease. *Fusarium oxysporum* f. sp. *ciceris* is internally seedborne and chlamydospore-like structures have been observed in the hilum region of the seed. Plants grown from infected seeds wilt faster than infected plants that originated from healthy seeds sown in infested soil (Haware, Nene and Rajeswari, 1978). Infected seeds play an important role in the long-distance dispersal of the pathogen and in its introduction into *Fusarium oxysporum* f. sp. *ciceris*-free soils and geographic areas (Pande, Rao and Sharma, 2007). Short-distance spread of the pathogen can also occur by dispersal of infested soil or chickpea debris through human activity, machinery, water, or wind.

Chlamydospores in soil are the primary inoculum for Fusarium wilt in chickpea, their germination being stimulated by seed and root exudates of hosts and non-hosts. *Fusarium oxysporum* f. sp. *ciceris* gains ingress in germinating seeds and growing seedlings directly without need of wounds soon after sowing in infested soil. Invasion takes place mainly through the cotyledons and zones of the epicotyl and hypocotyl at the junction of or close to cotyledons, and to a lesser extent in the zone of root elongation and maturation (Stevenson, Turner and Haware, 1997). Later studies in infested hydroponic cultures showed that races 0 and 5 of the pathogen colonize the surface of the tap and lateral roots in both susceptible and resistant cultivars, and preferentially penetrate the meristematic cells of the root apex (Jimenez-Fernandez *et al.*, 2013). Then, the fungus grows in the intercellular spaces of the root cortex to reach the central root cylinder and enter into the xylem vessels. Further colonization by the pathogen takes place by means of hyphal

growth and micro conidia carried in the vessels by transpiration stream, as well as by lateral mycelia spread to adjacent vessels from infected ones. The systemic colonization along the plant axis is then followed by development of symptoms once intense colonization of xylem vessels in root and lower stem has occurred by 10 to 20 days after inoculation (Jimenez-Fernandez *et al.*, 2013).

The fungus is pathogenic only to cicer species (Kaiser *et al.*, 1994) of which chickpea is the only cultivated species. However, *Fusarium oxysporum* f.sp. *ciceris* can also invade root tissues of other grain legumes, such as common bean (*Phaseolus vulgaris* L.), faba bean (*Vicia faba* L.), lentil (*Lens culinaris*), field pea (*Pisum sativum* L.), and pigeon pea (*Cajanus cajan*s) without causing external symptoms, thus serving as symptomless carriers of the pathogen. Other crops and dicotyledonous weeds can also serve as symptomless carriers (Trapero-Casas and Jimenez-Diaz, 1985).

2.6.3. Chickpea Fusarium wilt distribution and intensity

Chickpea Fusarium wilt is wide spread in nature and reported from at least 33 countries (Singh and Kumar, 2014; Dubey *et al.*, 2010). It was first reported in India by Butler in 1918 with unknown etiology until 1940 by Padwick (Jendoubi *et al.*, 2017). The status of chickpea diseases varies from country to country and is highly variable and dynamic due to biophysical variations. Chickpea Fusarium wilt in Ethiopia spreads to almost all chickpea-producing areas with increasing trends of its pressure. It is reported over 50 districts in major chickpea producing districts of Oromia, Amhara, Tigray and Southern Nation Nationalities and Peoples Region (SNNPR) in Ethiopia (Figure 2.2.). The disease occurred in all chickpea producing zones of Amhara (11-58%), Oromia (8-17%) and Tigray (5-31%) mean incidence rate (Sultan Mohamed *et al.*, 2018; Dagnachew Bekele *et al.*, 2021).

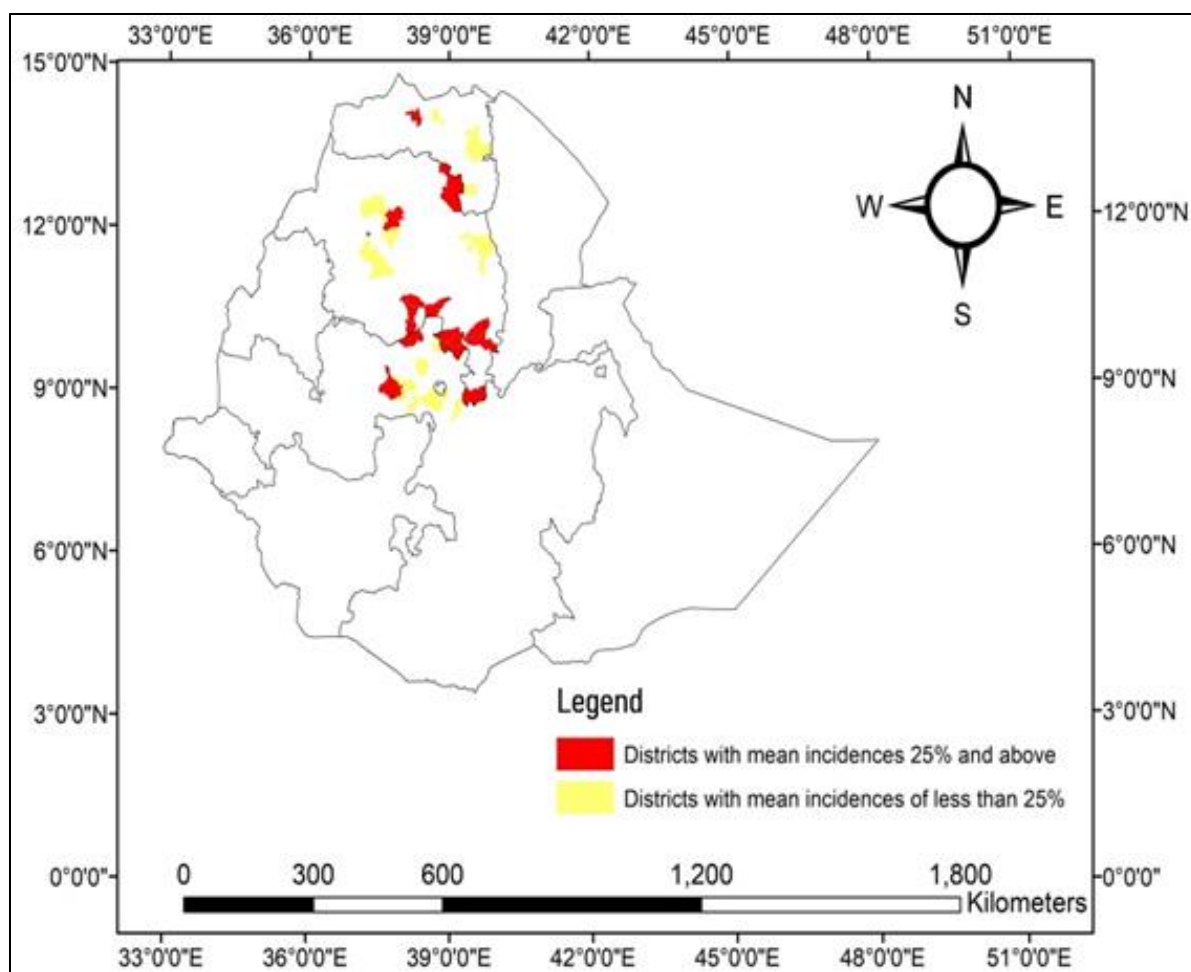


Figure 2.1. Distribution and intensity of chickpea Fusarium wilt across the major chickpea-producing districts of Ethiopia. Source: (Sultan Mohamed *et al.*, 2018; Bereket Ali and Habtamu Terefe , 2021; Dagnachew Bekele *et al.*, 2021; Edeo Negash, 2021)

In Amhara, where the disease is found to be severe, almost all chickpea-growing districts retained more than 40% mean wilt incidence (Figure 2.1.). The the disease was distributed over 36 districts of the country during the study 2011 to 2021 cropping seasons (Table 2.1.). Thus, the maximum (58%) wilt incidence occurred from Gonji Kolela in Amhara Regional State, while the lowest (5%) occurred in Endamehoni in Tigray, and Becho in Oromia region. The mean incidence rate of chickpea Fusarium wilt varied from 5% (Endamehoni) to 58% and in Gonj kolela and 51% Enemay districts, whereas the mean percent severity index was ranged between 3 to 42% (Sultan Mohamed *et al.*, 2018).

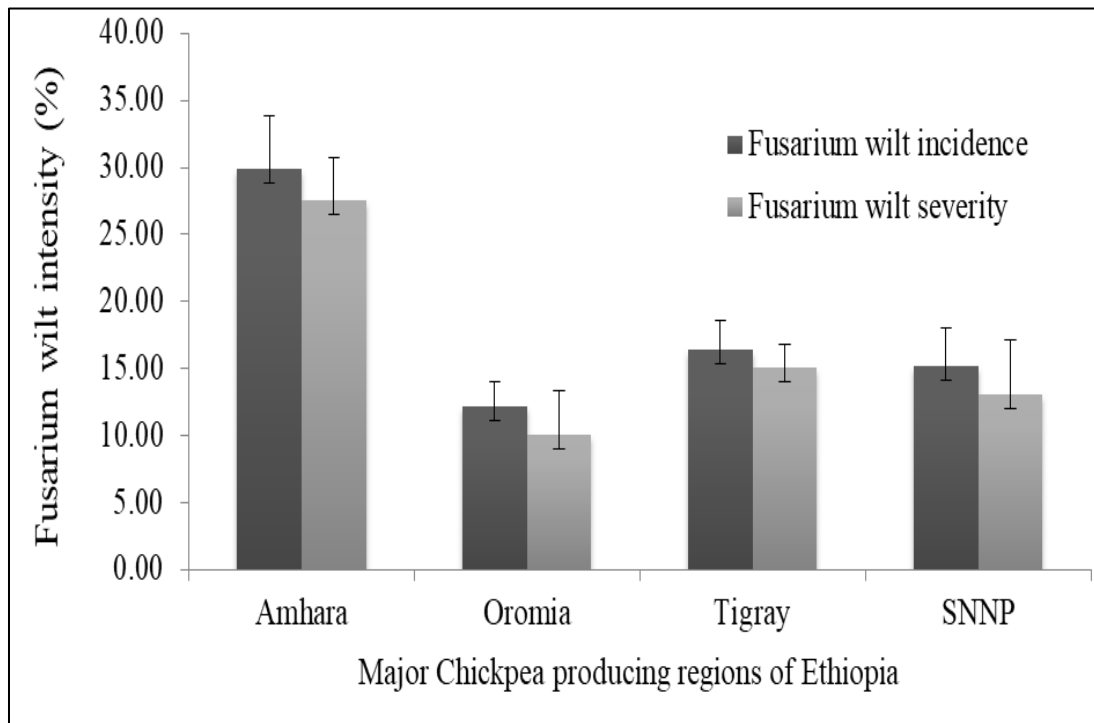


Figure 2.2. Intensity of Chickpea Fusarium wilt in major chickpea growing regional states of Ethiopia (Source: Sultan Mohammed, 2018; Bereket Ali and Habtamu Terefe, 2021)

Table 2.1. Economic importance, incidence and severity of chickpea Fusarium wilt in chickpea producing districts of Ethiopia

Districts	Regions	Incidence (%)	PSI (%)	References
Ensaro	Amhara	50.19	50.29	(Bereket Ali and Habtamu Terefe, 2021)
Menz Mama	Amhara	37.39	38.53	
Merhabete	Amhara	47.71	48.33	
Moretna Jiru	Amhara	43.06	43.06	
Mojana wedera	Amhara	34.27	34.27	
Gondar Zuria	Amhara	12.37-45.11	-	(Merkuz Abera <i>et al.</i> , 2011)
Dembia	Amhara	31.2-42.2	-	
Libo Kemkem	Amhara	30.99-39.99	-	
Fogera	Amhara	19.24-34.3	-	
Debrework	Amhara	32.6	-	(Tebkew Damte and Ojiewo, 2016)
Motta	Amhara	34.1	-	
Ambo	Oromia	40.0	-	(Daniel Assfaw and Tilahun Negash, 2020)
Dendi	Oromia	29.1	-	
Gonji Kolela	Amhara	58.0	42.0	(Sultan Mohamed <i>et al.</i> , 2018)
Enarji Enawga	Amhara	40.0	30.0	

Bahir Dar Zuria	Amhara	11.0	8.0	
Enemay	Amhara	51.0	38.0	
Yilmana Densa	Amhara	19.0	19.0	
Dejen	Amhara	25.0	26.0	
Wegde	Amhara	27.0	27.0	
Tehuledere	Amhara	10.0	10.0	
Lome	Oromia	14.0	11.0	
Ada'a	Oromia	16.0	12.0	
Illu	Oromia	13.0	11.0	
Gerar Jarso	Oromia	16.0	13.0	
Wara Jarso	Oromia	17.0	17.0	
Becho	Oromia	5.0	3.0	
Sebeta	Oromia	8.0	5.0	
Gumbichu	Oromia	55.81	-	
Bora	Oromia	44.32	-	
Adea	Oromia	36.46	-	(Edeo Negash, 2021)
Lume	Oromia	31.79	-	
Tahtay Koraro	Tigray	31.0	32.0	
Wukro	Tigray	21.0	18.0	
Maychew	Tigray	16.0	14.0	(Sultan Mohamed <i>et al.</i> , 2018)
Enderta	Tigray	9.0	6.0	
Endamehoni	Tigray	5.0	5.0	

Where PSI= percent severity index

2.6.4. Pathogenic diversity of chickpea *Fusarium* wilt

The fungus *Fusarium oxysporum* f. sp. *ciceris* exhibits pathogenic variability encompassing distinct races and pathotypes that differ in their ability to infect chickpea and the symptoms they cause. According to Shehabu Meki *et al.* (2008), all isolates of *Fusarium oxysporum* f.sp. *ciceris* collected from farmers' fields and wilt sick plots induced different level of disease severity and the reaction of the isolates varied in causing infection. The chickpea varieties Marye and DZ-10-11 were susceptible to isolate 2 and race 4 of *Fusarium oxysporum* f.sp.*ciceris* whereas the varieties Habru and Chefe were moderately susceptible to isolate 2 and resistant to race 0, 4 and 3 (Shehabu Meki *et al.*, 2008). Besides, according to Hossain *et al.* (2013), isolates of *Fusarium oxysporum* resulted in an infection potential that ranged from weekly virulent to highly virulent against their origin of chickpea seed samples in pot culture based on the pathogenicity

test. Bereket Ali and Habtamu Terefe (2021) also disclosed that samples collected from North Shewa Zone of 5 districts indicated that twenty-six *Fusarium oxysporum* f.sp. *ciceris* isolates were identified. All isolates were highly varied in their colony color colony texture, sporulation capacity, conidial shape and size, septation character, and chlamydospore types. Most of the isolates were highly pathogenic, causing $\geq 50\%$ wilting (Bereket Ali and Habtamu Terefe, 2021).

2.6.5. Chickpea Fusarium wilt management practices

2.6.5.1. Agronomic practices

Fusarium wilt of chickpea is a monocyclic disease in which its development is driven by the pathogen's primary inoculum. Therefore, management of the disease should be targeted to exclusion of the pathogen as well as by reducing the amount and/or efficiency of the initial inoculum. Management practices directed of the disease occurrence could be exclusion and eradication of the pathogen and to reduce its inoculum. Various cultural management practices are employed and resulted in partial control against chickpea wilt; including, manure application; adjusted sowing dates; intercropping; crop rotation and optimum spacing (Table 2.2.). According to Merkuz Abera *et al.* (2011), Fusarium wilt incidence was reduced with application of green manure and dried plant residue although complete disease suppression was not observed.

Chickpea intercropped with mustard is an efficient practice in reducing disease incidence and pathogen population in the soil with enhanced seed emergence, number of root nodules, number of pods per plant and yield (Jamil, Ashraf and Jamil, 2020). On the other hand chickpea sown with 40 cm inter-row spacing exhibited less percentage of wilt incidence (28 and 33%) than 20 cm inter-row spacing with a maximum wilt incidence percentage (38 and 41%) (Jamil, Ashraf and Jamil, 2020). It is also suggested that late planting and appropriate weed management are important agronomic practices to tackle chickpea Fusarium wilt and associated wilt root complex (Sultan Mohamed *et al.*, 2018; Bereket Ali and Habtamu Terefe, 2021; Dagnachew Bekele *et al.*, 2021).

Vermicompost treatment showed significant reduction in the incidence of Fusarium wilt and increased plant height, stem diameter, leaf area and ultimately increased yield (Zhang *et al.*, 2020). Further more, Kaur, Kumar and Singh (2023) reported application of vermicompost alone at the rate of 5t ha⁻¹ gave the maximum yield of 1679 kg ha⁻¹ and harvest index of 43.88% which resulted yield advantage of 27.4% over the control. According to Yadav and Garg (2015), the number of pods per plant is an important yield contributing parameter in chickpea and was significantly affected by the application of vermicompost which varied from 5.3 in control to 19.3 in vermicompost treated chickpea at a rate of 20%.

Table 2.2. Incidence of chickpea Fusarium wilt as influenced by agronomic practices and cropping systems

Variables	Variable classes	Incidences (%)	References
Planting time	Early	27.57±2.83	(Dagnachew Bekele <i>et al.</i> , 2021)
	Intermediate	23.43±2.46	
	Late	17.11±3.06	
Planting time	August 16	36.46 ^a	(Bereket Ali and Habtamu Terefe, 2023)
	August 23	25.67 ^{ab}	
	August 30	20.93 ^b	
Weed Management	Weeded	43.63±2.07	(Bereket Ali and Habtamu Terefe, 2021)
	Un weeded	46.35±2.63	
Weed Management	Good	47.53±16.77	(Edeo Negash, 2021)
	Poor	39.61±17.76	
Rotational crop	Common bean	53.17±17.85	(Edeo Negash, 2021)
	Lentil	49.62±21.74	
	Faba bean	46.12±21.53	
	Wheat	41.61±15.68	
	Maize	37.03±11.99	
	Tef	35.06±13.41	

2.6.5.2. Host plant resistance

The development of plant lines resistant to Fusarium wilt is the most effective approach for managing this disease: chickpea resistant varieties include Arerti and Chefe (Assfaw, Selvara and Gezahegn Getaneh, 2019). Wilt/root rot resistant varieties were evaluated at Debre Zeit for resistance to Fusarium wilt of chickpea on sick plot progressively and

continually (Subhani *et al.*, 2011; Yigerem Mengist *et al.*, 2018; Jamil, Ashraf and Jamil, 2020). Breeding of resistant lines and identification of DNA markers for resistance to Fusarium wilt has been successfully achieved in chickpea (Sharma, Chen and Muehlbauer, 2005).

It is important to note that in some cases, resistant plant varieties are only suitable for use against certain Fusarium wilt races (Jiménez-Gasco, Milgroom and Jiménez-Díaz, 2004). Awoke Ayana, Negash Hailu and Wendimneh Taye (2019) also reported that the chickpea variety Dhera gave the lowest wilt incidence as compared to other tested varieties in northwestern part of Ethiopia. Similarly, Mekonnen Gebeyaw *et al.* (2024b) reported that the varieties Dalota and Eshete were found to be moderately resistant to the occurrence of chickpea Fusarium wilt with mean incidence of 2.7 and 2.8%, respectively, over local chickpea, which expressed mean wilt incidence of 13.5% at Adet, North Gojam, Ethiopia. Furthermore, Zemenu Endalew, Gizachew Haylemariam and Ahmed Mohamed, (2022) depicted that the variety Mitik retained the minimum (6.23%) mean Fusarium wilt incidence, while the local variety expressed the maximum (43.6%) wilt incidence at Lasta Lalibela district of eastern Amhara.

2.6.5.3. Biological management

Due to the soil-borne nature of chickpea Fusarium wilt, application of fungicides for effective management of the disease is rarely successful (Abed *et al.*, 2016). Inconsistencies in biological control under varying environmental conditions have been a common limitation of soil borne pathogens (Abed *et al.*, 2016). The great interest in eco-friendly and sustainable agriculture, push towards gradually shifting to biological control instead of dependence on agrochemical (Abdalla *et al.*, 2022). The existence of many microorganisms which can be serving as an effective means of plant diseases management is found to be an important opportunity. Seed treatment with *P. fluorescens* at the rate of 6g kg⁻¹ was effective in suppressing *Fusarium oxysporum* with disease incidence value of 46.05 whereas the disease incidence for the control was 74.62% (Kala, Gangopadhyay and Godara, 2020). Besides, Bekkar, Zaim and Belabid (2018) reported that chickpea seeds

treated with *Trichoderma harzianum* resulted in the lowest diseases incidence (6.33%) over the control (98.33%).

Moreover, chickpea seeds inoculated with *Bacillus subtilis* showed the minimum (1.73%) disease severity than the control with mean disease severity of 3.8% scored based on 0-4 diseases severity scale (Bekkar, Zaim and Belabid, 2018). However, this method has been given no or little attention in managing chickpea wilt in Ethiopia. Five tested biological control agents, *Pseudomonas fluorescens*, *Trichoderma asperellum*, *Pseudomonas chlororaphis*, *Bacillus subtilis* and *Trichoderma harzianum* were significantly reduced the wilt incidence, among them the strain CPs3 (*Pseudomonas chlororaphis*) significantly reduced the wilt incidence compared than other bio-control agents. The treatment of CPs3 (*Pseudomonas chlororaphis*) was more effective than other bio-control agents with incidence of 14.3% followed by Pf1 (*Pseudomonas fluorescens*) with recorded 35.3% however, the incidence recorded from the control /untreated was 74.3% (Sankar *et al.*, 2019).

2.6.5.4. Fungicides and non-conventional pesticides

The application of fungicides, like Thiram and Apron star offers a good protection against wilt (Yigerem Mengist *et al.* 2018; Zemenu Endalew, Gizachew Haylemariam and Ahmed Mohamed, 2022). The minimum (6%) disease incidence was recorded from treatment with the application of 70% Thiophanate-methyl as compared to untreated plot with 80% disease incidence (Maitlo *et al.*, 2014). Moreover, Yadav, Yadav and Singh (2018) reported that out of ten fungicides, namely, Bavistin, Benlate, Chlorothalonil, Companion, Indofil M-45, Thiram, Topsin-M, Vitavax Power, Tilt and Copper oxychloride tested in the laboratory, the five fungicides: Bavistin, Benlate, Chlorothalonil, Companion, and Thiram absolutely (100%) inhibited the fungus growth. Other fungicides like, Topsin-M , Vitavax power and Indofil M-45 were also found effective to check the growth of fungus with inhibition rate of 81.0%, 60.3%, and 46.9%, respectively (Yadav, Yadav and Singh, 2018).

Moreover, Yigerem Mengist *et al.* (2018) reported that the chickpea variety Shasho treated with fungicide Apron star resulted in significant reduction in chickpea Fusarium

wilt incidence. Similarly, Zemenu Endalew, Gizachew Haylemariam and Ahmed Mohamed (2022) also demonstrated that chickpea seeds treated with Thiram and Apron star resulted in lower wilt incidence level at Sekota Zuria district and Lalibela district in eastern Amhara, Ethiopia. Furthermore, Bhimani (2020) reported that Carbendazim 50% WP showed the least (23.3%) disease incidence and 76.7% yield increase over the control which retained incidence of 100%. With respect to non-conventional chemicals; wilt incidence percentage was reduced in pots sown with seed treated with Zinc chloride, Calcium carbonate, Manganese sulphate and Boric acid with wilt incidence of 14.8%, 14.8% and 18.0%, respectively, whereas the untreated wilt incidence was 45.0% under glasshouse conditions (Zope, Rakhonde and Awadhiya, 2018).

2.6.5.5. Integrated disease management

Promising results that combine effective microorganisms, Apron star, stubble-free and resistant varieties have become suppressive to Fusarium wilt and integration of effective microorganisms, neem seed extracts and resistant varieties had also shown significant effects on yield and yield components. According to Asrat Zewdie and Tolesa Bedasa (2020), the chickpea variety Arerti treated with protective fungicide and sown on raised seed-bed resulted in 41.2% yield advantage over the untreated Arerti variety planted on flat seed-bed. Moreover, Kl and Huilgol (2021) disclosed that chickpea seed treated with Carbendazim 12% + *Curcuma longa* (turmeric) rhizome extract @150 mL kg⁻¹ of seeds gave minimum (1.5%) wilt incidence and a maximum (1037 kg ha⁻¹) yield, whereas wilt incidence of 12.7% and yield of 602 kg ha⁻¹ was recorded from the untreated control.

Chickpea seed treated with Mancozeb 63% @ 2 g kg⁻¹ of seeds combined with carbendazim 12% resulted in a yield advantage of 34.4% as compared to the control (Kl and Huilgol, 2021). Merkuz Abera and Getachew Alemayehu (2012) reported that raised bed preparation, tolerant variety and optimum time of planting managed the wilt incidence and reduced plant mortality due to wilt. Application of Trichoderma species integrated with moderately susceptible or resistant cultivars is a more effective measure in curtailing chickpea Fusarium wilt by 30–46% (Meki *et al.*, 2011). According to Sahni (2021), the combined treatment with 15% vermicompost, seed bacterization, and pre-inoculation with salicylic acid foliar spray resulted in complete suppression against

Fusarium oxysporum f.sp. *ciceris*. Planting time and varieties significantly impacted the intensity of chickpea Fusarium wilt. Thus, the chickpea variety Mastewal sown late in the season recorded the minimum (10.2%) wilt incidence, however the early planted Arerti variety expressed a maximum (50.6%) mean wilt incidence at Alem Ketema, suggesting the significant contribution of combining sowing date and varieties for Fusarium wilt management in chickpea (Bereket Ali and Habtamu Terefe, 2023).

To this effect, a comprehensive study that integrates these different management strategies and validates their synergistic effects under the specific conditions of Western Amhara is currently lacking. Generally, the integration of two or more compatible management practices can sustainably overcome the disease problem despite less works have been done previously. Therefore, evaluation of interaction effect, compatibility study and mechanism of interaction under field condition would be beneficial.

CHAPTER 3: General Materials and Method

3.1. Description of the Study Areas

The study was carried out in six districts, namely, Bahir Dar Zuria, Enarj Enawga, Enemay, Fogera, Libo Kemkem and Yilmana Densa situated within the North Gojam, East Gojam and South Gondar Administrative Zones of the Amhara region, Ethiopia. Agriculture is the primary economic activity in the study areas, with nearly the entire population depending on this sector (CSA, 2021). The smallholder farmers are most commonly involved in mixed farming systems, integrating crop production with animal husbandry practices. Vertisol kinds of soil; mixed farming systems and uni-modal rainfall patterns are common features of the surveyed districts. The major crops grown in all the six study districts included maize (*Zea mays* L.), tef [*Eragrostis tef* (Zucc.) Trotter], wheat (*Triticum aestivum* L.), and chickpea (*Cicer arietinum* L.). However, rice (*Oryza sativa* L.) is exceptionally cultivated as a major crop in Fogera and Libo Kemkem districts (CSA, 2021). The geographical location of the study districts is presented (Figure 3.1.). The mean temperature falls between 25 and 30 °C, and received annual rainfall ranging from 1500 to 2200 mm (Figure 3.2.; NASA Power, 2023).

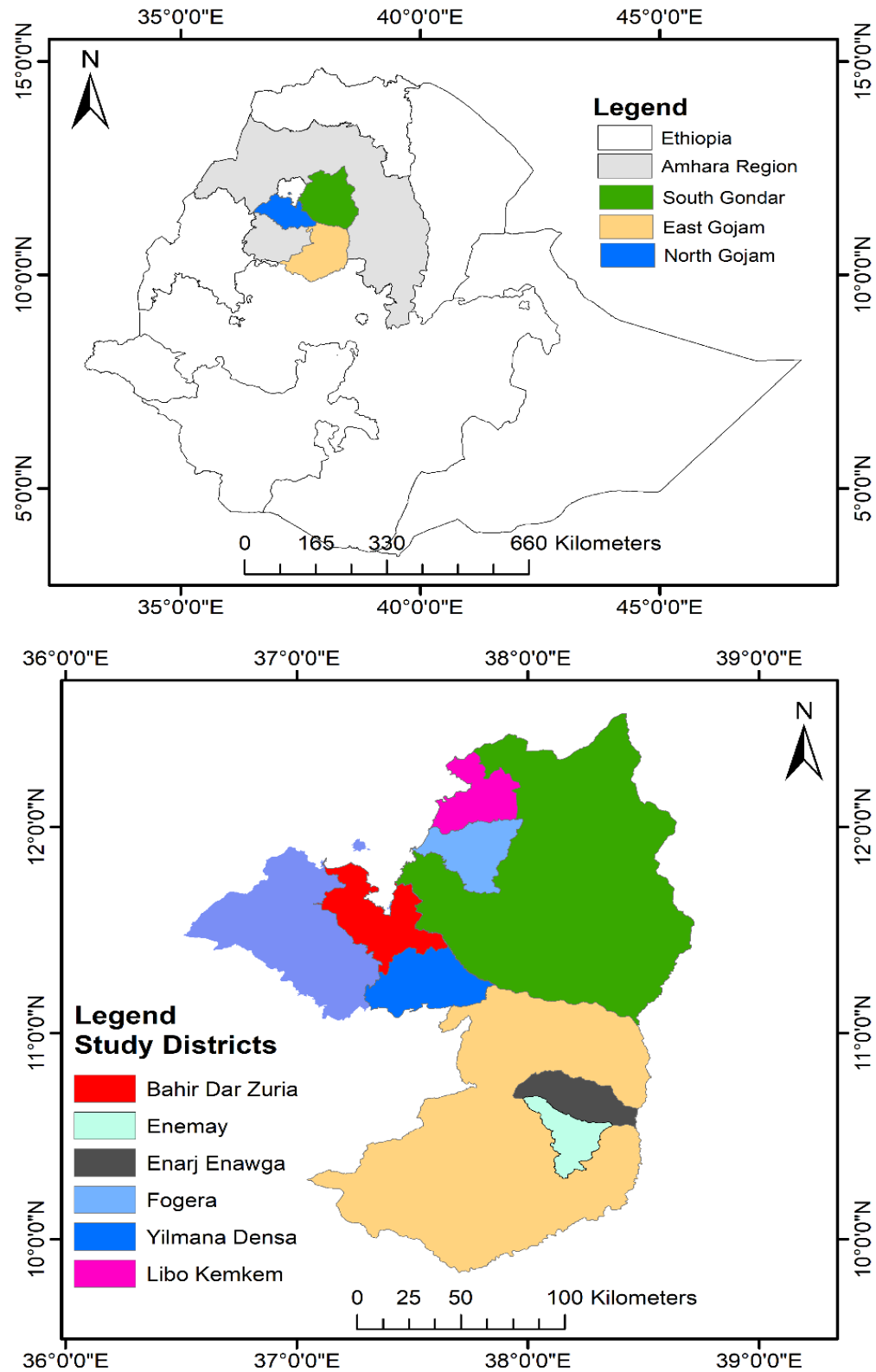
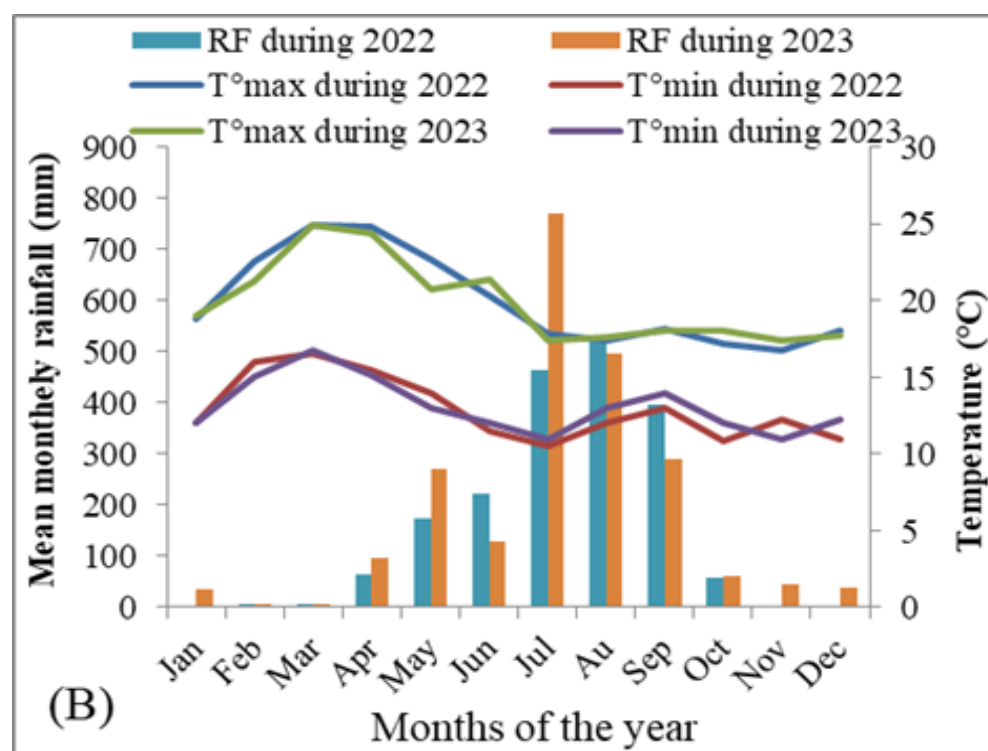
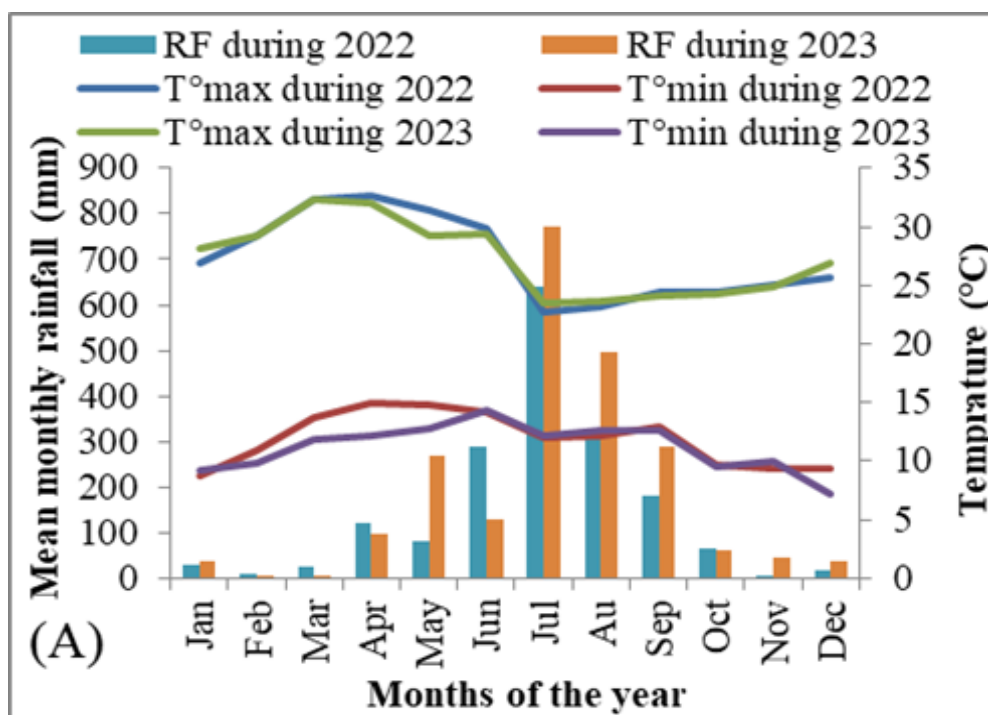
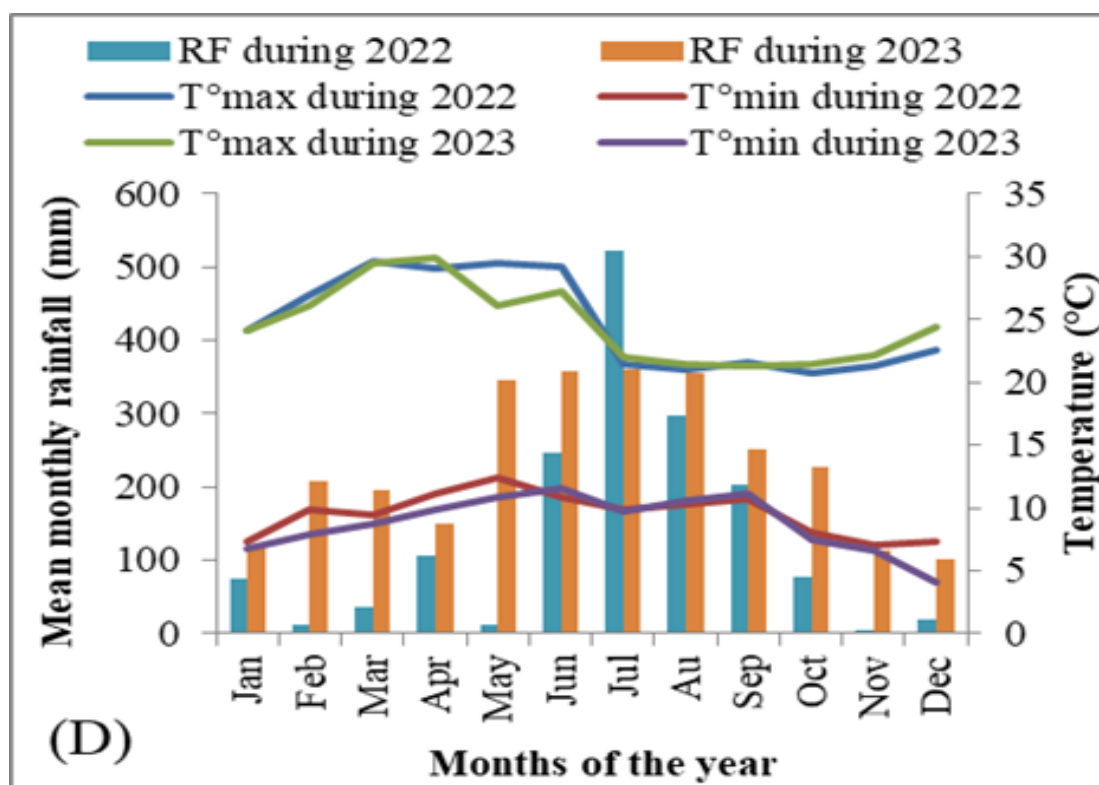
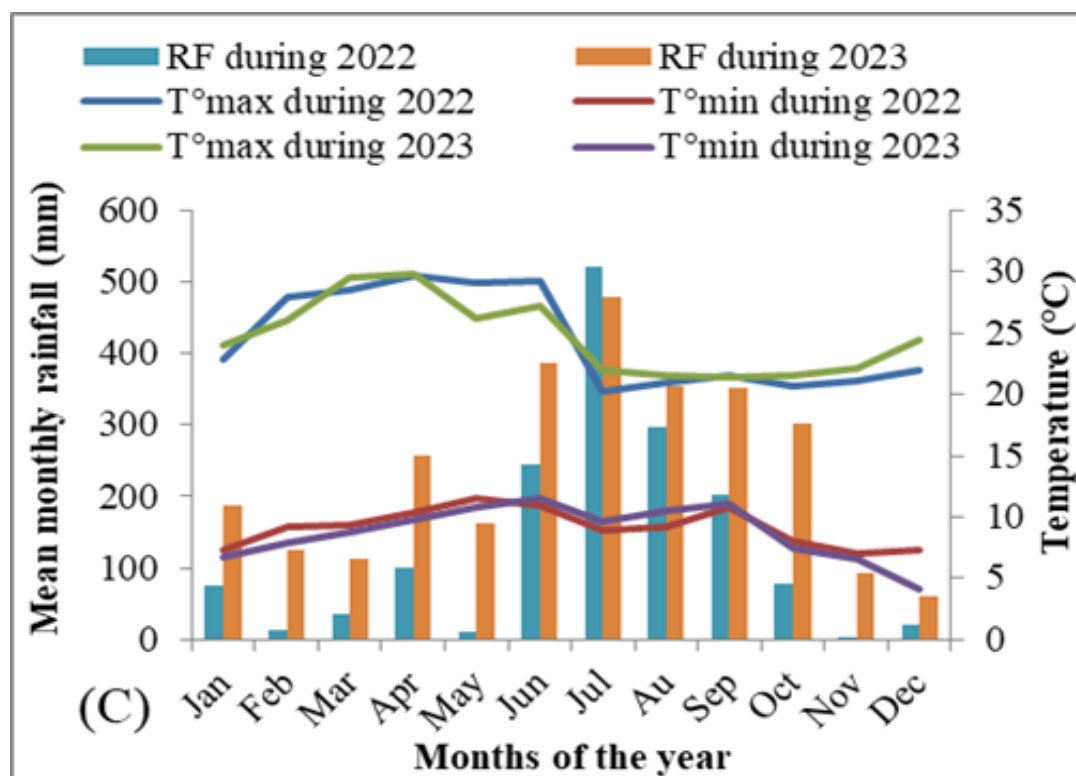


Figure 3.1. Map of Ethiopia showing the study areas for chickpea *Fusarium* wilt study during 2022-2024 growing seasons.





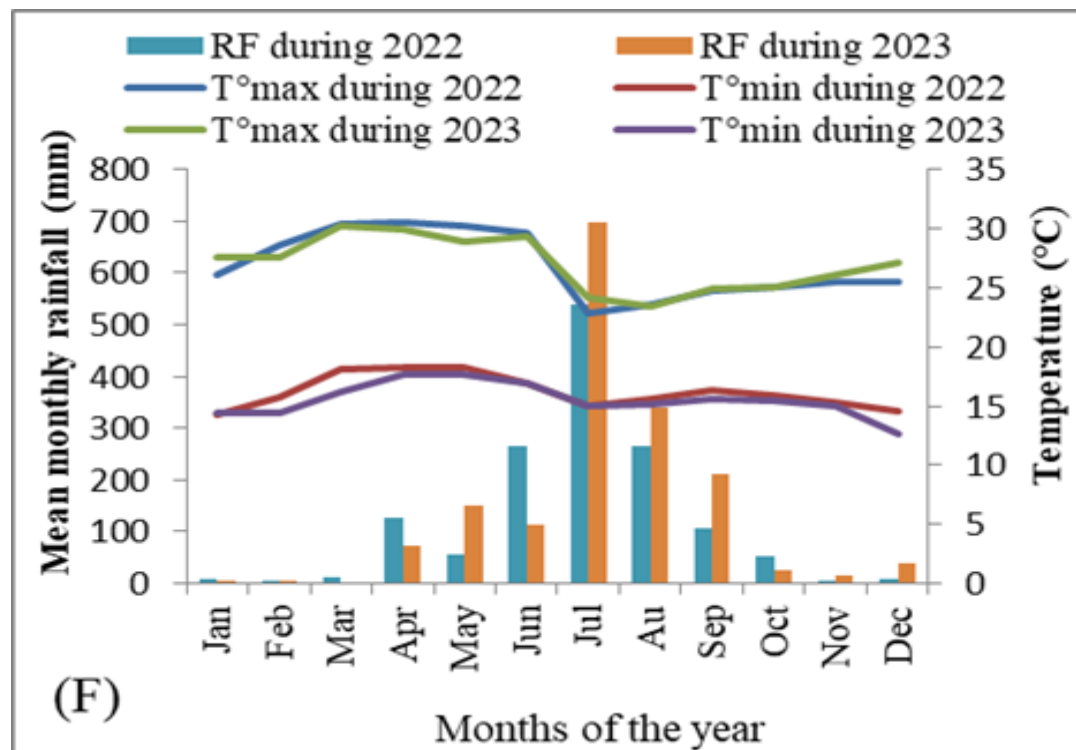
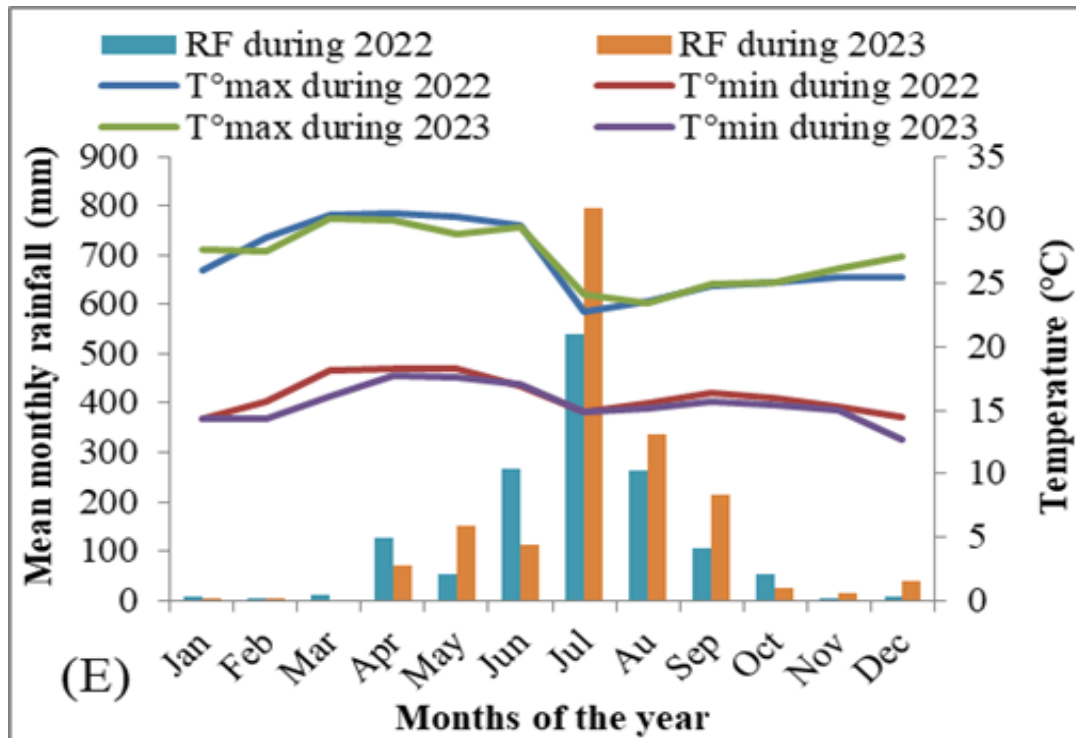


Figure 3.2. Mean monthly rain fall and temperature of each study districts: Bahir Dar Zuria (A), Yilmana Densa (B), Enarji Enawga (C), Enemay (D) Fogera (E) and Libo Kemkem (F). Source: NASA Power, 2022; 2023).

3.2. Sampling Procedure and Experimental Design

The socio economic and epidemiological survey employed a multi-stage sampling design. In the first stage, six districts were purposefully selected from three major chickpea-growing Zones based on production and risk situation (East Gojam; North Gojam and South Gondar) of Amhara National Regional State. For assessing farmers' knowledge and their practices of CFW management, two selected zones (North and East Gojam) and 12 representative kebeles, three from each district were identified based on the evidence from district level agricultural offices. The final stage involved selecting individual farmers using Systematic Random Sampling: which was limited to those who had cultivated chickpea within the previous three to five years, and every n^{th} eligible farmer was systematically chosen from the available lists and interviewed (Canifo, Mexia and Santos, 2021).

For epidemiological survey, fields of farmers who planted chickpea were assessed for two consecutive cropping seasons (2022-2024) in the selected six districts of West Amhara, Ethiopia. Random sampling design methods were employed for the survey; as chickpea fields were patchy and randomly distributed; fields at about 5 km drive having the crop was visited. In each chickpea sown field, a quadrat of 1 m² with frequency of 4 quadrat per field was placed randomly following a W-pattern. During the field survey, chickpea plants with wilting or yellowing symptoms were uprooted cautiously using hand hoes. The collected samples were kept in polythene bags independently and kept inside icebox of about 4 °C and brought to Bahir Dar University Biotechnology Laboratory for isolation and identification. The root samples were labeled with necessary information (location, sample code, date of collection).

Virulence and pathogenic potential of FOC isolates associated with seeds of chickpea were evaluated based on seed samples that were sourced from naturally-Fusarium infested fields in Amhara Regional States in North Gojam Zone (Yilmana Densa and Bahir Dar Zuria districts) and East Gojam Zone (Enarj Enawga and Enemay districts). Seeds were collected from wilted plants of the chickpea cultivars that were already infected by the Fusarium wilt disease (Pande, Rao and Sharma, 2007) during 2023

cropping season. Collection was made based on distinct wilting and yellow symptoms, typical symptoms for chickpea Fusarium wilt symptoms. A corresponding healthy seed samples were collected from fields from mother plants without symptoms. Apart from this, chickpea seed samples were collected without considering wilt symptoms and healthiness of the mother plant to represent farmers practice as they don't harvest the diseased and the healthy separately. These seeds were air dried at room temperature and stored at 5 °C in the refrigerator at the Biotechnology Laboratory, Bahir Dar University and kept 25±2 °C. The treatments were consisted of three chickpea varieties (Dhera, Natoli and Arerti) combined with two seed-dressing fungicides (Goldazim 500 SC, Nobel 250 EC and untreated control) and vermicompost application (treated and untreated control). Synonyms for Goldazim 500 SC include Carbendazim 500 g/L and Golder Super 500 SC, while the synonyms for Nobel 250 SC include Chlorothalonil 500 SC and Daconil 2787 SC, and Bravo 500 SC (Suspension Concentrate/Flowable). The interrow and intra-row spacings were 30 and 15cm, respectively. Each treatment was assigned randomly to experimental units within a block. The field experiment, which focused on integrated management of CFW, consisted of 18 treatment combinations that were randomly arranged in factorial randomized complete block design (RCBD) with three replications.

3.3. Data Collection

The number of wilted plants (plants showing typical Fusarium wilt and yellowing symptoms), weeds and healthy plants were separately counted in the quadrat and recorded (Tebkew Damte and Ojiewo, 2016; Sultan Mohammed *et al.*, 2018; Daniel Assfaw and Tilahun Negash, 2020). The severity of Fusarium wilt disease was noted in a 1m² quadrat using a five-point severity scale ranged from 0 (no wilting/no yellowing) to 4 (plant death) based on the percentage of plant portion exhibiting wilting or yellowing symptoms (Wheeler, 1969); where 0 = 0% wilted plant; 1=1–20% wilted plant; 2=21–50% wilted plant; 3=51–100% wilted plant and 4 = plants collapsed or dead.

3.4. Data Analysis

The statistical analysis softwares employed to analyse this research were STATA (version 17.0) and SAS (Version 9.4). The statistical tools were selected based on the specific nature of the research questions across socioeconomic, epidemiological, and experimental components. STATA (version 17.0) was specifically meant for analyzing the socio-economic survey data, the epidemiological biophysical factors, and the pathogen virulence/seed-health metrics, while SAS (version 9.4) was exclusively employed for the multi-location field experiments using analysis of variance (ANOVA).

STATA was used to analyze the household-level data and farmers' knowledge and their practices of CFW management. Using descriptive statistics, including frequencies, percentages, and mean rankings, the study quantified farmers' knowledge of CFW disease including the management practices. This social data was then connected to the biological reality through a logistic regression model in STATA, which was used to analyze the epidemiological survey results. By classifying disease incidence and the Percent Severity Index (PSI) as binomial qualitative data as dependent variable classes, the model identified important biophysical risk factors using the Likelihood Ratio Test (LRT) to evaluate the reduction in deviance and determine the significance of each predictor through Odds Ratios.

Data on disease, yield and yield components collected from field experiments were subjected to SAS (version 9.4) software. A factorial Analysis of Variance (ANOVA) was performed using the PROC GLM procedure to evaluate the main effects and the three-way interactions between chickpea varieties, seed-dressing fungicides, and vermicompost. Upon finding significant F-values, mean comparisons were conducted using the Least Significant Difference (LSD) test at a 5% probability level.

CHAPTER 4: Farmers' Knowledge and Management Practices of Chickpea Fusarium Wilt (*Fusarium oxysporum* f.sp. *ciceris*) in West Amhara, Ethiopia

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Abstract

Despite chickpea is one of the most important legumes crops to which low-cost protein is sourced. It is vulnerable to plenty of fungal pathogens, of which chickpea Fusarium wilt is regarded as the most destructive disease of economic importance, causing 80-100% yield loss. The study was therefore carried out during 2022/23 cropping season to evaluate farmers' knowledge, and their chickpea Fusarium wilt management. Semi-structured questionnaires were employed and a survey was conducted to randomly selected farmers to assess their knowledge and practices on chickpea production and Fusarium wilt management. Findings from 246 farmers stated that CFW was a dominant production hurdle by 73.9% of smallholders. Overall, 56.1% of the farmers in the surveyed areas explained that soil was the main cause, followed by moisture as the most mentioned cause (28.5%), with farmers in Enemay (41.9%) and Enarj Enawga (34.4%). In conclusion, farmers affirmed that the management practices used by producers, like, long crop rotation, delayed planting, and suitable land selection were found to be principal practices as suggested by 71.3, 59.0, and 33.6% of chickpea producers, respectively. Also, about 86.1% of the growers pointed out that crop rotation and delayed planting alone or in combination can result in lower disease pressure and higher yields than without crop rotation and early planting.

Keywords: Assess, cropping system, crop rotation, farming experience, fungi, moisture

4.1. Introduction

Globally, chickpea is the second most important cool season food legume crop in terms of production, next to common bean (*Phaseolus vulgaris* L.), cultivated on about 15 million hectares, with production exceeding 18.1 million tons during 2022-2023 cropping seasons (Charitha, Paslawar and Darekar, 2025). Chickpea plays an important role in the diet of human being; its seeds are rich in fiber, vitamins, carbohydrates, mineral salts, unsaturated fatty acids and β -carotene (Gaur *et al.*, 2014; Osman, 2019). It is considered as one of the most important food legume, providing a major source of low-cost protein for masses of low-income groups (Nasr Esfahani *et al.*, 2014; Shevkani *et al.*, 2019). It plays a key role in the food security of developing countries and is an important component of subsistence agriculture (Gaur *et al.*, 2014). Apart from being an important source of dietary protein for human consumption, it is also important for management of the soil fertility due to its nitrogen-fixing ability (Nasr Esfahani *et al.*, 2014; Koul *et al.*, 2022).

In spite of its considerable economic contribution to Ethiopia, its productivity is relatively as low as 2.14 tons per hectare (FAOSTAT, 2024) compared to its potential yield of 5 tons per hectare under properly managed production system (Gemechu Keneni *et al.*, 2012). Chickpea Fusarium wilt caused by *Fusarium oxysporum* f.sp. *ciceris* is one of the most widely distributed and causing severe yield losses in many chickpea growing countries worldwide (Dubey, Singh and Singh, 2010). As a result, developing sustainable management is critical which essentially relies on integrated management. However, setting integrated management program is not an overnight task and troubled by many factors which could be an integral part of it.

One of the major constraints up on establishing effective and sustainable integrated management package is lack of adequate information about farmer's knowledge, perception and practices in pest management (Heong *et al.*, 2002; Parsa *et al.*, 2014). Lack of involvement by small holder farmers is believed to be a major cause of sub-optimal research impact in Africa, where problems are diverse and farmer participation might help research to become better focused. Farmers are excluded because of a linear

approach in which research is seen as a source of technology, extension as the delivery mechanism, followed by a straight forward adoption by farmers (Kiros-Meles and Abang, 2008). Convergence of sciences is increasingly recognized as a viable alternative for organizing and implementing research, whereby the agricultural innovation process is recognized as a multi stakeholder process (Kudadjie, 2006). To ensure that integrated disease management packages developed to address the problem of crop diseases are sustainable, and to guarantee the acceptance and adoption of disease control recommendations, these packages must be developed in close collaboration with farmers.

Considering farmers' knowledge and practices of disease management options is fundamental to establish research priorities, for planning campaign strategies and developing messages for communication (Midega *et al.*, 2016; Okolle *et al.*, 2016). Moreover, exploring farmers' perception, knowledge, and management of crop diseases is an important element in furthering such collaboration and is crucial for harnessing farmers' knowledge in the participatory development of integrated disease management tactics (Kiros Meles and Abang, 2008). Farmers' perception based on local experience and their indigenous knowledge, which offer valuable insight into not presently well documented in scientific literature, is important in pest management endeavors (Daniel Getahun and Emanu Getu, 2015).

Recognizing farmers' constraints and their creative potential and technical knowledge is crucial to improve crop production and crop protection (Okolle *et al.*, 2016; Rijal *et al.*, 2018) and understanding on how research could be conducted to address the needs and constraints of farmers (Gudeta Eldesemayat *et al.*, 2008; Ayuke, 2010). However, farmers' knowledge and practices of diseases management with emphasis in chickpea wilt has not been well understood and, updated information on knowledge and perception of disease management in chick pea is lacking under Ethiopian condition with no exception in West Amhara region. Moreover, updated and current information is crucial to map future disease management directions for resource poor chickpea farmers in northwestern Ethiopia. Therefore, the current research was initiated to explore farmers'

knowledge, and their practices of chickpea Fusarium wilt management in East and North Gojam Zones, west Amhara.

4.1. Materials and Methods

4.1.1. Description of the study areas

The survey was conducted in Amhara National Regional States covering four districts across two administrative zones: East Gojam (Enarj Enawga and Enemay) and North Gojam (Bahir Dar Zuria and Yilmana Densa) (Figure 4.1.). Mixed farming systems, predominantly cereal-based crop cultivation along with livestock rearing, are the common features of the smallholder farmers in all study districts. Although modern agricultural technologies and external input remain largely inaccessible, farmers in the region practice better agricultural resourcefulness. They proactively manage resources and produce crops through highly effective traditional practices, such as crop rotations, intercropping, double cropping, and irrigation (Genanaw Agitew, Zewdu Berhanie and Samson Gebremedhin, 2024).

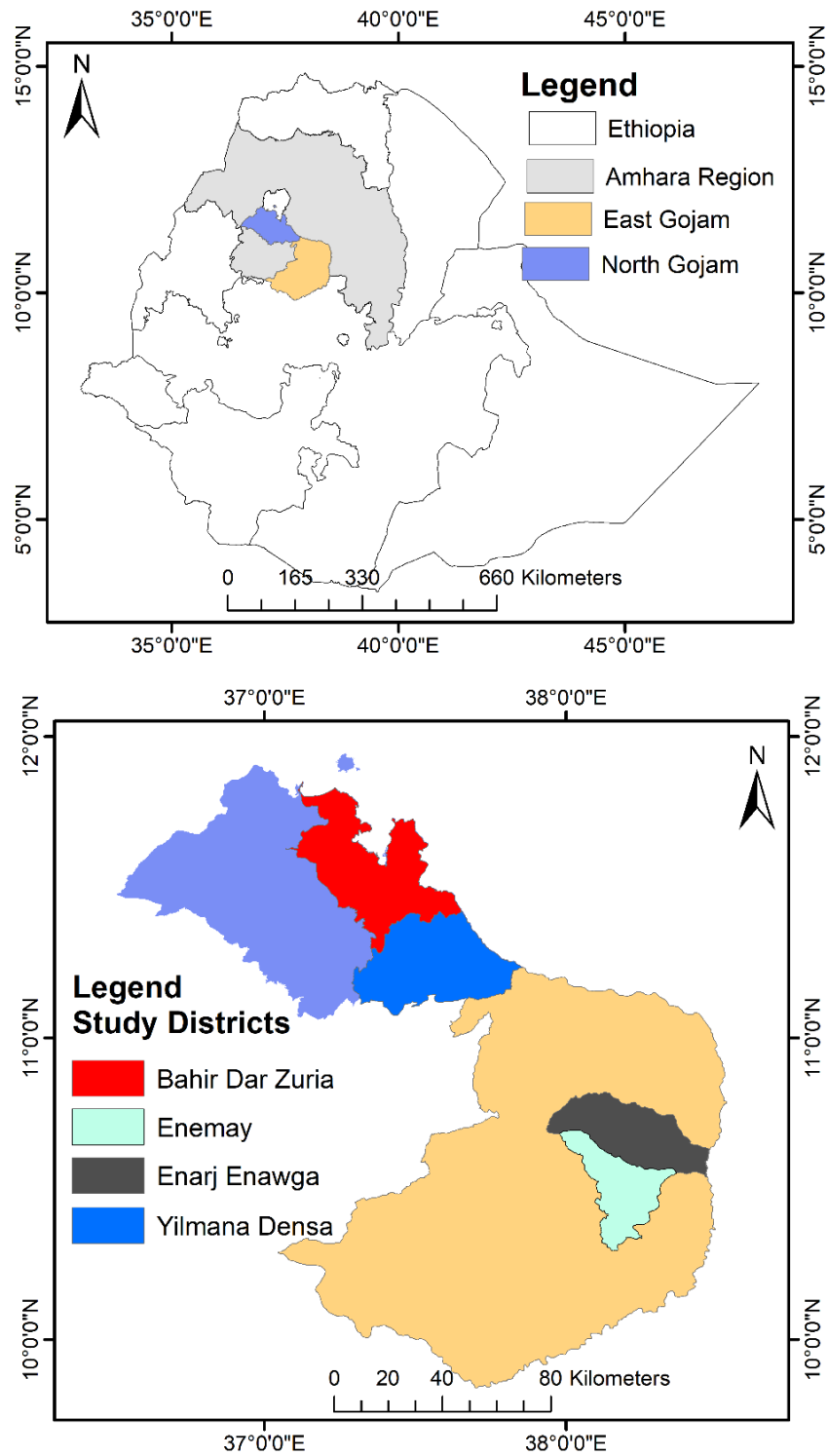


Figure 4.1. Map of Ethiopia showing geographical location of the four study districts.

4.1.2. Sampling procedures and sample size determination

The study involved in a multi-stage sampling design. In the first stage, aforementioned four districts were purposefully selected from two major chickpea growing Zones based on production and risk situation (East Gojam and North Gojam) of Amhara National Regional State. Due to variations in physical conditions like agro-ecologies; agricultural production and cropping systems; the districts were selected purposefully for the study expecting variations in farmers' practices of chickpea Fusarium wilt management and all over crop husbandry practices. Subsequently, 12 representative kebeles (three from each district) were identified based on the evidence from district level agricultural offices. The final stage involved selecting individual farmers using Systematic Random Sampling: the sampling frame was limited to those who had cultivated chickpea within the previous three to five years, and every n^{th} eligible farmer was systematically chosen from the available lists and interviewed (Caniço, Mexia and Santos, 2021).

The sample size (n = number of farmers to be interviewed) was determined using the formula suggested by (Uakarn Chanuan, Chaokromthong Kajohnsak and Sintao Nittaya, 2021) $n = \frac{Z^2 P(1-P)}{Q^2}$

Where, n = required sample size, Z = confidence level at 95% (standard value of 1.96), p = estimated proportion of an attribute, estimated at 80% based on available number of farmers who are experiencing chickpea production in the area for the past three to five years and the Q = margin of error at 5% (standard value of 0.05). Therefore, the number of farmers interviewed was determined as:

$$n = \frac{Z^2 P(1-P)}{Q^2} = (1.96)^2 (0.8) (1-0.8)/(0.05)^2 \approx 246$$

Therefore, 246 participants were chosen in the area.

4.1.3. Data collection

Semi-structured questionnaires were employed to carry out a survey in the designated study districts to assess farmers' knowledge and their practices of chickpea Fusarium wilt disease management (Appendix Table 16). The questionnaires contained majorly focused on knowledge of farmers about diseases, disease management, cropping systems, cultural diseases management options and related thoughts. The semi-structured interview was administered in the local language (Amharic) spoken by the producers. The Agricultural Development Agents, possessing a college diploma or degree in agriculture, received a concise overview of the study objectives and the procedures for data collection, along with instructions on how to engage with the farmers. Farmers were also informed to take part in the study voluntarily. Before the main survey, the questionnaires were pre-tested with 15 farmers in the study areas to refine the interview techniques, which resulted in the conceptualization of some questions.

Farmers were asked two kinds of questions: closed yes/no questions and open-ended questions, which allowed them to express their views freely. Throughout these interviews, farmers conveyed their viewpoints on production difficulties, their views on chickpea Fusarium wilt disease, and their management alternatives. To evaluate their knowledge of the diseases, the participants were shown a series of colored images showing chickpea plants clearly infected by chickpea Fusarium wilt, along with various other disease symptoms assisted by a field visit nearby farms (Schreinemachers *et al.*, 2015). The collected data included the socioeconomic characteristics of chickpea producers, such as age, gender, marital status and educational background, farm holding size trends in chickpea production and the perceptions and knowledge of farmers regarding the cause, spread mechanism, and the management practices used by the farmers to overcome the disease. An extensive survey on the disease was conducted by researchers in the selected districts to triangulate the relationship between farmers' knowledge of chickpea Fusarium wilt disease and its occurrence and severity in those areas.

4.1.3. Data analysis

Before analysis, the raw household survey data were subjected to a process of organization, sorting, and coding within Microsoft Excel. The processed and arranged dataset was then exported to STATA (version 17.0) for statistical evaluation. Data interpretation was carried out through a combination of descriptive statistics, frequency distributions, and cross-tabulations to ensure an accurate representation of the findings. To evaluate the relationships between variables, Pearson chi-square tests ($p \leq 0.05$) were performed using frequency table with measure of associations. This enabled empirical analysis and description of parameter associations across the categorical variables (Uwamahoro *et al.*, 2018).

4.2. Results and Discussion

4.2.1. Overview of demographic characteristics of participants

The analysis of smallholder characteristics in west Amhara revealed a complex interplay between demographic structure, land holding sizes, and severe constraints on the effective management of chickpea Fusarium wilt (Table 4.1.). The participants' socio-demographic characteristics were predominantly constituting male (95.2%), with only remaining 4.76% being female. These high levels of gender disparity mirror regional trends reported in other findings, which revealed that 96.7% male participation in agricultural production (Tewedros Mulugeta *et al.*, 2024), indicating that the low inclusion of women was likely due to the small number of actual farming population. Women in agricultural activities were mostly serving as assistant workers. Respondent age was broad, ranging from 18 to 75 years. Notably, educational background varied very highly significantly among participants ($\chi^2 = 52.16$; $P = 0.001$) (Table 4.1.).

Table 4.1. Summary of socio-economic characteristics of the interviewed farmers in the two surveyed zones (East Gojam and North Gojam) of West Amhara, Ethiopia.

Variable claseses	Surveyed districts				Total (246)	X^2	P value
	Bahir Dar Zuria (n=61)	Yilmana Densa (n=62)	Enarj Enawga (n=61)	Enemay (n=62)			
Age category of farmers						56.4	0.025

≤ 30	12 (19.7)	7 (11.3)	10 (16.3)	5 (8.1)	34 (13.8)		
31-48	22 (34.4)	33 (53.2)	28 (45.9)	41(66.1)	133 (54.1)		
> 49	28 (45.9)	22 (35.5)	23 (37.7)	16 (25.8)	100 (40.7)		
Sex of farmers'						7.6	0.27
Male	59 (96.7)	56 (90.3)	61 (100)	60 (96.8)	236 (95.9)		
Female	2 (3.3)	6 (9.7)	-	2 (3.2)	10 (4.1)		
Farming experience						31.75	0.02
≤ 10 years	1 (1.6)	8 (12.9)	6 (9.8)	4 (6.5)	19 (7.7)		
11-20 years	9 (14.8)	13 (22.6)	19 (31.1)	13 (21.9)	41 (21.9)		
21-30 years	14 (23)	21 (33.9)	25 (41)	26 (41.9)	86 (34.9)		
≥ 31 years	37 (60.7)	20 (32.3)	11 (18.1)	19 (30.6)	88 (35.8)		
Marital status						20.3	0.38
Married	54 (88.5)	53 (85.3)	57 (93.4)	52 (83.9)	216(87.8)		
Unmarried	-	1 (1.6)	2 (3.3)	-	3 (1.2)		
Widowed	4 (6.6)	5 (8.1)	2 (3.3)	5 (8.1)	16 (6.5)		
Divorced	3 (4.9)	3 (4.8)	-	4 (6.5)	10 (4.1)		
Educational background						22.5	0.032
No educ.	17 (27.9)	20 (32.3)	28 (45.9)	32 (51.6)	97 (39.4)		
Inf. educ.	15 (24.6)	9 (14.5)	11(18)	6 (9.7)	41 (16.7)		
Pr. educ.	26 (42.6)	23 (37.1)	16 (26.3)	19 (30.6)	84 (34.1)		
Sec.& above	3 (4.9)	10 (16.1)	6 (9.8)	5 (8.1)	24 (9.8)		
Farm holding size						14.4	0.08
< 1 ha	8 (13.1)	17 (27.4)	20 (32.8)	26 (41.9)	71 (28.9)		
1-2 ha	22 (36.1)	25 (40.3)	30 (49.2)	28 (45.2)	85 (42.7)		
2-3 ha	24 (39.3)	16 (25.8)	11 (18.1)	2 (3.2)	53 (21.5)		
> 3 ha	7 (11.5)	4 (6.5)	-	6 (9.7)	16 (6.5)		

Where, ha=hectare; Inf. educ.= informal education; Pr. educ.=primary education; Sec. &above=Secondary education and above.

Values in parenthesis are percentages and values outside parenthesis are frequency.

The socio-economic characteristics of chickpea farmers in West Amhara present a profile of a highly experienced but educationally disadvantaged population, factors that

collectively impede the adoption of modern, knowledge-intensive disease management practices. The farming community is overwhelmingly mature and experienced. Thus, 40.7% of participants are over 49 years old, and majority (70.7%) possesses 21 or more years of farming experience. The farming population on the other hand is characterized by a substantial deficit in formal education, with 39.4% reporting no education. Economically, the farmers are severely resource-constrained, with 71.6% cultivating two hectares or less.

These limitations highly hinder the basic knowledge and effective disease management protocols necessary for integrated disease management. The low literacy level significantly constrains the capacity of the majority of the farmers to transition from traditional observational knowledge to scientifically informed knowledge and disease management practices. Socioeconomic factors like age, land size, and farming experience, collectively have a positive and significant effect on integrated crop management technology (Febrianti *et al.*, 2024). Farmers with larger farm land can have financial capacity to purchase agrochemicals and more concerned about protecting their crops from pest attack (Berhan Agmas and Marshet Adugna, 2020; Gezahegne Getaneh *et al.*, 2021).

Land fragmentation and small farm size directly restrict the feasibility of implementing essential long-term CFW management strategies, such as long-term crop rotations, due to the high economic opportunity cost on scarce, crucial land. This profile describes a smallholder system that is structurally predisposed to high disease pressure risk, where resource constraints collectively inhibit adoption of necessary disease management options. Similarly, Gezahegne Getaneh *et al.* (2021) reported that farm size had positively and highly significantly ($p = 0.01$) influenced fungicide utilization in chickpea crop production. Their finding described that a unit increase in land holding size, increased the likelihood of utilizing fungicides on chickpea crop by 11%. Over years of farming, older farmers build a substantial knowledge base about their local agro-ecological conditions. This includes understanding the impact of different weather

patterns, the specific characteristics of their soil and other biophysical factors that could maintain the disease incidence to an acceptable level.

4.2.2. Farmers' knowledge of CFW detection and spread

The statistical analysis of the surveyed districts revealed that socioeconomic characteristics of farmers, particularly age, farming experience, and educational background were significantly associated with the farmers' knowledge of CFW and their subsequent management practices (Table 4.1). The significant Chi-square results for age ($X^2 = 56.4$, $P = 0.025$) and farming experience ($X^2 = 31.75$, $P = 0.02$) suggest that older, more experienced farmers possessed a deeper observational understanding of the disease, likely due to life time interacting with local agro-ecological conditions, and associated biophysical factors influencing epidemics of the disease. This is reflected in the high (over 70%) percentage of farmers who relied on long-term farming experience to identify the disease. Furthermore, the data suggested that while socioeconomic factors, like farm size ($X^2 = 14.4$, $P = 0.08$) showed a trend towards knowledge on disease and influencing management. In all districts, CFW detection and knowledge of the farmers was based on wilting or yellowing of chickpea crops. Overall, about 63% of the producers were able to identify chickpea Fusarium wilt based on wilting symptoms, while 27.2% were based on yellowing symptoms. Only few proportions of the farmers (about 2.5%) in the study districts could correctly describe brown discoloration symptoms of vascular bundles when the root is split open longitudinally.

On the other hand, about 7% of the farmers did not know any detection method for chickpea Fusarium wilt (Table 4.2.). The knowledge of the farmers on how CFW causing fungus (*Fusarium oxysporum*) spread in their farms varied among districts. Infested soils, followed by infected planting seeds, were the commonly known modes of spread for *Fusarium oxysporum*, mentioned by 55.5 and 24.4% of the farmers, respectively (Table 4.2.). Farm tools as a means for the pathogen spread was mentioned by only 11.4% of the farmers in all districts. In addition, about 4.5% of the farmers in the major chickpea-growing districts mentioned flood/water as a way of spreading *Fusarium oxysporum*.

Table 4.2. Farmers' knowledge regarding the causes, mechanisms of spread, management practices of chickpea Fusarium wilt and ranking.

Variables		Variable classes	Districts				Total (246)	Rank
			Bahir Dar Zuria (n=61)	Yilmana Densa (n=62)	Enarj Enawga (n=61)	Enemay (n=62)		
Is CFW major challenge?	Yes		42 (68.9)	49 (79)	52 (85.2)	39 (62.9)	182 (73.9)	
	No		19 (31.1)	13 (21)	9 (14.8)	23 (37.1)	64 (26.1)	
Possible causal agents	Pathogen		2(3.3)	-	-	1 (1.6)	3 (1.2)	
	Soils		31 (50.8)	44 (70.9)	35 (57.4)	28 (45.2)	138 (56.1)	
	Moisture		18 (29.5)	5 (8.1)	21 (34.4)	26 (41.9)	70 (28.5)	
	Unknown		11 (18)	13 (20.9)	5 (8.2)	6 (9.7)	35 (14.3)	
Source of inoculum /spreading mechanism	Sharing farm tools		2 (8.2)	9 (14.5)	11 (18)	3 (4.8)	28 (11.4)	3
	Infected seeds		18 (29.5)	14 (22.6)	9 (14.8)	19 (30.6)	60 (24.4)	2
	Infested soils		37(60.7)	29 (46.8)	36 (59)	35 (56.5)	137 (55.5)	1
	Flood/water		1 (1.6)	-	5 (8.2)	5 (8.1)	11 (4.5)	4
	Unknown		3 (4.92)	5(8.1)	2 (3.3)	-	11 (4.06)	5
Symptoms associated with CFW	Yellowing		19 (31.15)	12 (19.4)	15 (24.6)	21 (33.9)	67 (27.2)	
	Wilting		32 (54.1)	46 (74.2)	40 (65.6)	37 (59.7)	156 (63.4)	
	Vascular browning		2 (3.27)	-	3 (4.92)	1 (1.61)	6 (2.4)	
	Unknown		8 (13.11)	4 (6.5)	3 (4.9)	3 (4.84)	18 (7.32)	
Farmers' Fusarium wilt management Practices	Crop rotation		52 (85.2)	55 (90.2)	47 (77)	42 (67.7)	196 (79.7)	1
	Delayed planting		45 (73.7)	50 (80.6)	30 (49.2)	23 (37.1)	148 (60.2)	2
	Deep tillage		13 (21.3)	21 (34.4)	8 (13.1)	16 (25.8)	58 (23.6)	3
	Removing infected plants		7 (11.5)	12 (19.7)	21 (34.4)	4 (6.5)	44 (17.9)	4
	Tillage frequency		29	6	5 (8.2)	2 (3.2)	42 (17.1)	5
	Fungicides		-	9	14 (23)	1 (1.6)	24 (9.8)	6

Note that, values in parenthesis are percentages and values outside parenthesis are frequencies.

The farmers locally named the disease "Abektie" in North and East Gojam which they roughly translated as excess moisture caused the disease. The farmers suggested various

descriptions and confused a causal agent of the disease with various environmental factors, resulting from planting the crop to high moisture conditions, farmers who claimed that soil moisture is the cause of Fusarium wilt seemed to perceive it as a normal plant wilting from over moisture. Too much soil moisture as a cause Fusarium wilt was particularly mentioned by farmers who were producing chickpea late after the harvest of main season crops, using residual moisture in the post-rainy season. Only a few farmers suspected that the wilt disease resulted from a microscopic pathogen that survives either in the soil or in seeds and can be spread through farming implements.

Chickpea Fusarium Wilt (CFW) is primarily recognized as a primary constraint, with 73.9% of the total 246 respondents identifying it as a major challenge to their chickpea production. The severity of this perception fluctuates across the four districts but remains a major concern in every location. The most significant impact is felt in Enarj Enawga, where a substantial 85.2% of farmers classified the disease as a major threat. This is followed closely by Yilmana Densa at 79% and Bahir Dar Zuria at 68.9%. Even in Enemay, which reported the lowest level of concern among the study areas, a clear majority of 62.9% of farmers still considered CFW to be a significant problem. Conversely, only about one-quarter (26.1%) of the total population surveyed did not view the disease as a major challenge, highlighting the urgent need for effective intervention and management strategies throughout these regions.

Almost all (98.7%) farmers in all surveyed districts failed to recognize the causative chickpea Fusarium wilt is caused by microscopic pathogen and explain their own opinions from their experience and/or from what they heard and acquired from different sources. Causal understanding of the disease remained negligible: only 1.2% of farmers correctly identified the pathogen as the cause, while the majority attributed CFW to non-biological factors, like soils itself (56.1%) and moisture (28.5%) (Table 4.2). This profound misattribution, where a vascular, microscopic, soil-borne fungus is perceived as a simple environmental stressor, directly reflects the failure of formal extension channels. Information dissemination is dominated by informal, horizontal communication: Most farmers obtained knowledge from fellow farmers, from parents and relatives, with very

few receiving information from formal agronomists or development agents (DA). This reliance on peer-to-peer and generational knowledge transmission, while culturally rooted, guarantees the perpetuation of incorrect, observational-based diagnoses and management practices, preventing the adoption of integrated disease management.

Most (96.8%) of the farmers could understand at least one possible mechanism by which chickpea *Fusarium* wilt is spreading, while the remaining 4.01% failed to mention at least one mechanism of spread. Among these farmers, 55.5 and 11.4% of them mentioned infested soils and sharing farm tools, respectively, as a means of inoculum dispersal. In this regard, there is critically low (33% overall) awareness of farm tools as a vector for pathogen spread, which, combined with the small and fragmented land tenure system, guaranteed the mechanical dispersal of FOC across agricultural arable lands. This research report established that the prevailing socio-economic context predisposes the farmers to high disease occurrence and prevalence. Only a few (24.4%) farmers pointed out that infected seeds are a means for the spread of chickpea *Fusarium* wilt. But none of the farmers mentioned other *Fusarium* wilt spreading mechanisms, such as infected alternate host plants.

The evaluation of the farmers' knowledge clearly indicated that a significant majority perceive the soil itself as the primary causal agent of chickpea wilt, rather than the specific microbial pathogen. Overall, 56.1% of the farmers surveyed explained that soil was the main cause. This belief was strongest among farmers in Yilmana Densa, where the highest (70.9%) held this perception, followed by Enarj Enawga (57.4%) and Bahir Dar Zuria (50.8%). This strong focus on soil aligns with the nature of *Fusarium oxysporum* as a soil-borne fungus, but shows a gap in understanding the microbial cause. Conversely, only a tiny (1.2% overall) fraction of farmers explicitly suspected unknown pathogen entity as the agent, suggesting that the scientific concept of the disease's etiology is largely unfamiliar. Furthermore, moisture was the second most mentioned cause (28.5%), with farmers in Enemay (41.9%) and Enarj Enawga (34.4%), particularly suspecting high moisture levels to be responsible, an observation likely based on the disease's tendency to flourish in wet conditions.

This low awareness of mechanical and hydrological dispersal (tools, water) represents vulnerability in a fragmented smallholder system, as FOC is notoriously spread through contaminated soil particles clinging to tools and equipment. Furthermore, a behavioral paradox exists: 23% of farmers reported that they did not share farm tools, yet only 16% were aware that this practice reduces disease spread risk. This suggests the practice is driven by resource ownership or trust issues, rather than a deliberate, technical biosecurity strategy. When the knowledge of tool sanitation is virtually absent, the physical act of using equipment across numerous, a small, infested plot guarantees the rapid cross-contamination of fields.

This perception of soil as the cause is strongly reflected in the farmers' knowledge of the disease's spread. Infested soil was confirmed by 55.6% of the farmers as the number one spreading mechanism. This consistency between the perceived cause and the perceived spread mechanism suggests a logical, experience-based understanding of the disease being rooted in the field where the crop grows. The second most (24.4%) suspected spreading mechanism was infected seeds, a critical observation by the farmers, especially those in Enemay (30.6%), as seeds are a well-documented primary means of long-distance dissemination. Sharing farm tools was explained as a spread mechanism as mentioned by 11.4% of farmers, indicating they understood the risk of mechanically transferring infested soil between plots.

4.2.3. Farmers' practices of CFW management

Chickpea Fusarium wilt management by the farmers varied in the surveyed districts. In general, the farmers experienced different levels of awareness and management practices (Table 4.2). The farmers' strong emphasis on soil management is directly reflected in their most widely adopted control practices. Crop rotation was tremendously the primary management practice reported, with 79.7% of all farmers confirming its use, making it the top-ranked strategy. Thus, most (86.2%) farmers in the surveyed districts reported that they grew chickpea after at least two years of rotation and only 13.8% of farmers planted chickpea after only one year of rotation. According to the finding by Birhanu

Gizaw *et al.* (2018), research results proved the advantage of chickpea by tef rotational production, where high productivity of both crops was sustainably realized.

Delayed planting was the second most common management strategy, its overall adoption rate of 60.2% is still lower than crop rotation (79.7%), and its use is highly inconsistent across the districts. This practice is crucial because farmers (28.5% overall) suspect high moisture levels were causal factor, and delaying planting is an experience-based cultural practice used to manipulate the planting window to avoid conditions (like early, heavy rains or high soil temperatures) that favored the germination of the *Fusarium* spores and subsequent rapid disease development. The high adoption in Yilmana Densa (80.6%) and Bahir Dar Zuria (73.7%) confirmed a strong belief in its efficacy in these areas, suggesting farmers have observed a direct benefit of delayed planting in reducing wilt incidence.

However, the adoption rates dropped dramatically in Enarj Enawga (49.2%) and Enemay (37.1%), where less than half of the farmers confirmed using it. This variation suggests that environmental differences (e.g., rainfall patterns or soil types), which affected the optimal planting time, or competing demands for the land, may limit its feasibility or perceived effectiveness in these districts, leading to a significant weakness in the overall disease management strategy for a large portion of the surveyed farmers. The remaining management practices are much less common, as fewer farmers use them. Deep tillage is ranked third overall and is practiced by 23.6% of all surveyed farmers. Removing infected plants from the field is ranked fourth, with 17.9% of all farmers practicing it. This practice is fairly common in Enarj Enawga, where 34.4% of farmers remove diseased plants, but it drops to just 6.5% in Enemay. Meanwhile, the tillage frequency ranks fifth, with only 17.1% of the total farmers using it to control the disease. Lastly, fungicides application is the least method, ranking sixth with a total adoption rate of only 9.8%.

Most (77.6%) farmers in all districts reported that planting healthy seeds contributed to CFW management. However, they claimed that the exchange of seeds between farmers is

a common practice for planting. The data revealed a critical failure in the transfer of technical agricultural knowledge, fundamentally compromising farmers' capacity to manage chickpea Fusarium wilt. The current result is supported by previous evidences; for instance, Bereket ali and Habtamu Terefe (2023) reported that late planting of chickpea resulted in higher harvest stand counts, number of pods per plant, and ultimately lower area under disease progress curve (AUDPC). Similarly, Dagnachew Bekele *et al.* (2021) and Edeo Negash (2021) disclosed that relatively lower chickpea Fusarium wilt incidence was noted from late-planted chickpea compared to early planted. Further to this, Bereket Ali and Habtamu Terefe (2023) suggested that chickpea planted during September reduced disease incidence by up to 14.6% over early planting by the end of August.

4.3. Conclusion and Recomendations

In this study some valuable information on farmers' status, knowledge and management practices of chickpea Fusarium wilt were evaluated. Chickpea wilt disease was regarded as the most production constraint of chickpeas by most of the farmers. Farmers possessed an effective, experience-based wisdom regarding soil and biophysical management that formed effective curtailment against chickpea Fusarium wilt. Their reliance on crop rotation ($\approx 80\%$), delayed planting ($\approx 60\%$), deep tillage, removal of infected plants and use of healthy seeds were scientifically sound, as these practices successfully manipulated the environment to reduce the inoculum density serving to reduce the fungal inoculum and avoid peak infection periods, respectively. In conclusion, farmers' knowledge has the multidimensional advantage for chickpea Fusarium wilt management and must be the foundation upon which future interventions will be built as an integral part of integrated management. Thus, the collaborations among farmers and agricultural offices/researchers should be linked strongly to share technical knowledge on the disease spread and its managements.

CHAPTER 5: Chickpea Fusarium Wilt (*Fusarium oxysporum* f.sp. *ciceris*): Current Status and Biophysical Factors Influencing Its Epidemics in Western Amhara, Ethiopia

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Abstract

Chickpea is a legume of immense nutritional and economic significance that has carved a unique niche in Ethiopian agriculture. However, its productivity in Ethiopia is incredibly low compared to its potential yield of 5 tons per hectare. This could be partially attributed to chickpea Fusarium wilt; one of the most devastating diseases that gave rise to considerable grain yield loss. Chickpea field surveillance was conducted to quantify the status of chickpea Fusarium wilt intensity and its association with biophysical and socioeconomic factors. Chickpea Fusarium wilt incidence and severity were assessed across six districts, eighteen farmer associations and 303 farmers' fields using random sampling design methods during October-January cropping seasons of 2022/23 and 2023/2024. Descriptive statistics was employed to summarize the data using STATA Software (version 17.0). The association of chickpea Fusarium wilt disease intensity parameters with independent variables was tested using the logistic regression model. The findings depicted that chickpea Fusarium wilt was ubiquitously detected in all inspected chickpea-sown fields. The disease incidence and percent severity index were significantly impacted by the biophysical factor studied. The minimum (8.63%) wilt incidence and percent severity index (8.78%) were noted from chickpea fields planted late in the season after four or more consecutive years of crop rotation practice. Conversely, the maximum (43.74%) wilt incidence and percent severity index (39.58%) were obtained from fields

owning early planted chickpeas after one year of crop rotation practice. Pathogenicity tests revealed that all isolates were found to be pathogenic; inducing yellowing and wilting symptoms with a mean incidence percentage ranging from 7.94 to 62.96%. Thus, about 61% of the isolates were moderately pathogenic causing a 30-50% wilt incidence. The rest 16.7 and 22.2% of the isolates were less pathogenic and highly pathogenic by inducing less than 30 and above 50%, respectively, mean wilt incidences. The regression analysis exhibited that the duration of crop rotation and farming experience retained a strong negative association with incidence of chickpea Fusarium wilt. Besides, planting time and weed density showed a moderate association with the disease intensity in a negative manner. In conclusion, delayed planting, long-term crop rotation practices and maintaining a weed-free environment were pivotal for effective management of chickpea Fusarium wilt. The combined synergistic implementation of these practices is crucial for reducing disease intensity and restraining chickpea yield loss.

Keywords: Crop rotation, Incidence, Pathogenicity, Planting time, Percent severity index, Yield loss

5.1. Introduction

The world's human population is moving forward with its increasing trend and urbanization is snatching ample agricultural lands. Besides, risk factors associated with climate change are making field crop production quite menacing. The influence of such diversified issues can simply be well perceived in a country like Ethiopia since the entire economic growth is profoundly dependent on the achievement of the agriculture sector (Biru Alemu *et al.*, 2017). Thus, the importance of pulse crops like chickpea should not be disregarded because of their foremost contribution to harmonize and maintaining soil health, generating income, sustaining food and nutritional security, and increasing the foreign exchange of the country (Mekonnen Gebeyaw, Asnake Fikre, Alemu Abate, 2024a).

Chickpea (*Cicer arietinum* L.) in Ethiopia is the third most important cool season food legume crop in its volume of production, next to common bean (*Phaseolus vulgaris* L.) and peas (*Pisum sativum* L.) in the world (Bulti Merga and Jema Haji, 2019) with an annual production of over 16.8 million metric tons (FAOSTAT, 2024). It plays an important role in the diet of human beings as a source of fiber, vitamins, carbohydrates, mineral salts, unsaturated fatty acids and β -carotene (Shevkani *et al.*, 2019). It is considered one of the most important food pulse legumes, providing a major source of low-cost protein for multitudes of low-income households (Nasr Esfahani *et al.*, 2014). Its significant contribution to the food security of lower-income countries like Ethiopia is an indisputable truth and it is a key component of subsistence agriculture (Varshney *et al.*, 2014).

Despite its importance and considerable economic, food and nutrition security contribution in Ethiopia, its average productivity is as low as 2 tons per hectare (CSA, 2021) which is too low compared to its potential productivity of 5 tons per hectare (Gemechu Keneni *et al.*, 2012; Verkaart *et al.*, 2017). This lower productivity of chickpea could be due to the susceptibility of genotypes to diverse biotic and abiotic constraints that adversely affect grain yield (Biru Alemu *et al.*, 2014; Jha *et al.*, 2014); socioeconomic related challenges (Asrat Mulat, Almaz Giziew and Dereje Ayalew,

2022). Among the abiotic yield-limiting constraints poor crop management and husbandry practices and water logging (Getachew Agegnehu and Weldeyesus Sinebo, 2012) and is also further affected by drought, salinity and erratic weather (Jha *et al.*, 2014; Dagnachew Bekele Besha, 2021). Chickpea Fusarium wilt (*Fusarium oxysporum* f.sp. *ciceris*), Ascochyta blight (*Ascochyta rabiei*), and dry root rot (*Rhizoctonia bataticola*) are among the principal biotic production constraints that adversely affect chickpea grain yield across the globe, including Ethiopia (Gaur *et al.*, 2014; Sultan Mohamed *et al.*, 2018). Weeds are also reported among the major biotic factors responsible for considerable yield loss due to the crop's slow early growth and short stature, which render it vulnerable to competition and smothering (Bulti Merga and Nano Alemu, 2019).

Chickpea Fusarium wilt is a widespread and leads to a major cause of yield losses in numerous chickpea growing nations globally (Dubey, Singh and Singh, 2010; Venkataramanamma *et al.*, 2023), including many chickpea-producing areas of Ethiopia (Sharma *et al.*, 2012; Sultan Mohamed *et al.*, 2018; Bekele *et al.*, 2021). It is the most damaging disease inducing an estimated mean annual yield loss ranging from 10 to 90% under Ethiopian condition based on favorable biophysical factors, like atmospheric humidity and temperature (Zemenu Endalew, Gizachew Haylemariam and Ahmed Mohamed, 2022). It does not only reduce grain yield but also leads to detrimental secondary effects, notably production of low quality seeds, as evidenced by the lighter, rougher, and duller seeds harvested from late wilted chickpea plants than those sourced from healthy plants (Navas-Cortes, Hau and Jimenez-Diaz, 2000; Alsamman *et al.*, 2023). Therefore, assuring effective sustainable management is critically important and heavily dependent on an integrated management approach. However, setting an integrated Fusarium wilt management program is not an overnight task which entails understanding the disease distribution, magnitude of disease pressure and its association with biophysical factors influencing its epidemic development (Sultan Mohamed *et al.*, 2018).

Climate change has already, and increasingly affected the prevalence, severity and all over intensity of plant diseases across a spectrum of important crops in natural ecosystems

(Elad and Pertot, 2014). Consequently, within this context of climate driven changes, the intensity of chickpea Fusarium wilt disease is further influenced by specific cropping systems and biophysical factors to a considerable extent (Tebikew Damte and Ojiewo, 2016; Dagnachew Bekele *et al.*, 2021). Planting time, chickpea seed type, crop growth stage preceding crop, weed management and crop rotation practices were found to be significantly associated with wilt disease incidence in the surveyed areas of Ethiopia (Dagnachew Bekele *et al.*, 2021; Edeo Negash, 2021; Awoke Yemataw *et al.*, 2025). For instance, the cropping sequence profoundly affect the prevalence and incidence of wilt disease in chickpea in the upcoming season, with faba bean preceding chickpea resulting in 82% wilt disease (Dagnachew Bekele *et al.*, 2021). Thus, disease surveillance is an important tool for studying such diversified conditions to distinguish the foremost determinant variables and focus efforts on developing integrated and sustainable management practices of plant diseases (Edema, Adipala and Florini, 1997; Rusuku *et al.*, 1997).

Although efforts were attempted on the aforementioned important outline; the West Amhara region, which is known for its distinct and diversified chickpea production system, was not sufficiently addressed and most of the studies were limited to central Ethiopia. According to Daniel Assfaw and Tilahun Negash (2020), mean wilt incidence of 20.9 and 40 % was reported in Dendi and Ambo districts respectively in West Shewa Zone, central Ethiopia. Moreover, the current status of chickpea Fusarium wilt associated with the changing weather variation and cropping system in West Amhara remained unknown and information is lacking. Therefore, information on its distribution, magnitude, economic importance and its association with the factor influencing its epidemics is lacking in most parts of West Amhara sub-region. Therefore, the study was under taken to quantify the current status and incidence of chickpea Fusarium wilt disease in west Amhara and to identify the association of biophysical factors and cropping system influencing chickpea Fusarium wilt epidemics.

5.2. Materials and Method

5.2.1. Description of the study areas

The disease survey was conducted in six districts, known for their chickpea production, of Amhara National Regional State. The districts were Bahir Dar zuria, Enarj Enawga, Enemay, Fogera, Libo Kemekem and Yilmana Densa, during October-January cropping seasons of 2022/23 and 2023/24. The soil type was *Vertisol*, mixed farming systems and uni-modal rainfall patterns are common and characteristic features of the surveyed districts. The altitude in the inspected areas ranged from 1805 to 2568 m.a.s.l. The major crops grown in all the six study districts included chickpea (*Cicer arietinum* L.), maize (*Zea mays* L.), tef [*Eragrostis tef* (Zucc.) Trotter], and wheat (*Triticum aestivum* L.). However, rice (*Oryza sativa* L.) is cultivated as a major crop only in Fogera and Libo Kemkem districts (CSA, 2021). The geographical location of the study districts is presented (Figure 5.1). Rainfal in the study districts is characterized by strongly unimodal with the vast majority of precipitation falling during the June to September. Generally ranges between 995 mm and 1,780 mm (NASA Power, 2023), making it one of the more humid and agriculturally favorable parts of the region compared to the eastern zones.

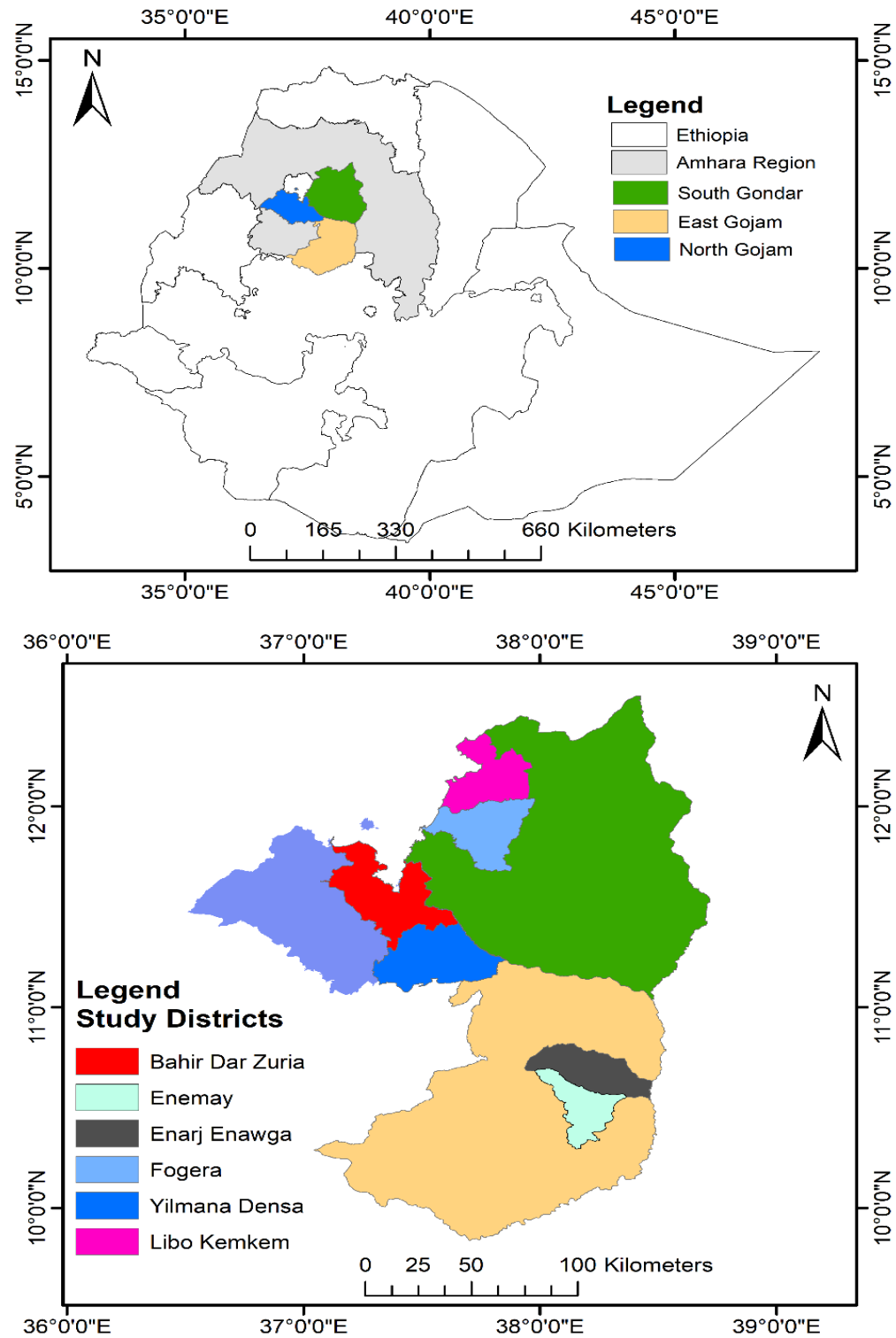


Figure 5.1. Map of Ethiopia showing the six surveyed districts of East Gojam, South Gondar and North Gojam Zones of West Amhara, Ethiopia, during two consecutive years of disease survey.

5.2.2. Sampling techniques and procedures

A multi-stage purposive sampling technique was employed to select representative chickpea fields and chickpea producers. Initially, three zones (East Gojam, South Gondar, and North Gojam) known for significant chickpea production were selected based on secondary sources. Subsequently, within these zones, six districts were purposively chosen, followed by the selection of three Farmers' Associations (FAs) per district utilizing expert knowledge from local agricultural offices. Finally, farmers' field, considering 10 fields within these selected Farmers Associations were assessed following random sampling technique. This approach was adopted to account for the patchy dispersed nature of chickpea cultivation in the area, while still capturing a representative sample of chickpea growing areas.

5.2.3. Biophysical and agronomic data

Data collection was conducted through a combination of field-based assessments and on-site farmers' interview. A global positioning system (GPS) was employed to record the onsite coordinates (latitude and longitude) and altitude of each field inspected. A GPS-based survey data collection sheet was arranged to collect all information related to disease status parameters in each chickpea field. Besides, data on agronomic and cultural practices like weed management practice (weed density), planting pattern, plant population density per square meter, cropping system, crop growth stage and all other related agronomic performance were collected from on-farm observation and measurements for upcoming association with disease intensity.

Background information on each field like planting date, duration of crop rotation, source of planting seeds, previous farm history, chickpea types/variety used, and fungicide application was obtained from onsite interview of chickpea growers based on the checklist. The plant population and weed density were assessed using quadrat measuring 1m^{-2} area placed diagonally by taking four measurements per field following zigzag pattern. Mean values of plant and weed population density were considered from four quadrants. Meteorological data (mean annual rainfall, mean monthly temperature, and

relative humidity) of each district during cropping season was obtained from National Meteorological Agency of Bahir Dar Station.

5.2.4. Disease assessment and sample collection

Chickpea-planted farmers' fields were assessed in the selected six districts of West Amhara, Ethiopia. Random sampling design methods were employed for the survey; as chickpea fields were patchy and randomly distributed; fields at about 5 km drive interval and having the crop were visited. In each chickpea sown field, a quadrat of 1m² was placed randomly following a W-pattern and in each arm, the number of wilted plants (plants showing typical *Fusarium* wilt and yellowing symptoms), weeds and healthy plants were separately counted in the quadrat and recorded (Tebkew Damte and Ojiewo, 2016; Sultan Mohamed *et al.*, 2018; Daniel Assfaw and Tilahun Negash, 2020). During the field survey, chickpea plants with wilting or yellowing symptoms were uprooted cautiously using hand hoes. Following this operation, uprooted diseased samples of chickpea plants were checked for the presence of vascular discoloration/browning upon splitting chickpea roots longitudinally in most samples and set aside into polythene bags independently and kept inside an icebox of about 4 °C temperature and brought to Bahir Dar University Biotechnology Laboratory for isolation identification of the pathogen.

The root samples were labeled with necessary information (location, sample code, and date of collection). The severity of *Fusarium* wilt disease was estimated in a 1m² quadrat using a five-point severity scale ranging from 0 (no wilting/yellowing) to 4 (plant death) based on the percentage of plant portion exhibiting wilting or yellowing symptoms (Bereket Ali and Habtamu Terefe, 2021); where 0 = 0% wilted plant; 1=1–20% wilted plant; 2=21-50% wilted plant; 3=51–100% wilted plant and 4 = plants collapsed or dead. Percentage severity index (PSI) was determined from the severity scores for analysis. Disease incidence and percent severity index were calculated following the formula described by Wheeler (1969).

5.2.5. Pathogen isolation and identification

The collected root samples of plant specimens were washed to remove adhered soils, contaminants and other impurities, and the roots were split longitudinally to detect the presence of vascular browning; the discoloured portion was then cut into about 3 mm pieces at the collar region. Root pieces were surface sterilized with 5% sodium hypochlorite (NaOCl) solution for 3 min followed by washing with sterile distilled water (SDW) three times, and allowed to dry in between sheets of sterile filter paper. Root pieces were placed on a sterilized Petri dish measuring 9cm in diameter containing PDA supplemented with chloramphenicol (120 mg L^{-1}) to inhibit the growth of other non-targeted contaminants of bacterial origin. The contents were incubated at $27 \pm 1^\circ\text{C}$ for 7 days as described by Zemankova and Lebeda (2001). Sub-culturing was performed 3-5 days after inoculation and incubation to purify the primary culture and obtain pure cultures. The pure cultures were examined under a compound microscope and identified the presence of *Fusarium oxysporum* f.sp. *ciceris* based on its particular morphocultural features and for further cultural and morphological characteristic.

5.2.6. Pathogenicity test and pathogenic variability assay

Pathogenicity test was performed using well-characterized *Fusarium oxysporum* f.sp. *ciceris* isolates as the sources of inoculum following the modified description by Dubey, Singh and Singh (2010). Concisely, 50 g of maize was added into 250 milliliter Erlenmeyer flasks containing 60% distilled water, followed by autoclaving the preparation at 121°C for 2 hours and allowed to cool under room temperature. Immediately after cooling, spore suspension of the isolate containing 10^6 conidia per ml was inoculated aseptically and incubated at $25 \pm 2^\circ\text{C}$ for 7 days (Bereket Ali and Habtamu Terefe, 2021). A growing pot-mix medium composed of farm soil, sand, and manure was prepared with equal proportion and sterilized carefully. Then, 2 kg of the soil mix per pot was filled into plastic pots and moistened with tap water. Then after, inoculated and incubated substrate of each *Fusarium oxysporum* f.sp. *ciceris* isolate was separately mixed thoroughly with the pot-mix aseptically and all pots were allowed in the glasshouse for four days before planting. Then, 10 seeds of the surface-sterilized JG-62

susceptible chickpea variety were planted per pot and pots without inoculum inoculation were used as control.

Experimental pots were arranged in a completely randomized design (CRD) with three replications and kept in a greenhouse for further data recording. Data on wilt incidence was recorded starting from the onset of the first wilting and yellowing symptom; 30 days after planting and continued two times at 45 and 60 days after planting. Based on incidence values, isolates were grouped as less pathogenic; up to 30% wilt incidence, moderately pathogenic; 31-50% wilt incidence and highly pathogenic; >50% wilt incidences as employed by Dubey *et al.* (2010) and Bereket Ali and Habtamu Terefe (2021). Plants showing typical wilting symptoms were used for re-isolation of the causal fungal pathogen. The re-isolated fungus was cultured on PDA medium for comparison with the original culture of the isolates.

5.3. Statistical Analysis

Summary of the incidence and severity of chickpea Fusarium wilt was presented for each explanatory variable class. Disease incidence and percept severity index (PSI) data were categorized into distinct classes of bivariate qualitative data. Class boundaries were chosen so that classes contained approximately equal frequency. Descriptive statistics was employed to summarize the data obtained from fields using STATA Software (version 17). The descriptive statistics were suitable for analysing the distribution and the magnitude of chickpea Fusarium wilt disease across each dependent variable class. The association of chickpea Fusarium wilt disease intensity parameters with independent variables was tested using the logistic regression model (Yuen, 2006). Mean chickpea Fusarium wilt disease incidence was classified into distinct groups of binomial qualitative data (Chemeda Fininsa and Yuen, 2001; Habtamu Terefe and Getachew Gudero, 2019) to analyse the relationship between chickpea Fusarium wilt disease intensity parameters and biophysical factors.

5.4. Results and Discussion

5.4.1. Overview of surveyed fields

Generally, the surveyed chickpea fields were geographically suited to an altitude range of 1805 meters above sea levels in Bahir Dar Zuria to 2568 meters above sea levels in Enemay district. Overall, about 49.6% of the fields were located at altitude of 2000 meters and above while 50.4% of the fields were located at an altitude below 2000 m.a.s.l. The cropping system, particularly crop rotation practices and its length of time interval between chickpea cultivation, was found to be the most determinant factor influencing chickpea Fusarium wilt intensity. Regarding the previous cropping history of examined chickpea sown fields, about 12 crop species were used in the cropping systems as a rotation with chickpea under the classification cereals (67.27%), legumes (18.7%) and other crops (14.2%). Thus, 16.4, 36.2, 29.9 and 17.5% of the fields were rotated for one, two, three, and four years, respectively (Table 5.1.).

The planting pattern of chickpea was all broadcasting, resulting in asymmetrical and wider variation in plant population density ranging between 12.8 and 35.8 plants m⁻². During the survey, three crop growth stages, notably vegetative, flowering and pod setting were encountered, which accounted for 43.6, 35.1 and 21.3%, respectively. Chickpea growers in the area experienced diverse planting times of chickpea as the farmers perceived different viewpoints and disease-tackling mechanisms associated with chickpea crop. Hence, about 30.7% of growers planted their chickpea within the first three weeks of September as a main crop; 27.7% of the farmers planted between the last week of September to the second week of October and 41.58% planted starting from 3rd week of October up to the second week of November soon after the harvest of early rotational matured crops (Table 5.1).

Table 5.1. Descriptive statistics of surveyed-chickpea fields and producers during 2022/23 and 2023/24 cropping years showing the frequency and the percentage distribution of key contributing variables

Variables	Variable classes	Cropping years					
		2022/2023		2023/2024		Total	
		Frequency	Percentage (%)	Frequency	Percentage (%)	Frequency	Percentage (%)
Altitude (m.a.s.l.)	< 2000	66	53.66	84	46.67	150	49.6
	≥ 2000	57	46.34	96	53.33	153	50.4
Previous crop	Cereals	71	57.72	133	73.89	204	67.32
	Legumes	19	15.45	37	20.56	56	18.48
	Other crops	33	26.83	10	5.56	43	14.19
Duration of crop rotation (year)	1	17	13.82	33	18.33	50	16.5
	2	46	37.4	64	35.56	110	36.2
	3	38	30.89	52	28.89	90	29.9
	≥ 4	22	17.88	31	17.22	53	17.5
Crop growth stage	Vegetative	54	43.90	78	43.33	132	43.6
	Flowering	42	34.15	65	36.1	107	35.1
	Post flowering	27	21.95	37	20.55	64	21.3
Planting time	Early	34	27.64	59	32.78	93	30.69
	Intermediate	36	29.27	48	26.67	84	27.72
	Late	53	40.09	73	40.56	126	41.58
Farm size (hectare)	< 1	33	26.83	58	32.22	33	10.9
	1-2	33	26.83	72	40.0	89	29.4
	≥ 2	57	46.34	50	27.78	81	59.7
Farming	<15	45	36.59	67	37.22	112	36.96
Experience (year)	15-30	36	29.27	55	30.56	90	30.03
	≥ 30	42	34.15	58	32.22	100	33.00

Weed density	<10 weeds	70	56.91	107	59.44	177	58.42
(m ⁻²)	≥10 weeds	53	43.09	73	40.56	126	41.58

Where, Early planting: chickpea planted during the first three weeks of September; Intermediate planting: chickpea is planted between last week of September to second weeks of October; Late: chickpea planted from third week of October to second week of November in both growing seasons. Cereal crops noted were barley, maize, rice, tef, and wheat'; legumes included common bean, fenugreek, field pea, lentil, and vetch and other crops were noug, onion and potato.

5.4.2. Chickpea Fusarium wilt as influenced by growing districts

Chickpea Fusarium wilt was detected almost in all visited farms with the mean prevalence rate of 99.2 and 100% during the 2022/23 and 2023/24 cropping seasons, respectively. The mean Fusarium wilt incidence and percent severity index significantly varied among districts during both growing years (Appendix Table 1). Thus, Bahir Dar Zuria district took the minimum of 11.69 and 12.74% mean wilt incidence and percent severity index, respectively, during the 2022/23 cropping year. On the other hand, the maximum (38.2%) wilt incidence and percent severity index (36.3%) were acquired from Enarj Enawga district in the year 2023/24 (Figure 5.2.).

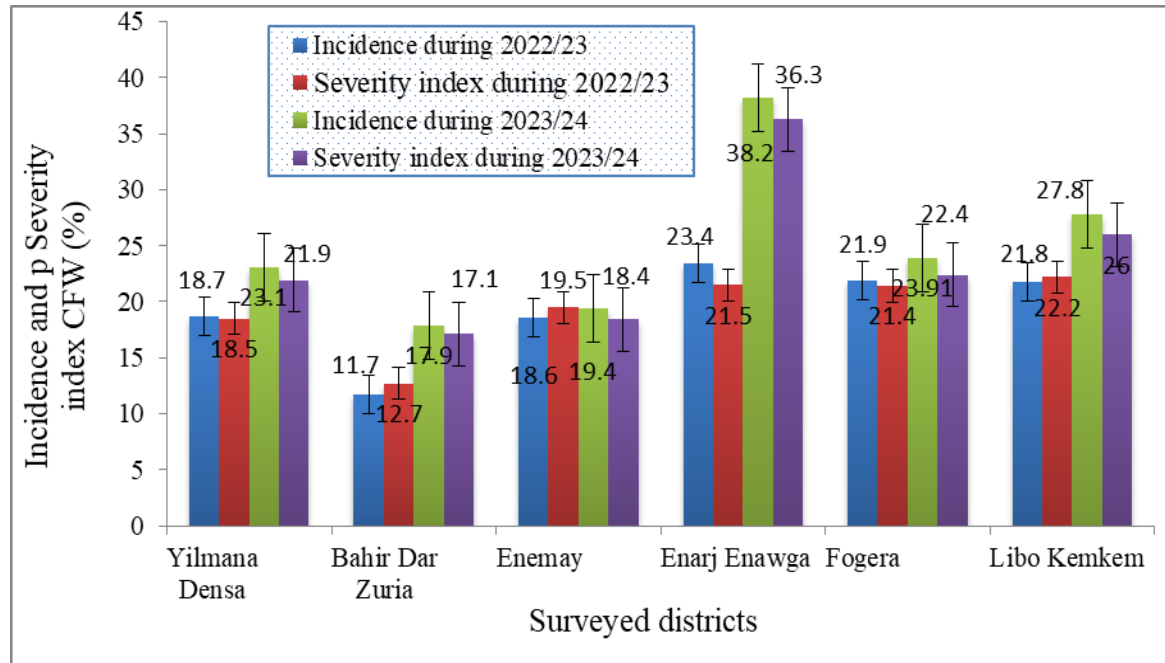


Figure 5.2. CFW mean incidence and percent severity index (PSI) in the respective surveyed districts of West Amhara, Ethiopia

The incidence and percent severity index of chickpea Fusarium wilt considerably varied among different variable classes. The wider disparity of mean incidence and percent severity index scored among growing districts could be attributed to the variations in temperature, rainfall pattern, and preferably all over farmers' production system, agronomic and cultural practices. For instance, Enarj Enawga district was primarily characterized by early planting and short rotation exhibited the wilt incidence and percent

severity index. In contrast, Bahir Dar Zuria district, where late planting, long rotations and better weed management were common practices, recorded the minimum wilt incidence. In line with this finding, Merkuz Abera, *et al.* (2011) and Tebkew Damte and Ojiewo (2016) disclosed that Fusarium wilt incidences greatly varied among different chickpea growing localities as influenced by edaphic, environmental, cropping systems and agronomic management perspectives. Similarly, Patra and Kumar Biswas (2016) and Biswas (2017) disclosed that abiotic factors like rainfall, soil temperature and moisture had substantial effects on the multiplication and subsequent development of CFW disease. Moreover, Bereket Ali and Habtamu Terefe (2021) demonstrated that mean incidence of CFW was found to be considerably varied among Ensaro, Menz Mama, Minjar, Mojana Wedera and Moretna Jiru districts, in North Shewa Zone of Ahara region.

5.4.3. Chickpea Fusarium wilt as influenced by cultural practices

Most of the agronomic practices and cropping systems evaluated during the survey showed significant ($p \leq 0.05$) variations in their degree of association with CFW intensity throughout both cropping years. The duration of crop rotation practices significantly influenced the wilt intensity of chickpea in both growing years (Figure 5.3.). Chickpea sown after four or more years of rotation practice expressed the least (10.0%) wilt incidence and percent severity index (10.2%) during 2022/23 growing years. In contrast, the highest (38.2%) mean wilt incidence and percent severity index (32.8%) were noted from chickpea fields sown after only one year of rotation practices during the 2023/24 cropping season.

Chickpea planted after a short period of crop rotation practice profoundly 2 years and less were exceedingly associated with a high risk of CFW pressure in both growing years. That could be related to the survival ability of the causal pathogen in the soil in the absence of its host. Whenever chickpea plants or their residue is lacking followed by continuous cultivation and soil disturbance; the pathogen inoculum for the upcoming season tends to be reduced. Both planting density and weed management practices were associated with chickpea Fusarium wilt intensity expressed in incidence and percent

severity index. Thus, high incidence of chickpea Fusarium wilt disease is associated with densely populated chickpea plants and high weed infestation.

This might be due to the fact that the high competition in densely populated plants and poor weed management might lead the crops to severe stress which can predispose the plant to wilt diseases. Besides, densely populated plants and weeds could share a common rhizosphere of interconnected roots of diseased and healthy plants which enables the causal pathogen to easily disperse from diseased to healthy plants and result subsequent infection. Negash (2021) also reported that lower crop density with <22 plants m^{-2} retained relatively low wilt incidence as compared to the reverse variable class. Chickpea fields with good weed management expressed relatively low wilt incidence of chickpea Fusarium wilt as compared to chickpea sown fields of poor weed management (Bereket Ali and Habtamu Terefe 2021; Edeo Negash 2021). Moreover, Awoke Yemataw *et al.* (2025) reported that wilt incidence in chickpea was higher (37.9%) in fields with densely populated plants (with 20 or more plants per square metre) than sparsely planted (less than 20 plants per square metre), where the incidence was 33.3%.

Examining the temporal dimension of crop rotation, the data compellingly illustrate the protective efficacy of extended rotation cycles. Thus, crop rotation duration exhibited a strong negative association with chickpea Fusarium wilt incidence. Extending the crop rotation cycle to four or more years resulted in an extraordinary level of chickpea Fusarium wilt management, resulting in a substantial 89.5% decrease in the likelihood of chickpea Fusarium wilt, signifying an approximately, 162.3 times lower risk than continuous monoculture. The temporal aspect of planting also emerges as a salient modulator of chickpea Fusarium wilt risk. A more pronounced risk reduction is observed with late planting, which correlates with odds 9.4 times lower odds than early planting. This temporal dynamic strongly suggests that judicious adjustment to planting schedules, potentially to avoid periods conducive to pathogen proliferation can serve as an effective tactical maneuver in integrated chickpea Fusarium wilt management.

Conversely, the spatial arrangement of plants, as indicated by planting density, revealed a contrasting trend. Higher (≥ 22 plants per square meter) planting densities are associated with a significantly higher risk of disease incidence, i.e. approximately 3.6 times higher odds than lower planting densities (< 22 plants per square meter). Finally, the inherent genetic predisposition to plants to disease is highlighted by the finding that Desi chickpea type exhibit a significantly higher risk of chickpea Fusarium wilt incidence with 2.82 times higher odds than the Kabuli type. The influence of accumulated agricultural knowledge, as represented by farming experience, revealed a compelling inverse relationship with the risk of chickpea Fusarium wilt incidence. Farmers with above 30 years of farming experience exhibit a significant reduction in the odds of chickpea Fusarium wilt occurrence approximately 4.31 times lower odds than farmers possessing less than 15 years of farming experience

The late planted chickpea retained minimum (13.23%) wilt incidence and percent severity index (13.45%) during the 2022/2023 cropping season. Conversely, the uppermost 28.0% mean incidence and percent severity (27.3%) during 2023/24 growing year was recoded from chickpea fields having early planted chickpea (Table 5.2.). The high disease pressure under early planted chickpea could be linked with excess soil moisture left immediately after the rainy season; which initiates the inoculum and enables inhibiting more space in the soil. High moisture favours the causal pathogen to a high multiplication and host invasion in the case of early planted chickpea crops.

On the contrary, the lower disease magnitude in late-planted chickpea possibly associated with soil moisture manipulation and drainage. The current finding is in line with the report of Bereket Ali and Habtamu Terefe (2023) who concluded that late planting of chickpea resulted in higher harvest stand counts (132.08 and 102.08) than early August planting, , number of pods per plant (50.28 and 40.62), and (1030.86 and 1122.08), and lower area under disease progress curve (AUDPC) values of 321.30%-days and 540.34%-days at Alem Ketema and Enewari, respectively. The findings of the current study also align with the finding of Gezahegne Getaneh *et al.* (2021) who reported that

the cause of wilt disease in chickpea was due to high soil moisture as reported by 52.8% of the respondents.

Similarly, Dagnachew Bekele *et al.* (2021) and Edeo Negash (2021) stated that relatively lower chickpea Fusarium wilt incidence was noted from late-planted chickpeas over early planted under Ethiopian conditions. Further, Bereket Ali and Habtamu Terefe (2021) suggested that chickpea planted during September reduced disease incidence by up to 14.6% over early planted by the end of August. Moreover, Asrat Zewdie (2019) reported that the lowest chickpea Fusarium wilt incidence was obtained from chickpea planted on raised seedbed plots, reflecting raised bed targets on soil moisture management making niche unfavorable to the pathogen as the principle of late planting does. A field experiment conducted by Merkuz Abera (2012) also revealed that the late planting of chickpea on 27th October gave the lowest wilt incidence, better yield and yield components of chickpea over the early planted chickpea crop.

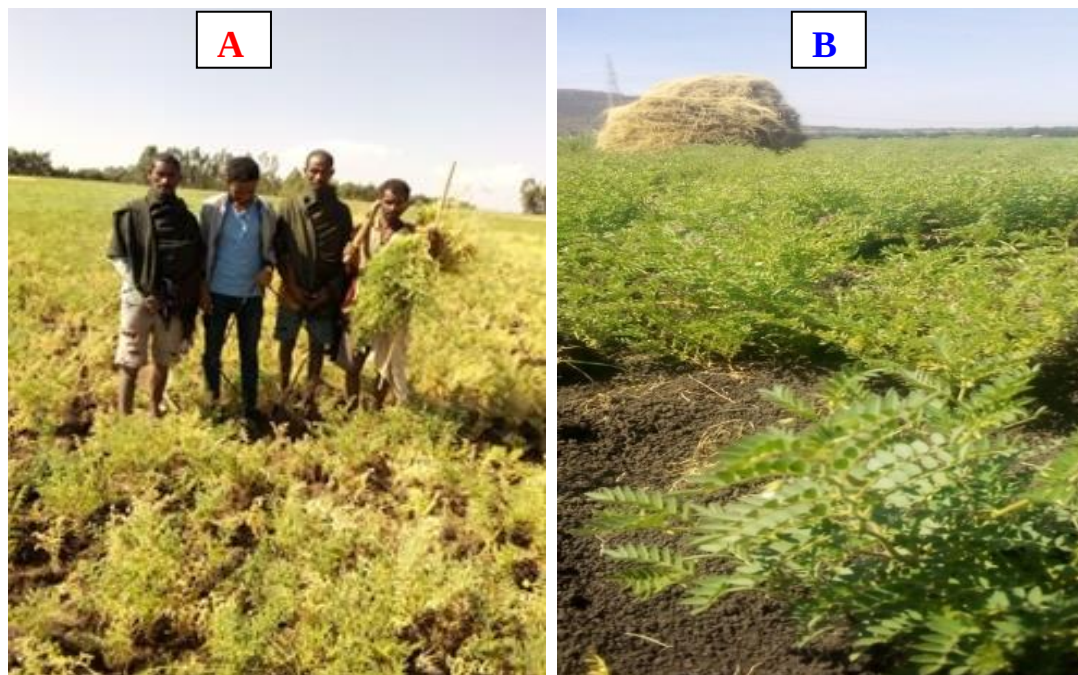


Figure 5.3. Chickpea Fusarium wilt intensity influenced by planting time: (A) early planted with shorter rotation time cycle chickpea (left); and (B) late planted chickpea after long crop rotation cycle practices (right).

Table 5.2. Chickpea Fusarium wilt incidence and severity (mean $\pm$ SE) in the respective variable classes during two consecutive growing seasons, in West Amhara, Ethiopia

Variables	Variable classes	2022/2023		2023/2024	
		Incidence	Severity	Incidence	Severity
Planting time	Early	23.86 $\pm$ 0.74	23.68 $\pm$ 0.74	31.64 $\pm$ 0.82	29.79 $\pm$ 0.78
	Intermediate	20.85 $\pm$ 0.72	21.51 $\pm$ 0.72	25.07 $\pm$ 0.59	24.69 $\pm$ 0.69
	Late	13.23 $\pm$ 0.49	13.45 $\pm$ 0.50	17.53 $\pm$ 0.39	16.38 $\pm$ 0.43
P value		**	**	***	***
Preceding crop	Legumes	25.05 $\pm$ 0.77	25.37 $\pm$ 0.87	29.53 $\pm$ 0.63	28.28 $\pm$ 0.55
	Cereals	16.87 $\pm$ 0.80	17.23 $\pm$ 0.79	23.78 $\pm$ 0.60	22.51 $\pm$ 0.61
	Other crops	17.84 $\pm$ 0.48	17.78 $\pm$ 0.41	25.54 $\pm$ 0.66	22.29 $\pm$ 0.75
P value		***	***	***	***
duration of crop rotation	1 years	28.75 $\pm$ 0.77	28.15 $\pm$ 0.82	37.3 $\pm$ 0.76	34.24 $\pm$ 0.77
	2 years	22.02 $\pm$ 0.54	22.01 $\pm$ 0.59	27.37 $\pm$ 0.45	26.59 $\pm$ 0.59
	3 years	14.27 $\pm$ 0.42	15.21 $\pm$ 0.43	19.21 $\pm$ 0.31	18.42 $\pm$ 0.40
	$\geq$ 4 years	9.99 $\pm$ 0.46	10.16 $\pm$ 0.42	13.75 $\pm$ 0.31	12.99 $\pm$ 0.35
P value		***	***	***	***
Growth stage	Vegetative	17.32 $\pm$ 0.75	17.44 $\pm$ 0.78	21.85 $\pm$ 0.64	20.66 $\pm$ 0.7
	Flowering	19.17 $\pm$ 0.83	19.09 $\pm$ 0.81	25.2 $\pm$ 0.79	23.97 $\pm$ 0.76
	Post flowering	19.34 $\pm$ 0.69	20.34 $\pm$ 0.61	27.42 $\pm$ 0.76	26.3 $\pm$ 0.81
P value		ns	Ns	ns	Ns
Planting density	< 22 plants m ⁻²	15.29 $\pm$ 0.57	15.1 $\pm$ 0.55	21.96 $\pm$ 0.67	21.08 $\pm$ 0.68
	$\geq$ 22 plants m ⁻²	21.26 $\pm$ 0.83	21.9 $\pm$ 0.81	27.64 $\pm$ 0.78	25.22 $\pm$ 0.80
P value		**	**	*	*
Weed density	<10 weeds m ⁻²	16.64 $\pm$ 0.80	17.2 $\pm$ 0.83	22.42 $\pm$ 0.52	20.91 $\pm$ 0.52
	$\geq$ 10 weeds m ⁻²	20.71 $\pm$ 0.90	20.55 $\pm$ 0.63	28.93 $\pm$ 1.00	27.75 $\pm$ 0.96
P value		**	*	**	**

Where, Early planting: Chickpea is planted during the first three weeks of September; Intermediate planting: Chickpea is planted between the last week of September and the second week of October; Late planting: Chickpea is planted after the third week of

October to the second week of November in both growing seasons. * $p \leq 0.05$, ** $p \leq 0.01$ and *** $p \leq 0.001$.

5.4.4. Interaction effect of biophysical factors on intensity of CFW

Analysis of variance (ANOVA) exhibited that planting time and duration of crop rotation showed significant ($p < 0.05$) variations in the degree of association with CFW intensity when two factors interacted ($p < 0.05$) (Appendix Table 2.). Planting time and duration of crop rotation practices were resulting in substantial variation in the intensity of CFW (Table 5.3). Thus, the least mean incidence (8.63%) and percent severity index (8.78%) were obtained from chickpea fields sown late in the season after four or more years of crop rotation practices during the 2022/2023 survey period. Conversely, the topmost (43.74% and 39.58%) mean incidence and percent severity index respectively, were recorded from chickpea fields characterized by early planting and one-year rotation practices in the year 2023/2024 (Table 5.3.).

Table 5.3. Interaction effect of planting time and crop rotation duration on incidences and PSI (mean $\pm$ SE) of chickpea Fusarium wilt during 2022-2024 cropping seasons

Disease intensity parameter	Duration of crop rotation	Planting time					
		2022/2023			2023/2024		
		Early	Intermediate	Late	Early	Intermediate	Late
Incidence (%)	1 year	29.39 $\pm$ 0.78	32.17 $\pm$ 0.91	21.18 $\pm$ 0.22	43.74 $\pm$ 0.46	37.57 $\pm$ 0.21	33.34 $\pm$ 0.94
	2 years	23.98 $\pm$ 0.40	21.64 $\pm$ 0.68	20.59 $\pm$ 0.24	28.63 $\pm$ 0.47	27.40 $\pm$ 0.55	26.95 $\pm$ 0.38
	3 years	17.3 $\pm$ 0.57	17.57 $\pm$ 0.63	12.59 $\pm$ 0.23	20.43 $\pm$ 0.38	20.07 $\pm$ 0.38	17.95 $\pm$ 0.96
	$\geq$ 4 years	14.89 $\pm$ 0.21	12.62 $\pm$ 0.18	8.63 $\pm$ 0.36	16.29 $\pm$ 0.42	13.97 $\pm$ 0.18	12.89 $\pm$ 0.23
PSI (%)	1 year	29.24 $\pm$ 0.81	31.07 $\pm$ 0.70	18.18 $\pm$ 0.72	39.58 $\pm$ 0.52	35.64 $\pm$ 0.24	32.54 $\pm$ 0.96
	2 years	22.83 $\pm$ 0.48	22.67 $\pm$ 0.69	19.73 $\pm$ 0.46	26.59 $\pm$ 0.42	26.51 $\pm$ 0.62	26.45 $\pm$ 0.62
	3 years	16.71 $\pm$ 0.33	17.62 $\pm$ 0.65	13.71 $\pm$ 0.27	19.19 $\pm$ 0.39	18.54 $\pm$ 0.38	17.15 $\pm$ 0.29
	$\geq$ 4 years	16.92 $\pm$ 0.40	14.82 $\pm$ 0.00	8.78 $\pm$ 0.33	15.33 $\pm$ 0.46	13.46 $\pm$ 0.39	12.14 $\pm$ 0.27

Where, PSI= percent severity index; Early planting: Chickpea planted during the first three weeks of September; Intermediate planting: Chickpea is planted between last week of September to second week of October; Late: Chickpea planted after third week of October to second week of November in both growing years

The interaction effects of most biophysical factors were significantly associated with the epidemic development of CFW disease. The reduced wilt incidence in late-planted chickpeas after long rotation practice could be due to reduced inoculum levels in the soil from extended period without the host, and unfavourable environmental conditions for inoculum survival and disease development, particularly late in the season when the soil moisture is no longer support the inoculum. However, the maximum wilt incidence from early planted chickpeas after short periods of crop rotation practice can be arisen from much inoculum in the soil coincides with high soil moisture and relatively high equilibrium relative humidity. The use of cropping systems like crop rotation practices in the integrated management of Fusarium wilt disease should not be disregarded to avoid recurrent increase of inoculum in soil (Jiménez-díaz and Jiménez-gasco, 2011). Besides, Dagnachew Bekele *et al.* (2021) reported that crop rotation and late planting were correlated with decreased disease incidence and clarified that in the absence of rotation or when chickpea was grown after other pulse crops, disease was more severe than with late planting and long rotation cycles.

5.4.5. Association of CFW incidence and severity with biophysical factors

Biophysical factors evaluated during the survey, displayed significant variations in their association with chickpea Fusarium wilt intensity, measured in incidence and severity index (Table 5.4 and 5.5). Preceding crop, crop rotation duration, farming experiences and planting density all demonstrate substantial deviance reduction and a very high statistical significance ($p \leq 0.001$), suggesting a strong initial influence on the likelihood of chickpea Fusarium wilt occurrence. Notably, planting time also showed a very highly significant ($p = 0.0038$) initial association, indicating that the time of planting plays a significant role in disease incidence. However, other variables, like altitude, growth stage, weed density and fungicide use exhibit less pronounced initial associations.

When considering the independent effects of these variables on incidence of chickpea Fusarium wilt (type 3 analysis), the significance and magnitude of their shift. Crop rotation duration and chickpea type maintain a very highly significant ($p \leq 0.001$) and substantial deviance reduction, reflecting their robust and independent effect on chickpea

Fusarium wilt incidence. Interestingly, planting time showed a considerable increase in deviance reduction and remained very highly significant ($p \leq 0.001$) in the type 3 analysis, suggesting a strong independent effect of planting time on disease incidence. Farming experience also exhibited a significant independent association. The reduced significance of the preceding crop and planting density in the type 3 analysis suggests that their initial impact might be partly explained by their relationships with other variables in the model.

Regarding the severity of the disease, type 1 analysis identified crop rotation duration and preceding crop as having the most significant ($p \leq 0.001$) impact on chickpea Fusarium wilt epidemics. Farming experiences and planting density also showed significant initial associations. Planting time exhibits a weak or no initial significance ($p \leq 0.0682$). However, the type 3 analysis revealed that the crop rotation duration and preceding crop manifested a significant association with disease severity, indicating their independent influence on the extent of chickpea Fusarium wilt. Planting density and farming experience also showed significant independent contributions. Notably, the significance of planting time diminishes in the type 3 analysis, suggesting that its influence on chickpea Fusarium wilt severity might be largely mediated through its association with other factors in the model..

The strong negative association between the duration of crop rotation with incidence of chickpea Fusarium wilt suggested that crop rotation potentially serves as a powerful protective shield against the development of chickpea Fusarium wilt. Thus, for one year increase in the duration of crop rotation, the odds of chickpea Fusarium wilt occurrence decreased by about 87.7%. Similarly, a farmers' field with long years of farming experience was associated with a 78.9% decrease in the odds of chickpea Fusarium wilt occurrence. Weed density was strongly associated with the occurrence of chickpea Fusarium wilt occurrence in a negative manner. This confirmed that effective weed management practices are capable of reducing the risk of chickpea Fusarium wilt occurrence by up to 69.5%. A statistically significant association was also observed between planting time and chickpea Fusarium wilt incidence (odds ratio=0.928). This again suggested that delayed planting of chickpeas decreased disease incidence by about

7.2%. In agreement with this finding Bereket Ali and Habtamu Terefe (2021) demonstrated that the probability of occurrence of high disease incidence and severity in pod setting stage was twice higher than the vegetative growth stage. Moreover, Sultan Mohamed *et al.* (2018) reported that higher levels of chickpea wilt and root rot epidemics on chickpea grown under poor weed management fields than those in weeded fields. According to the finding by Birhanu Gizaw *et al.* (2019), research results proved the advantage of chickpea by tef rotational production, where high productivity of both crops was sustainably realized.

Table 5.4. Logistic regression model for chickpea Fusarium wilt incidence (%) and severity (%) and likelihood ratio test on independent variables in six districts of West Amhara, Ethiopia

Independent variable	df	incidence LRT ^a				severity LRT ^a			
		Type 1		Type 3		Type 1		Type 3	
		analysis (VEF)		analysis (VEL)		analysis (VEF)		analysis (VEL)	
		DR	Pr> χ^2	DR	Pr> χ^2	DR	Pr> χ^2	DR	Pr> χ^2
District	5	0.18	0.6750	2.32	0.1277	0.12	0.7334	0.62	0.4205
Altitude	1	7.65	0.0057	1.32	0.2499	6.19	0.0129	0.67	0.4135
Preceding crop	2	14.02	0.0002	3.40	0.0652	14.10	0.0002	4.75	0.0292
Crop rotation duration	3	161.34	0.0000	56.90	0.0000	151.05	0.0000	61.67	0.0000
Farming experience	2	14.73	0.0001	13.65	0.0002	8.94	0.0028	8.87	0.0029
Planting density	1	27.33	0.0000	0.75	0.0563	19.05	0.0000	14.96	0.0001
Planting time	2	8.38	0.0038	27.24	0.0000	3.32	0.0682	1.01	0.3155
Growth stage	2	0.11	0.7360	0.77	0.3803	1.95	0.1624	0.81	0.3668
Weed density	1	0.40	0.5262	0.14	0.7127	0.70	0.4040	0.39	0.5337
Chickpea type	1	3.20	0.0748	22.06	0.0000	0.67	0.4147	0.33	0.5657
Fungicide use	1	3.93	0.1403	0.73	0.3928	3.68	0.0552	3.94	0.0471

^aLRT = likelihood ratio test; VEF = variable entered first; VEL = variable entered last; DR = deviance reduction; Pr = probability of an χ^2 exceeding the deviance reduction; χ^2 = chi-square; df = degrees of freedom

The logistic regression analysis explored the factor influencing the likelihood of chickpea Fusarium wilt incidence (Table 5.4). The odd ratios derived from the model provided a measure of the magnitude and direction of association between each variable category and the probability of chickpea Fusarium wilt occurrence. Considering the preceding crop, planting chickpea following cereal crops including barley, maize, rice, tef, and wheat resulted in a 66.2% in the odds of chickpea Fusarium wilt, representing about 2.96 times lower risk than planting after legumes. Similarly, planting chickpea after crops, like potato and onion was associated with a substantial (78.3%) reduction in the odds of chickpea Fusarium wilt, indicating an approximately 4.61 times lower risk than legumes (Table 5.5. and Table 5.6.). These results underscore the pivotal role of prolonged crop rotation as a fundamental strategy for disrupting the pathogen's cycle and effectively mitigating disease intensity within chickpea cultivation system.

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Table 5.5. Analysis of deviance, natural logarithms of odds ratio and standard error of chickpea Fusarium wilt incidence (%) and likelihood ratio test on independent variables in reduced regression model in six districts and three zones in West Amhara, Ethiopia.

Added variable	Residual deviance	df	incidence LRT		Variable class	Est. log	SE	Odds ratio
			DR	$\text{Pr} > \chi^2$				
Preceding crop	138	2	5.280	0.001	Cereals	-1.084	0.110	0.338
			6.001	0.0001	Others	-1.530	0.024	0.217
					Legumes	0.000*		1.000
					1 year	0*		1.000
Crop rotation duration	123.87	3	14.130	0.130	2 years	-0.877	0.241	0.416
			2.530	0.0054	3 years	-4.052	0.010	0.174
			0.720	0.001	4 and more	-5.259	0.004	0.052
					<15 years	0.000*		1.000
Farming experience	113.75	2	10.120	0.0123	15-30 years	-1.461	0.075	0.232
			3.560	0.021	> 30 years	-3.194	0.015	0.041
					Early planting	0.000*		1.000
			1.060	0.309	Intermediate	-0.526	0.196	0.591
Planting time	107.44	2	6.310	0.037	Late planting	-2.235	0.034	0.107
					< 22 plants	0.000*		1.000
Planting density (m ⁻²)	87.44	1	13.090	0.000	≥ 22 plants	1.268	0.861	3.554
				0.000	Desi	1.039	0.671	2.824

Chickpea type	73.44	1	14.000	Kabuli	0.000*	1.000
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Where, Early planting: Chickpea planted during the first three weeks of September; Intermediate planting: Chickpea is planted between last week of September to second week of October; Late: Chickpea planted after third week of October to second week of November in both growing years; LRT = likelihood ratio test; DR = deviance reduction; SE= standard error; *= reference group; Pr = probability of an χ^2 exceeding the deviance reduction.

Table 5.6. Analysis of deviance, natural logarithms of odds ratio and standard error of Chickpea Fusarium wilt severity (%) and likelihood ratio test on independent variables in reduced regression model in six districts of West Amhara, Ethiopia

Added variable	Residual deviance	df	severity LRT		Variable Class	Est. log	SE	Odds ratio
			DR	Pr> χ^2				
Preceding crop	126	2	7.06	0.147	Cereals	-2.34	0.096	0.285
			4.18	0.042	Others	-2.35	0.095	0.218
					Legumes	0.00*		1.000
					1 year	0.00*		1.000
Rotation duration	132.87	3	10.65	0.113	2 years	-1.61	0.1994	0.348
			3.8	0.0054	3 years	-4.58	0.0103	0.017
			1.02	0.0017	4 and more	-5.26	0.0052	0.007
					<15 years	0.00*		1.000
Farming experience	142.91	2	11.47	0.143	15-30 years	-2.49	0.083	0.264
			5.23	0.029	> 30 years	-3.91	0.020	0.057
					Early	0.00*		1.000

			4.66	0.391	Intermediate	-1.44	0.237	0.736
Planting time	112.13	2	17.74	0.079	Late	-3.12	0.044	0.145
					< 22 plants m ⁻²	0.00*		1.000
Planting density	100.61	1	6.09	1.985	≥ 22 plants m ⁻²	1.16	0.763	3.177
				1.51	Desi	0.87	0.562	2.389
Chickpea type	59.52	1	8.98		Kabuli	0.00*		1.000

Where, Early planting: Chickpea planted during the first three weeks of September; Intermediate planting: Chickpea is planted between last week of September to second week of October; Late: Chickpea planted after third week of October to second week of November in both growing years; LRT = likelihood ratio test; DR = deviance reduction; *= reference group; Pr = probability of an χ^2 exceeding the deviance reduction.

5.4.6. Morpho-cultural variability of CFW isolates

Wilting and yellowing were the typical symptoms detected under field conditions thereby sample collection was directed based on these symptoms. Subsequently, vascular discoloration was observed upon longitudinal splitting roots of chickpea plants exhibiting wilting and yellowing symptoms, confirming the presence of the pathogen. This discoloration was a key indicator for laboratory inoculation, resulting in successful growth and sporulation of *Fusarium oxysporum* f.sp. *ciceris* from all wilted/yellowing plant samples. Following a seven-day inoculation and incubation period at 25±2°C, *Fusarium oxysporum* f.sp. *ciceris* (FOC) isolates showed variations in their colony color, texture and radial growth. Radial growth of isolates was measured and found to range between 33.41 and 76.17 mm, with the later representing the maximum growth recorded for isolate FOC 15. Based on radial growth patterns, isolates were grouped into three categories as slow (<50 mm), moderate (50-60 mm) and fast growth (> 60 mm) after seven days of inoculation and incubation. Proportional to their growth rate, 27.7% of the isolates were regarded as slow-growing, 50% as moderately growing and 22.3% rapid growth (Table 5.7). Besides, the colony of the isolates exhibited three distinct color variations of white, dull white and purplish.

Table 5.7. Cultural characteristics of *Fusarium oxysporum* f.sp. *ciceris* isolates collected from West Amhara, Ethiopia, during the 2022/23 cropping season.

Isolates	Colony colour	Colony texture	Radial growth (mm)			Growth performance	Elevation
			3 rd	5 th	7 th		
FOC 1	White	fluffy	12.53	30.24	51.09	moderate	raised
FOC 2	dull white	less fluffy	26.72	49.06	64.51	fast	raised
FOC 3	Purplish	appressed	9.08	22.71	33.41	slow	flat
FOC 4	White	fluffy	13.6	32.91	50.74	moderate	raised
FOC 5	White	fluffy	9.87	23.91	35.72	slow	flat
FOC 6	White	fluffy	8.19	19.77	36.12	slow	raised
FOC 7	dull white	fluffy	28.61	55.17	69.75	fast	raised
FOC 8	White	fluffy	10.82	25.19	39.57	slow	flat
FOC 9	dull white	appressed	14.17	34.81	50.24	moderate	raised

FOC 10	White	fluffy	13.94	35.12	51.85	moderate	raised
FOC 11	Purplish	appressed	16.22	38.59	63.14	moderate	raised
FOC 12	dull white	appressed	15.93	41.3	50.72	moderate	raised
FOC 13	White	fluffy	11.18	27.73	42.63	slow	flat
FOC 14	White	fluffy	23.61	43.61	62.14	fast	raised
FOC 15	White	fluffy	28.16	53.67	76.17	fast	raised
FOC 16	White	fluffy	19.46	43.45	53.62	moderate	raised
FOC 17	White	fluffy	13.34	23.86	50.52	moderate	raised
FOC 18	White	fluffy	17.05	40.67	52.87	moderate	raised

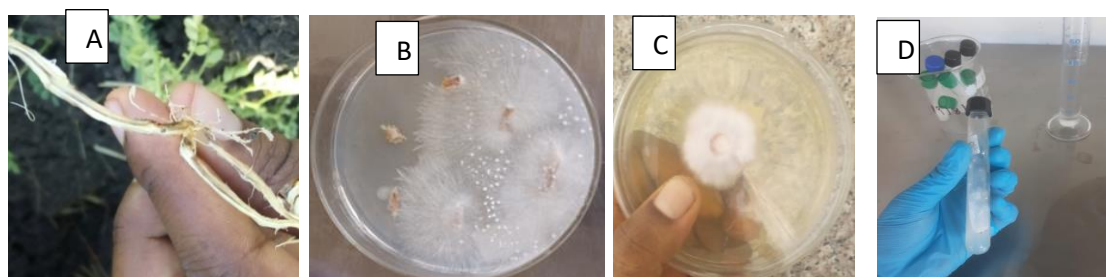


Figure 5.4. Isolation and characterization of *Fusarium oxysporum* f.sp. *ciceris*. Infected plant with vascular discoloration (A); mother culture grown on PDA (B); pure culture purified from the mother culture (C); and preserved isolate /slant preservation (D)

5.4.7. Pathogenic variability of chickpea *Fusarium* wilt isolates

All *Fusarium oxysporum* f.sp. *ciceris* isolates tested on JG-62 susceptible chickpea variety were found to be pathogenic, able to induce yellowing and wilting symptoms though variations in their levels of wilt intensity were noticed. About 61% of the isolates were moderately pathogenic by causing wilt incidence of 30-50%. The rest 22.2 and 16.7% of the isolates were found to be highly pathogenic and less pathogenic by inducing above 50% and less than 30% wilt incidences respectively. Pots planted without inoculum were used as control plots and retained healthy and symptom-free chickpea stands (Figure 5.5 and Table 5.8). Pathogenicity of *Fusarium oxysporum* f.sp. *ciceris* isolates was rigorously confirmed through fulfilment of Koch's postulate, the fungus was isolated cultured and inoculated into healthy JG-62 chickpea plants resulting in the occurrence of disease symptoms (yellowing and wilting). Following re-isolation, the pathogen then displayed cultural characteristics consistent with the original isolate.



Figure 5.5. Pathogenicity test of *Fusarium* isolates on chickpea, left: inoculated chickpea. Right: un inoculated control chickpea

Previous studies also reported that the level of pathogenicity and virulence of FOC isolates significantly varied. According to Shehabu Meki *et al.* (2008), all FOC isolates collected from farmers' fields and wilt sick plots infected and caused different levels of *Fusarium* wilt severity. Besides, according to the report by Hossain *et al.* (2013) it is documented that isolates of *Fusarium oxysporum* resulted in an infection potential of weekly virulent to highly virulent against their origin of chickpea seed samples in pot culture based on pathogenicity test. Moreover, Bereket Ali and Habtamu Terefe (2021) also disclosed that infected chickpea samples collected from North Shewa Zone of 5 districts showed that twenty six *Fusarium oxysporum* f.sp. *ciceris* isolates were identified. All isolates were considerably diverse in their colony color colony texture, sporulation capacity, conidial shape and size, septation character, and chlamydospore types. Most of the isolates were highly pathogenic, causing $\geq 50\%$ wilting (Bereket Ali and Habtamu Terefe, 2021).

Table 5.8. Chickpea Fusarium wilt incidence (%) induced from *Fusarium oxysporum* f.sp. *ciceris* isolates tested on the susceptible variety JG-62 under greenhouse conditions

Sampling districts ^x	Isolates ^y	Wilt incidences (%) ^z				Sampling districts	Isolates ^y	Wilt incidences (%) ^z			
		30DAE	45DAE	60DAE	Mean			30DAE	45WAE	60DAE	Mean
Bahir Dar zuria	FOC1	19.10	38.10	47.62	34.89	Libo Kemkem	FOC10	33.30	38.10	38.52	36.49
	FOC2	47.62	61.91	66.67	58.70		FOC11	23.81	42.86	52.38	39.68
	FOC3	0.00	38.95	57.14	32.03		FOC12	19.10	52.38	52.38	41.29
Enarj Enawga	FOC4	28.60	38.10	38.10	34.93	Fogera	FOC13	4.76	23.81	23.81	17.46
	FOC5	23.81	42.86	57.14	33.40		FOC14	19.05	61.90	76.19	52.38
	FOC6	0.00	9.52	14.28	7.94		FOC15	47.62	52.38	80.95	60.30
Yilmana Densa	FOC7	42.86	57.14	85.71	62.86	Enemay	FOC16	33.30	42.86	57.14	44.48
	FOC8	0.00	9.52	42.86	17.46		FOC17	19.09	28.57	47.61	31.76
	FOC9	14.28	47.62	47.62	36.51		FOC18	14.28	28.57	71.4	38.09
Control	-	0.00	0.00	0.00	0.00		-	-	-	-	-

^xDistricts where isolates were collected; ^yFO= *Fusarium oxysporum* f.sp. *ciceris* isolates; ^zDAE= days after emergence.

5.5. Conclusion and Recomendations

This study elucidated that chickpea Fusarium wilt was the most widely distributed disease of economic importance threatening chickpea productivity. Thus, the study generated indispensable information on the socio-economic status, cropping systems, cultural and agronomic practices found to be risk factors influencing chickpea Fusarium wilt epidemics in the area. Risk factors like farming experience, planting time, duration of crop rotation practices, and weed density were significantly associated with wilt intensity and strongly influenced wilt development alone or in combination. The relative importance of risk factors studied, which could imply that variables contributed roles to reduce or enhance wilt epidemic development in the study areas. Therefore, setting effective sustainable chickpea Fusarium wilt management could target the key biophysical factors are critically essential to overcome the disease pressure. Thus, based on the current finding; maintaining weed free environment; delayed planting of chickpea right after the harvest of early matured crops; planting of chickpea after extended crop rotation practice notably four or more years emphasis on integrating them together was identified as pivotal practices to achieve better management of chickpea Fusarium wilt. This could profoundly contribute to sustainable chickpea production and productivity due to the fact that minimization of agrochemical application.

CHAPTER 6: Pathogenic Potential and Virulence of *Fusarium oxysporum* f.sp. *ciceris* Isolates Associated with Chickpea Seeds

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Abstract

Chickpea *Fusarium* wilt caused by *Fusarium oxysporum* f. sp. *ciceris* is the most destructive disease in Ethiopia. Although it is both seed-borne and soil-borne pathogen, the role of seed-borne *Fusarium oxysporum* in causing pathogenicity in pathogen free soils is underestimated. Using *Fusarium oxysporum* infected chickpea seeds, directly collected from fields based on symptoms, evidence of establishing wilt disease in the FOC-free soils is provided. The result revealed that the mean germination percentage for seeds harvested from infected chickpea plants dropped dramatically to $72.66\% \pm 8.6$, representing an average reduction of over 17.5% due to the presence of the pathogen compared to those sourced from healthy mother plants. It was also noted that there was a substantial reduction (41%) in seedling dry weight from the infected samples compared to the healthy ones due to the pre-harvest impairment of the naturally infected chickpea seeds. Wilting and yellowing symptoms appeared in 62.5% of the isolates collected from infected chickpea seed and symptoms started 22 days after inoculation. In conclusion, the current result confirmed that *Fusarium* wilt of chickpea expressed seed-borne nature apart from being soil borne and seeds harvested from wilted plants when mixed with healthy seeds can carry the wilt fungus to new areas and can establish the disease in the soil which can result in subsequent infection.

Keywords: Disease, germination, infection, pathogenicity test, seed-borne, symptom, wilting, yellowing

6.1. Introduction

Seed is the basic input of agricultural production on which the performance and efficacy of other inputs depend (Girma Abebe and Amanuel Alemu, 2017; Merkebu Ayalew, 2020). It is not only a carrier of the genetic resources for food and agriculture, it is also a basic element of any crop production system and thus fundamental for food security (Merkebu Ayalew, 2020). Seed plays a critical role in increasing agricultural productivity as it determines the upper limit of crop yields and the productivity of all other agricultural inputs to the farming system. Increasing the quality of seeds can increase the yield potential of the crop by significant folds and, is one of the most economical and efficient inputs to agricultural development (Girma Abebe and Amanuel Alemu, 2017). The use of high quality seeds is one of the most important elements in increasing agricultural production in any farming system (Sabry Elias, 2018; Akpo *et al.*, 2020; Kansiime *et al.*, 2021).

A healthy seed is an assurance and proxy of crop establishment for sustainable production and productivity (Gezahegn Getaneh, *et al.*, 2020). However, there are a variety of factors involved in the yield loss in which many of the plant pathogenic organisms being seed-borne that can cause considerable crop losses, reduction in plant growth and productivity of crops. Seed-borne diseases are among the most important biotic constraints for both pre- and post-emergence death of plants, affect seedling vigor, and cause a reduction in germination, poor crop stand and variation in plant morphology (Niaz and Dawar, 2009; Gezahegn Getaneh *et al.*, 2020). The seed-borne pathogens associated with seeds externally or internally may cause various infection, viz., seed rot, seed necrosis, reduction or elimination of germination capacity, as well as seedling damage resulting in development of disease at later stages of plant growth by systemic infection (Kesho and Abebe, 2020). The infected seeds may fail to germinate, transmit disease from seed to seedling and from seedling to growing plants (Fakir *et al.*, 2002).

Chickpea Fusarium wilt caused by *Fusarium oxysporum* f. sp. *ciceri*, is a seed and soil-borne disease of economic importance. The fungus is systemic and can be isolated from all parts of the infected plant including seeds (Haware, Nene and Natarajan, 1996). It was demonstrated that the fungus was found in the hilum of cotyledons and axis of the seed in the form of chlamydospore like structures (Haware and Nene, 1978; Asrat Zewdie 2017). Different seed sources and way of disease management could influence the status of chickpea seed infection rate and health. Assessing seed quality and health is critically important for improving the production and productivity of chickpea; besides, it is a critical step towards developing sustainable integrated chickpea wilt diseases management. Understanding the pathogen survival and source of inoculum is an important aspect of Chickpea Fusarium wilt management. Therefore, there is a need to identify the causal organisms and determine its seed-borne nature in for implementation of appropriate disease management strategies.

The disease compromises the quality, making affected products less marketable mainly through the production of shriveled, lighter seeds and decreased protein content (Alsamman *et al.*, 2023). In Ethiopia, Gezahegn Getaneh *et al.* (2020) reported that *Fusarium oxysporum* f.sp. *ciceris* was one of the most frequently detected fungi after *Aspergillus flavus* and *Penicillium crustosum* isolated from the seeds of chickpea. However, the authors concentrated on the fungal presence and frequency; no clue was reported whether the pathogen caused chickpea wilt diseases or not. Besides, Hossain *et al.* (2018) reported that different isolates of *Fusarium oxysporum* f.sp. *ciceris* resulted in an infection potential that ranged from weakly virulent to highly virulent against their origin of chickpea seed samples in pot culture based on the pathogenicity test. However, in Ethiopia, very limited efforts were made regarding the infection rate by *Fusarium oxysporum* f.sp. *ciceris* in the seeds of chickpea. Besides, scientific evidence is lacking on the pathogenic ability of *Fusarium oxysporum* f.sp. *ciceris* isolated from seeds of chickpea in Ethiopia particularly in northwestern parts of the country, a potential chickpea producer area. The seasonal climatic variation of Ethiopia and improper traditional storage condition contribute to make the storage environment highly supportive for fungal attack to the nutrient rich seeds.

Chickpea wilt caused by *Fusarium oxysporum* f.sp. *ciceris*, is the most destructive disease worldwide, including many chickpea producing areas of Ethiopia. However, the role of seed-borne FOC in introducing and establishing wilt in FOC free soils is unknown (Pande, Rao and Sharma, 2007). Following infection of host roots, the fungus enters the xylem tissues and spreads rapidly up through the vascular system, becoming systemic in the host tissues, and may directly infect the seed (Hossain *et al.*, 2013). There is insufficient or no updated information on the current chickpea seed health status in Ethiopia, one of the major producers of chickpea globally (Gezahegn Getaneh, *et al.*, 2020). Regrettably, there is limited existing knowledge regarding the pathogenic potential and virulence of FOC pathogen associated with chickpea seed and their influence on seed viability and seedling vigor. Therefore, the present study was under taken to evaluate pathogenic potential and virulence of *Fusarium oxysporium* f.sp. isolates sourced from chickpea seeds.

6.2. Materials and Method

6.2.1. Description of the study area

Chickpea seed sample collection was carried out from four districts, known for their chickpea production in East and North Gojam Zone of Amhara National Regional State (Figure 6.1.). The districts were Bahir Dar zuria, Enarj Enawga, Enemay, and Yilmana Densa, from October-January cropping seasons of 2022/23 and 2023/24. Cereal based mixed farming systems and uni-modal rainfall patterns are common features of the selected districts. Generally, the soil is commonly characterized by its vertisol nature in most areas of the districts. The altitude in the surveyed areas ranged between 1805 and 2568 m.a.s.l. (Table 6.1.). The major common crops grown in all four study districts included tef [*Eragrostis tef* (Zucc.) Trotter], bread wheat (*Triticum aestivum* L.), and chickpea (*Cicer arietinum* L.) (CSA, 2021).

Table 6.1. Description of the study districts: Mean altitude, average rainfall, temperature and major crops grown in the respective districts of West Amhara, Ethiopia.

Average	Average	Temperature (°C)
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Districts	Altitude (m.a.s.l)	RF (mm)				Major crops grown
			T min	T max	T mean	
Bahir Dar Zuria	1950	1050	15.3	32.5	22.80	chickpea, maize, millet, tef,
Enarj Enawga	2400	2751	11.8	22.6	17.20	barley, chickpea, tef, wheat,
Enemay	2570	1610	14.3	22.4	17.86	Chickpea, tef, wheat,
Yilmana Densa	2130	2241	10.6	21.8	16.20	barley, chickpea maize ,tef,

Where RF= rainfall; m.a.s.l.= meters above sea level; Sources (Central Statistical Agency (CSA), 2021) and National Meteorological Agency

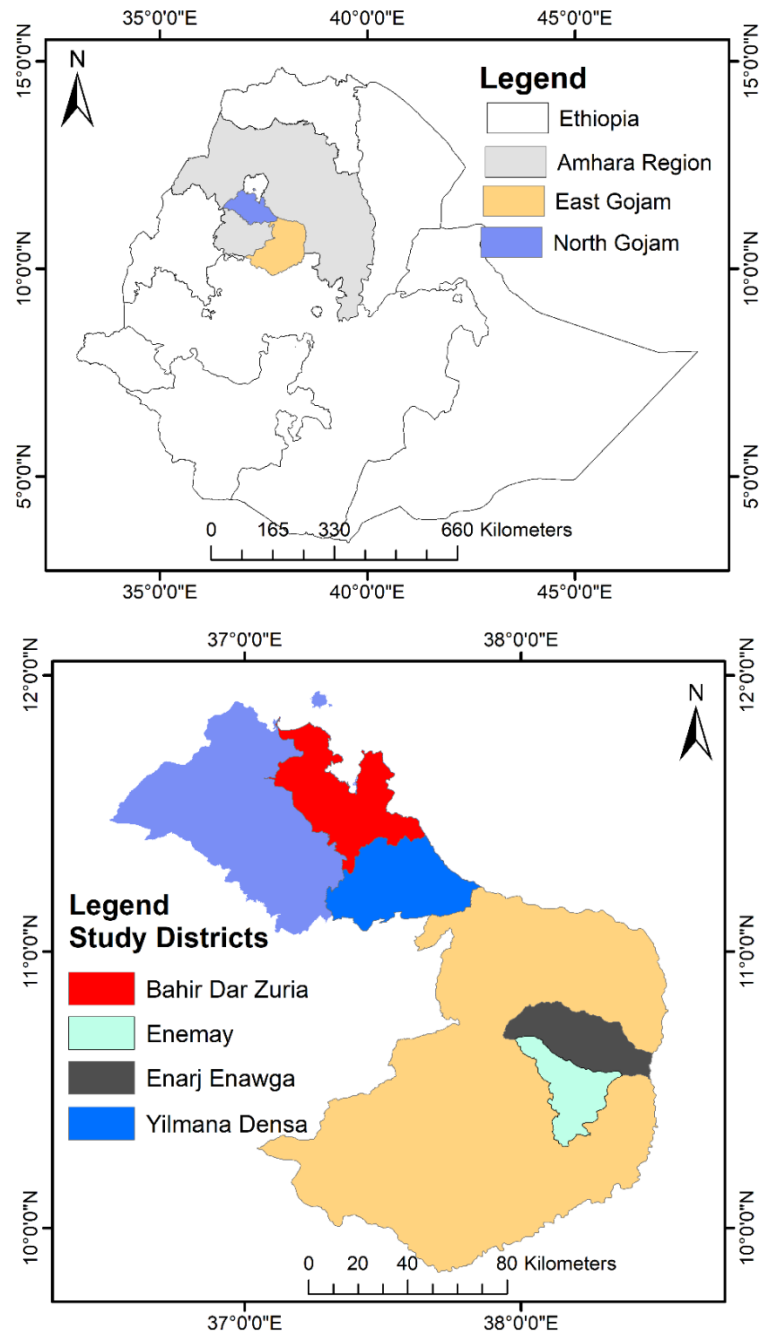


Figure 6.1. Map of Ethiopia showing the study areas: Two Zones and four districts.

6.2.2. Sampling procedures and techniques

Chickpea seed samples were collected from naturally *Fusarium*-infested fields in in East and North Gojam Zones of Amhara National Regional State, namely, Yilmana Densa and Bahir Dar Zuria districts in North Zone; and Enarj Enawga and Enemay districts in East Gojam Zone. Seeds were collected from wilted plants of the chickpea cultivar that area

already infected by the Fusarium wilt disease (Pande, Rao and Sharma, 2007) during 2023 cropping season. Infected seed samples collection was made based on distinct wilting, yellowing symptoms and dropping, typical symptoms for chickpea Fusarium wilt. Healthy seed samples were selectively harvested from healthy mother plants that were completely devoid of any visible external symptoms of chlorosis, wilting, or vascular degradation, serving as the baseline for high physiological quality. Farmers' practice samples were obtained by representing the local traditional harvesting method, which consists of mass harvesting the entire field plot simultaneously. In this category, bulk seeds were gathered together as a single lot without any sorting, grading, or separation into diseased or healthy categories. These seeds were air-dried at room temperature and stored at 5 °C in the refrigerator in the Biotechnology Laboratory, Bahir Dar University, and kept at 25 ± 2 °C.

6.2.3. Isolation and identification procedures

Identification of fungi was conducted using the agar plate method, which is the most common approach for identifying seed-borne fungi (Rao and Bramel, 2000). Exactly 100 seeds per sample were surface-sterilized quickly by rinsing in 70% ethanol, then soaking in 1% sodium hypochlorite (NaOCl) solution for two minutes, and then washing with distilled water. Then, five seeds per dish were plated at equidistance on general-purpose agar medium under aseptic conditions and incubated for ten days. Petri dishes containing the sample were incubated at 27 ± 1 °C with 12 hours alternating cycles of day and darkness, and fruiting bodies of pathogens were examined under a compound microscope. The growth of fungi was inspected every two days and sub-cultured until the eleventh day. The seeds were examined under a microscope for identification. The seed-borne fungi found on each seed was isolated and identified using standard microbiological methods following the techniques developed by ISTA (1976) and brought into pure cultures and maintained on potato dextrose agar (PDA) slants. Light microscopy was used for identification based on morphological characters of mycelia structure, form of colony growth and fruiting bodies according Watanabe (2002).

The location of the fungi in the seed was detected by employing component plating technique. Seeds were washed four times with tap water, then surface-sterilized in 1% NaOCl solution as mentioned above. These seeds were washed again with sterile distilled water (SDW) and soaked in water for 30 min. On the other hand, other seed samples were used without sterilization, just soaked in pure water for 30 minutes. Seeds were dissected aseptically using sterile needle and forceps. The separated seed parts, viz., seed-coat, cotyledons and embryos were plated immediately before drying on plates containing PDA. The plates were incubated at 27±1 °C for seven days. Then, the preparation was examined under stereo-binocular microscope for the presence of the pathogen in different seed parts. The number of contaminated parts was counted every 3 days for a period of 15 days. The infection level of each part was evaluated according to the following formula:

$$\text{Infection level (\%)} = \frac{\text{Total number of infected seeds} \times 100}{\text{Total number of tested seeds}}$$

The fungal colonies, which developed around every seed part, were replicated on PDA (potato dextrose agar) added with the antibiotic streptomycin sulphate.

6.2.4. Data collection

Germination test-Standard seed germination test was carried out for all seed samples in a completely randomized design (CRD). Three hundred seeds from the pure seeds' component were taken and replicated three times of 100 seeds each and planted in sand media at room temperature. The first count was done 6 days after planting, and the final count 8 days after planting as specified by International Seed Testing Association (ISTA) rules, ISTA (2008). The result of the germination test was calculated as the average of three replications. It was expressed as the percentage of normal seedlings. The percentages of abnormal seedlings, hard, fresh and dead seed were calculated in the same way.

$$\text{Germination (\%)} = \frac{\text{Total number of normal seedlings}}{\text{Total number of seeds planted}} \times 100$$

Seedling dry weight (g) - The seedling dry weights was measured after the final count of the Standard germination test. Ten randomly selected seedlings from each replication were taken and placed in envelopes and dried in an oven at 80°C for 24 hours then the dried seedlings were weighed using digital sensitive balance and the average seedling dry weight was calculated.

Seedling Vigor Index-II: Seedling vigor index-II was calculated by multiplying the standard germination with the average sum of shoot and root length after the final days of germination: Vigor Index II= Seedling dry weight * Germination percentage. Out of the 500 grams of sample, a sub-sample of 200 hundred seeds from each sample was taken and placed on three layers of moistened blotters in 12cm diameter Petri-plates at the rate of 25seeds per petri-plate following ISTA (1976).

The frequency of infection and percent of infection were determined following Bishaw *et al.* (2013), formulae given below.

$$\text{Infection Frequency (IF) (\%)} = \frac{\text{No. of sample of occurrence of species}}{\text{Total number of samples}} * 100$$

$$\text{Percent Infection (PI) (\%)} = \frac{\text{Number of infected seeds}}{\text{Total number of seeds examined}} * 100$$

Pathogenicity test: Fusarium isolates were grown on PDA and the conidia were harvested by flooding the cultures, and the suspension was collected and filtered through two layers of sterilized cheesecloth. The spores were then adjusted to 1×10^6 conidia per milliliter (mL^{-1}) by repeated hemocytometer counts. Chickpea plants were grown in plastic pots, with 3 plants per pot, containing sterilized potting medium (soil, sand, farmyard manure at a ratio of 1:1:1). For inoculation, a channel, about 1 cm long and 3 cm deep, was created in the soil near each seedling and filled with 10 mL spore suspension. Controls were treated with sterile distilled water only. Four replicate pots per treatment were employed. Inoculated plants were covered with clear plastic bags for 24

hours to maintain high humidity and placed in the glasshouse at 25 °C day/night temperature and irrigated with distilled water on alternate days. Symptoms were recorded 30 days after treatment. Disease symptoms on roots and stems were scored using a four-point (0-3 scoring scale) categorical disease severity scale, where 0 = no wilting symptoms, 1 = 25% wilting, 2 = 50% wilting and 3 = 100% wilting and plant death.

Re-Isolation: To verify that the inoculated *Fusarium* isolates caused the symptoms on the chickpea seedlings, re-isolations were conducted from symptomatic parts of inoculated plants. Seven days after inoculation, symptomatic tissues were surface-sterilized in 10% NaOCl twice for 2 min, followed by rinsing with autoclaved distilled water for 2 min. Three pieces (3-6 mm long) of roots or stems per plant were excised under aseptic conditions and transferred to PDA in Petri dishes. Dishes were incubated at 28 °C until the appearance of typical *Fusarium* colonies, approx. 6 days after plating.

6.3. Statistical Analysis

The collected data were subjected to a series of independent samples T-tests to compare the performance between the two independent groups defined by seed health (infected seed samples and healthy seed samples) using STATA (version 17.0) software. The independent samples T-test was performed separately for each parameter to assess if the observed differences in group means were statistically significant, conducted at the 95% level of significance. The mean and standard deviation were computed for each dependent variable using summary and descriptive statistics.

6.4. Results and Discussion

6.4.1. Seed viability and germination percentage

The overall mean germination percentage for samples sourced from healthy plants was (90.42% $\pm$ 9.91), which served as a robust baseline for high seed vigor. In contrast the mean germination percentage for seeds harvested from infected chickpea plants dropped dramatically to 72.66% $\pm$ 8.61, representing an average reduction over 17.5% due to the presence of the pathogen (Figure 6.2).

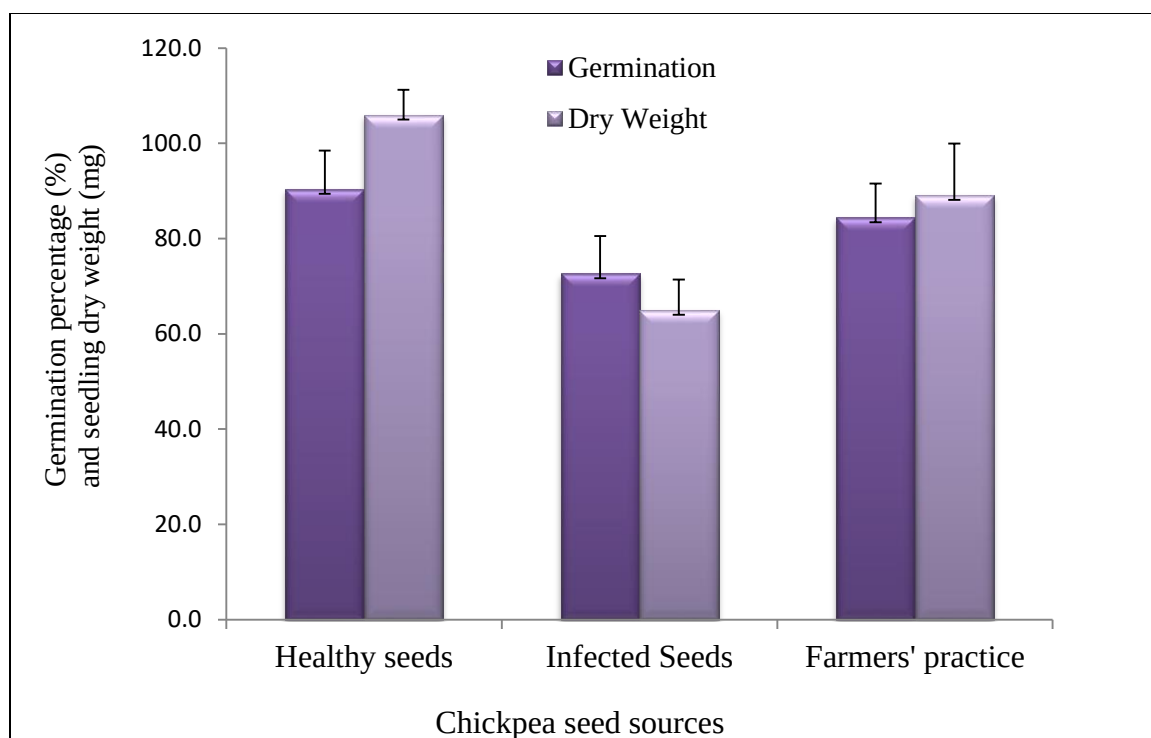


Figure 6.2. Effect of chickpea seed infection by *Fusarium oxysporum* f.sp. *ciceris* on germination percentage and dry weight of chickpea

Germination percentage of chickpea was significantly associated with FOC infection. The result clearly indicated that the fungal isolates significantly compromised seed viability, resulting in a substantial reduction in germination percentage across all tested samples. This confirms the severity of the disease, suggesting that the pathogen can cause significant pre-emergence infection. The low germination rate in *Fusarium* infected seeds could be linked to key physiological mechanisms induced by the FOC pathogen (Table 6.2.). The systematic infection compromises the hosts' vascular system, leading to rapid water stress and visible symptoms such as premature death of the chickpea plant. This directly contributes to premature senescence and desiccation, which results in the premature drying of seeds in the field. The cessation of normal physiological process, coupled with the impaired translocation, means the seed develop with less dry matter accumulation, resulting in shriveled and lower weight seeds when harvested. This confluence of factors reduced nutritional reserves, structural damage, and poor physical quality and poor seed quality and ultimately resulted in failure to germinate successfully.

A wide range of variations was observed among the infected seed lots with germination percentage ranging from 51.3% to a high germination percentage of 73.8%. In agreement with this finding, Rathi (2019) previously reported that seed germination of chickpea was reduced significantly in artificially-inoculated seeds with *Fusarium oxysporum* f.sp. *ciceris* as compared to the uninoculated seeds, which were due to the influence of seed borne infection. It also caused maximum number of seedling mortality in the inoculated seeds. Further to this investigation, Salerno and Lori (2007) disclosed that various seed-borne fungi affected the viability of seeds and caused damping-off. The presence of fungi does hamper effective seedling production through loss of out-planted stock, as pathogenic fungi weaken seeds.

Table 6.2. Germination percentage and seedling dry weight of seeds as influenced by *Fusarium oxysporum* infection

Chickpea Seed Samples	Germination percentage (%)				Seedling dry weight (g)			
	Infected seeds	Std. dv.	Healthy seeds	Std. dv.	Infected seeds	Std. dv.	Healthy seeds	Std. dv.
CSS1	58.75	8.54	93.75	4.79	0.061	0.0010	0.149	0.0220
CSS2	68.75	12.50	95.0	10.00	0.069	0.0009	0.157	0.0180
CSS3	60.00	7.07	83.75	7.50	0.057	0.0020	0.079	0.0110
CSS4	51.25	4.79	93.75	2.50	0.061	0.0070	0.125	0.0230
CSS5	62.50	5.00	86.25	7.50	0.064	0.0125	0.103	0.0140
CSS6	57.50	4.08	90.00	11.55	0.066	0.0110	0.095	0.0170
CSS7	60.00	2.50	77.50	5.00	0.054	0.0109	0.081	0.0130
CSS8	67.50	10.41	92.50	5.00	0.077	0.0130	0.146	0.0240
CSS9	57.50	2.89	90.00	7.07	0.053	0.0106	0.138	0.0201
CSS10	63.75	6.29	85.00	9.13	0.062	0.0121	0.088	0.0150
CSS11	68.75	6.29	86.25	11.08	0.070	0.0022	0.091	0.0129
CSS12	61.25	2.50	93.75	6.29	0.057	0.0060	0.102	0.0162
CSS13	63.75	2.50	91.25	7.50	0.066	0.0132	0.124	0.0174
CSS14	66.25	4.79	96.25	4.98	0.073	0.0014	0.185	0.0281
CSS15	58.75	7.50	92.50	2.89	0.068	0.0050	0.141	0.0232
CSS16	57.50	5.00	87.50	6.45	0.054	0.0090	0.110	0.0146
CSS17	60.00	8.17	91.25	7.50	0.065	0.0052	0.096	0.0117
CSS18	63.75	8.54	92.50	8.66	0.067	0.0034	0.113	0.0186
CSS19	53.75	2.50	93.75	9.46	0.060	0.0071	0.114	0.0159
CSS20	61.25	6.29	93.75	2.50	0.056	0.0062	0.131	0.0247
CSS21	71.25	7.50	90.00	8.16	0.075	0.0113	0.099	0.0183

CSS22	62.25	2.50	91.25	11.81	0.072	0.0041	0.113	0.0138
CSS23	73.75	2.50	93.75	9.46	0.079	0.0081	0.107	0.0210
CSS24	56.25	4.79	88.75	6.29	0.066	0.0062	0.097	0.0125
Total	62.66	8.61	90.42	7.91	0.065	0.0071	0.116	0.0178

6.4.2. Seedling dry weight (g)

The mean dry weight for seedlings from healthy seeds across all comparisons was approximately 0.106 g, whereas the mean for seedlings from infected seeds was only about 0.065 g. This represents a significant decrease of nearly 41% in biomass accumulation during the initial growth phase (Figure 6.2.). The reduction in dry weight is a direct consequence of infection by the fungi, which likely consume seed reserves and/or release phytotoxic metabolites that impair seedling growth and nutrient uptake immediately after germination, thereby hindering the overall establishment and retarding the initial photosynthetic capacity of the young plants. The substantial reduction in seedling dry weight from the infected seed samples (0.065 g mean) compared to the healthy control (0.106 g mean) could be due to the pre-harvest impairment of the naturally infected chickpea seeds. Another adverse effect of seed-borne pathogen is that it will contaminate the areas, which were previously disease-free (Agustina, 2019).

Chickpea seeds collected from the field were inherently compromised, shriveled, and of low quality because the infection by the seed-borne *Fusarium oxysporum* f.sp. *ciceris*, likely initiated the disease process of Fusarium wilt early in the crop's development. This infection causes a blockage of the systemic vascular tissues, leading to a severe restriction in the translocation of water and essential nutrients to the developing seeds/seedlings during the critical pod-filling and maturation stages in the field. Consequently, the infected seeds are not fully provisioned with the necessary carbohydrates, proteins, and lipids, resulting in a significantly lower initial seed mass and, therefore, lower seedling dry weight than the healthy seeds. Furthermore, these shriveled and low-reserve seeds yield weak, low-vigor seedlings that are unable to compensate for the nutritional deficit during the initial establishment phase.

Thus, the dry weight result analysis reveals that the pathogenic potential of the seed-borne isolates is expressed in a two-fold manner: first, by causing poor seed fill and quality in the maternal plant, and second, by perpetuating the systemic infection, leading to poor seedling establishment and reduced biomass in the greenhouse. This current finding underscores the profound and enduring damage caused by seed-borne *F. oxysporum* f.sp. *ciceris* starting directly from the field. This observed reduction in dry weight is a critical indicator of the pathogenic potential of the fungal isolates, confirming that the seed-borne nature of the pathogen poses a significant threat to the yield potential and vigor of the pulse crop. The dry weight of the chickpea seeds were found to be reduced variably according to the fungal capacity of the seed-borne fungi in chickpea, including other pulse crops (Kandhare, 2016).

6.4.3. Seedling vigor index

The current study revealed a drastic reduction in the Seedling Vigor Index (SVI) across all 24 chickpea seed samples evaluated when healthy seeds were compared to those with fungal infection (Table 6.3). The seedling vigor index for healthy seeds was consistently and substantially higher, typically ranging from 6.28 to 17.81%.g, whereas the infected seeds showed significantly lower vigor, falling between 3.05 and 5.83 %.g. This profound difference strongly indicates that the presence of fungal pathogens severely compromises the physiological quality of the seed, interfering with either germination success, initial seedling growth, or both, leading to poor seedling establishment. In agreement to this result, it is revealed that *Fusarium oxysporum* caused the greatest (39.89%) reduction in protein content in chickpea seeds. Thus, the impact of seed mycoflora was deciphered on the germination, seedling vigor and the nutritional quality of chickpea seeds in storage (Parth, Hariprasath, and Jyotika, 2025).

Table 6.3. Effect of fungal infection on chickpea seedling vigor index: a comparison between healthy and infected seed samples

Chickpea Seed Samples	Seedling vigor index (%. g)				Chickpea Seed Samples	Seedling vigor index (%.g)			
	Infected seeds	Std. dv.	Healthy seeds	Std. dv		Infected seeds	Std. dv	Healthy seeds	Std. dv
CSS1	3.584	0.009	13.969	0.105	CSS13	4.208	0.033	11.315	0.131
CSS2	4.744	0.011	14.915	0.180	CSS14	4.836	0.007	17.806	0.140
CSS3	3.420	0.014	6.616	0.083	CSS15	3.995	0.038	13.043	0.067
CSS4	3.126	0.034	11.719	0.058	CSS16	3.105	0.045	9.625	0.094
CSS5	4.000	0.063	8.884	0.105	CSS17	3.900	0.042	8.760	0.088
CSS6	3.795	0.045	8.550	0.196	CSS18	4.271	0.029	10.453	0.161
CSS7	3.240	0.027	6.278	0.065	CSS19	3.225	0.018	10.688	0.150
CSS8	5.198	0.135	13.505	0.120	CSS20	3.430	0.039	12.281	0.062
CSS9	3.048	0.031	12.420	0.142	CSS21	5.344	0.085	8.910	0.149
CSS10	3.953	0.076	7.480	0.137	CSS22	4.482	0.02	10.311	0.163
CSS11	4.813	0.014	7.849	0.143	CSS23	5.826	0.023	10.031	0.199
CSS12	3.491	0.015	9.563	0.102	CSS24	3.713	0.035	8.609	0.079

Where CSS= chickpea seed sample

This compromised seedling vigor has significant implications for field performance, suggesting that fungal infection is a critical factor limiting the successful crop stand and

ultimate yield potential in chickpea cultivation. The infected seeds produce weak seedlings, less capable or less resilient of surviving environmental stress and competing with weeds. Consequently, the findings emphasize the vital necessity of effective seed treatment and strict disease management protocols. Implementing measures to manage fungal pathogens on chickpea seeds is essential to maintain high Seedling Vigor Index values, thereby ensuring robust and successful crop establishment in the field. According to Walia *et al.* (2020), seedling vigor is directly related to a plant's seedling establishment and ability to compete against weeds for rapid establishment of crop seedlings for competitive resource utilization that is critical for both organic and conventional production systems.

6.4.4. Pathogenicity and virulence of FOC isolates

The wilt-susceptible cultivar JG-62 exhibited yellowing and wilt symptoms starting from 15 days after inoculation with *Fusarium* isolates that colonized the wilted chickpea seeds. More than 62% of *Fusarium oxysporum* f.sp. *ciceris* isolates obtained from infected chickpea seeds were found to be pathogenic, able to induce yellowing and wilting symptoms tested on JG-62 susceptible chickpea variety, with sizable variations in their level of wilt intensity. However, the rest 38% of the isolates were incapable of inducing neither wilting nor yellowing symptoms. The mean incidence caused by the pathogenic isolates ranged from 55 to 80% (Table 6.4). The 38% isolates that failed to induce yellowing or wilting in the susceptible JG-62 cultivar were not necessarily non-pathogenic, but might instead represent low-aggressive strains or late-wilting races of *Fusarium oxysporum* f.sp. *ciceris* (FOC).

The current finding is in agreement with investigations by early researchers who reported that Fusarium wilt of chickpea caused by *Fusarium oxysporum* f. sp. *ciceris*, is a seed- and soil-borne disease of economic importance (Haware, Nene and Natarajan, 1996; Pande, Rao and Sharma, 2007). The fungus is systemic and can be isolated from all parts of the infected plant, including chickpea seeds (Haware, Nene and Natarajan, 1996). Further supporting evidences of current result is the finding of Leisso *et al.* (2011), who reported *Fusarium* spp. were isolated from 83% of the chickpea seeds tested and all isolates were able to cause disease on kabuli chickpea seeds and seedlings.

Table 6.4. Pathogenic potential of FOC isolates, and incidences among FOC isolates sourced from infected chickpea seeds.

Isolates	FOC symptoms	No of days to wilt	Mean wilt incidence	Pathogenic ability
CSS1	+	24	55	Strongly pathogenic
CSS2	+	75	75	Highly pathogenic
CSS3	+	55	55	Strongly pathogenic
CSS4	-	-	-	Not pathogenic
CSS5	-	-	-	Not pathogenic
CSS6	+	60	60	Strongly pathogenic
CSS7	-	-	-	Not pathogenic
CSS8	-	-	-	Not pathogenic
CSS9	+	55	55	Strongly pathogenic
CSS10	+	70	70	Strongly pathogenic
CSS11	-	-	-	Not pathogenic
CSS12	-	-	-	Not pathogenic
CSS13	+	65	65	Strongly pathogenic
CSS14	+	65	65	Strongly pathogenic
CSS15	-	-	-	Not Pathogenic
CSS16	+	55	55	Strongly pathogenic
CSS17	-	-	-	Not Pathogenic
CSS18	-	-	-	Not Pathogenic
CSS19	-	-	-	Not Pathogenic
CSS20	+	60	60	Strongly pathogenic
CSS21	+	75	75	Highly pathogenic
CSS22	+	80	80	Highly pathogenic
CSS23	+	75	75	Highly pathogenic
CSS24	-	-	-	Not pathogenic
Control	-	-	-	Non pathogenic

Where CSS= chickpea seed samples

The non-pathogenic appearance of the 38% of isolates can be compellingly justified by the presence of latent infection and the characteristics of late-wilting Foc races, which require an observation period significantly longer than the 15 days used in the current assay. Pathogens exhibit a wide spectrum of virulence, and these isolates likely possess the genetic components for disease but express them weakly or slowly. They might require a significantly longer latent period extending until the final maturity observation to fully colonize the host's vascular system and induce visible symptoms. According to Singh, Singh and Gangwar (2020), chickpea wilt caused by *Fusarium oxysporum* f.sp. *ciceris* was detected in susceptible varieties of chickpea seeds with differences in the recovery of seed infection. Its symptoms can be seen on the seedlings as well as at the maturity stage of the diseased plants. It starts out looking like vein clearing on the younger leaves and drooping of the older lower leaves, followed by stunting and pale yellowing of the lower plant leaves and ultimately drying up. Yellow dry leaves are defoliated; marginal necrosis (halo) of infected leaves is also seen.

Furthermore, the lack of symptom development in these isolates could be attributed to suboptimal environmental factors in the pathogenicity trial that specifically suppressed their virulence. Pathogenicity in FOC is highly sensitive to variations in soil salinity, temperature, pH, and moisture (Cruz *et al.*, 2020). While the test conditions were suitable for the highly aggressive 70% of isolates, they might have been restrictive for the remaining 30%, preventing them from effectively penetrating the root cortex. Soil salinity favors mycelial growth and sporulation in FOC-49, leading to an early and severe wilt development in chickpea. There was a shift in FOC-49 virulence strategy from hemi-biotrophy to necrotrophy under the saline environment. This shift in the life-style of FOC-49 was predicted based on lack of evidence regarding effector-mediated defense suppression in chickpea and presence of evidence regarding production of cell wall degrading enzymes (CWDEs) along with Fusaric acid by FOC-49 under high salinity (Maharshi *et al.*, 2021).

6.5. Conclusion and Recommendations

The present study confirmed a dual mechanism of pathogenesis beginning in the field and continuing into the establishment phase. Firstly, FOC infection initiates a systemic disease in the maternal plant, leading to vascular impairment, premature senescence, and ultimately, the formation of shriveled, low-reserve seeds due to restricted nutrient translocation during grain filling and seed development. Secondly, these infected seeds act as a potent source of primary inoculum, directly causing a massive reduction in viability and vigor. The mean germination percentage dropped significantly from 90.42% for healthy seed samples to 62.66% for infected seed samples, representing an average reduction of about 27%. Furthermore, the pathogenic potential of the seed-borne isolates was confirmed by the high (47%) infection rate and the observation that over 62% of the isolates were virulent, inducing wilt symptoms and yellowing in susceptible cultivars. The adverse impact of seed-borne FOC extends beyond germination failure to a major impairment of seedling vigor. Seedlings grown from infected material showed a drastic decrease in early biomass accumulation, with mean dry weight reduced by nearly 44%. The result underscores the critical role of seed health as a foundational determinant of successful chickpea cultivation, confirming that the seed serves as a primary vehicle for the perpetuation and dissemination of this economically important disease. Given that the seed is a source of inoculum for *Fusarium oxysporum* f.sp. *ciceris* (FOC), the management options must aggressively target the seed health pathway to break the disease cycle and maximize crop performance.

CHAPTER 7: Integrated Management of Chickpea Fusarium Wilt: A Synergistic Approach Using Seed Dressing Fungicides, Vermicompost Applications and Host Resistance

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Abstract

Chickpea Fusarium wilt is the foremost devastating fungal disease that leads to massive grain yield loss in chickpea. Hence, a field experiments were therefore carried out to appraise the synergistic effect of seed dressing fungicides, vermi-compost and chickpea varieties on Fusarium wilt intensity, and the yield of chickpea. Over all 18 treatment combinations were arranged in a factorial randomized complete block design. The experiments were conducted in naturally Fusarium wilt infected fields in Bahir Dar Zuria and Fogera during 2023 cropping season. The research finding revealed that the interaction among seed dressing fungicides, chickpea varieties and vermi-compost application had a significant effect on wilt intensity, yield, and related yield attributes of chickpea. Thus, the Natoli chickpea variety when treated with Goldazim 500 SC seed dressing fungicide supplemented with vermi-compost showed the lowest (2.19%) wilt incidence and lowest disease severity (0.67%) at Fogera site. Conversely, the untreated Dhera chickpea variety retained the highest (26.83%) mean wilt incidence and disease severity (30.67%) at Bahir Dar Zuria. The maximum (2953.8 kg ha⁻¹) grain yield was achieved by the chickpea variety Natoli treated with Goldazim 500 SC and that was treated with vermicompost application. The study also exhibited the highest (27.8%)

grain yield loss due to Fusarium wilt at Bahir Dar Zuria and in Fogera district (23.96%), correlating with increased disease incidence and severity. The correlation analysis between disease intensity parameters and yield components in chickpeas also demonstrated significant negative relationships, indicating that the increased Fusarium wilt intensity adversely affected yield and yield contributing components. Therefore, the integrated application of seed dressing fungicides Goldazim 500SC and vermicompost, particularly in moderately resistant varieties like Natoli, offers a promising strategy for minimizing the adverse impact of Fusarium wilt and maximizing chickpea productivity.

Keywords: Disease severity, grain yield/loss, incidence, intensity, interaction, treatment, variety

7.1. Introduction

The sharply changing climate is threatening the food security for the ever fast-growing global population (Farooq *et al.*, 2023). The influence of such issues is evident in Ethiopia, a nation where a livelihood of its economy hinges on the success of its agricultural sector. In this country, where fertile land stretched across the horizon, the prosperity of the entire country relies heavily on the productivity and resilience of its farmers (Biru *et al.*, 2017). Thus, the importance of pulse crops like, chickpea should not be disregarded because of its foremost contribution for harmonizing and maintaining soil health, generating income, sustaining food and nutritional security, and increasing the foreign exchange of the country. Growing legumes like chickpea and soybean provides significant benefits to cropping systems and the environment due to their natural ability to perform symbiotic atmospheric nitrogen fixation, which enhances both soil fertility and water-use efficiency (Thudi *et al.*, 2016; Sahruzaini *et al.*, 2020).

Chickpea is currently grown on approximately 16.8 million hectares of land worldwide, with an average annual production of 12.8 million tonnes (FAOSTAT, 2024). Asia remains the top producer of pulses, accounting for 82% of global chickpea production between 2010 and 2019. Asia, Oceania and Africa contribute 82, 6, and 5%, respectively of the world chickpea production, respectively (Afzal 2021; Bulti Merga and Jema Haji

2019). In Ethiopia, where 90% of chickpea production is achieved in Sub-Saharan Africa; it is an economically valuable pulse crop grown by about one million smallholder farmers (Lijalem Korbu *et al.*, 2022). Despite its significance for economic stability and food security in Ethiopia, chickpea experiences low average productivity levels, currently at only 2 tons per hectare (CSA, 2021). This productivity falls far short of its potential yield of 5 tons per hectare (Gemechu Keneni *et al.*, 2012; Verkaart *et al.*, 2017). The underlying causes of this underperformance in chickpea yield can be attributed to various biotic and abiotic constraints, with chickpea Fusarium wilt emerging as a particular determinant factor (Asnake Fikre and Dagnachew Bekele, 2020). This fungal disease known for its widespread occurrence, has led to substantial yield losses in numerous chickpea growing nations globally (Dubey *et al.* 2015; Navas-Cortes *et al.* 2000; Venkataramanamma *et al.* 2023) including many regions in Ethiopia (Dagnachew Bekele *et al.* 2021; Sultan Mohamed *et al.* 2018).

The impact of chickpea Fusarium on production extends beyond immediate yield losses; it threatens farmers' livelihoods and exacerbates food insecurity in a region heavily reliant on chickpea as a staple crop. The disease not only reduces the quantity of the harvest but also compromises the quality, making affected products less marketable mainly through production of shriveled, lighter seeds and decreased protein content (Alsamman *et al.*, 2023). *Fusarium oxysporum* f.sp. *ciceris* causing chickpea Fusarium wilt is a vascular pathogen that perpetuates in seed and soil making it difficult to manage by the use of chemical protection alone (Sharma *et al.*, 2012).

Thus, the need for effective and sustainable integrated Fusarium wilt management is critical; as addressing Fusarium wilt is contribute to improve chickpea productivity. Moderately resistant chickpea varieties treated with seed dressing fungicides can reduce Fusarium wilt incidence to just 8% compared to 20% in untreated control plot (Asrat Zewdie, 2019). Similarly, Yigerem Mengist *et al.* (2018) reported the substantial protective fungicidal seed treatment, observing a markedly less Fusarium wilt incidence of 23.4% in the Shasho chickpea variety when treated with Apron Star fungicide, than a significantly higher 65.6% disease incidence in untreated local variety. However,

previous research lacks sufficient integration of multiple compatible management practices for sustainable Fusarium wilt suppression in chickpea. Additionally, the synergistic effects and combined management strategies on both disease suppression and crop performance remain poorly understood by the vast majority of the farming communities, particularly in Ethiopia. Assuring effective sustainable management is critically important, which is heavily dependent on integrated management approach. Therefore, the current research is initiated to appraise the synergistic effect of seed dressing fungicides, vermicompost application and varieties on Fusarium wilt pressure and yield of chickpea and pick out the best combinations.

7.2. Materials and Method

7.2.1. Description of the study areas

A Field experiments were conducted in naturally Fusarium wilt infected fields in two selected districts, namely, Bahir Dar Zuria and Fogera (Figure 7.1). Mixed farming system and uni-modal rainfall distribution are common features of the two experimental districts.

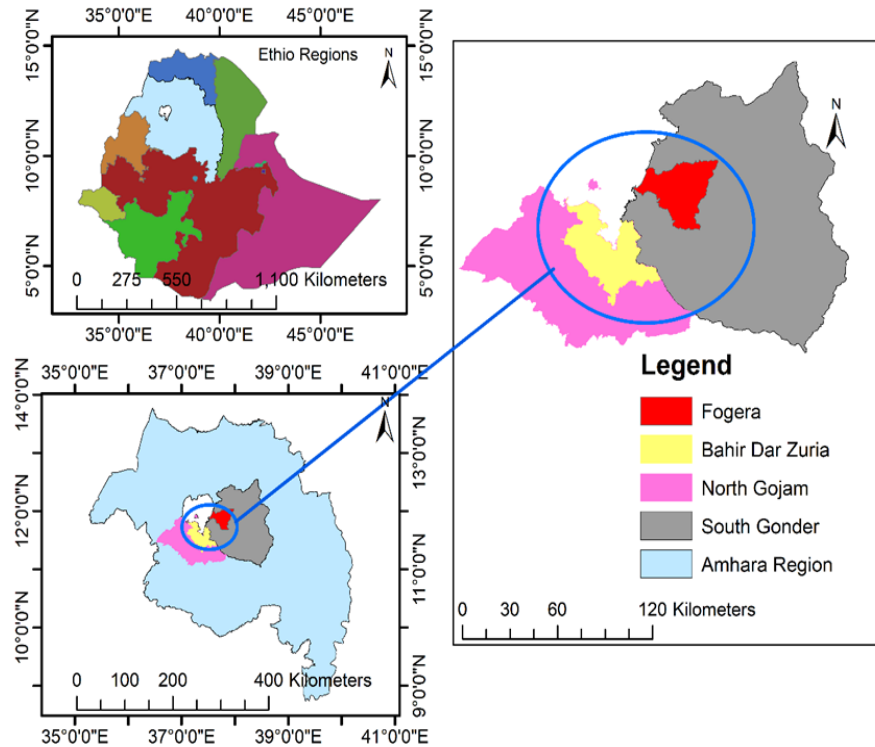


Figure 7.1. Map of Ethiopia displaying the geographical positionss of the experimental locations, viz., Fogera and Bahir Dar Zuria districts, Amhara Region, Ethiopia.

Bahir Dar Zuria District: It is geographically located at 11° 15' North Latitude and 37° 10' East Longitude, with an altitude ranging from 1700 to 2300 meter above sea level (Asmare Bimrew, 2018; Fentahun Abebe and Mengistu Nega, 2023) (Figure 7.1.). Agriculture is the primary economic activity in the study area, with nearly the entire population depending on this sector (CSA, 2021). The major crops grown in the area include chickpea (*Cicer arietinum* L.), maize (*Zea mays* L.), tef [*Eragrostis tef* (Zucc.) Trotter], and wheat (*Triticum aestivum* L.) (CSA, 2021). The soil in Bahir Dar Zuria has a clay texture, a black color, a pH of approximately 6.5. Furthermore, it possesses a cation exchange capacity of 58.7 meq/100 g and contains 3.3% organic carbon and total nitrogen of 681 mg/kg (Anteneh Abewa *et al.*, 2019).

Fogera District: Fogera district is located on the south eastern shore of Lake Tana under South Gondar administrative zone (Fisseha Alebachew *et al.*, 2023). It is geographically located at 37°35'0" E - 37°58'0" E and 11° 57'0" N-12° 30'0" N in the northwest highland of Amhara Region, Ethiopia (Figure 7.1.). The major crops grown in this district are maize (*Zea mays* L.), rice (*Oryza sativa* L.) and tef [*Eragrostis tef* (Zucc.) Trotter] (Gizachew Ayalew Tiruneh *et al.*, 2021). The district is also among the top producer of chickpea in in Amhara Region of Ethiopia (Warner, Stehulak and Kasa, 2015). The soil pH in the cultivated lands of Fogera reached up to 8.9 and is characterized by low organic carbon content (Gizachew Ayalew *et al.*, 2021). The temperature and rainfall across the Fogera and Bahir Dar Zuria districts are generally characterized by a warm sub-tropical to temperate climate with a distinct unimodal rainfall pattern. According to NASA POWER (2023) meteorological data, the mean annual temperature for the districts ranges between 19°C and 23°C, with average maximum temperatures reaching 27°C to 30°C during the dry season and average minimum temperatures dropping to 11°C to 14°C. The areas receive a mean monthly rainfall ranging from 100 mm to 1,100 mm, with the vast majority of the precipitation concentrated during the main rainy season from June to September (Figure 7.2.).

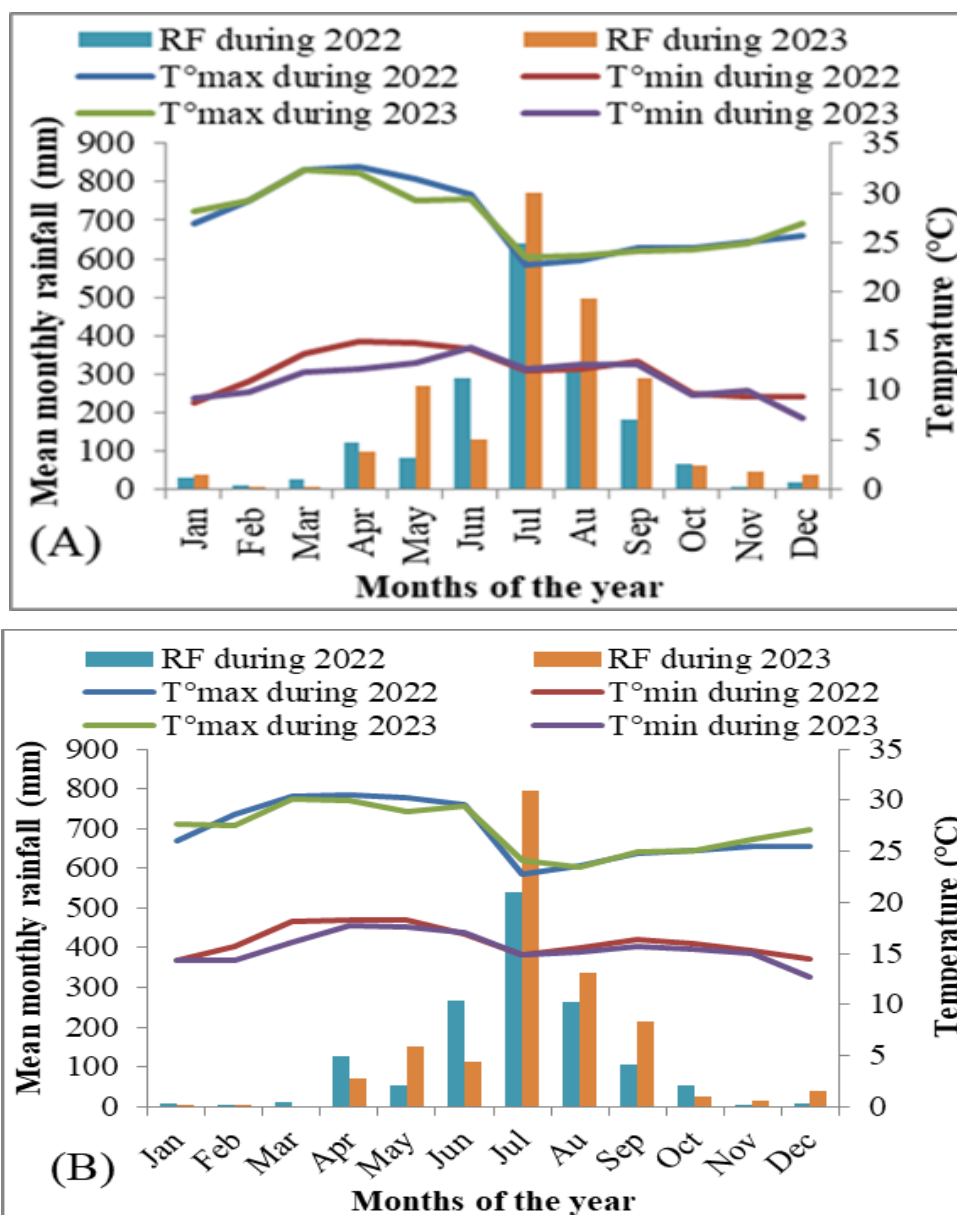


Figure 7.2. Mean monthly rainfall (mm) and temperature (°C) of the study districts: Bahir Dar Zuria. (A) and Fogera (B) districts of Amhara Region, Ethiopia, during the study period 2023 cropping season (Source: NASA Power, 2023).

7.2.2. Treatments and experimental design

The treatments were consisted of three chickpea varieties (Dhera, Natoli and Arerti) combined with two seed dressing fungicides (Goldazim 500 SC, Nobel 250 EC and untreated control) and vermicompost application (treated and untreated). The treatment combinations were randomly arranged in a factorial randomized complete block design replicated three times. The inter-row and intra-row spacing was 30 and 15 cm,

respectively. Each treatment was assigned randomly to the experimental units within a block. The gross plot size was 1.5 m by 2 (3 m²) with a distance of 1 meter and 0.5 meter between blocks and plots, respectively. Each gross plot was consisting of five rows of 2 m length. Vermicompost was applied manually and uniformly by broadcasting across the designated treatment plots at the rate of 5 tons per hectare during the first ploughing to ensure deep integration and organic matter decomposition before planting. Chickpea seeds were treated prior to sowing using a slurry method to ensure uniform seed coverage. Goldazim 500 SC was applied at a rate of 2 g kg⁻¹ of seed, while Nobel 250 EC was applied at a rate of 2.5 mL kg⁻¹ of seed. Clean, healthy seeds of each variety were thoroughly mixed with their respective fungicide slurry in a plastic container for 5 minutes and air-dried in the shade before being sown directly into the experimental rows.

7.2.3. Data collection

7.2.3.1. Disease data collection

Disease data were collected upon the appearance of common chickpea Fusarium wilt symptoms, typically wilting and yellowing. Chickpea plants exhibiting wilting and yellowing symptoms were counted separately in each plot. Severity of Fusarium wilt disease was noted in a 1 m² quadrat using a seven-point severity scale (0-6) based on percentage of foliar tissue exhibiting wilting and yellowing symptoms. This scale ranged from 0 (0% wilting) to 6 (100% wilting), with intermediate grades defined as 1 (1-5%), 2 (6-10%), 3 (11-25%), 4 (26-50%), and 5 (51-75%). For subsequent statistical analysis, all raw disease grades underwent a back transformation from these visual grades to their respective mid-point severity percentage prior to computations. The specific conversions used are: Grade 0 (0%), Grade 1 (3%), Grade 2 (8%), Grade 3 (18%), Grade 4 (38%), 5 (63%) and Grade 6 (88%) (Willcoquet, Savary and Singh, 2023).

Disease incidence was calculated using the mathematical formula as follows as

The percent severity index was computed as follows:

$$\text{Disease incidence (\%)} = \frac{\text{No. of infected plants per quadrat}}{\text{Total number of plants inspected per quadrat}} * 100 \quad (1)$$

$$\text{Severity index (\%)} = \frac{\text{Sum of numerical ratings}}{\text{Total number of plants scored} \times \text{maximum score on scale}} * 100 \quad (2)$$

Where; X_i = the disease incidence at the i^{th} assessment; t_i is the time of the i^{th} assessment in days from the first assessment date, and n is the total number of disease assessments.

7.2.3.2. Crop data collection

Data encompassing pertinent crop growth yield and yield-related parameters were recorded from each experimental plot. Specifically, the data for growth parameters and yield related traits of chickpea were recorded from 10 randomly pre-tagged plants in each experimental plot.

Seedling stand count: The total numbers of seedlings per plot were recorded in an early stage of plant growth.

Days to 50 % flowering: it was recorded as the number of days from planting to 50 % of the plants produced flower per plot through visual observation.

Days to 90 % physiological maturity: It was considered as the number of days from planting to when 90% of the plants showed yellowing pods and leaves through visual observation.

Stand count at harvest: The total number of plants in the net plot area was calculated at harvest maturity.

Number of branches per plant: This variable was determined by averaging the count of branches from 10 randomly pre-tagged plants with in the net plot area.

Plant height (cm): It was measured in centimeters using tape meter, the average height of 10 randomly pre-tagged plants in the net plot area was recorded, with measurements taken from the soil surface to the topmost point of the plant canopy.

Number of pods per plant: The mean number of pods per plant was determined by counting all pods on 10 randomly pre-tagged plants within the designated net plot area.

Hundred seeds weight: It was measured by counting hundred seeds from each variety and measuring each on a sensitive balance in gram.

Grain yield (kg): It was ascertained following harvesting all plants from each net plot area. The harvested biomass was then subjected to mechanical threshing to separate the grain from straw. The resultant grain was adjusted to 11% grain moisture content and weighed in kilogram using sensitive balance and it was computed to hectare basis (kg ha⁻¹).

Harvest index: Harvest index of each treatment was computed by dividing the weight of grain yield by the weight of total aboveground dry biomass as follows based on the formula developed by Hay (1995).

$$\text{Harvest index (\%)} = \frac{\text{Grain yield}}{\text{Biomass yield}} * 100 \quad (3)$$

The grain and aboveground dry biomass were measured based on the net plot area.

Besides, relative yield loss was computed on the basis of grain yield in each respective treatment using the formula as follows.

$$\text{Grain yield loss} = 1 - \frac{\text{Grain yield of chickpea in treatment}}{\text{Grain yield of chickpea in treatment Y}} \times 100 \quad (4)$$

Where; Y= the treatments which gave maximum grain yield

7.2.4. Statistical data analysis

The collected data were subjected to analysis of variance (ANOVA) using SAS software (version 9.4). Mean comparison among all treatments was performed based on least significant difference (LSD) test at 5% level of significance upon the presence of significant difference among treatments for ANOVA. Correlation analysis was performed to determine the linear relationship between disease intensity parameters (incidence and

severity) and yield and yield related components. The strength and direction of these linear associations were determined using Pearson correlation coefficients (r).

7.2.5. Partial economic analysis

As farmers endeavor to evaluate the economic benefits of one management practice over another, partial budget analysis was done to identify the payoff treatments. The economic feasibility of treatments was determined based on net benefit analysis and marginal rate of return (MRR) following the procedure developed by CIMMYT (1988). The cost and benefit of each treatment were analyzed partially, and the marginal rate of return was computed by considering the variable cost available in the respective treatment. CIMMYT (1988) reported that marginal analysis is concerned with the process of making choice between alternative factor-product combinations, considering small changes. Economic analysis was conducted to evaluate the profitability of chickpea Fusarium wilt management options. The study included three chickpea varieties and assessed the effect of two seed dressing fungicides and vermicompost application.

Average chickpea yield (kg ha^{-1}) was recorded for each treatment and adjusted yield was calculated. Thus, the yields from on-farm experimental plots were adjusted downward by 10% for management difference to reconcile the difference between the experimental yield and the yield that farmers could expect from the same treatment. Gross revenue (USD ha^{-1}) was determined by multiplying adjusted yield by the prevailing market price of chickpea. Total variable costs, including seed, fungicide, vermicompost and application costs, were recorded for each treatment. Net benefit (USD ha^{-1}) was calculated by subtracting total variable costs from gross revenue of the respective treatments. A dominance analysis was first performed to eliminate treatments that were less profitable yet more costly than others. It was performed to identify economical inefficient treatments. Treatments were considered dominated if another treatment yields a higher net benefit with a lower or equal total variable cost. For the remaining non-dominated treatments, the Marginal Rate of Return (MRR) was calculated to determine the financial return on each additional dollar invested in a given management option.

Marginal rate of return was also calculated to assess the profitability of incremental investments.

7.3. Results and Discussion

7.3.1. Chickpea Fusarium wilt incidence and severity

The analysis of variance (ANOVA) revealed that Fusarium wilt incidence and severity were significantly impacted by the integrated management practices in both locations (Appendix Table 3-7.). The mean incidence of Fusarium wilt varied from 2.19% in Goldazim 500 SC-treated Natoli variety with vermicompost application to 26.83% in the untreated Dhera variety. Similarly, the lowest (0.67%) disease severity was recorded in the Natoli variety treated with Goldazim 500 SC and vermicompost. In contrast, the untreated Dhera variety exhibited highest (30.67%) disease severity, followed by the Dhera variety treated with only vermicompost, which had a severity of 26.17% and the untreated Arerti variety with disease severity of 23.33% (Table 7.1.). The study results showed that the maximum relative yield loss of chickpea grain due to chickpea Fusarium wilt interference was 22.9% in the Bahir Dar Zuria and 27.8% in Fogera district, both recorded in the untreated Dhera variety in the plots with the highest wilt intensity at these locations.

Table 7.1. Effect of fungicides, vermicompost and host resistance on disease incidence, severity and the yield loss caused by it at Fogera and Bahir Dar Zuria districts during 2023/2024 cropping season

Treatments	Bahir Dar Zuria			Fogera		
	Inc. (%)	Sev. (%)	YL (%)	Inc. (%)	Sev. (%)	YL (%)
Dhera (untreated)	26.83 ^a	30.67 ^a	27.80	21.8 ^a	24.83 ^a	22.96
Dhera +vermicompost	24.47 ^{ab}	26.17 ^{ab}	19.40	19.3 ^{ab}	20.76 ^{ab}	17.62
Arerti (untreated)	21.72 ^{bc}	23.33 ^{ab}	14.17	17.5 ^{bc}	17.17 ^{abcd}	12.27
Dhera +Nobel 250 EC	20.86 ^{cd}	22.33 ^b	19.01	16.2 ^{cd}	17.00 ^{abcd}	17.22
Arerti+Nobel 250 EC	18.44 ^d	19.90 ^{bc}	14.04	15.8 ^{cd}	12.00 ^{cde}	12.14
Dhera +Nobel 250 EC+vermicompost	18.23 ^{de}	20.00 ^{bc}	17.69	15.7 ^{cd}	16.67 ^{bcd}	19.37
Dhera +Goldazim 500 SC	18.07 ^{de}	19.83 ^{de}	18.42	15.6 ^{cd}	19.00 ^{abc}	16.61
Arerti+Vermicompost	18.02 ^{de}	19.90 ^{bc}	13.8	15.1 ^{cd}	14.5 ^{bcde}	11.94
Dhera +Goldazim 500 SC+vermicompost	17.15 ^e	18.90 ^{bc}	14.01	14.4 ^d	14.5 ^{bcde}	12.10
Arerti+Goldazim 500 SC	13.34 ^f	14.40 ^{cd}	12.10	11.2 ^e	12.17 ^{cde}	10.12
Natoli+vermicompost	13.08 ^{fg}	14.00 ^{cd}	4.06	10.9 ^e	12.67 ^{cdef}	1.81
Natoli (untreated)	12.8 ^{fg}	13.66 ^{cd}	7.34	10.7 ^e	12.57 ^{cde}	5.52
Natoli+Nobel 250 EC	12.16 ^{fg}	13.50 ^{cd}	6.64	10.2 ^e	12.00 ^{cde}	4.57
Arerti+Nobel 250 EC+vermicompost	10.30 ^{gh}	11.33 ^d	14.00	8.6 ^{ef}	12.50 ^{cde}	12.09
Arerti+Goldazim 500 SC+vermicompost	8.90 ^{hi}	9.63 ^d	8.46	7.4 ^{fg}	10.40 ^{def}	6.43
Natoli+Nobel 250 EC+vermicompost	8.83 ^{hi}	10.40 ^d	6.38	7.3 ^{fg}	9.00 ^{ef}	4.31
Natoli+Goldazim 500 SC	7.05 ^h	8.93 ^d	4.12	5.9 ^g	5.13 ^{ef}	2.01

Natoli+Goldazim 500 SC+vermicompost	0.67 ^j	3.47 ^e	0.00	2.19 ^h	0.67 ^f	0.00
P value	0.036	0.019	-	0.034	0.208	-
CV	11.38	14.52	-	12.91	16.43	-
LSD _(0.05)	3.2	5.32	-	2.67	5.22	-

Means followed by the same letters in the same columns are statistically not significant. Where; Inc.= incidence; Sev.= severity and YL= yield loss due to chickpea Fusarium wilt disease.

The significant disparity in disease intensity, yield component, and yield of chickpea across different treatments stems from the affirmative interaction of dressing fungicides, varieties and vermicompost application. The aforementioned three factors could greatly contribute to reduction of the causal pathogen epidemics, promoting the rapid growth and establishment of chickpea crop, thereby reducing overall wilt intensity and enhancing upcoming grain yield. Chickpea Fusarium wilt incidence and percent severity index were significantly influenced by the application of integrated management. Thus, the highest (26.83%) mean wilt incidence and severity (25.94%) were recorded from the untreated Dhera variety. On the other hand, the Natoli variety treated with Goldazim 500 SC seed dressing fungicide supplemented with vermicompost application expressed mean wilt incidence and percent severity of only 0.67%

The synergetic interaction among seed dressing fungicides, vermicompost applications and varieties could lead reduction of inoculum amount in the soil and hindering the development and subsequent infection by Fusarium wilt to the host crop. Likewise, Zemenu Endalew, Gizachew Haylemariam and Ahmed Mohamed (2022) reported that moderately resistant chickpea varieties treated with dressing fungicides reduced the disease incidence to a considerable extent in Sekota Zuria and Lasta Lalibela districts. Besides, Asrat Zewdie (2019) reported that Arerti variety treated with seed dressing fungicide resulted in a lower incidence of Fusarium wilt. Further to this, Bhimani (2020) reported that Carbendazim 50% WP showed least 23.33% disease incidence and yield increase (76.66%) over the control, which retained 99.98% wilt disease incidence. According to Sahni (2021), the combined treatment of 15% vermicompost, seed bacterization and pre-inoculation foliar spray with salicylic acid (SA) resulted complete suppression against *Fusarium oxysporum* f.sp. *ciceris*. Different chickpea varieties expressed significant variation in wilt incidence that ranged from 2.7% in Dalota variety to 13.5% in the local check at Adet in North Gojam Zone of Amhara Regional State (Mekonnen Gebeyaw, Asnake Fikre, and Abate Alemu, 2024b). A study conducted on cucumber plant with vermicompost treatment showed significant reduction in the incidence of Fusarium wilt and increased plant height, stem diameter, leaf area and ultimately increased fruit yield (Zhang *et al.*, 2020).

7.3.2. Disease progress curve

The disease progress curve of chickpea Fusarium wilt incidence in the tested chickpea varieties, treated with the seed dressing fungicides Goldazim 500 SC and Nobel 250 EC alongside untreated control and application of vermicompost is compellingly illustrated in Figure 1. Notably, the incidence of chickpea Fusarium wilt rose significantly from the initial to final assessments, showcasing a concerning upward trend in disease development among all three untreated chickpea varieties. This evidence underscores the critical impact of fungicide treatments in managing chickpea Fusarium wilt, highlighting the importance of integrated Fusarium wilt management practices to safeguard chickpea crop health. The research results indicated that the Fusarium wilt progression rate was slower in the Natoli variety, followed by the Arerti variety, than the Dhera Variety (Figure 7.3 and 7.4). Chickpea Fusarium wilt progress rate in three chickpea varieties treated with seed dressing fungicides is illustrated hereunder (Figure 7.3 and Figure 7.4.). Thus, the result revealed that the rate of Fusarium wilt progression was slowest in the varieties treated with Goldazim 500 SC, followed by those treated with Nobel 250 EC, compared to untreated chickpea varieties. Notably, the Natoli chickpea variety treated with Goldazim 500 SC seed dressing fungicide and organic matter exhibited the lowest disease progress curve value. The chickpea variety Arerti, under similar treatment conditions, also showed a comparable performance. In contrast, the untreated Dhera chickpea variety retained the highest disease progress curve, followed by untreated Arerti variety.

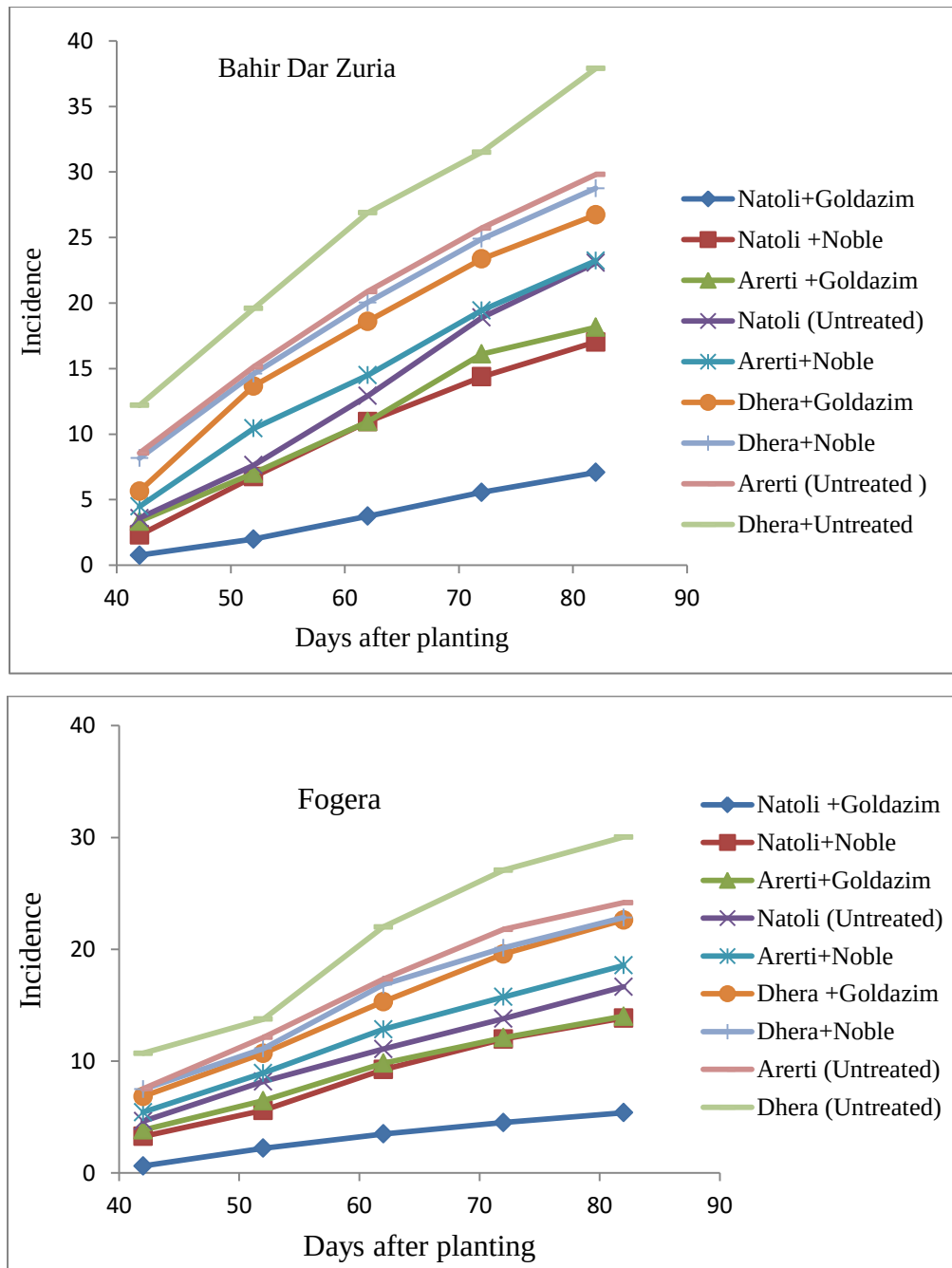


Figure 7.3. Comparative progress of chickpea Fusarium wilt incidence in chickpea varieties treated with seed dressing fungicides at Bahir Dar Zuria (A); and Fogera (B) districts.

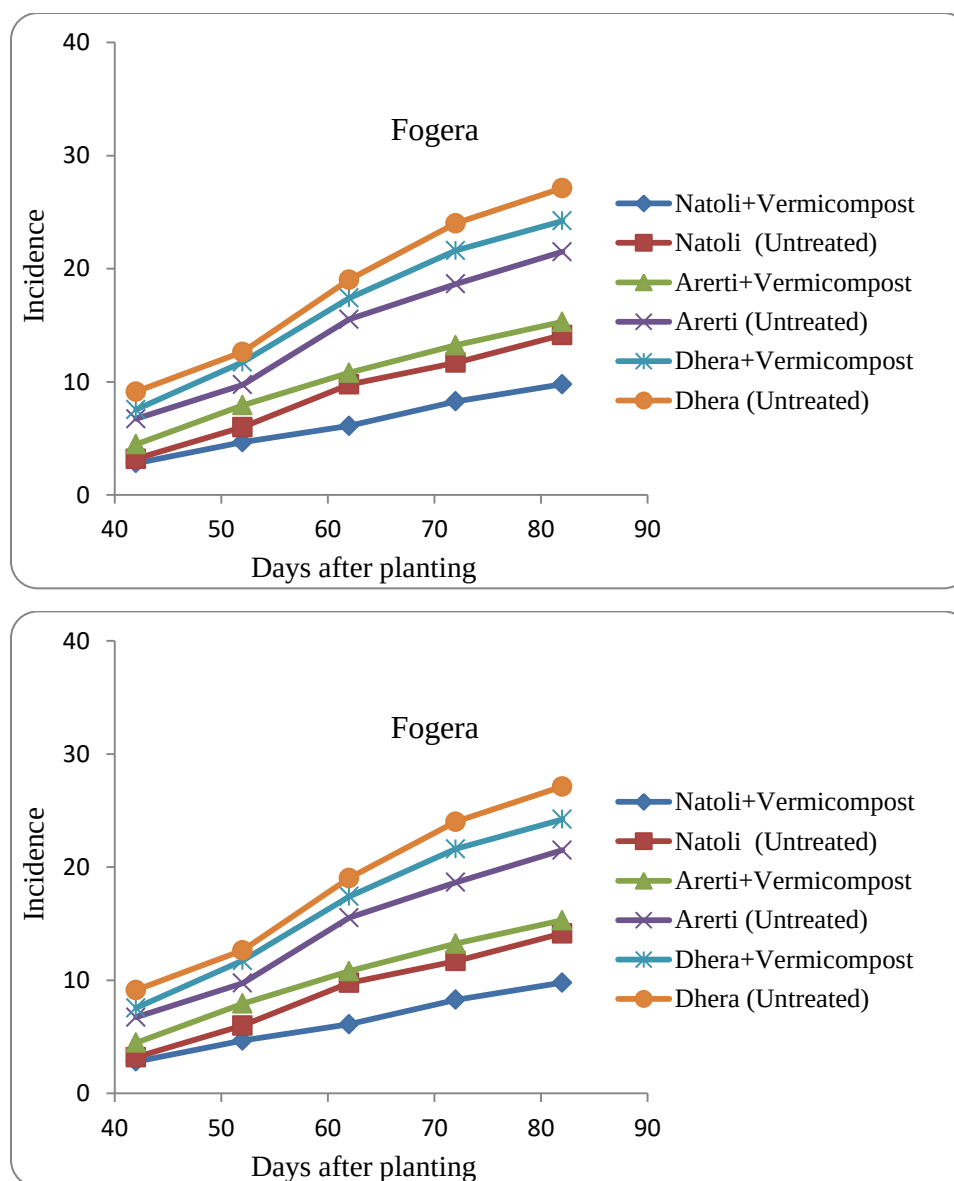


Figure 7.4. Comparative progress of Chickpea Fusarium wilt incidence in chickpea varieties treated with and without vermicompost at Bahir Dar Zuria (A); and Fogera (B) districts.

7.3.3. Yield components of chickpea

The analysis of variance revealed that the interaction of seed dressing fungicides, vermicompost application and chickpea varieties had significantly influenced the number of branches per plant, number of pods per plant, hundred seeds weight, and grain yield of chickpea (Appendix 12-15). In general, all treated chickpea varieties had at least better mean value than the untreated similar varieties. Thus, Natoli variety treated with seed

dressings Goldazim 500 SC and application with vermicompost scored the maximum (7.7) number of branches per plant; maximum (45.6) number of pods per plant, at Bahir Dar Zuria and hundred seed weight (30.74) at Fogera. However, the lowest number of pods and branches per plant was recorded from untreated Dhera variety with mean values of 32.2 and 4.8 respectively. The least hundred seed weight was acquired from untreated Arerti variety having mean value of 18.09 (Table 7.2.). In addition, the harvest index was also greatly impacted by the integrated management practices. The highest (49.6%) harvest index was obtained from Natoli variety treated with Goldazim 500 SC and Vermicompost, which is statistically in par with other management combinations with Natoli except the untreated one (Table 7.2.).

Table 7.2. Effect of fungicides, vermicompost and host resistance on yield components of chickpea at Bahir Dar Zuria district and Fogera districts during 2023/2024 cropping season.

Treatments	Bahir Dar Zuria			Fogera		
	NPP	NBP	HSW	NPP	NBP	HSW
Natoli+Goldazim 500 SC+vermicompost	45.6 ^a	7.7 ^a	28.64 ^{de}	43.98 ^a	6.79 ^a	30.74 ^{bcd}
Natoli+Goldazim 500 SC	38.4 ^b	6.2 ^b	28.49 ^{ef}	36.97 ^b	5.94 ^{ab}	29.76 ^{cde}
Natoli+Vermicompost	38.1 ^b	6.1 ^b	28.75 ^{cde}	37.07 ^b	5.88 ^b	30.02 ^{bcd}
Natoli+Nobel 250 EC+vermicompost	37.5 ^b	5.9 ^{bc}	28.68 ^{cde}	36.47 ^{bcd}	5.77 ^{bc}	29.95 ^{bcd}
Natoli+Nobel 250 EC	37.4 ^{bc}	5.8 ^{bc}	27.00 ^f	36.37 ^{bcd}	5.65 ^{bcd}	28.27 ^e
Natoli (untreated)	37.1 ^{bc}	5.9 ^{bc}	27.76 ^{ef}	35.79 ^{bcde}	5.70 ^{bcd}	29.03 ^{de}
Arerti+Goldazim 500 SC+vermicompost	36.7 ^{bcd}	5.8 ^{bcd}	21.93 ^g	35.65 ^{bcde}	4.94 ^{cdefg}	23.2 ^f
Arerti+Goldazim 500 SC	35.2 ^{cde}	5.5 ^{cde}	21.45 ^{gh}	34.21 ^{bcde}	5.33 ^{bcd}	22.72 ^f
Arerti+Vermicompost	34.5 ^{def}	5.4 ^{def}	20.33 ^h	33.48 ^{bcde}	5.19 ^{bcd}	23.16 ^f
Arerti+Nobel 250 EC+vermicompost	34.4 ^{efg}	5.3 ^{def}	20.90 ^{gh}	33.44 ^{bcde}	5.45 ^{bcd}	22.17 ^f
Dhera+Goldazim 500 SC+vermicompost	34.4 ^{efg}	5.3 ^{def}	32.40 ^a	32.57 ^{bcd}	5.35 ^{bcd}	34.15 ^a
Arerti+Nobel 250 EC	34.4 ^{efg}	5.4 ^{def}	21.55 ^{gh}	33.42 ^{bcde}	5.18 ^{bcd}	22.32 ^f
Arerti (untreated)	34.3 ^{efgh}	5.3 ^{def}	18.09 ⁱ	33.37 ^{bcde}	4.83 ^{defg}	17.95 ^g
Dhera+Nobel 250 EC+vermicompost	32.9 ^{fgh}	5.2 ^{efg}	30.11 ^{bcd}	32.14 ^{bcd}	4.90 ^{cdefg}	31.51 ^{bc}
Dhera+Goldazim 500 SC	32.7 ^{fgh}	5.0 ^{fg}	30.26 ^{bc}	31.68 ^{cdef}	4.84 ^{defg}	31.53 ^{bc}
Dhera+Nobel 250 EC	32.4 ^{fgh}	4.9 ^{fg}	30.21 ^{bcd}	31.44 ^{def}	4.79 ^{fg}	31.08 ^{bc}

Dhera+vermicompost	32.3 ^{gh}	4.9 ^{fg}	30.98 ^{ab}	30.89 ^{ef}	4.76 ^{fg}	32.01 ^a
Dhera (untreated)	32.2 ^h	4.8 ^g	30.48 ^b	27.90 ^f	4.11 ^g	30.41 ^{bcde}
LCD _(0.05)	2.18	0.47	1.58	2.69	0.88	2.2
CV (%)	3.7	5.06	3.5	4.74	10.05	4.9
P value	0.048	0.041	0.042	0.042	ns	0.039

Means followed by the same letters in the same columns are statistically not significant; Where; NPP= number of pods per plant, NBP= number of branches per plant, and HSW=hundred seed weight.

The yield and yield components of chickpea were significantly influenced by the integrated chickpea wilt management. Biomass yield, grain yield, and yield attributes of chickpea, including number of primary branches per plant, number of pods per plant, and hundred seed weight, were significantly affected by the interaction of seed dressing fungicides and vermicompost application in different varieties. Thus, varieties that received seed dressing fungicide treatment and vermicompost application retained improved yield and yield component over untreated control. The highest yield in chickpea varieties treated with both seed dressing fungicides and vermicompost compared to untreated varieties is likely due to a reduction in disease pressure. This resulted in a better crop stand; increasing branching, and greater accumulation of dry matter.

Seed dressing fungicides effectively reduced the causal pathogen inoculum, while vermicompost provided essential nutrient and improved soil health, and supported beneficial soil microorganisms. Together, these factors enhanced yield attributes and yield of chickpea. Several studies indicated that chickpea receiving vermicompost fortification exhibited significantly higher plant height, aboveground biomass, number of pods per plant and photosynthetic pigments, significantly enhanced the chickpea productivity than the untreated controls (Yadav and Garg, 2015; Rehman *et al.*, 2023). This current investigation aligns with finding of Merkuza Abera *et al.* (2011) who reported that incorporating green manure and dried plant residue into the soil enhanced chickpea grain yield. Furthermore, Yigerem Mengist *et al.* (2018) demonstrated that chickpea varieties treated with the protective fungicide Apron star achieved maximum grain yield and most yield-related traits of chickpea in the northwest Ethiopia. Application of vermicompost alone at the rate of 5 t ha⁻¹ gave maximum (1679 kg ha⁻¹) yield, and harvest index (43.88%), which resulted in yield advantage of 27.4% over the control (Kaur, Kumar and Singh, 2023). According to Yadav and Garg (2015), the number of pods per plant is an important yield contributing parameter in chickpea and is significantly affected by the application of vermicompost, which varied from 5.3 in the control to 19.3 in vermicompost treated chickpea at a rate of 20%.

7.3.4. Yield of chickpea

The analysis of variance depicted that seed dressing fungicides, vermi-compost application and varieties were optimally interacted and significantly influenced grain and biological yield of chickpea (Appendix Table 8-11). Broadly speaking, the grain yield of chickpea harvested from vermicompost treated plots and seed dressing fungicides was increased over untreated varieties. In examining the three-way interaction effects, the Natoli chickpea variety stood out with an impressive grain yield of 2965.1 kg ha⁻¹ when treated with Goldazim 500 SC and organic matter at Bahir Dar Zuria, reflecting the remarkable potential of the combination. The Arerti chickpea variety also displayed significant result in yielding 2714.3 kg ha⁻¹ under the same treatment. Conversely, the untreated Dhera variety fell short producing only 2334.1 kg ha⁻¹ in Fogera district (Table 7.3.).

The grain yield loss of chickpea due to Fusarium wilt represents a significant challenge to chickpea growers, impacting both productivity and economic viability. The yield loss of 23.0 and 27.8% recorded obtained from Fogera and Bahir Dar Zuria, respectively, at the maximum disease incidence and severity could be due to the the disease effect on yield contributing components and ultimately the grain yield. Shehabu Meki *et al.* (2008) reported about 30% loss in grain yield of chickpea due to chickpea Fusarium wilt interference under Ethiopian conditions, showcasing the impact of chickpea Fusarium wilt in chickpea production. Besides, the yield losses due to Fusarium wilt could escalate to 100% reliant on varietal susceptibility, and favorable climatic variables (Chand and Khirbat 2009). Furthermore, Yigerem Mengist *et al.* (2018) reported that relative grain yield losses due to chickpea Fusarium wilt varied from 13.4% in Arerti variety treated with Apron star fungicide to of 95.4% in the untreated local chickpea variety under sick plot conditions.

The susceptibility of chickpea varieties to Fusarium wilt also plays a critical role in determining yield losses, as plant resistance to disease results from the dynamic interaction between host, pathogen, environment, and temporal factors (Shikha *et al.*, 2024). The inclusion of more diverse chickpea genotypes would provide a broader

representation of the genetic variations associated with Fusarium wilt resistance and ultimately associated with yield loss reduction (Alsamman *et al.*, 2023). Besides, it is a considerable capital virtue to consider that the yield loss caused by Fusarium wilt not only be attributed to direct damage but also to secondary effects such as lower quality seeds (Navas-Cortes, Hau and Jimenez-Diaz, 2000; Alsamman *et al.*, 2023). Seeds sourced from wilted chickpea plants are often lighter, rougher, duller and less likely to produce viable seeds than those harvested from healthy chickpea plants (Navas-Cortes, Hau and Jimenez-Diaz, 2000).

Table 7.3. Effect of integrated management on biological yield, grain yield, and harvest index at Bahir Dar Zuria and Fogera districts during 2023/2024 cropping season.

Treatments	Bahir Dar Zuria			Fogera		
	Yield (kg ha ⁻¹)	Biological Y (kg ha ⁻¹)	HI (%)	Yield (kg ha ⁻¹)	Biological Y (kg ha ⁻¹)	HI (%)
Natoli+Goldazim 500 SC+vermicompost	2965.1 ^a	5979.2 ^a	49.6 ^a	2819.5 ^a	6153.8 ^a	46.34 ^a
Natoli +vermicompost	2844.7 ^b	5955.6 ^{ab}	48.68 ^{ab}	2768.4 ^a	6142.6 ^a	44.97 ^{ab}
Natoli+Goldazim 500 SC	2842.8 ^b	5905.2 ^{abc}	48.2 ^{ab}	2763.2 ^{ab}	6123.7 ^a	45.12 ^{ab}
Natoli+Nobel 250 EC+vermicompost	2775.9 ^c	5704.2 ^{abcdef}	48.18 ^{ab}	2698.1 ^{bc}	5915.1 ^{bcde}	45.63 ^{ab}
Natoli+Nobel 250 EC	2768.1 ^c	5742.6 ^{abcde}	48.14 ^{ab}	2690.6 ^c	5951.4 ^{bc}	45.2 ^{ab}
Natoli (untreated)	2747.6 ^c	5702.4 ^{abcdef}	47.89 ^b	2664.0 ^c	5912.9 ^{bcde}	43.36 ^c
Arerti+Goldazim 500 SC+vermicompost	2714.3 ^C	5666.9 ^{bcdef}	47.76 ^b	2638.3 ^d	5876.6 ^{bcde}	44.89 ^b
Arerti+Goldazim 500 SC	2607.2 ^d	5715.7 ^{abcdef}	45.63 ^c	2534.2 ^{de}	5927.1 ^{bcd}	42.77 ^c
Arerti+Vermicompost	2554.3 ^d	5608.1 ^{cdef}	45.59 ^{cd}	2482.8 ^{ef}	5815.6 ^{cdef}	42.74 ^c
Arerti +Nobel 250 EC+vermicompost	2550.1 ^d	5708.8 ^{abcd}	44.23 ^{cde}	2478.7 ^{ef}	6023.27 ^{ab}	41.15 ^d
Dhera+Goldazim 500 SC+vermicompost	2549.8 ^d	5789.8 ^{abcd}	44.1d ^e	2478.4 ^{ef}	6007.3 ^{ab}	41.26 ^d
Arerti+Nobel 250 EC	2548.7 ^d	5777.4 ^{abcd}	44.04 ^e	2477.3 ^{ef}	5991.2 ^{ab}	41.35 ^d
Arerti (untreated)	2544.8 ^d	5784.4 ^{abcd}	44.02 ^e	2473.6 ^f	5998.4 ^{ab}	41.12 ^d
Dhera +Nobel 250 EC+vermicompost	2440.6 ^e	5544.1 ^{def}	43.98 ^e	2273.3 ^g	5749.2 ^{efg}	41.26 ^d
Dhera +Goldazim 500 SC	2419.0 ^e	5561.6 ^{def}	43.90 ^e	2351.2 ^g	5767.4 ^{defg}	40.77 ^d
Dhera +Nobel 250 EC	2401.4 ^e	5429.2 ^f	43.75 ^e	2334.1 ^g	5630.1 ^{gh}	41.46 ^d

Dhera+vermicompost	2389.8 ^e	5461.8 ^{ef}	43.49 ^e	2322.8 ^g	5663.9 ^{tgh}	41.01 ^d
Dhera (untreated)	2140.7 ^f	5428.4 ^f	39.45 ^f	2172.2 ^h	5559.3 ^h	37.49 ^e
LCD (5%)	63.59	165.79	1.503	65.91	269.52	1.218
CV (%)	1.47	1.75	1.99	1.57	2.02	1.72
P value	0.011	0.032	0.0023	0.013	0.018	0.047

Means followed by the same letters in the same columns are statistically not significant; Biological Y= biological yield; HI= harvest index

7.3.5. Association of disease, yield and yield components

The correlation analysis reveals a clear and concerning trend: the intensity of chickpea Fusarium wilt, measured by incidences and disease severity is strongly and negatively correlated with grain yield in both Bahir Dar Zuria and Fogera districts. This indicates that as disease pressure increases, there is a significant reduction in harvestable grain. In Bahir Dar Zuria, incidence of chickpea Fusarium wilt showed a strong negative correlation between number of pods per plant ($r = -0.814$), number of branches per plant ($r = -0.756$), grain yield ($r = -0.857$) and harvest index ($r = -0.795$). Thus, as chickpea Fusarium wilt incidence increases the yield component parameters decrease significantly. Similar to Bahir Dar Zuria, incidence exhibited a strong negative correlation with number of pods per plant ($r = -0.823$), grain yield ($r = -0.831$) and harvest index ($r = -0.806$) in Fogera. On the other hand, plant height and hundred seeds weight were strongly correlated in a positive manner (Table 7.4.). However, it was due to the characteristics of varieties in which Dhera variety was taller and has large seeds, whereas Natoli and Arerti were characterized by short height and smaller seeds.

The high correlation coefficient (r) with negative values, particularly between grain yield and number of pods per plant, highlight direct and harmful impact of chickpea Fusarium wilt on key yield components. Notably, the strong positive correlations observed between plant height and 100-seeds weight, suggest that taller plants tend to produce heavier seeds. This may indicate a link between plant vigor and seed development. However, the significant negative correlation between disease intensity and harvest index is particularly noteworthy, as it suggests a reduction in the plant's efficiency to convert biomass into grain under disease pressure. This implies that not only does disease reduce overall yield, but it also disrupts allocation of resources, consequently affecting both the quality and quantity of the harvest. Finally, the consistent correlation patterns observed between Bahir Dar Zuria and Fogera districts suggest that these relationships are not confined to specific locations but reflect a broader trend in chickpea production. Overall, the correlation analysis offers valuable insight into the impact of chickpea Fusarium wilt disease, emphasizing the importance of integrated management to mitigate yield loss and ensure sustainable production and productivity.

Table 7.4. Correlation coefficient (r) between disease intensity parameters and yield and yield contributing components of chickpea in Bahir Dar Zuria and Fogera districts during 2023 cropping season

		Incidence	Severity	PH	NPP	NBPP	GRY	BMY	HI	100SW
Bahir Zuria	Incidence	1.000**								
	Severity	0.949**	1.000**							
	PH	-0.104	-0.109	1.000**						
	NPP	-0.814**	-0.764**	0.150	1.000**					
	NBPP	-0.756**	-0.669*	0.141	0.915**	1.000**				
	GRY	-0.857**	-0.798**	0.097	0.878**	0.754**	1.000**			
	BMY	-0.652*	-0.624*	0.087	0.685*	0.548*	0.755**	1.000**		
	HI	-0.795**	-0.776**	0.155	0.745*	0.685*	0.870**	0.469	1.000**	
	100SW	0.091**	0.095	0.892**	-0.007	0.011	-0.124	0.224	-0.057	1.000**
Fogera	Incidence	1.000**								
	Severity	0.958**	1.000**							
	PH	-0.088	-0.102	1.000**						
	NPP	-0.823**	-0.812**	0.104	1.000**					
	NBPP	-0.642	-0.707*	0.126	0.736**	1.000**				
	GRY	-0.831**	-0.808**	0.071	0.863**	0.649*	1.000**			
	BMY	-0.493	-0.435	-0.143	0.546*	0.485	0.695*	1.000**		
	HI	-0.810**	-0.813**	0.164	0.816**	0.574*	0.912**	0.339	1.000**	

100SW	0.056	0.038	0.884**	-0.006	0.157	-0.062	-0.169	0.003	1.000**
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Where, Inc.=incidence; Sev.= disease severity; PH= plant height; NBPP= number of branches per pod; NPP=Number of pods per plant; aboveground dry biomass; GRY=grain yield; BMY= HI= harvest index; 100SW= Hundred seeds weight; *Significant at the 0.05 level, and **Significant at the 0.01 level.

7.3.6. Partial economic analysis

The research result of the partial economic analysis showed that the uppermost total (USD 164.48 ha⁻¹) variable cost was recorded for the Dhera chickpea variety treated with Nobel 250 EC and that received vermicompost application. The maximum (USD 2048.93 ha⁻¹) net benefit was achieved by the Natoli variety treated with Goldazim 500 SC fungicide. This was followed by the Natoli variety treated with Goldazim 500 SC and supplemented with vermicompost application, which resulted in USD 1998.07 ha⁻¹ net benefit. The highest (USD 628.92 ha⁻¹) marginal rate of return was computed for the Natoli chickpea variety treated with Goldazim 500 SC supplemented with vermicompost. This was followed by the chickpea Natoli variety that received only vermicompost, which gave USD 519.96 marginal rate of return per hectare. Thus, Natoli-based treatments, particularly those involving Goldazim 500 SC and vermicompost, consistently demonstrated the highest net benefits and marginal rate of return, suggesting that they are the most profitable options. On the other hand, untreated control treatments involving Dhera generally showed lower net benefits and often more dominance, indicating they are less economically viable (Table 7.5.).

Table 7.5. Partial economic analysis of integrated chickpea management options, showing the impact of varieties, vermicompost treatment and fungicide application

Treatments	Average yield (kg ha ⁻¹)	Adjusted yield- (kg ha ⁻¹)	Gross revenue (USD ha ⁻¹)	Total variable cost (USD ha ⁻¹)	Net benefit (USD ha ⁻¹)	MRR (USD ha ⁻¹)	Dominance
Arerti (untreated)	2509.2	2258.3	1829.21	40.5	1788.71		
Natoli (untreated)	2705.8	2435.2	2021.23	41.5	1979.73	191.02	
Dhera (untreated)	2156.5	1940.8	1669.32	43.0	1626.32	-235.61	D
Arerti+Goldazim 500 SC	2570.7	2313.6	1874.04	43.98	1830.06	207.9	
Arerti+Nobel 250 EC	2513.0	2261.7	1831.98	44.46	1787.52	-88.63	D
Natoli+Goldazim 500 SC	2803.1	2522.8	2093.91	44.98	2048.93	502.71	
Natoli+Nobel 250 EC	2729.4	2456.5	2038.86	45.48	1993.38	-111.1	D
Dhera+Goldazim 500 SC	2385.1	2146.6	1846.07	46.48	1799.59	-193.79	D
Dhera+Nobel 250 EC	2367.7	2130.9	1832.60	46.96	1785.64	29.06	
Arerti+vermicompost	2518.6	2266.7	1836.05	158.0	1678.05	-0.97	
Natoli+vermicompost	2806.6	2525.9	2096.53	158.5	1938.03	519.96	
Dhera+vermicompost	2356.3	2120.7	1823.78	160.5	1663.28	-137.38	D
Arerti+Goldazim 500 SC+vermicompost	2676.3	2408.7	1951.02	161.48	1789.54	128.84	
Arerti+Nobel 250 EC+vermicompost	2514.4	2263.0	1832.99	161.96	1671.03	-246.89	
Natoli+Goldazim 500 SC+vermicompost	2892.3	2603.1	2116.55	162.48	1998.07	628.92	

Natoli+Nobel 250 EC+vermicompost	2737.0	2463.3	2044.54	162.96	1881.58	-242.69	D
Dhera+Goldazim 500 SC+vermicompost	2514.1	2262.7	1945.92	163.98	1781.94	-97.69	
Dhera+Nobel 250 EC+vermicompost	2356.9	2121.2	1824.24	164.48	1659.76	-244.36	D

Where, MRR= marginal rate of return

7.4. Conclusion and Recommendation

The study comprehensively evaluated the efficacy of integrated management practices, including seed dressing fungicides and vermicompost application on different varieties, in mitigating chickpea Fusarium wilt and enhancing chickpea yield. The result unequivocally demonstrated that an integrated approach significantly reduced disease incidence and severity, leading to substantial improvement in chickpea grain yield and yield components. The Natoli chickpea variety, particularly when treated with Goldazim 500SC and vermicompost, consistently exhibited the lowest disease incidence and severity, alongside the highest grain yield, number of pods per plant and hundred seeds weight. This highlights the synergetic effect of combining fungicides and organic interventions and Goldazim 500 SC effectively reduced pathogen inoculum, while vermicompost improves soil health and nutrient availability, fostering robust plant growth and resilience. In conclusion, this study provides valuable insights into the effective management of chickpea Fusarium wilt. The integrated application of seed dressing fungicide, Goldazim 500SC and vermicompost, particularly in moderately resistant chickpea varieties, like Natoli, offer a promising strategy for minimizing the adverse impact of Fusarium wilt and maximizing chickpea productivity.

CHAPTER 8: General Conclusions and Recommendation

8.1. Conclusions

Chickpea plays a pivotal role in the cereal based cropping system in the highlands of Ethiopia, where the crop serves as a primary source of affordable protein, a high-value export commodity. Beyond its economic and nutritional value, chickpea is essential for maintaining soil health through its natural ability for biological nitrogen fixation, making it an integral component of sustainable cropping systems. Despite this importance, a persistent yield gap exists with actual yields of approximately 2 tons per hectare falling far below its potential of 5 tons per hectare due largely to the widespread impact of Chickpea Fusarium Wilt. This research was therefore mainly designed to address the devastating impact of chickpea Fusarium wilt in western Amhara by synthesizing epidemiological data, farmer knowledge, and integrated management practices. This concluding chapter provides a holistic synthesis of the work, demonstrating how the individual research components collectively address the core challenge of chickpea productivity in Ethiopia.

The result revealed that CFW is a ubiquitous and severe constraint to chickpea production across western Amhara, with disease incidence and severity significantly dictated by biophysical factors and management practices applied. Epidemiological assessments confirmed that the disease is most intense in early-planted fields with short rotations, whereas late-season planting and rotations of four or more years significantly reduced wilt intensity. Evidences from socioeconomic data showed that farmers in west Amhara demonstrated long-standing traditional experience, with approximately 80% utilizing crop rotation and 60% employing delayed planting. Nearly 99% of farmers failed to recognize the causal pathogen of the disease often misattributing the disease to environmental stressors like soil moisture (locally termed “Abektie”). This reliance on horizontal, peer-to-peer knowledge transmission without scientific foundation explains why the disease remains ubiquitous despite the application of traditional cultural practices.

This socio-economic reality connects directly into the epidemiological field assessments, which confirmed that CFW is universally present across all surveyed districts. The field data validated that traditional practices are only effective when applied correctly; for instance, the highest wilt incidence occurred in fields with early planting and short rotations, while the lowest were observed in fields with late planting and rotations of four or more years. These findings bridged the gap between farmer observation and biological reality, proving that while cultural methods can reduce the disease intensity, they are insufficient as standalone solutions in high-pressure areas.

The pathogenicity test further identified a critical transmission route that the pathogen causing CFW has seed-borne nature, with 62.5% of isolates from infected seeds capable of inducing wilt, while also reducing germination, overall seedling biomass and vigor index. This systemic infection loop means that even with soil management, the disease can be reintroduced through poor seed health. Recognizing these complexities, the field experiment was specifically focused on developing actionable solutions to fill the gap between high disease pressure and low productivity of the crop. The synthesis of this experimental provides a validated solution to these challenges through an Integrated Disease Management approach. By synergistically combining the moderately resistant Natoli variety with Goldazim 500SC seed treatment and vermicompost soil amendment, a dramatic reduction in disease incidence (2.19%) and a maximum grain yield of 2953.8 kg ha⁻¹ was achieved. This holistic approach not only addresses the biological threat of CFW but also proves economically superior, offering the highest marginal rate of return for producers. Therefore, while CFW remains a predominant threat to chickpea production, the results of this study demonstrate that the transition from traditional, single-tactic approaches to a scientifically integrated framework is both biologically effective and economically rewarding.

This work provides the comprehensive analysis of CFW epidemics specifically in western Amhara, linking farmers' indigenous knowledge with rigorous field validation of IDM strategies. It establishes the critical role of seed-borne inoculum in CFW epidemics

and provides a field-validated, cost-effective, and economically viable (high marginal rate of return) management package for smallholder farmers.

8.2. Recommendation

1. Chickpea producers are strongly advised to avoid using seeds harvested from previously wilted mother plants, even if the plants were only partially affected, as these are primary carriers of the pathogen.
2. Farmers should adopt the integrated approach particularly Natoli variety, Goldazim treatment, and vermicompost applications while strictly adhering to at least four-year crop rotations and avoiding early-season planting.
3. Producers should also at least minimize the informal exchange of chickpea seeds of unknown or poor health status, as this practice can unintentionally introduce the pathogen to disease-free areas. Traditional farmer-to-farmer seed sharing can inadvertently result in the introduction of the pathogen into previously uninfested, clean soil areas particularly for pathogens with seed borne nature like FOC. At a minimum, if seeds must be sourced locally, farmers must be fully aware of the previous history of the field and the mother plants to ensure they were not sourced from infested fields.
4. The regional and/or the zonal Bureau of Agriculture should prioritize large-scale awareness creation campaigns and knowledge-sharing platforms to address the existing gap among chickpea producers.
5. Efforts should focus on training farmers about hidden transmission pathways particularly seed-borne infection, and the benefits of the IDM approach.
6. The regional office of agriculture should also collaborate closely with agricultural research centers to scale up the multiplication and distribution of superior promising varieties, such as Natoli, ensuring they reach the farming community efficiently.
7. Future research should focus on the molecular race identification of FOC isolates in Ethiopia to ensure breeding programs stay ahead of pathogen evolution. In addition, while the field experiment offers integrated management strategies, it was conducted in two study locations for one growing season; longer-term, multi-location trials are needed to evaluate the IDM package's resilience against extreme climate shifts. The specific crop rotation and planting patterns identified through the epidemiological surveys and socio-

economic assessments must be directly confirmed through controlled field experiments. Such controlled trials are necessary to validate the survey findings and ensure that the recommended sequence of preceding crops is empirically proven to suppress disease. Furthermore, future research must focus on site-specific planting times schedules tailored to local rainfall patterns. Since soil moisture and temperature are critical drivers FOC biological activity, aligning planting windows with specific moisture regimes will be vital for optimizing yield and minimizing infection risks in a changing climate.

REFERENCES

- Alemu Nega (2025) ‘Climate Change Impacts on Agriculture: A Review of Plant Diseases and Insect Pests in Ethiopia and East Africa, With Adaptation and Mitigation Strategies’, *Advances in Agriculture*, 2025(1). Available at: <https://doi.org/10.1155/aia/5606701>.
- Asrat Mulat Asegie, Almaz Giziew and Dereje Ayalew (2022) ‘Analyzing constraints of smallholders’ chickpea (*Cicer arietinum* L.) production systems in Gondar Zuria Woreda of Ethiopia using the Henry Garrett’s ranking technique’, *Heliyon*, Available at: <https://doi.org/10.1016/j.heliyon.2022.e11126>.
- Abdalla, S.A. et al. (2022) ‘Screening of Rhizobacterial Isolates for Biological Control of Fusarium Wilt Disease of Chickpea’, (July), pp. 0–7. Available at: <https://doi.org/10.12691/wjar-10-2-2>.
- Abed, H. et al. (2016) ‘Screening for Pseudomonas and Bacillus antagonistic rhizobacteria strains for the biocontrol of Fusarium wilt of chickpea’, 5(3), pp. 182–191. available at: <http://dx.doi.org/10.18393/ejss.2016>.
- Afzal, M.K. (2021) ‘Afs- advances in food sciences’, *Advances in food science*, 43(4), pp. 211–219. Available at: <https://doi.org/10.1016/j.ejogrb.2018.09.023>.
- Agustina, N. laras (2019) 'Studies on Seed born nature of Fusarium oxysporium f. spp ciceri incited wilt in chickpea (*Cicer arietinum* L.)' Submitted to Vijayaraje Scindia Krishi Vishwa Vidyalaya, Gwalior College of Agriculture Indore (M. P.).Msc Thesis, 93pp
- Akpo, E. et al. (2020) ‘Legume seed production for sustainable seed supply and crop productivity: case of groundnut in Tanzania and Uganda’, *Journal of Crop Improvement*, 00(00), pp. 1–22. Available at: <https://doi.org/10.1080/15427528.2020.1740368>.
- Alsamman, A.M. et al. (2023) ‘Unveiling the genetic basis of Fusarium wilt resistance in chickpea using GWAS analysis and characterization of candidate genes’, *Frontiers in Genetics*, 14(January), pp. 1–11. Available at: <https://doi.org/10.3389/fgene.2023.1292009>.

- Al-Taae, A.K. and Al-Jobory, S.E. (2013) 'Pathogenic Variability in Isolates of *Fusarium Oxysporum* f.sp. *ciceris*', Journal of University of Zakho(JUOZ), 1(1), pp. 108–114. Available at: <https://sjuoz.uoz.edu.krd/index.php/sjuoz/article/view/52>.
- Anteneh Abewa et al. (2019) 'agronomy Te ff Grain Physical and Chemical Quality Responses to Soil Physicochemical Properties and the Environment', PLoS ONE, pp. 1–19.
- Asnake Fikre and Dagnachew Bekele (2020) 'Chickpea breeding and crop improvement in Ethiopia: Past, present and the future', Universal Journal of Agricultural Research, 8(2), pp. 33–40. Available at: <https://doi.org/10.13189/ujar.2020.080202>.
- Asnake Fikre and Tulu Degefu (2019) 'A Guide to Accelerated Breeding Cycle in Chickpea to Enhance Rate of Gain A Guide to Accelerated Breeding Cycle in Chickpea to Enhance Rate of Gain', (1).
- Asnake Fikre, Haile Desmae and Seid Ahmed (2020) 'Tapping the Economic Potential of Chickpea in', MDPI Agronomy [Preprint].
- Asrat Z. (2017) 'Significance and Management of Chickpea Wilt/root rot and Future Prospects in Ethiopia. A Review', 5(1), pp. 117–126.
- Asrat Zewdie and Tolesa Bedasa (2020) 'Source of resistance to chickpea Fusarium wilt (*Fusarium oxysporum* f.sp. *ciceris*) under field conditions in Ethiopia', 15(1), pp. 85–89. Available at: <https://doi.org/10.5897/AJAR2019.14595>.
- Assfaw, Selvara and Gezahegn Getaneh (2019) 'Pathogen Identification and Evaluation of Chickpea Varieties for Resistance Against the Pathogens in West Shewa , Oromia Regional State , Ethiopia', pp. 29–42. Available at: <https://doi.org/10.7176/ALST>.
- Awoke Ayana, Negash Hailu and Wendimneh Taye (2019) 'Screening Desi and Kabuli Chick Pea Varieties against Fusarium Wilt Plant Pathology & Microbiology Screening Desi and Kabuli Chick Pea Varieties against Fusarium Wilt Resistance in West , Northwestern Ethiopia', Journal of Plant Pathology & Microbiology, 10(2). Available at: <https://doi.org/10.4172/2157-7471.1000474>.
- Awoke Yemataw et al. (2025) 'Analysis of the distribution status of chickpea Fusarium wilt (*Fusarium oxysporum* f .sp . *ciceri*) and association of factors influencing the

- disease in Central and South Gondar , Northwestern Ethiopia’, Archives of Phytopathology and plant protection, 1-21 available at <https://doi.org/10.1080/03235408.2025.2489137>
- Ayuke, F.O. (2010) Soil macrofauna functional groups and their effects on soil structure , as related to agricultural management practices across agroecological zones of Sub-Saharan Africa.
- Basu P.S., Masood Ali and S.K. Chaturvedi (2009) "Terminal Heat Stress Adversely Affects Chickpea Productivity In Northern India— Strategies To Improve Thermotolerance In The Crop Under Climate Change", 189-193
- Bekkar, A.A., Zaim, S. and Belabid, L. (2018) ‘Archives of Phytopathology and Plant Protection Induction of systemic resistance in chickpea against Fusarium wilt by Bacillus strains’, Archives of Phytopathology and Plant Protection, 5408, pp. 1–11. Available at: <https://doi.org/10.1080/03235408.2018.1438819>.
- Bereket Ali and Habtamu Terefe (2021) ‘Spatial distribution and characterization of Fusarium wilt (*Fusarium oxysporum* f.sp. *ciceris*) of chickpea in Northern Shoa, Ethiopia’, Archives of Phytopathology and Plant Protection, 54(19–20), pp. 1578–1602. Available at: <https://doi.org/10.1080/03235408.2021.1929689>.
- Bereket Ali and Habtamu Terefe (2023) ‘Host resistance by sowing date interaction reduced Fusarium wilt pressure and improved grain yield of chickpea (*Cicer arietinum* L.) in North Shoa, Ethiopia’, Agrosystems, Geosciences and Environment, 6(3), pp. 1–16. Available at: <https://doi.org/10.1002/agg2.20400>.
- Berger, R.J.R.A.J.D. (2007). Chickpea Breeding and Management. CABI international, 664pp
- Berhan Agmas and Marshet Adugna (2020) ‘Attitudes and practices of farmers with regard to pesticide use in NorthWest Ethiopia’, Cogent Environmental Science, 6(1). Available at: <https://doi.org/10.1080/23311843.2020.1791462>.
- Bhimani, M. (2020) ‘Efficacy of different fungicides for the management of chickpea wilt (Fusarium Efficacy of different fungicides for the management of chickpea wilt (*Fusarium oxysporum* f.sp. *ciceri*)’, (January 2018). Available at: <https://doi.org/10.13140/RG.2.2.32521.88160>.

- Bimrew Bimrew, A. (2018) ‘Smallholder farmers livestock production and marketing in Bahir Dar Zuria District, Northwestern Ethiopia’, *Journal of Development and Agricultural Economics*, 10(5), pp. 159–164. Available at: <https://doi.org/10.5897/jdae2017.0897>.
- Birhanu Gizaw, ZerihunTsegay, Genene Tefera, Endegen Aynalem, E.A. and G.A. (2018) ‘Traditional Knowledge on Teff (*Eragrostis tef*) Farming Practice and Role of Crop Rotation to Enrich Plant Growth Promoting Microbes for Soil Fertility in East Showa: Ethiopia’, *Agricultural Research & Technology: Open Access Journal*, 16(5), pp. 139–155. Available at: <https://doi.org/10.19080/artoaj.2018.16.556001>.
- Biru Alemu et al. (2017) ‘Genotype by environment interactions and grain yield stability of released and advanced Desi type chickpea (*Cicer arietinum* L.) genotypes in western Ethiopia’, *International Journal of Biotechnology and Molecular Biology Research*, 8(3), pp. 30–37. Available at: <https://doi.org/10.5897/ijbmbr2017.0281>.
- Biru Alemu et al. (2014) ‘Adaptation Study of Improved Kabuli Chickpea (*Cicer arietinum* L) Varieties at Kellem Wollega Zone, Haro Sabu, Ethiopia’, *Journal of Natural Sciences Research* www.iiste.org ISSN, 4(18), pp. 220–225. Available at: <http://faostat.fao.org/site/567/DesktopDefault.aspx>.
- Biswas, S.P. (2017) ‘Eco-Friendly Management of *Fusarium oxysporum* f. sp. *ciceri* the Causal Agent of Chickpea Wilt Disease under In-vitro Condition’, *International Journal of Current Microbiology and Applied Sciences*, 6(3), pp. 1852–1858. Available at: <https://doi.org/10.20546/ijcmas.2017.603.211>.
- Bulti Merga and Jema Haji (2019) ‘Economic importance of chickpea: Production, value, and world trade’, *Cogent Food and Agriculture*, 5(1). Available at: <https://doi.org/10.1080/23311932.2019.1615718>.
- Bulti Merga and Nano Alemu (2019) ‘Integrated weed management in chickpea (*Cicer arietinum* L.)’, *Cogent Food and Agriculture*, 5(1). Available at: <https://doi.org/10.1080/23311932.2019.1620152>.
- Canıço, A., Mexia, A. and Santos, L. (2021) ‘Farmers ’ knowledge , perception and management practices of fall armyworm (*Spodoptera frugiperda* Smith) in

- Manica province , Mozambique’, 143, pp. 127–143. Available at: <https://doi.org/10.3897/neobiota.68.62844>.
- Central Statistical Agency (CSA) (2021) The Federa Democratic Republic of Ethiopia Report on Area and Production of Majr Crops.
- Chand, H., Khirbat, S.K. and L, C.C. (2009) ‘CHICKPEA WILT AND ITS MANAGEMENT - A REVIEW’, 30(1), pp. 1–12.
- Charitha, N., Paslawar, A.N. and Darekar, N.K. (2025) ‘Chickpea Thrive : Unleashing Potential in Intercropping Systems with Different Organic and Natural Farming Practices’, 48(9), pp. 1547–1552. Available at: <https://doi.org/10.18805/LR-5517.Submitted>.
- Chemeda Fininsa and Yuen J. (2001) ‘Association of maize rust and leaf blight epidemics with cropping systems in Hararghe highlands, eastern Ethiopia’, 20, pp. 669–678.
- CIMMYT (1988) Correct Citation : CIMMYT . 1988 . From Agronomic Data to Farmer Recommendations : An Economics Training Manual.
- Cruz, D.R. *et al.* (2020) ‘Effects of soil conditions on root rot of soybean caused by *Fusarium graminearum*’, *Phytopathology*, 110(10), pp. 1693–1703. Available at: <https://doi.org/10.1094/PHYTO-02-20-0052-R>.
- Dagnachew Bekele Besha, (2021) Mapping of Novel Quantitative Trait Loci (QTL) for *Fusarium* Wilt Resistance in Chickpea (*Cicer arietinum* L.) and Analysis of the Genomic Diversity of *Fusarium oxysporum* f.sp. *ciceris* in Ethiopia, PhD Dissertation Addis ababa university, institute of biotechnology, 218.
- Dagnachew Bekele *et al.* (2021) ‘The extent and association of chickpea *Fusarium* wilt and root rot disease pressure with major biophysical factors in Ethiopia’, *Journal of Plant Pathology*, 103(2), pp. 409–419. Available at: <https://doi.org/10.1007/s42161-021-00779-4>.
- Daniel Assfaw and Tilahun Negash, 2020 (2020) ‘Spatial Distribution and Association of Chickpea Wilt / Root Rots Epidemics with Biophysical Factors at West Shewa , Oromia Regional State , Ethiopia Plant Pathology & Microbiology’, *Journal of Plant Pathology and Microbiology*, 11(9), pp. 7–12. Available at: <https://doi.org/10.35248/2157-7471.20.11.513>.

- Daniel Getahun Debelo and Emana Getu Degaga (2015) 'Farmers knowledge, perceptions and management practices of termites in the central rift valley of Ethiopia', *African Journal of Agricultural Research*, 10(36), pp. 3625–3635. Available at: <https://doi.org/10.5897/ajar2014.9283>.
- Devasirvatham, V. and Tan, D.K.Y. (2018) 'Impact of high temperature and drought stresses on Chickpea production', *Agronomy*, 8(8). Available at: <https://doi.org/10.3390/agronomy8080145>.
- Dhawale, S. N., & Dhale, D. A. (2021) 'Effects of Fusarium wilt on chickpea in India: A review', *International Journal of Botany Studies*, 6(4), 884-890.
- Dubey, S.C. et al. (2020) 'Microbial Diversity and Plant Disease Management Diversity and management of *Fusarium oxysporum* f.sp. *ciceris* causing chickpea wilt Diversity and management of *Fusarium oxysporum* f.sp. *ciceris* causing chickpea', (June), pp. 72–86.
- Dubey, S.C., Singh, S.R. and Singh, B. (2010) 'Morphological and pathogenic variability of Indian isolates of *Fusarium oxysporum* f. sp. *ciceris* causing chickpea wilt', *Archives of Phytopathology and Plant Protection*, 43(2), pp. 174–190. Available at: <https://doi.org/10.1080/03235400802021108>.
- Dubey, S.C., Singh, V. and Priyanka, K. (2015) 'Combined application of fungal and bacterial bio-agents , together with fungicide and Mesorhizobium for integrated management of Fusarium wilt of chickpea'. Available at: <https://doi.org/10.1007/s10526-015-9653-8>.
- Dutta, D. and Bandyopadhyay, P. (2009) 'Performance of chickpea (*Cicer arietinum* L.) to application of phosphorus and bio-fertilizer in laterite soil', *Archives of Agronomy and Soil Science*, 55(2), pp. 147–155. Available at: <https://doi.org/10.1080/03650340802398864>.
- Edema, R., Adipala, E. and Florini, D.A. (1997) 'Influence of season and cropping system on occurrence of cowpea diseases in Uganda', *Plant Disease*, 81(5), pp. 465–468. Available at: <https://doi.org/10.1094/PDIS.1997.81.5.465>.
- Edeo Negash (2021) Distribution of Fusarium Wilt of Chickpea and its Association with Biophysical Factors in East Shewa Zone, Central Ethiopia, *Pest Mgt. J. Eth.*

- Elad, Y. and Pertot, I. (2014) 'Climate Change Impacts on Plant Pathogens and Plant Diseases', *Journal of Crop Improvement*, 28(1), pp. 99–139. Available at: <https://doi.org/10.1080/15427528.2014.865412>.
- FAOSTAT (2024) 'Crops and Livestock production data. Food and Agricultural Organization, Rome, Italy. <https://www.fao.org/faostat/en/#data/QCL>.
- Farooq, A. et al. (2023) 'Impact at a Global Scale on Cereal Crop Production', *Agronomy*, 13(1), pp. 1–19.
- Febrianti, T. et al. (2024) 'Socio-Economic Factors Influencing the Adoption of Integrated Crop Management Technology in Rice For Sustainable Agribusiness Development', *Jurnal Penelitian Pendidikan IPA*, 10(8), pp. 5984–5991. Available at: <https://doi.org/10.29303/jppipa.v10i8.8123>.
- Fentahun Abebe Debebe and Mengistu Nega Miteku (2023) 'Effects of land use / land cover Changes on land surface Temperature and Agricultural lands in Bahir Dar Zuria Woreda', *Journal of Urban Development Studies*, 3(1).
- Fisseha Alebachew et al. (2023) 'Pesticide use safety practices and associated factors among farmers in Fogera district wetland areas, south Gondar zone, Northwest Ethiopia', *PLoS ONE*, 18(1January), pp. 1–15. Available at: <https://doi.org/10.1371/journal.pone.0280185>.
- Garret, S.D., (1956) 'Biology of Root Infecting Fungi'. Cambridge University Press, Cambridge, UK.
- Gizachew Ayalew Tiruneh et al. (2021) 'Spatial variability of soil chemical properties under different land-uses in Northwest Ethiopia', *PLoS ONE*, 16(6 June), pp. 1–18. Available at: <https://doi.org/10.1371/journal.pone.0253156>.
- Gaur, P.M. et al. (2014) *Advances in Chickpea Genomics Legumes in the Omic Era* DOI : http://dx.doi.org/10.1007/978-1-4614-8370-0_4.
- Gemechu Keneni, et al. (2012) 'Genetic Diversity and Population Structure of Ethiopian Chickpea (*Cicer arietinum* L.) Germplasm Accessions from Different Geographical Origins as Revealed by Microsatellite Markers', *Plant Molecular Biology Reporter*, 30(3), pp. 654–665. Available at: <https://doi.org/10.1007/s11105-011-0374-6>.

- Genanaw Agitew, Zewudu Berhanieand Samson Gebremedhin (2024) ‘Production pathway of smallholders to nutrition - sensitive agriculture in Northwest Ethiopia’, Discover Agriculture [Preprint]. Available at: <https://doi.org/10.1007/s44279-024-00036-z>.
- Getachew Agegnehu, and Weldeyesus Sinebo (2012) ‘Drainage, sowing date and variety effects on chickpea grown on a Vertisol in Ethiopia’, Archives of Agronomy and Soil Science, 58(1), pp. 101–113. Available at: <https://doi.org/10.1080/03650340.2010.503958>.
- Gezahegne Getaneh Damessa (2020) ‘Seed quality and mycoflora associated with chickpea ’, 20(6), pp. 16761–16778.
- Gezahegne Getaneh Damessa *et al.* (2021) ‘Farmers ’ knowledge and practices on chickpea production and disease management in major chickpea growing areas of Ethiopia’, Archives of Phytopathology and Plant Protection, 0(0), pp. 1–22. Available at: <https://doi.org/10.1080/03235408.2021.1994269>.
- Girma Abebe and Amanuel Alemu (2017) ‘Role of Improved Seeds Towards Improving Livelihood’, 5, pp. 338–356. DOI: <https://doi.org/10.29121/granthaalayah.v5.i2.2017.1746>
- Gudeta Eldesemayat Sileshi *et al.* (2008) ‘Farmers’ perceptions of tree mortality, pests and pest management practices in agroforestry in Malawi, Mozambique and Zambia’, Agroforestry Systems, 72(2), pp. 87–101. Available at: <https://doi.org/10.1007/s10457-007-9082-5>.
- Habtamu Terefe and Getachew Gude (2019) ‘Distribution and association of factors influencing emerging maize lethal necrosis disease epidemics in Southern Ethiopia’, Cogent Food and Agriculture, 5(1). Available at: <https://doi.org/10.1080/23311932.2019.1683950>.
- Haware, M.P., Nene, Y.L. and Natarajan, M. (1996) ‘The survival of *Fusarium oxysporum* f.sp . *ciceri* in the soil in the absence of chickpea Author (s)
- Haware, M.P., Nene, Y.L., Rajeswari, R.(1978) ‘Eradication of *Fusarium oxysporum* f. sp. *ciceris* transmitted in chickpea seed’ Phytopathology 68, pp,1364-1368.

- Haware , Y . L . (1978) Nene and M . Natarajan Published by : Firenze University Press on behalf of the Mediterranean Phytopathological Union Stable U', 35(1), pp. 9–12.
- Hay, R. K. M. (1995) 'Harvest index: a review of its use in plant breeding and crop physiology', *Annals of applied biology*, 126(1), 197-216.
- Heong, K.L. *et al.* (2002) 'Insect management beliefs and practices of rice farmers in Laos', *Agriculture, Ecosystems and Environment*, 92(2–3), pp. 137–145. Available at: [https://doi.org/10.1016/S0167-8809\(01\)00304-8](https://doi.org/10.1016/S0167-8809(01)00304-8).
- Hossain, M. *et al.* (2013) 'Integrated management of Fusarium wilt of chickpea (*Cicer arietinum* L .) caused by *Fusarium oxysporum* f.sp. *ciceris* with microbial antagonist , botanical extract and fungicide', 12(29), pp. 4699–4706. Available at: <https://doi.org/10.5897/AJB2013.12503>.
- Imtiaz, M., Malhotra, R.S. and Yadav, S.S. (2011) 'Chapter 9 Gene ti c Ad j us t men t to Ch ang i ng Cli ma t es : Chi c k pea'.
- Jamil, A., Ashraf, S. and Jamil, A. (2020) 'Archives of Phytopathology and Plant Protection Utilization of chemical fungicides in managing the wilt disease of chickpea caused by *Fusarium oxysporum* f.sp. *ciceri*', *Archives of Phytopathology and Plant Protection*, 0(0), pp. 1–23. Available at: <https://doi.org/10.1080/03235408.2020.1803705>.
- Jemberu, T. *et al.* (2018) 'Agronomic and Economic Evaluation of Wheat-Chickpea Double Cropping on the Vertisol of Takusa, North Western Ethiopia.', *Ethiop. J. Crop Sci.*, 6(2), pp. 67–78.
- Jendoubi, W. *et al.* (2017) 'Fusarium wilt affecting chickpea crop', *Agriculture (Switzerland)*, 7(3), pp. 1–16. Available at: <https://doi.org/10.3390/agriculture7030023>.
- Jha, U.C. *et al.* (2014) 'Abiotic stresses, constraints and improvement strategies in chickpea', *Plant Breeding*, 133(2), pp. 163–178. Available at: <https://doi.org/10.1111/pbr.12150>.
- Jiménez-díaz, R.M. and Jiménez-gasco, M.M. (2011) *Integrated Management of Fusarium Wilt Diseases, Control of Fusarium Diseases*.

- Jiménez-Díaz, R.M. et al. (2015) 'Fusarium wilt of chickpeas: Biology, ecology and management', Crop Protection, 73, pp. 16–27. Available at: <https://doi.org/10.1016/j.cropro.2015.02.023>.
- Jimenez-Fernandez, D., Landa, B.B., Kang, S., Jimenez-Díaz, R.M., Navas-Cortes, J.A., (2013) 'Quantitative and microscopic assessment of compatible and incompatible interactions between chickpea cultivars and *Fusarium oxysporum* f. sp. *ciceris* races', PLoS One 8 (4), 61360. <http://dx.doi.org/10.1371/journal.pone.0061360>.
- Jiménez-Gasco, M.D.M., Milgroom, M.G. and Jiménez-Díaz, R.M. (2004) 'Stepwise evolution of races in *Fusarium oxysporum* f.sp. *ciceris* inferred from fingerprinting with repetitive DNA sequences', Phytopathology, 94(3), pp. 228–235. Available at: <https://doi.org/10.1094/phyto.2004.94.3.228>.
- Singh, K.B. (1997) 'Chickpea (*Cicer arietinum* L.)', Field Crops Research, 53, pp. 161–170.
- Kaiser, W.J. et al. (1994) 'Screening of wild Cicer species for resistance to races 0 and 5 of *Fusarium oxysporum* f. sp. *ciceris*', Plant Disease, pp. 962–967. Available at: <https://doi.org/10.1094/PD-78-0962>.
- Kala, C., Gangopadhyay, S. and Godara, S.L. (2020) 'Eco-friendly management of wilt caused by *Fusarium oxysporum* f.sp. *Ciceri* in chickpea Eco-friendly management of wilt caused by *Fusarium oxysporum* f. sp. *Ciceri* in chickpea', (May). Available at: <https://doi.org/10.18805/lr.v0iOF.6789>.
- Kansiime, M.K. et al. (2021) 'Assessing sustainability factors of farmer seed production : a case of the Good Seed Initiative project in Tanzania', Agriculture & Food Security, pp. 1–10. Available at: <https://doi.org/10.1186/s40066-021-00289-7>.
- Kaulage, S. A., Raghuwanshi, K. S., & Pawar, P. U. (2018) 'Effect of different organic amendment on population dynamics and incidence of Fusarium wilt in chickpea', Int J Chem Stud, 6, 25-28.
- Kaur, G., Kumar, A. and Singh, R. (2023) 'Effect of Vermicompost , Biofertilizers and in Organic Fertilizers on Nutrient Uptake and Physico-chemical Properties of Soil : A Case Study of Chickpea (*Cicer arietinum* L.)', 13(10), pp. 4519–4525. Available at: <https://doi.org/10.9734/IJECC/2023/v13i103130>.

- Kesho, A. and Abebe, W. (2020) ‘Detection of Seed Borne Fungi Associated with Some Cereals and Legume Crops of Seeds Grown in Main Season at Holetta Agricultural Research Center’, 8(5), pp. 91–95. Available at: <https://doi.org/10.11648/j.ajls.20200805.11>.
- Kiros-Meles, A. and Abang, M.M. (2008) ‘Farmers’ knowledge of crop diseases and control strategies in the Regional State of Tigray, northern Ethiopia: Implications for farmer-researcher collaboration in disease management’, *Agriculture and Human Values*, 25(3), pp. 433–452. Available at: <https://doi.org/10.1007/s10460-007-9109-6>.
- Kl, N. and Huilgol, S.N. (2021) ‘In vitro evaluation of fungicides against *Fusarium oxysporum* f. sp. *ciceri*’, 10(7), pp. 181–184.
- Koul, B. et al. (2022) ‘Chickpea (*Cicer arietinum* L.) Biology and Biotechnology: From Domestication to Biofortification and Biopharming, Plants, pp. 1–28.
- Kudadjie, C.Y. (2006) ‘Integrating science with farmer knowledge: sorghum diversity management in north-east Ghana’, *Integrating science with farmer knowledge: sorghum diversity management in north east Ghana*, p. 220.
- Kumar, S. et al. (2023) ‘Pulse-based cropping systems for soil health restoration, resources conservation, and nutritional and environmental security in rainfed agroecosystems’, *Frontiers in Microbiology*, 13. Available at: <https://doi.org/10.3389/fmicb.2022.1041124>.
- Laxmipathi Gowda, P.G. and S.S. (2016) ‘The Seed Constraint: New approaches for smallholder agriculture in eastern and southern Africa’, in *Harnessing Chickpea Value Chain for Nutrition Security and Commercialization of Smallholder Agriculture in Africa*, pp. 1–24. Available at: http://tropicallegumes.icrisat.org/wp-content/uploads/2017/04/Conference-Proceedings_Harnessing-Chickpea-Value-Chain-for-Nutrition-Security-and-Commercialization-of-Smallholder-Agriculture-in-Africa.pdf#page=307.
- Leisso, R. et al. (2011) ‘Pathogenicity of *Fusarium* spp. to chickpea seed and seedlings (*Cicer arietinum* L.)’, *Canadian Journal of Plant Pathology*, 33(3), pp. 400–409. Available at: <https://doi.org/10.1080/07060661.2011.588249>.

- Lijalem Korbu et al. (2020) 'Unlocking the genetic potential of chickpea through improved crop management practices in Ethiopia. A review', *Agronomy for Sustainable Development*, 40(2). Available at: <https://doi.org/10.1007/s13593-020-00618-3>.
- Lijalem Korbu et al. (2022) 'Response of chickpea to varying moisture stress conditions in Ethiopia', *Agrosystems, Geosciences and Environment*, 5(1), pp. 1–18. Available at: <https://doi.org/10.1002/agg2.20234>.
- Martin Luther, M.S.K., K. L. Narasimha Rao, C.P.R. and Prasad, P.R. (2020) 'Growing Degree Days and Heat Use Efficiency Influenced by Dates of Sowing and Irrigation Levels on Rainfed Chickpea', *International Journal of Current Microbiology and Applied Sciences*, 9(8), pp. 3996–4002. Available at: <https://doi.org/10.20546/ijcmas.2020.908.460>.
- Mekonnen Gebeyaw, Asnake Fikre, and Abate Alemu (2024a) 'Genotype by Environment ($G \times E$) Interaction and Yield Stability of Chickpea (*Cicer arietinum* L.) Varieties Across Agroecological Regions of Ethiopia', pp. 1–16. Available at: <https://doi.org/10.1002/leg3.227>.
- Mekonnen Gebeyaw, Asnake Fikre, and Abate Alemu (2024b) 'Participatory variety evaluation and selection of chickpea (*Cicer arietinum* L.) varieties; an underpinning to novel technology uptake in northwestern Ethiopia', *Heliyon*, 10(8), p. e29801. Available at: <https://doi.org/10.1016/j.heliyon.2024.e29801>.
- Haware, Y.L. Nene, and R.R. (1978) 'Eradication of *Fusarium oxysporum* f.sp. *ciceris* Transmitted in Chickpea Seeds' *Diseases Control and Pest Management*, pp. 1364–1367.
- Maharshi, A. et al. (2021) 'Salt stress alters pathogenic behaviour of *Fusarium oxysporum* f. sp. *ciceris* and contributes to severity in chickpea wilt incidence', *Physiological and Molecular Plant Pathology*, 113(September 2020), p. 101602. Available at: <https://doi.org/10.1016/j.pmpp.2021.101602>.
- Maitlo, S.A. et al. (2014) 'Comparative Efficacy Of Different Fungicides Against *Fusarium* Wilt Of Chickpea (*Cicer arietinum* L.)', 46(6), pp. 2305–2312.
- Meki, S. et al. (2008) 'Archives Of Phytopathology And Plant Protection Control of chickpea wilt (*Fusarium oxysporum* f .sp. *ciceris*) using *Trichoderma* spp . in

- Ethiopia', Archives of Phytopathology and Plant Protection, (January 2015), pp. 37–41. Available at: <https://doi.org/10.1080/03235400903093071>.
- Merkeb Ayalew, M. (2020) 'Effects of Agronomic Factors , Physiological Factors , Seed Supply Systems and Seed Marketing Systems on Sustainability of Crop and Quality Seed Production: A Review', 80(v), pp. 6–16. Available at: <https://doi.org/10.7176/ALST/80-02>.
- Merkuz Abera and Getachew Alemayehu (2012) 'Influence Of Chickpea Fusarium Wilt (*Fusarium oxysporum* f.sp. *ciceris*) On Desi And Kabuli-Type of Chickpea In Integrated Disease Management Option At Wilt Sick Plot in North Western Ethiopia', International Journal of Current Research, 4(04), pp. 046–052.
- Merkuz Abera, M., Sakhuja, P.K., *et al.* (2011) 'Status of chickpea fusarium wilt (*Fusarium oxysporum* f.sp. *ciceris*) in northwestern Ethiopia', Archives of Phytopathology and Plant Protection, 44(13), pp. 1261–1272. Available at: <https://doi.org/10.1080/03235408.2010.490410>.
- Merkuz Abera, Seid Ahmad, *et al.* (2011) 'Effect of mustard green manure and dried plant residue on chickpea wilt (*Fusarium oxysporum* f.sp . *ciceris*)', 44(9), pp. 821–831. Available at: <https://doi.org/10.1080/03235408.2010.490390>.
- Midega, C.A.O. *et al.* (2016) 'Managing storage pests of maize: Farmers' knowledge, perceptions and practices in western Kenya', Crop Protection, 90, pp. 142–149. Available at: <https://doi.org/10.1016/j.cropro.2016.08.033>.
- Nasr Esfahani, M. *et al.* (2014) 'Mechanisms of physiological adjustment of N₂ fixation in *Cicer arietinum* L. (chickpea) during early stages of water deficit: Single or multi-factor controls', Plant Journal, 79(6), pp. 964–980. Available at: <https://doi.org/10.1111/tpj.12599>.
- Navas-Cortes, J.A., Hau, B. and Jimenez-Diaz, R.M. (2000) 'Yield loss in chickpeas in relation to development of Fusarium wilt epidemics', Phytopathology, 90(11), pp. 1269–1278. Available at: <https://doi.org/10.1094/PHYTO.2000.90.11.1269>.
- Negussie Tadesse, Seid Ahmed, Asrat Zewdie, Million Eshete, Asnake Fikre, Gemechu Keneni, Wulita Wondwosen, Beyene Bitew, A.T. and Berhanu Bekele, Samuel Sahile, Ermias Teshome, Teklay Abebe, Tolessa Bedassa, Y.G. and E.L. (2018)

- ‘Ethiopian Journal of Crop Science’, in Progresses in Diseases Management Research in Highland Food Legumes of Ethiopia.
- Niaz, I. and Dawar, S. (2009) ‘Detection of Seed Borne Mycoflora In Maize (*Zea mays* L.)’, 41(1), pp. 443–451.
- Nigusie Girma, Asnake Fikre and Ojiewo (2017) ‘The Genotypic and Phenotypic Basis of Chickpea (*Cicer arietinum* L.) Cultivars for Irrigation-Based Production in Ethiopia’, Journal of Agricultural Science, 9(8), p. 229. Available at: <https://doi.org/10.5539/jas.v9n8p229>.
- Okolle, N.J. *et al.* (2016) ‘An evaluation of smallholder farmers’ knowledge, perceptions, choices and gender perspectives in vegetable pests and diseases control practices in the humid tropics of Cameroon’, International Journal of Pest Management, 62(3), pp. 165–174. Available at: <https://doi.org/10.1080/09670874.2016.1184772>.
- Olika, E., Abera, S. and Fikre, A. (2019) ‘Physicochemical properties and effect of processing methods on mineral composition and antinutritional factors of improved chickpea (*Cicer arietinum* L.) Varieties Grown in Ethiopia’, International Journal of Food Science, 2019. Available at: <https://doi.org/10.1155/2019/9614570>.
- Osman, O.M. (2019) ‘Identification and Control of Fungus Wilt Disease Caused by *Fusarium oxysporum* f.sp. *Ciceris* in Chickpea. Sudan University of Science and Technology Msc. Thesis
- Pande, S., Rao, J.N. and Sharma, M. (2007) ‘Establishment of the Chickpea Wilt Pathogen *Fusarium oxysporum* f.sp. *ciceris* in the Soil through Seed Transmission’, 23(1), pp. 3–6.
- parashar, A. and Jaidev Sharma (2024) ‘Effect of varying levels of phosphorus and bio-fertilizers on growth and yield of chickpea under sub-tropical condition’, *Indian Journal of Agronomy*, 69(4), pp. 410–416. Available at: <https://doi.org/10.59797/ija.v69i4.5544>.
- Parsa, S. *et al.* (2014) ‘Obstacles to integrated pest management adoption in developing countries’, Proceedings of the National Academy of Sciences of the United States

- of America, 111(10), pp. 3889–3894. Available at: <https://doi.org/10.1073/pnas.1312693111>.
- Parth, T. and , Hariprasath M, RL Meena , Jyotika Purohit¹, M.T. and A.C. (2025) ‘Impact of seed mycoflora on seed quality , germination and seedling vigour of chickpea in storage’, Journal of Food Legumes, 38(3), pp. 382–390. Available at: <https://doi.org/10.53550/jfl.v38.i3.283>.
- Patra, S. and Kumar Biswas, M. (2017) ‘Studies On Cultural, Morphological and Pathogenic Variability Among The Isolates Of *Fusarium oxysporum* f. sp. *ciceri* Causing Wilt of Chickpea In vitro Evaluation of Bio-control Agents against Alternaria brassicae View project’. Available at: <https://doi.org/10.21276/Ijpaes>.
- Pooniya, V. et al. (2021) ‘Long - term conservation agriculture and best nutrient management improves productivity and profitability coupled with soil properties of a maize – chickpea rotation’, Scientific Reports, pp. 1–13. Available at: <https://doi.org/10.1038/s41598-021-89737-9>.
- Prakash, B. et al. (2019) ‘Field Crops Research Long-term sustaining crop productivity and soil health in maize – chickpea system through integrated nutrient management practices in Vertisols of central India’, Field Crops Research, 232(August 2018), pp. 62–76. Available at: <https://doi.org/10.1016/j.fcr.2018.12.012>.
- Rani, A. et al. (2020) ‘Developing Climate-Resilient Chickpea Involving Physiological and Molecular Approaches With a Focus on Temperature and Drought Stresses’, Frontiers in Plant Science, 10(February), pp. 1–29. Available at: <https://doi.org/10.3389/fpls.2019.01759>.
- Rathi, L.T. and Y.P.S. (2019) ‘Detection of Seed Mycoflora From Chickpea Wilt Complex Detection Of Seed Mycoflora From Chickpea Wilt Complex Seedborne *Fusarium oxysporum* f.sp. *ciceri*’, (March).
- Rehman, S. ur et al. (2023) ‘Vermicompost: Enhancing Plant Growth and Combating Abiotic and Biotic Stress’, Agronomy, 13(4). Available at: <https://doi.org/10.3390/agronomy13041134>.

- Richards, M.F., Maphosa, L. and Preston, A.L. (2022) 'Impact of Sowing Time on Chickpea (*Cicer arietinum* L.) Biomass Accumulation and Yield', *Agronomy*, 12(1). Available at: <https://doi.org/10.3390/agronomy12010160>.
- Rijal, J.P. et al. (2018) 'Farmers' knowledge on pesticide safety and pest management practices: A case study of vegetable growers in Chitwan, Nepal', *Agriculture (Switzerland)*, 8(1). Available at: <https://doi.org/10.3390/agriculture8010016>.
- Rubyogo, J.C. et al. (2019) 'Market-led options to scale up legume seeds in developing countries: Experiences from the Tropical Legumes Project', *Plant Breeding*, 138(4), pp. 474–486. Available at: <https://doi.org/10.1111/pbr.12732>.
- Rusuku, G. et al. (1997) 'Occurrence and distribution in Rwanda of soilborne fungi pathogenic to the common bean', *Plant Disease*, 81(5), pp. 445–449. Available at: <https://doi.org/10.1094/PDIS.1997.81.5.445>.
- Kandhare, A. (2016) 'Effect of Common and Dominant Seed-Borne Fungi on Protein Content of Pulses', *American Journal of Biological and Environmental Statistics*, 2(4), p. 41. Available at: <https://doi.org/10.11648/j.ajbes.20160204.13>.
- Sahni, S.K. and B.D.P. (2021) 'Influence of Seed-Borne Fungi on the Growth and Yield of Common Bean', *Environmental Biology*, 42(September), pp. 1274–1280. Available at: <https://doi.org/10.22438/jeb/42/5/MRN-1745>.
- Sabry G.Elias (2018) 'The Importance of Using High Quality Seeds in Agriculture Systems The Importance of Using High Quality Seeds in Agriculture Systems', (April 2018), *Agri Res & Tech.* 15(2)14–16. Available at: <https://doi.org/10.19080/ARTOAJ.2018.14.555961>.
- Sahruzaini, N.A. et al. (2020) 'Pulse Crop Genetics for a Sustainable Future: Where We Are Now and Where We Should Be Heading', *Frontiers in Plant Science*, 11(April), pp. 1–9. Available at: <https://doi.org/10.3389/fpls.2020.00531>.
- Salerno, M.I. and Lori, G.A. (2007) 'Association of seed-borne *Fusarium* species on *Pinus ponderosa* with germination and seedling viability in Argentina', *Forest Pathology*, 37(4), pp. 263–271. Available at: <https://doi.org/10.1111/j.1439-0329.2007.00505.x>.

- Sankar, P.M. et al. (2019) 'Biological Management of Fusarium Wilt in Chickpea (*Cicer arietinum* L.) Caused by *Fusarium oxysporum* f.sp. *ciceris*'. Legume Research, 1-6.
- Schreinemachers, P. et al. (2015) 'Farmers' perceptions and management of plant viruses in vegetables and legumes in tropical and subtropical Asia', Crop Protection, 75, pp. 115–123. Available at: <https://doi.org/10.1016/j.cropro.2015.05.012>.
- Setotaw Ferede, Nigusie Girma and Sherif Aliy (2019) Validating Product Concepts for Optimizing Chickpea Breeding, Ethiopian Institute of Agricultural Research. Available at: <http://www.eiar.gov.et>.
- Sharma, K.D., Chen, W. and Muehlbauer, F.J. (2005) 'Genetics of chickpea resistance to five races of fusarium wilt and a concise set of race differentials for *Fusarium oxysporum* f.sp. *ciceris*', Plant Disease, 89(4), pp. 385–390. Available at: <https://doi.org/10.1094/PD-89-0385>.
- Sharma, M. et al. (2012) 'Identification and multi-environment validation of resistance to *Fusarium oxysporum* f.sp. *ciceris* in chickpea', Field Crops Research, 135, pp. 82–88. Available at: <https://doi.org/10.1016/j.fcr.2012.07.004>.
- Shehabu Meki, Seid Ahmed and Sakhuja (2008) 'Pathogenic variability in Ethiopian isolates of *Fusarium oxysporum* f.sp. *ciceris* and reaction of chickpea improved varieties to the isolates', International Journal of Pest Management, 54(2), pp. 143–149. Available at: <https://doi.org/10.1080/09670870701780153>.
- Shevkani, K. et al. (2019) 'Pulse proteins: secondary structure, functionality and applications', Journal of Food Science and Technology [Preprint]. Available at: <https://doi.org/10.1007/s13197-019-03723-8>.
- Shikha, K. et al. (2024) 'Components of slow disease development: a key to enhance resistance in crops', CABI Agriculture and Bioscience, 5(1), pp. 1–14. Available at: <https://doi.org/10.1186/s43170-024-00293-4>.
- Singh, C. and Vyas, D. (2021) 'The Trends in the Evaluation of Fusarium Wilt of Chickpea', in Diagnostics of Plant Diseases. Available at: <https://doi.org/10.5772/intechopen.95612>.

- Singh, M. and Kumar, S. (2014) 'Broadening the genetic base of grain cereals', in Broadening the Genetic Base of Grain Cereals, pp. 1–275. Available at: <https://doi.org/10.1007/978-81-322-3613-9>.
- Singh, V.D., Singh, S. and Gangwar, R.K. (2020) 'Location Assessment of Wilt Causing Pathogen *Fusarium oxysporum* f.sp. *ciceri* in Seeds of Chickpea Varieties', 9(4).
- Stevenson, P.C., Turner, H.C., Haware, M.P. (1997) 'Phytoalexin accumulation in the roots of chickpea (*Cicer arietinum* L.) seedlings associated with resistance to Fusarium wilt (*Fusarium oxysporum* f. sp. *ciceris*)', *Physiol. Mol. Plant Pathol.* 50, pp,167-178.
- Subhani, M.N. et al. (2011) 'Evaluation of various fungicides for the control of gram wilt caused by *Fusarium oxysporum* f. sp. *ciceris*', 6(19), pp. 4555–4559. Available at: <https://doi.org/10.5897/AJAR11.767>.
- Sultan Mohamed Yimer, et al. (2018) 'Distribution and factors influencing chickpea wilt and root rot epidemics in Ethiopia', *Crop Protection*, 106, pp. 150–155. Available at: <https://doi.org/10.1016/j.cropro.2017.12.027>.
- Tabe-Ojong, M.P.J. and Mausch, K. (2017) 'Impacts of Improved Chickpea Adoption on Smallholder Production and Commercialization in Ethiopia', Conference on International Research on Food Security, Natural Resource Management and Rural Development organised by the University of Bonn, Bonn, Germany from September 20-22, 2017, pp. 1–4. Available at: www.tropentag.de/2017/abstracts/full/211.pdf.
- Tarafdar, A. et al. (2018) 'Exploring combined effect of abiotic (soil moisture) and biotic (*sclerotium rolfsii* sacc.) stress on collar rot development in chickpea', *Frontiers in Plant Science*, 9(August), pp. 1–13. Available at: <https://doi.org/10.3389/fpls.2018.01154>.
- Tarekegn Fite et al. (2018) 'Farmers Status, Knowledge & Management Practices on Major Chickpea Insect Pests in Some Selected Zones of Ethiopia', *Journal of Agricultural Science*, 11(1), p. 31. Available at: <https://doi.org/10.5539/jas.v11n1p31>.
- Tebkew Damte and Ojiewo, C.O. (2016) 'Current status of wilt/root rot diseases in major chickpea growing areas of Ethiopia', *Archives of Phytopathology and Plant*

- Protection, 49(9–10), pp. 222–238. Available at: <https://doi.org/10.1080/03235408.2016.1180925>.
- Tewedros Mulugeta et al. (2024) ‘Heliyon Smallholder farmers ’ knowledge , attitudes , and practices (KAP) regarding agricultural inputs with a focus on agricultural biologicals’, Heliyon, 10(4), p. e26719. Available at: <https://doi.org/10.1016/j.heliyon.2024.e26719>.
- Thudi, M. et al. (2016) ‘Recent breeding programs enhanced genetic diversity in both desi and kabuli varieties of chickpea (*Cicer arietinum* L.)’, Scientific Reports, 6(December), pp. 1–10. Available at: <https://doi.org/10.1038/srep38636>.
- Trapero-Casas A and Jimenez-Diaz RM (1985) ‘Fungal wilt and root rot diseases of chickpea in southern Spain’, Phytopathology, pp. 1146–1151.
- Uakarn Chanuan, Chaokromthong Kajohnsak and Sintao Nittaya (2021) ‘Sample Size Estimation using Yamane and Cochran and Krejcie and Morgan and Green Formulas and Cohen Statistical Power Analysis by G*Power and Comparisons’, Apheit International Journal, 10(2), pp. 76–86.
- Uwamahoro, F. et al. (2018) ‘Potato bacterial wilt in Rwanda: occurrence, risk factors, farmers’ knowledge and attitudes’, Food Security, 10(5), pp. 1221–1235. Available at: <https://doi.org/10.1007/s12571-018-0834-z>.
- V, T. et al. (2025) ‘Legumes: Breeding Strategies and Adaptive Traits for Drought Tolerance’, International Journal of Environment and Climate Change, 15(7), pp. 278–298. Available at: <https://doi.org/10.9734/ijecc/2025/v15i74929>.
- Varshney, R.K. et al. (2014) ‘Genetic dissection of drought tolerance in chickpea (*Cicer arietinum* L.)’, Theoretical and Applied Genetics, 127(2), pp. 445–462. Available at: <https://doi.org/10.1007/s00122-013-2230-6>.
- Venkataramanamma, K. et al. (2023) ‘Publisher: Integrated disease management of Fusarium wilt (*Fusarium oxysporum* f. sp. *ciceris*) of chickpea (2023), 76, 2, (497–509), 10.1007/s42360-023-00625-w’, Indian Phytopathology, 76(3), pp. 955–957. Available at: <https://doi.org/10.1007/s42360-023-00638-5>.
- Verkaart, S. et al. (2017) ‘Welfare impacts of improved chickpea adoption: A pathway for rural development in Ethiopia?’, Food Policy, 66, pp. 50–61. Available at: <https://doi.org/10.1016/j.foodpol.2016.11.007>.

- Walia, M.K. *et al.* (2020) 'Evaluation of early seedling development of Chickpea and its relation to seed yield', *Agrosystems, Geosciences and Environment*, 3(1), pp. 1–9. Available at: <https://doi.org/10.1002/agg2.20005>.
- Warner, J., Stehulak, T. and Kasa, L. (2015) 'Woreda -Level Crop Production Rankings in Ethiopia : A Pooled Data Approach James Warner Tim Stehulak Leulseged Kasa International Food Policy Research Institute (IFPRI) Addis Ababa , Ethiopia.
- Wasihun Yaregal Wubneh (2016) 'Biological control of chickpea pod borer, *Helicoverpa armigera* Hubner (Lepidoptera : Noctuidae): A global concern', *World Scientific News* 45(2), pp. 92–110.
- Wheeler, B.E.J., (1969) 'An introduction to plant diseases.
- Willoquet, L., Savary, S. and Singh, K.P. (2023) 'Revisiting the use of disease index and of disease scores in plant pathology', (0123456789).
- Yadav, A. and Garg, V.K. (2015) 'Influence of vermi-fortification on chickpea (*Cicer arietinum* L.) growth and photosynthetic pigments', *International Journal of Recycling of Organic Waste in Agriculture*, 4(4), pp. 299–305. Available at: <https://doi.org/10.1007/s40093-015-0109-z>.
- Yadav, A.S., Yadav, S. and Singh, R. (2018) 'Screening of fungicides in vitro and seed treatment against fusarium wilt of chickpea caused by *Fusarium oxysporum* f.sp. *ciceris*', 7(3), pp. 2908–2911.
- Yigerem Mengist *et al.* (2018) 'Evaluation of Chickpea Varieties and Fungicides for the Management of Chickpea Fusarium Wilt Disease (*Fusarium oxysporum* f.sp. *ciceris*) at Adet Sick Plot in Northwest Ethiopia', 2018.
- Nene, V.. S. and S.B.S. (1996) A world list of periodicals. 5th edn, Science. 5th edn. Andhra Pradesh: International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). Available at: <https://doi.org/10.1126/science.59.1521.184-a>.
- Younesi, H. *et al.* (2021) 'Morphological, molecular and pathogenic characterization of *Fusarium* spp. associated with chickpea wilt in western Iran', *Journal of Plant Protection Research*, 61(4), pp. 402–413. Available at: <https://doi.org/10.24425/jppr.2021.139250>.

- Yuen, J. (2006) ‘Deriving Decision Rules’, The Plant Health Instructor, (018), pp. 1–43.
Available at: <https://doi.org/10.1094/phi-a-2006-0517-01>.
- Zemankova, M. and Lebeda, A. (2001) ‘Fusarium Species, their Taxonomy, Variability and Significance in Plant Pathology’, Plant Protection Sciences, pp. 25–42.
- Zemenu Endalew Alefe, Gizachew Haylemariam Betselot and Ahmed Mohamed Yasin, (2022) ‘Evaluations of Different Seed-Dressing Fungicides with Chickpea Varieties for the Management of Fusarium Wilt in Eastern’, 2022.
- Asrat Zewdie, A. (2019) ‘Verification of integrated management of chickpea Fusarium wilt (*Fusarium oxysporum* f. sp. *ciceris*) in major chickpea growing areas of East Shewa’, 14(20), pp. 862–866. Available at: <https://doi.org/10.5897/AJAR2019.14016>.
- Zhang, K., Wong, K.P. and Chow, P. (2003) ‘Conjugation of chlorambucil with GSH by GST purified from human colon adenocarcinoma cells and its inhibition by plant polyphenols’, Life Sciences, 72(23), pp. 2629–2640. Available at: [https://doi.org/10.1016/S0024-3205\(03\)00173-5](https://doi.org/10.1016/S0024-3205(03)00173-5).
- Zhang, X. *et al.* (2020) ‘Preventive effect of vermicompost against cucumber fusarium wilt and improvement of cucumber growth and soil properties’, International Journal of Agriculture and Biology, 23(3), pp. 515–521. Available at: <https://doi.org/10.17957/IJAB/15.1316>.
- Zhao, M. and Running, S.W. (2010) ‘Drought-induced reduction in global terrestrial net primary production from 2000 through 2009’, Science, 329(5994), pp. 940–943. Available at: <https://doi.org/10.1126/science.1192666>.
- Zope, A. V, Rakhonde, O.S. and Awadhiya, G.K. (2018) ‘Efficacy of Different Non Conventional Chemicals on Incidence of Chickpea Wilt Complex Under Glass House Condition’, International Journal of Research and Innovations in Earth Science, 4(6), pp. 87–88.

LIST OF APPENDIXES

Appendix Table 1. Chickpea Fusarium wilt incidence and severity in the respective surveyed locality/kebele during 2022/2023 and 2023/2024 cropping seasons.

Location/district	Localities	Cropping years					
		2022/2023		2023/2024		Cumulative	
		Incidence	Severity (%)	Incidence	Severity (%)	Incidence	Severity (%)
Enemay	Weyra	15.07±6.3	14.38±4.61	16.62±3.58	16.66±4.09	15.87±6.3	14.38±4.61
	Telma	18.51±4.7	19.09±4.29	22.34±4.9	21.1±6.63	20.43±5.11	20.08±5.41
	Gotera	19.98±6.02	20.34±4.32	20.78±5.11	19.77±5.14	20.52±5.23	19.96±4.92
	Mean	17.85±6.67	17.94±4.39	19.92±4.53	19.18±5.28	18.94±5.54	18.14±4.98
Enarji Enawga	Dejagamina	35.53±4.71	35.52±3.67	37.68±4.17	36.18±2.77	36.54±4.71	35.52±3.67
	Gole	25.76±8.96	25.72±6.18	45.52±8.55	42.62±7.31	35.64±8.27	34.17±9.15
	Gedeb	32.59±6.71	30.72±7.24	31.82±5.81	29.48±3.99	32.13±6.14	30.12±3.88
	Mean	31.29±6.64	30.65±5.69	38.34±6.18	36.09±4.69	36.21±6.37	33.27±5.57
Yilmana Densa	Abika	17.67±5.16	16.08±7.09	22.24±5.1	21.68±3.94	20.04±5.5	19.38±5.5
	Agita	16.5±4.34	16.59±6.15	20.61±4.21	19.79±2.84	18.56±4.66	18.19±4.46
	Kililit	21.94±4.99	21.79±5.22	26.48±4.68	24.19±4.38	24.21±5.25	22.99±4.81
	Mean	18.71±4.83	18.15±6.15	23.11±5.33	21.89±3.72	20.94±5.14	20.19±4.92
Bahir Dar zuria	Kimbaba	9.42±3.27	10.85±1.99	17.07±3.77	15.74±3.84	13.25±5.21	13.29±5.91
	Wendata	11.15±5.03	12.21±4.54	17.49±5.45	17.85±5.96	14.32±6.06	15.03±5.92
	Sebatamit	14.31±5.44	15.02±5.03	19.18±6.38	17.62±6.21	16.75±6.29	16.32±5.36

	Mean	11.63±4.58	16.69	18.01±4.87	17.07±5.36	14.77±5.83	14.88±5.37
Fogera	Shina Tsion	19.87±4.02	18.52±4.63	21.81±6.18	19.12±3.55	20.84±7.95	18.82±3.86
	Kidist hana	23.75±5.01	24.29±5.42	25.96±4.94	24.31±4.24	24.91±4.96	24.3±4.12
	Shaga	23.95±6.45	23.87±7.31	21.84±5.04	22.65±3.81	23.71±6.45	23.87±7.3
	Mean	22.52±5.16	22.26±5.79	23.2±5.39	22.03±3.86	23.15±6.45	22.33±5.1
Libokemkem	Ambo meda	26.72±2.83	13.9±3.81	31.59±3.89	15.9±3.63	13.34±3.28	14.9±3.63
	Shamo	39.34±6.14	29.61±5.64	33.19±7.33	36.59±6.04	33.75±6.66	30.24±5.72
	Berkutie	33.95±4.67	33.7±6.84	36.21±8.58	34.38±5.75	35.36±8.76	34.13±6.37
	Mean	33.36±4.55	25.74±5.43	33.66±6.57	28.96±5.11	27.48±5.23	26.42±16.39

Appendix Table 2. ANOVA for interaction effect of planting time and crop rotation duration on incidence and severity of chickpea Fusarium wilt

Sources	Seq.ss	df	MS	F	Prob>F
Model	19439	11	1767.18	42.4	0.000
Planting time# crop rotation	19439	11	1767.18	42.4	0.000
Residual	12125.6	291	41.67		
Total	31564.6	302	104.52		
Model	16506.85	11	1500.62	32.97	0.000
Planting time # crop rotation	16506.85	11	1500.62	32.97	0.000
Residual	13245.79	291	45.52		
Total	29752.65	302	98.52		

Appendix Table 3. ANOVA showing the significance of chickpea Fusarium wilt incidence as influenced by seed dressing fungicides, Vermicompost application and varieties and location during 2023/2024 cropping season

Sources of variation	DF	SS	MS	F value	P value
Replication	2	24.25	12.12		
Fungicides	2	1003.33	501.67	194.54	0.0000
Vermicompost	1	268.71	268.71	104.20	0.0000
Varieties	2	2101.85	1050.92	407.53	0.0000
Location	1	175.79	175.79	68.17	0.0000
Fungicides*Vermicompost	2	38.78	19.39	7.52	0.0011
Fungicides*Varieties	4	62.93	15.73	6.10	0.0003
Fungicides*location	2	20.93	10.47	4.06	0.0213
Vermicompost*Varieties	2	33.6	16.80	6.52	0.0025
Vermicompost*Location	1	2.69	2.69	1.04	0.3102
Varieties*Location	2	19.5	9.75	3.78	0.0274
Fungicides*Vermicompost*Varieties	4	62.42	15.61	6.05	0.0003
Fungicides*Vermicompost*Location	2	0.28	0.14	0.05	0.9477
Fungicides*Varieties*Location	4	2.89	0.72	0.28	0.8899

Vermicompost *Varieties*Location	2	2.09	1.04	0.40	0.6685
Fungicides*Vermicompost *Varieties*Location	4	2.50	0.63	0.23	0.9193
Error	73	188.25	2.58		

Where DF= degree of freedom; SS=sum square; MS= mean square

Appendix Table 4. ANOVA showing the significance of chickpea Fusarium wilt incidence as influenced by seed dressing fungicides, Vermicompost application and varieties in Fogera district during 2023/2024 cropping season

Sources	DF	SS	MS	F	P
Rep	2	9.74	4.870		
Varieties	2	860.19	430.095	165.74	0.0000
Fungicides	2	377.93	188.964	72.82	0.0000
Vermicompost	1	110.27	110.270	42.49	0.0000
Variety*Fungicides	4	26.15	6.539	2.52	0.0592
Variety*Vermicompost	2	9.69	4.847	1.87	0.1699
Fungicide*Vermicompost	2	21.07	10.537	4.06	0.0262
Variety*Fungicide*Vermicompost	4	30.60	7.650	2.95	0.0341
Error	34	88.23	2.595		
Total	53	1533.88			

Appendix Table 5. ANOVA showing the significance of chickpea Fusarium wilt incidence as influenced by seed dressing fungicides, Vermicompost application and varieties in Bahir Dar district during 2023/2024 cropping season

Sources	DF	SS	MS	F	P
Rep	2	14.76	7.379		
Varieties	2	1261.21	630.605	214.78	0.0000
Fungicides	2	641.58	320.79	109.26	0.0000
Vermicompost	1	161.45	161.45	54.99	0.0000
Variety*Fungicides	4	161.45	9.956	3.39	0.0198
Variety*Vermicompost	2	39.83	13.12	4.47	0.0192
Fungicide*Vermicompost	2	26.24	8.71	2.97	0.0654
Variety*Fungicide*Vermicompost	4	17.41	8.58	2.92	0.0654
Error	33	34.32	2.94		

Total	52	96.89
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Appendix Table 6. ANOVA showing the significance of chickpea Fusarium wilt severity influenced by integrated use of seed dressing fungicides, Vermicompost application and varieties in Fogera during 2023/2024 cropping season

Sources	DF	SS	MS	F	P
Rep	2	4.77	2.385		
Varieties	2	740.80	370.398	128.71	0.0000
Fungicides	2	354.03	177.013	61.51	0.0000
Vermicompost	1	83.18	83.179	28.90	0.0000
Variety*Fungicides	4	41.34	10.335	3.59	0.0151
Variety*Vermicompost	2	9.87	4.937	1.72	0.1950
Fungicide*Vermicompost	2	9.52	4.759	1.65	0.2064
Variety*Fungicide*Vermicompost	4	30.68	7.669	2.67	0.0490
Error	34	97.84	2.878		
Total	53	1372.02			

Appendix Table 7. ANOVA showing the significance of chickpea Fusarium wilt severity, influenced by seed dressing fungicides, Vermicompost application and varieties in Bahir Dar district during 2023/2024 cropping season

Sources	DF	SS	MS	F	P
Rep	2	246.10	123.052		
Varieties	2	1348.59	674.296	158.44	0.0000
Fungicides	2	728.41	364.206	85.58	0.0000
Vermicompost	1	181.44	181.436	42.63	0.0000
Variety*Fungicides	4	40.13	10.031	2.36	0.0732
Variety*Vermicompost	2	29.59	14.796	3.48	0.0423
Fungicide*Vermicompost	2	12.06	6.032	1.42	0.2563
Variety*Fungicide*Vermicompost	4	46.24	11.561	2.72	0.0459
Error	34	144.7	4.256		
Total	53	2777.26			

Appendix Table 8. ANOVA showing the significance of location on yield, yield components of Chickpea and intensity of chickpea Fusarium wilt during 2023/2024 cropping season

Sources	DF	SS	MS	F	P	Parameters
Rep	2	138071	69036			
Location	1	161455	161455	4.34	0.0396	Yield
Error	104	38647	37161			
Total	107	4164321				
Rep	2	93.51	46.755			
Location	1	189.12	189.116	4.85	0.0299	Severity
Error	34	4055.78	38.998			
Total	53	4338.40				
Rep	2	31.17	15.583			
Location	1	160.26	160.257	4.35	0.0395	Incidence
Error	103	3794.22	36.837			
Total	106					
Rep	2	5.5545	2.77723			Number of
Location	1	2.4143	2.41429	4.61	0.0342	branches
Error	104	54.4998	0.52404			per plant
Total	107	62.4685				
Rep	2	16.59	8.2930			Number of
Location	1	48.57	48.5678	3.91	0.049	Pods per
Error	104	1290.42	12.4079			plant
Total	107	1355.57				
Rep	2	2.2	1.1			Harvest
Location	1	56127.1	56127.1	15498.91	0.000	index
Error	104	376.6	3.6			
Total	107	56505.9				

Appendix Table 9. ANOVA showing the significance of chickpea grain yield influenced by seed dressing fungicides, Vermicompost application and varieties and location during 2023/2024 cropping season

Sources of variation	DF	SS	MS	F value	P value
Replication	2	138071	69036		
Fungicides	2	369818	184909	122.44	0.0000
Vermicompost	1	179927	179927	119.14	0.0000
Varieties	2	2978608	1489304	986.17	0.0000
Location	1	161455	161455	106.91	0.0000
Fungicides*Vermicompost	2	59057	29528	19.55	0.0000
Fungicides*Varieties	4	67811	16953	11.23	0.0000
Fungicides*location	2	940	470	0.31	0.7337
Vermicompost*Varieties	2	30719	15359	10.17	0.0001
Vermicompost*Location	1	291	291	0.19	0.662
Varieties*Location	2	13853	6926	4.59	0.0134
Fungicides*Vermicompost*Varieties	4	30548	7637	5.06	0.0012
Fungicides*Vermicompos*Location	2	1098	549	0.36	0.6965
Fungicides*Varieties*Location	4	8555	2139	1.42	0.2376
Vermicompost*Varieties*Location	2	2791	1395	0.92	0.4017
Fungicides*Vermicompost*Varieties*Location	4	15066	3766	2.49	0.049
Error	73	105713	1510		

Where DF= degree of freedom; SS=sum square; MS= mean square

Appendix Table 10. ANOVA showing the significance of chickpea grain yield influenced by seed dressing fungicides, Vermicompost application and varieties in Bahir Dar district during 2023/2024 cropping season

Sources	DF	SS	MS	F	P
Rep	2	67835	33917		
Varieties	2	1698885	849442	578.40	0.0000
Fungicides	2	202192	101096	68.84	0.0000
Vermicompost	1	97342	97342	66.28	0.0000
Variety*Fungicides	4	59185	14796	10.08	0.0000

Variety*Vermicompost	2	23238	11619	7.91	0.0015
Fungicide*Vermicompost	2	31916	15958	10.87	0.0002
Variety*Fungicide*Vermicompost	4	22495	5624	3.83	0.0113
Error	34	49932	1469		
Total	53	2253020			

Appendix Table 11. ANOVA showing the significance of chickpea grain yield influenced by integrated use of seed dressing fungicides, Vermicompost application and varieties in Fogera during 2023/2024 cropping season

Sources	DF	SS	MS	F	P
Rep	2	72380	36190		
Varieties	2	1293576	646788	409.99	0.0000
Fungicides	2	168566	84283	53.43	0.0000
Vermicompost	1	82875	82875	52.53	0.0000
Variety*Fungicides	4	17182	4295	2.72	0.0455
Variety*Vermicompost	2	10271	5136	3.26	0.0509
Fungicide*Vermicompost	2	28239	14120	8.95	0.0008
Variety*Fungicide*Vermicompost	4	23118	5780	3.66	0.0138
Error	34	53637	1578		
Total	53	1749845			

Appendix Table 12. ANOVA showing the significance of number of branches per plant influenced by integrated use of seed dressing fungicides, Vermicompost application and varieties in Bahir Dar district during 2023/2024 cropping season

Sources	DF	SS	MS	F	P
Rep	2	2.6398	1.31991		
Varieties	2	14.8079	7.40394	92.27	0.0000
Fungicides	2	3.1454	1.57268	19.60	0.0000
Vermicompost	1	1.3148	1.31482	16.39	0.0003
Variety*Fungicides	4	1.4243	0.35608	4.44	0.0054
Variety*Vermicompost	2	0.687	0.34376	4.28	0.0219
Fungicide*Vermicompost	2	1.2187	0.60933	7.59	0.0019
Variety*Fungicide*Vermicompost	4	0.8978	0.22446	2.80	0.0413

Error	34	2.7283	0.08024
Total	53	28.8645	

Appendix Table 13. ANOVA showing the significance of harvest index influenced by integrated use of seed dressing fungicides, Vermicompost application and varieties in Fogera during 2023/2024 cropping season

Sources	DF	SS	MS	F	P
Rep	2	3.772	1.8862		
Varieties	2	191.802	95.9008	178.02	0.0000
Fungicides	2	26.796	13.3979	24.87	0.0000
Vermicompost	1	19.095	19.0952	35.45	0.0000
Variety*Fungicides	4	17.709	4.4273	8.22	0.0001
Variety*Vermicompost	2	0.055	0.0273	0.05	0.9506
Fungicide*Vermicompost	2	11.721	5.8607	10.88	0.0002
Variety*Fungicide*Vermicompost	4	5.809	1.4524	2.70	0.0471
Error	34	18.317	0.5387		
Total	53	295.076			

Appendix Table 14. ANOVA showing the significance of hundred seeds weight influenced by integrated use of seed dressing fungicides, Vermicompost application and varieties in Fogera district during 2023/2024 cropping season

Sources	DF	SS	MS	F	P
Rep	2	9.44	4.718		
Varieties	2	968.24	484.120	261.60	0.0000
Fungicides	2	24.03	12.016	6.49	0.0041
Vermicompost	1	32.02	32.017	17.30	0.0002
Variety*Fungicides	4	8.36	2.090	1.13	0.3590
Variety*Vermicompost	2	0.90	0.450	0.24	0.7855
Fungicide*Vermicompost	2	8.74	4.371	2.36	0.1095
Variety*Fungicide*Vermicompost	4	21.04	5.259	2.84	0.0390
Error	34	62.92	1.851		
Total	53	1135.69			

Appendix Table 15. ANOVA showing the significance of number of pods per plant influenced by integrated use of seed dressing fungicides, Vermicompost application and varieties in Fogera during 2023/2024 cropping season

Sources	DF	SS	MS	F	P
Rep	2	11.693	5.847		
Varieties	2	403.622	201.811	76.42	0.0000
Fungicides	2	72.474	36.237	13.72	0.0000
Vermicompost	1	35.276	35.276	13.36	0.0009
Variety*Fungicides	4	28.724	7.181	2.72	0.0457
Variety*Vermicompost	2	11.638	5.819	2.20	0.1260
Fungicide*Vermicompost	2	18.292	9.146	3.46	0.0428
Variety*Fungicide*Vermicompost	4	29.356	7.339	2.78	0.0423
Error	34	89.789	2.641		
Total	53	700.864			

Appendix Table 16. Semistructured questionier prepared for assessing farmers' knowledge and management practices of CFW

Introductory and consent statement

“Dear Sir/Madam, I am a PhD Student at Bahir Dar University, College of Agriculture and Environmental Sciences, Department of Plant Sciences. I am conducting a research survey to study **"Farmers' Knowledge and their Practices of Chickpea Fusarium wilt Management in West Amhara, Ethiopia."** Your response to these questions would remain anonymous. Taking part in this study is voluntary. If you choose not to take part, you have the right not to participate and there will be no consequences. Do you and your family consent to provide information? 1=yes, 0=No. "Thank you for your kind co-operation"

A) Administrative location

Region_____

Zone_____

District_____

Kebele (locality)_____

B) Geographical location

Altitude_____

Longitude_____

Latitude_____

C) Farmers information

- 1) Name of Respondent_____ Age _____
- 2) Gender_____ (1=Male; 2= Female)
- 3) Marital status (1= Unmarried; 2= Married; 3=Divorced; 4= Widowed)
- 4) How much number of family members do you have?
- 5) Do you have a mobile phone? (1= Yes, 2= No). If yes, Phone number

- 6) Relationship with the head of the household_____ (1=head of the household; 2=Spouse; 3=Son/daughter 4=Grandson/daughter; 5= Others)
- 7) Educational background (1= none, 2= primary, 3= secondary, 4=tertiary 5= informal)

D: Chickpea Production System

- 1) Size of all your farms in acres/hectare/timad_____
- 2) Source of the farm land 1= own, 2=inherited, 3=rented
- 3) Size of your Chickpea fields in hectare (you can explain local measurements like Timad/Kada/Gemed) _____ Source 1= own, 2=inherited, 3=rented
- 4) Do you plant chickpea as a major crop? Yes No
- 5) Did you have chickpea sown field/s this year?
- 6) How much hectare of land is covered by chickpea this year?
- 7) How much seed rate did you used on hectare/timad/kada bases?
- 8) Did you practice weeding (1= yes 2=no)
- 9) Why did you practice weeding and which type of weed management practice did you apply? (1= hand weeding 2= herbicide spray 3= other/please mention)
- 10) Did you apply fertilization (1= yes 2= no). If yes, which type of fertilizer you have applied? (1= organic 2= inorganic 3= both)

- 11) Do you plant chickpea as a major crop? (1=Yes; 2= No) . If Yes, When is the exact planting date? _____
- 12) Why have you prefer these planting dates? _____
- 13) Why do you not plant your Chickpea crops outside the time you have indicated? _____
- 14) Does this have any relation to disease problem? Yes No
If yes, please explain. _____
- 15) Why do you grow chickpea for (1= Food only; 2= Cash only; 3= both)
- 16) How many years of chickpea farming experience do you have? (1= $\leq$ 5 years; 2=16-20 years; 3=21-30 years; 4=31-40 years; 5= $\geq$ 41 years)
- 17) Which chickpea types do you grow (1=desi 2=kabuli 3= both)
- 18) What kind of chickpea seeds do you grow? (1= Local, 2= Improved 3= both)
- 19) What are the sources of chickpea seeds you used? (1=own, 2= neighbors/friends 3=both 1and 2, 4= researchers 5= local market 6=others/specify)
- 20) During last year (2020), how many hectares of land did you use to grow Chickpea? _____
- 21) Do you practice cropping systems? Yes No
- 22) If yes which cropping systems you used most (1= crop rotation 2= intercropping 3= double cropping 4= relay cropping 5= if more than 1 please specify)
- 23) How many years of rotation did you used to plant your chickpea plants? (1= yes; 2= No). Does the rotation year manage the disease? (1= yes 2= No).
- 24) If yes, which crop do you recommend to be used for effective management?
- 25) (1= teff 2= Wheat 3= maize 4= sorghum 5= finger millet 6= oil crops 7 faba bean 8= common bean 9=other crops/please mention
- 26) What type of water source did you use (1=irrigation, 2=water stored in hole, 3=Rain fed)?

- 27) How far is your house from the nearest Agricultural input dealers/shops?
(1=walking distance, 2=travelling distance (3-5km) 3=travelling distance (5-10km) 4=no input shops around)
- 28) How far is your house from the nearest Agricultural Extension office?
(1=walking distance, 2 = travelling distance (3-5km) 3 = no extension office at all).

D) Farmers' Knowledge of Chickpea Fusarium Wilt Disease Spread and Management

1) Have you ever heard or observed chickpea Fusarium wilt (shown photos)? (1= yes, 2=no). If Yes, does it has local name? please mention

2) How do you understand plant diseases?

3) What are the causes of diseases?

4) Why do diseases appear in our crop? How do they affect our crop?

5) From where did you first hear or see this disease (1= friends/neighbors' field, 2=own field, 3= market place, 4= others/specify)

6) Has the disease ever been observed in your field or your neighbors' field? (1= Yes; 2= No)

If Yes; when did the disease for the first time observed? (Please mention the month and year)_____

7) What are the major means of dissemination of the above disease?

8) What percentage of your chickpea farm was infected by chickpea Fusarium wilt?

9) How did you identify weather the disease be Fusarium or any other disease of chickpea? (1=Wilting 2= Yellowing 3= Vascular discoloration 4= crop collapse/total drying 5= other/specify).

10) How severe were chickpea Fusarium wilt disease last year? 0=None, 1=Low, 2=Medium 3=High

- 11) Does the disease affect the chickpea crop in your farm throughout the growing season? (Please tick as appropriate) 1=yes 2=No If YES, indicate which time of the year that the disease is prevalent (Estimate in terms of days after planting).
- 12) Have you ever observed any other diseases in your farm? 1. Yes, 2. No x. If yes, which one 1= Fusarium wilt 2= Rust 3= Ascochyta blight 4= dry root rot, 4= if any other (specify) _____
- 13) How severe were above disease? (0=None, 1=Low, 2=Medium 3=High 4=unknown)
- 14) Have you seen chickpea Fusarium wilt in other farms or neighbors' farm? 1=Yes, 2= No If Yes, indicate the month, year and distance of the farm in reference to your field
- 15) How did you manage chickpea fusarium wilt disease in your chickpea farm? (1= fungicide 2= host resistance 3= crop rotation 4= adjusting date of planting 5= removing diseased plants 6= other/please mention)
- 16) Did you observe any diseases occurrence variation between chickpea planted in rotation with other crops? The duration of rotation? Different time of planting? Frequency of plowing, lands with different slopes, intercropped and sole cropping systems?
- 17) Which dissemination agents are involved for Fusarium wilt spread (1= contaminated farm tools; 2= infected seeds 3= contaminated irrigation water; 4=wind 5= others/specify)

Name of enumerator _____

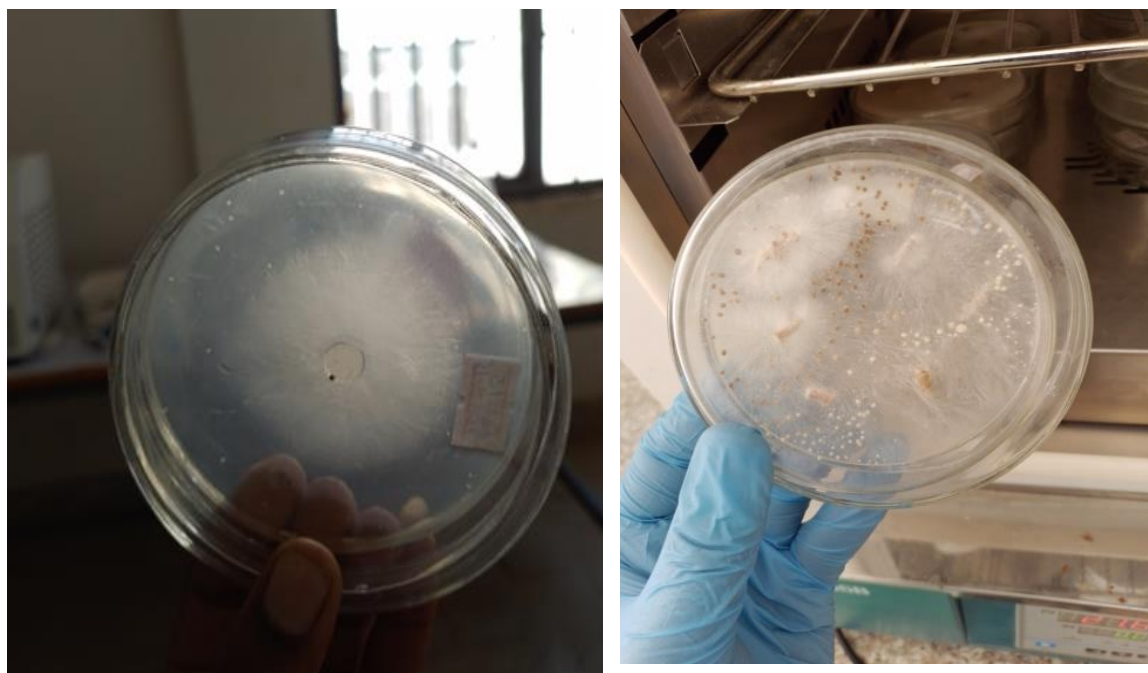
Date _____

Signature_____

Appendix Figures



Appendix Figure 1. Inoculation and culturing of *Fusarium oxysporum* isolates under aseptic conditions for isolation, characterization and pathogenicity test





Appendix Figure 2. Morpho-cultural view of *Fusarium oxysporum* (FOC) isolates sourced from infected roots of chickpea



Appendix Figure 3. Intensity measurement, sample collection, from chickpea heavily infested with chickpea *Fusarium* wilt (*Fusarium oxysporum* f.sp. *ciceris*)

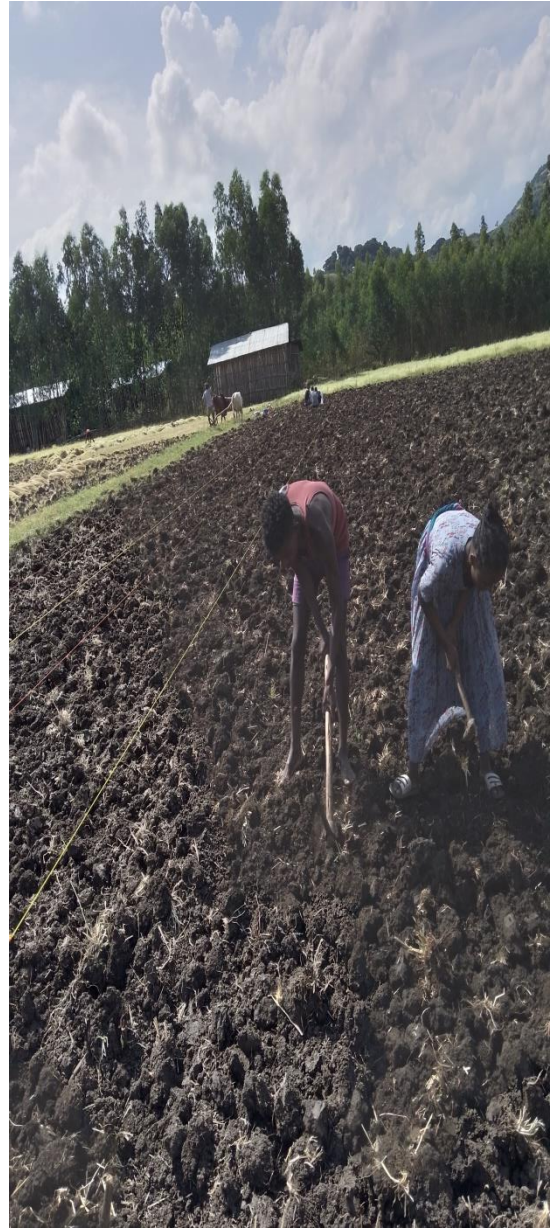


Appendix Figure 4. Photo showing Fusarium wilt infested chickpea fields: Farmers in their field explaining their viewpoints, knowledge and their practices of chickpea Fusarium wilt management





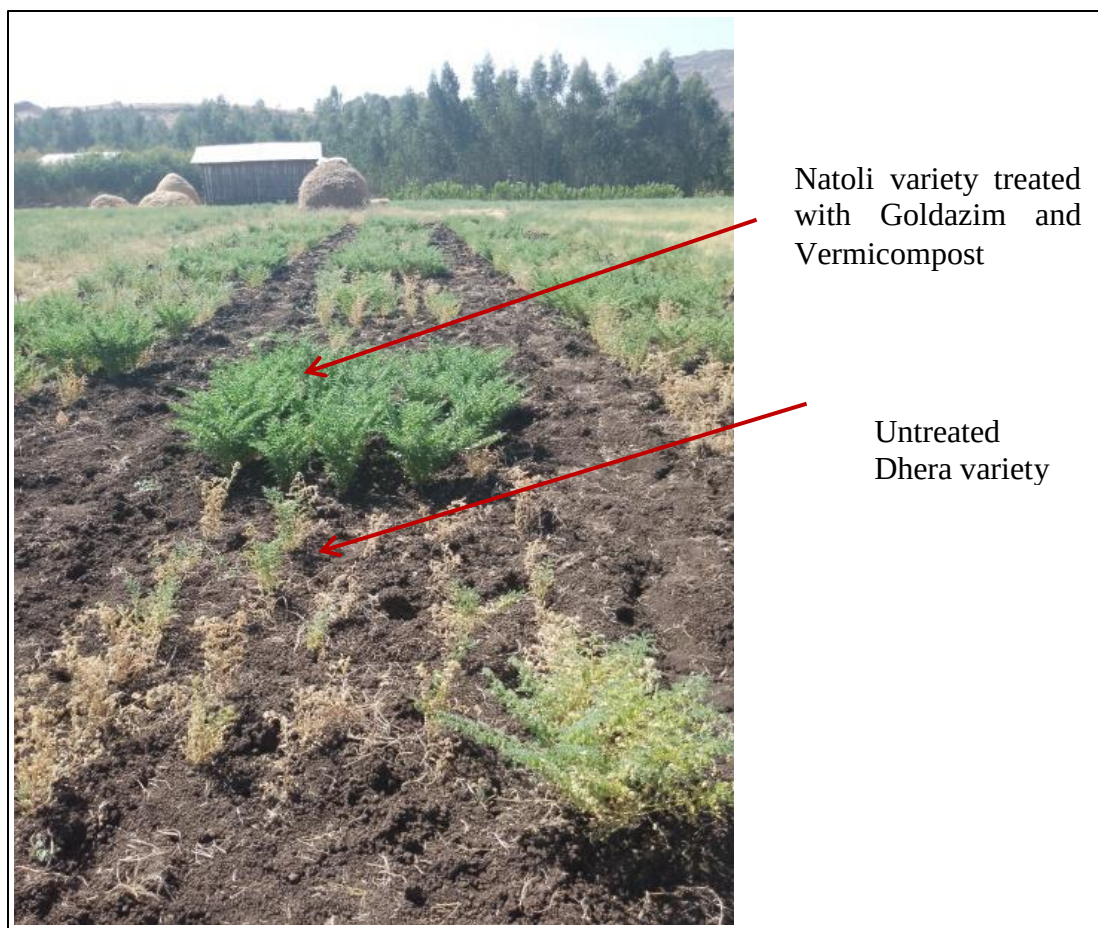
Appendix Figure 5. Different chickpea Fusarium wilt symptoms at different growth stage of the crop: early wilting (a), late wilting (b) and vascular discoloration (c)



Appendix Figure 6. Land preparation and leveling of the experimental site during 2023/204 cropping season



Appendix Figure 7. Partial view of the experiment comprising different set of factorial treatments laid in factorial RCBD design



Appendix Figure 8. Chickpea Fusarium wilt intensity as impacted by integrated managements: Natoli variety treated with Goldazim 500SC and Vermicompost application and Dhera variety without any treatment

BIOGRAPHY OF THE AUTHOR

The author, Abebe Yilma was born to his father Yilma Tasew and his mother Mrs. Aseged Mengistu on 24 November 1993 in Shewa Province of Merhabetie Awraja, around Meragna town. He completed his elementary education at Tedila Giorgis and Behera Primary schools during the years 2000 to 2008. Abebe Yilma then continued his secondary and preparatory education at Mida Model Secondary and Preparatory School from 2009-2012. He then joined Ambo University after having passed the Ethiopian higher education entrance examination to study his BSc degree in 2013. He demonstrates exceptional academic merit, graduated as the chancellor of Gold medal winner in his batch, with Bachelor of Science in Plant Science, on June, 2016. Immediately following his graduation, Abebe Yilma continued his academic pursuits. The ministry of education sent him directly to Haramaya University (the then Alemaya University) on September 2016 to pursue a Master of Science (MSc) degree in Weed Science, after he had passed the necessary national examination. He successfully completed his MSc degree in Weed Science on June 2018. Immediately after earning his master's degree he was employed by Injibara University as a lecturer in the college of Agriculture, Food and Climate Sciences, department of Horticulture. After serving the University for about 2 and half years, he then moved to Bahir Dar University Postgraduate studies on October, 2020 to pursue his PhD in Plant Pathology.

ARTICLE PUBLICATIONS

Peer Reviewed Journal Articles Emanated from this Dissertation

This dissertation is submitted as a partial fulfillment of the requirements for the degree of Doctor of Philosophy (Ph.D.) in Plant Pathology at Bahir Dar University (BDU), College of Agriculture and Environmental Sciences, Bahir Dar, Ethiopia. The dissertation is based on four research and two review paper, of which three researches and two review papers have been published, and one submitted for publication.

1. Abebe Yilma, Mekuz Abera, Berhanu Bekele, and Tesfaye Alemu. (2026). Dynamics of chickpea Fusarium wilt: associated risk factors, farmers' knowledge and management practices, in West Amhara, Ethiopia. Published by Taylor & Francis in *Archives of Phytopathology and Plant Protection*, 1–23. DOI: <https://doi.org/10.1080/03235408.2026.2621360> (Scopus and Web of Science indexed).
2. Abebe Yilma, Merkuz Abera, Berhanu Bekele, and Tesfaye Alemu. (2025). Chickpea Fusarium Wilt (*Fusarium oxysporum* f. sp. *ciceris*): Current status and biophysical factors influencing its epidemics in western Amhara, Ethiopia. Published by CABI International, in the journal *CABI Agriculture and Bioscience*, 6(1), p.0079. DOI: <https://doi.org/10.1079/ab.2025.0079> (Scopus and Web of Science indexed).
3. Abebe Yilma, Merkuz Abera, Berhanu Bekele, Tesfaye Alemu and Ramesh R. Vetukuri (2025). Synergistic effect of seed dressing fungicides, vermicompost application and varieties on Fusarium wilt intensity, yield, and yield components of chickpea (*Cicer arietinum* L.). Published by CABI International, in the journal *CABI Agriculture and Bioscience*, 6(1), p.0076. DOI: <https://doi.org/10.1079/ab.2025.0076> (Scopus and Web of Science indexed).
4. Abebe Yilma, Merkuz Abera, Berhanu Bekele, and Tesfaye Alemu. (2025). Prevalence, pathogen diversity and management practices of chickpea Fusarium wilt in Ethiopia. Published by CABI International, in the Journal, *CABI Reviews*, 20(1), 0043. DOI: <https://doi.org/10.1079/cabireviews.2025.0043> (Scopus indexed).

5. Abebe Yilma, Merkuza Abera, Berhanu Bekele, Tesfaye Alemu and Ramesh R. Vetukuri (2025). Chickpea Fusarium Wilt: A Review of Predominant Challenge to Chickpea Production in Ethiopia. Publisher: Indian Society of Pulse Research and Development (ISPRD), in *Journal of Food Legumes*, 38(4), 1-13. <https://pub.isprd.in/index.php/jfl/article/view/2153> (Scopus indexed).

CONFERENCE PRESENTATIONS



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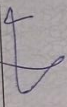
Bahir Dar University

CERTIFICATE OF APPRECIATION

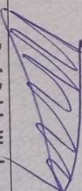
Awarded to

Abebe Yilma Tarew

**In recognition to your contribution as a Presenter
in the 5th African Graduate Students Conference
(AGSC V-BDU-2025)**


Tirango Dinku (PhD)
Dean, School of Graduate Studies



12-13 May 2025
BAHIR DAR, ETHIOPIA

Prof. Delele Worku
Corporate Director, School of Graduate
Studies

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Bahir Dar University

CERTIFICATE OF RECOGNITION

To: Mr. Abebe Yima

The College of Agriculture and Environmental Sciences of Bahir Dar University would like to appreciate your contribution by presenting your paper entitled “*Occurrence, diversity and potential of indigenous fungal pathogens associated with water hyacinth (Eichhornia Crassipes [Mart.] Solms)* for effective biological management in Ethiopia ” at the 9th Annual National Conference on the theme “Research and policy interventions for food systems transformation in Ethiopia” held from 04-05 June 2022. By recognizing your contribution, the college has issued this certificate.

Academic Vice Dean, College of Agriculture and Environmental Sciences
Bahir Dar University



Date of issue
05 June, 2022

Assemlaw Tassew Wolde (PhD)
Dean, College of Agriculture
and Environmental Sciences
Bahir Dar University