DISTRIBUTION, PATHOGENIC VARIATION AND INTEGRATED MANAGEMENT OF COMMON BEAN (*Phaseolus vulgaris* L.) ANGULAR LEAF SPOT *(Pseudocercospora griseola)* IN SOUTHWEST ETHIOPIA

MSc. THESIS

BY

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DISTRIBUTION, PATHOGENIC VARIATION, AND INTEGRATED MANAGEMENT OF COMMON BEAN (*Phaseolus vulgaris* L.) ANGULAR LEAF SPOT *(Pseudocercospora griseola)* IN SOUTHWEST ETHIOPIA

MSc. Thesis

By

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Submitted to Jimma University College of Agriculture and Veterinary Medicine, Department of Horticulture and Plant Science, in Partial Fulfillment of the Requirements for the Degree of Master of Science in Plant Pathology

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June, 2024

Jimma, Ethiopia

DEDICATION

This thesis is dedicated to my beloved parents, my father Abera Ergate and my mother Furne Yadessa Gondore, my wife Gadise Gebeyehu and my daughter Jinenus Getu, whose unwavering support and sacrifices have been instrumental in my success.

STATEMENT OF THE AUTHOR

First, I declare that this thesis is my work and that all sources of materials used for this thesis have been duly acknowledged. This thesis has been submitted in partial fulfillment of the requirements for a MSc. degree in plant pathology at Jimma University College of Agriculture and Veterinary Medicine (JUCAVM) and is deposited at the University Library to be made available to borrowers under rules of the library. I solemnly declare that this thesis is not submitted to any other institution anywhere for the award of an academic degree, diploma, or certificate. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgment of the source is made. Requests for permission for extended quotation from or reproduction of this manuscript in whole or in part may be granted by the head of the department when in his or her judgment the proposed use of the material is for scholarly interest. In all other instances, however, permission must be obtained from the author.

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BIOGRAPHIC SKETCH

The Author, Getu Abera Ergate was born in September 1996 GC in Gudeya Bila district of East Wollega Zone Oromia Regional State, Ethiopia to his father Abera Ergate and his mother Furne Yadessa. He attended his elementary education at Gudeya Bila Elementary School from 2002-2009. Then, he attended the first level of secondary and preparatory education at Gudeya Bila Secondary and Preparatory School from 2010 to 2013. He joined Haramaya University in 2014 and graduated with Bachelor degree in Plant Sciences on 24 August 2016. After graduation, he was employed by the Oromia Agricultural Research Institute in October 2017, as a junior researcher based at Bako Agricultural Research Center and served as a junior researcher for four years until he joined Jimma University College of Agriculture and Veterinary Medicine (JUCAVM) in September 2022 to pursue Master of Science in Plant Pathology.

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ABBREVIATIONS AND ACRONOMYS

AUDPC	Area Under Disease Progress Curve
CIMMYT	Spanish acronym for the International Maize Improvement Center
EIAR	Ethiopian Institute of Agricultural Research
CIAT	International Center for Tropical Agriculture
GS	Growth Stage
BARC	Bako Agricultural Research Center
SAS	Statistical Analysis Software
GPS	Global Positioning system (GPS)
ALS	Angular Leaf Spot
PDA	Potato dextrose agar
RCBD	Randomized Complete Block Design
CRD	Completely Randomized Design
DM	Days to maturity
CBALS	Common bean angular leaf spot
CV	Coefficients of variance
DF	Degree of freedom
RH	Relative humidity
DPR	Disease progress rate

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ABSTRACT

Common bean (Phaseolus vulgaris L.) is the most important grain directly consumed in the human diet, accounting to half of the grain legumes consumed worldwide. Angular leaf spots (ALS), caused by Pseudocercospora griseola is a major and frequently occurring disease of common bean in Ethiopia. Therefore, the current study was conducted with the objective of assessing the distribution of ALS, examining the relationship between ALS and biophysical and agronomic factors and evaluating the disease management strategies through host resistant and chemical fungicides in the southwest Ethiopia. Assessment of ALS severity and associated agronomic factors was carried out in six districts during the 2022 and 2023 main cropping season. Pseudocercospora griseola isolates collected from the study areas were characterized based on morphological features and pathogenesity test conducted under greenhouse conditions. Reaction of some released common bean varieties were investigated under greenhouse conditions. The integrated effect for common bean varieties (Mexican-142, Awash1, Waju and Awash Malka) and two foliar fungicide (Natura and Jaba) was evaluated for ALS disease reactions, on grain yield and yield component under field conditions. The survey results revealed varying distribution of angular leaf spot, with 88.0%, 64.8, 78.2, 79.9%, 69.7% and 57.2% ALS severity in Bako Tibe, Ilu Galan, Gobu Sayo, Bilo Boshe, Didessa and Gechi districts, respectively. The variations in disease intensity were significantly associated with different agronomic practices. Pearson correlation analysis showed tillage frequency (r=-0.71) and weeding frequency (r=-0.60) were identified as the most influential variables affecting disease intensity in the study areas. The characterization of Pseudocercospora griseola isolates, out of the 650 collected samples, 340 were identified as P. griseola and categorized in to 18 isolates based on macroscopic and microscopic characteristics. Of these, except DiGopg2 (isolated from Didessa district), were pathogenic to the susceptible common bean Dinkinesh variety, confirming the identity of the 17 isolates as Pseudocercospora griseola. Isolate BtDdpg2 was the most aggressive exhibiting 94.4% disease severity and was subsequently used to assess the level of disease resistance in 12 varieties. Ser125, Ser119 and Gobersha were the only promising materials that showed resistant reaction and greenhouse conditions. The sprayed moderately resistant variety Awash Malka exhibited the highest grain yield (3.75t/h), lower AUDPC (943.1) and lower disease progress rate (0.026) and showing a significant difference from untreated varieties and thus the resistant variety combined with Natura is advised for farmers. Overall, the present extensive study proved that Pseudocercospora griseola is found to be diverse populations with different degree of aggressiveness in southwest Ethiopia and can be considered as a potential threat for common bean production. Detailed studies should be conducted on the diversity of Pseudocercospora griseola populations employing molecular tools.

Key-Words: Biophysical factors, *Pseudocercospora*, angular leaf spot, common bean, fungicides, severity, Isolates, Pathogenicity, Resistance, incidence

1. INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is the most important grain directly consumed in the human diet, accounting to half of the grain legumes consumed worldwide. The global harvested area for common bean was 34.8 million ha, with a production 27.55 million tons (FAO STATS, 2020). Asia accounts for 50% of the global production of common beans, with and Myanmar, India, Brazil, China, America ranking at the top five dry bean producing countries in the world from 2000 to 2019. The crop occupies more than 3.5 million hectares in sub-Saharan Africa, particularly in regions like East Africa and the highlands of southern Africa. This crop ranks as the second most important crop after cow pea in eastern, central, and southern Africa. Widespread consumption of the grain is primarily attributed to its nutritional qualities. In certain countries in Americas and Africa, beans contribute an average of 15% of total daily calories, 36% of daily protein content, vitamins, and minerals (Schmutz *et al.*, 2014). Being a legume, resulting in significantly higher protein concentration compared to other species (Broughton *et al.*, 2003). Additionally, the common bean contributes to soil nitrogen fixation through symbiosis with rhizobium bacteria (Mukankusi *et al.*, 2019).

Economic significance of common bean in Ethiopia is quite considerable since it represents one of the major food and cash crops. It is often grown as cash crop by small-scale farmers and used as a major food legume in many parts of the country where it is consumed in different types of traditional dishes (Habtu, 1994). In the 2021 cropping season, the area covered and production potential were 311.5 thousand hectares and more than 0.56 million tones, respectively (CSA, 2021). It ranks third as an export commodity in Ethiopia, contributing about 9.5% of total export value from agriculture. Despite the fact that common bean is play the major role in contributing to the country economy among exported agricultural crop, the average bean yield obtained by farmers in Ethiopia is very low 1.73ton/ha compared to global 2.5-3ton/ha average productivity. This is mainly because common bean is constrained to several factors including a wide range of biotic and abiotic that limits the genetic potential of the crop (Kifle *et al.*, 2016). Among the constraints, diseases are recognized to be the major factors, which directly or indirectly affect production and productivity (Assefa *et al.*, 1996; Fininsa and Yuen, 2001). The major Diseases like rust, anthracnose, CBB, angular leaf spot, web blight, root rot, bean common mosaic virus and golden mosaic virus are the major diseases identified to cause yield reduction in Ethiopia (Tumsa *et al.*, 2015).

Among common bean diseases, the ALS caused by the fungus *Pseudocercospora griseola* is one of the most destructive diseases of common bean in tropical and subtropical regions of the world (Yesuf, 2005). Under favorable temperature conditions of 15 to 29 ^{o}C, high humidity (>70%) the pathogen has the ability to colonize different parts of common bean plants and is considered as the major problem in most common bean production areas of the world (Stenglein *et al.,* 2020). As reported by Stenglein *et al.* (2003) every 10% increase in ALS severity results 8% yield loss. In the absence of ALS disease control measures, yield losses of 45–80% were described under favorable conditions in Brazil and Colombia (Guzman *et al.,* 1999). In Uganda, yield losses due to planting ALS susceptible cultivars lead up to 54.7% (Pamela *et al.,* 2014). Depending up on variety susceptibility, environmental conditions and aggressiveness of *P. griseola*, yield loss could reach up to 70–80% (Singh and Schwartz, 2010). Disease severity was increasing through time with different agroecological condition (Aytenfsu *et al.,* 2019) the mean incidence 66.35% was recorded at Hawassa and 88.06% in Jimma the mean severity of the disease was 81.14% in Bako Tibe district and 90.58% in Hawassa Agricultural Center (Aytenfsu *et al.,* 2019). Reports indicated that disease caused the largest loss of yield in East Africa compared to other factors (Pretty *et al.,* 2011). A study reported by (Fikre *et al.,* 2011) in South and southwestern part of Ethiopia, also showed that the disease could cause about 47% yield reduction in commercial varieties.

Furthermore, common bean ALS is more severe when beans are infected during the pod-forming and pod-filling growth stages. Thus, the levels of damage caused by ALS diseases necessitated searching for and demanding efficient management options. To this effect, effective plant disease management is a key contributor to meeting the demands of local and global markets for food security and any other income sources in common bean production. Research done in different parts of Ethiopia in different times showed that ALS occurs in common bean growing areas in Ethiopia (Aytenfsu *et al.,* 2019). However, the prevalence and importance of common bean ALS diseases vary with altitudinal range, through time, and with the growth stage. Moreover, up to date detailed understanding of the diseases and factors associated with epidemic development in major common bean growing areas in Ethiopia needed. Thus, the current distribution and status of common bean angular leaf spot and its pathogen population in the major common bean growing areas of Ethiopia needs to be updated. It is important to know different factors associated with ALS disease development that aggravating the intensity of the disease and to provide

different disease management options (Mahuku *et al.,* 2002). It helps the present plant disease management tactics should be improved and adjusted in order to adapt to or reduce the effects of existing diseases and future emerging diseases dynamics. In addition it helps to have knowledge about the occurrence, distribution, relative importance of the diseases and helps for sustainable disease management alternatives (Rusuka *et al.,* 1997). Generating awareness about the associations between the disease and different biological and environmental factors through comprehensive survey is significant. Previously conducted activity does not consider isolation, identification and characterisation of the pathogen and variabilities of the pathogen is also not fully addressed in the study area. Because cultural and morphological variability of the pathogens are important to know the changes occurring in populations and individuals as it is indicate the existence of different pathotypes (Sofi *et al.,* 2013*)* and helps to suggest strong management options.

Moreover, disease management requires a thorough understanding of all such factors which contribute to reduce disease epidemics (Fininsa and Yuen 2001; Ddamulira *et al.,* 2014; Kijana *et al.,* 2017). Common beans are widely grown in southwest parts of the Ethiopia over a wide range of altitudes. There is a need to focus on alternative plant disease management options that are environmentally safe, accessible and affordable to small-scale farmers and commercial producers. The use of host resistance is currently seen as the best strategy for plant disease management because it is durable, economical, and environmentally safe. Consequently, selecting varieties with acceptable levels of disease resistance is an approach that and has been reported as an alternative for the management of common bean diseases (Fininsa and Tefera, 2006). This is because disease resistance is embedded within the seeds that farmers usually use. Fungicides application have helped to improve the yields of common bean crops by providing protection from pre and post emerging diseases and insurance of a uniform stand across a wide cultural practices and environmental conditions (Sharma *et al.,* 2015). Different fungicides are developed for ALS management, among triazole tebuconazole and Propiconazol systemic fungicides were the most effectiveness to ALS growth as management alternative (Rashid 2018). Integration of host resistance with available options of disease management could reduce the amount of yield loss caused due to prevalent diseases (Diego *et al.,* 2014).

For this reason, there is a need to integrate with the existing environmentally-friendly diseases management practices to prevail improved yield. In fact, the management of

common bean ALS diseases through host resistance integrated with foliar fungicides has not been studied for multiple disease management in study area. Extensive and repetitive research needed for the management of common bean ALS through wider host resistance and fungicide application with certified seed. Thus, the study was designed to address the following important research questions. What is the present distribution and significance of common bean ALS in common bean growing areas in Ethiopia, and what are the major factors that influence the epidemics of disease? How is the extent of genetic variability and population structure within *P.griseola* isolates in study area? What are the effects of host resistance and fungicide application on ALS epidemic development? What are the extents of the role of integrated use of host resistance and foliar fungicide on growth, yield parameters, grain yield and economic benefits of common bean?

Thus, this study was designed to address the following objectives;

General objective

To assess the distribution, characterize pathogenic variation and examine relationship between common bean angular leaf spot with biophysical and agronomic factors and integrated management of the disease through host resistance and chemical fungicides in southwest Ethiopia.

Specific objectives

1. To assess the distribution and association of biophysical and agronomic factors with the intensity of common bean angular leaf spot,
2. To study morphological and pathological variation of *P.griseola* isolates from different locations,
3. To evaluate the reactions of common bean varieties to aggressive isolate of the pathogen under greenhouse conditions and
4. To determine the effect of integrated management of common bean angular leaf spot (*P. griseola*) using host resistance and chemical applications on epidemics of the disease at Bako in southwest Ethiopia

2. LITERATURE REVIEW

2.1. Adaptation and Agro-ecology of Common Bean

Common bean is adapted to a wide range of climatic conditions ranging from1200 m. a. s. l. to nearly 3000 meters above sea level (m.a.s.l.) depending on variety. However, it does not grow well below 600 meters due to poor pod set caused by high temperature (Dev *et al.*, 1997). It grows best in warm climate at temperature range of 18°C to 24°C (Abebe *et al.*, 2005). Mekonnen (2007) suggested that common bean grows well between 1200 and 2000 m.a.s.l. In addition, Kay *et al*. (1979) reported that the crop is well adapted to areas that receive an annual average rainfall ranging from 500-1500 mm with optimum temperature range of 16°C-24°C, and a frost-free period of 105 to 120 days for maturity. Moreover, common bean performs best on deep, friable and well aerated soil types with optimum pH range of 6.0 to 6.8.

2.2. Common Bean Production and Productivity in Ethiopia

Common bean is one of the most major pulse crops cultivated in a wide range of agroecology's in Ethiopia. In Ethiopia, common bean ranks third as an export commodity, contributing about 9.5% of total export value from agriculture. The major producing regions are 51% Oromia (mainly East Shewa, East Hararghe, and West Hararghe, West Arsi, and Arsi zones), 26% SNNPR (Wolaita, Sidama, Gedeo, Alaba, Dauro and Guraghe zones), 19%Amhara and 2%Tigray region (CSA, 2018).

Common beans productivity depends on good weather condition and use of appropriate technologies (fertilizer, improved seed, and herbicide) with the recommended rate and time. The national agricultural research system has generated a number of improved agricultural technologies and recommendations such as crop variety, agronomic practices, crop protection measures as well as other technical advices and practices. The technologies promoted include improved varieties, recommended fertilizer rates and types, improved agronomic and weed control practices. National average productivity common bean in Ethiopia is generally low, 1.73 t/ha (CSA, 2021). However, the experience from experimental plots indicates that 2.5-3.0 tons ha^{-1} can be obtained (ERCA, 2014).

Common bean is one of the most important cash crops and source of protein for farmers in many lowlands and mid-altitude. The country's export earnings is estimated to be over 85% of export earnings from pulses, exceeding that of other pulses such as lentils, horse

(faba) bean and chickpea (Negash *et al.,* 2007). Common bean ranks third as an export commodity in Ethiopia, contributing about 9.5% of total export value from agriculture. Common bean is also highly favored by Ethiopian farmers because of its fast maturing characteristics that enables households to get cash income required to purchase food and other household needs when other crops have not yet matured (Gabremadhin *et al.,* 2012). Ethiopia has a geographic comparative advantage over other competitive countries. It takes nine weeks for sea shipments of beans from China to reach EU markets, whereas it only takes three weeks from Ethiopia (Ferries *et al.,* 2008). ERCA report shows that common bean exports increased in total value from 19 million $ in 2005 to 134 million $ in 2014, quantity of 43 thousand tons in 2005 to 171 thousand tons in 2014, exhibiting a growth of more than threefold (Ethiopia revenue 2014).

2.3. Major Constraints

The common bean production is affected by both biotic and abiotic factors in the world (Coyne *et al.,* 2003; Mukankusi *et al.,* 2019). Damages caused by insect pests, diseases, poor agronomic practices, such as soil infertility, moisture stresses, weed competition, and a lack of improved varieties are some of the major constraints (Mukankusi *et al.,* 2019). Insect pests and diseases cause the largest loss of yield in East Africa, as compared to factors like drought and soil infertility (Pretty *et al.,* 2011). Beanfly (Ophiomyia phaseoli), common bean bruchids (Acanthoscelides obtectus), and pod borer (Maruca vitrata) are some of the major common bean insect pests affecting common beans. Diseases are known to be the major factors that directly or indirectly affect the production of the crop in Ethiopia (Assefa *et al.,* 1996; Fininsa, 2001). Recently on farm trials, observed that simultaneous infection of common beans by multiple pathogens, where severity of all diseases exceeded 35% (Paparu *et al.,* 2014). The occurrence of more than one pathogen on a single crop is well known in the tropics. Often in such cases, the effect of a disease complex on yield is estimated by assuming that each disease acts independently. However, simultaneous occurrences of diseases can lead to cofounding effects on crop yield and on the population dynamics of infecting pathogens thus causing difficulties in disease management and partitioning of the primary cause of yield losses.

2.4. Angular Leaf Spot

2.4.1. Taxonomy

Angular leaf spot (ALS), caused by *Pseudocercospora griseola* (Sacc.) Ferr is considered as among the most devastating fungal diseases of common bean in the tropics and subtropics. Fungi, was until the 1980s considered being of minor importance in Latin America. However, in the mid-1980s, ALS began to be considered a significant constraint to dry bean production in Latin America, and eastern and southern Africa (Diego *et al.,* 2019). The disease is more prevalent in tropics due to intermittent cool and warm, wet and dry weather (Celetti et al., 2006), which accelerate disease development (Inglis & Hegedom, 1986).The pathogen is an imperfect fungus that belongs to the Phylum Ascomycota (Subphylum Pezizomycotina), class Dothideomycetes, order Capnodiales, family Mycosphaerellaceae and genus *Pseudocercospora* (Crous *et al.,* 2006). Dothideomycetes is the largest and most diverse class of Ascomycete fungi. It comprises 11 orders, 90 families, 1,300 genera and over 19,000 known species. It is highly variable with epidemics that rapidly spread under favorable environmental conditions (Mahuku *et al.,* 2009).

2.4.2. Economic importance

Angular leaf spot caused by *Pseudocercospora griseola* is particularly important disease in some African countries where legumes are major sources of protein and reported to be the important disease in bean growing areas characterized by a humid climate, high temperature and high rainfall in Ethiopia (Habtu *et al.,* 1996). The disease was most destructive around common bean growing areas in Southern and Southwestern parts of Ethiopia. The spots on the leaves eventually coalesce, causing premature defoliation and the spots on the pods lower quality (Crous *et al.,* 2006). Losses of more than 50 % on susceptible cultivars in India (Singh & Sharma, 1976), 80 % in Colombia (Schwartz *et al.,* 1981a), 51-70 % in Brazil (Mora 1985) and as much as 82 % in Costa Rica found highly significant differences in average yield (a yield loss of 31 % over two years) between inoculated plots and plots sprayed with fungicide. Yield losses are not limited to quantity alone also caused due to poor quality (shrivelled and discoloured seed) can be considerable. The precise yield loss due to ALS is often difficult to determine due to the frequent occurrence of multiple diseases.

2.4.3. Distribution

Angular leaf spot has been reported from at least 78 countries. The disease is widespread in tropical and subtropical areas, where it causes destruction on pod quality and results in

significant output losses (Jara *et al*., 2003). The Americas, Europe, Asia, Indonesia, Australia and Oceania (Anonymous *et al*., 1986). ALS has been reported in 18 eastern and southern African countries (Allen, 1995) and has been regarded as the most important dry bean disease in Malawi, in central and eastern African countries, and in the more humid southern African countries (Buruchara, 1992).

2.4.4. Host range

Pseudocercospora griseola is common on *Ph. Vulgaris* (common bean, field bean, French bean, kidney bean, string bean), cowpea, and soybean whether wild or cultivated, dry or green (snap) beans and on *Ph. lunatus* L. (lima bean) (Campos-Avila and Fucikovsky 1981). The disease has also been reported on *Ph. Coccineus.*

2.4.5. Life cycle

Pseudocercospora griseola spores germinate on the leaf surface after 3 days of moist conditions, enter the leaf through the stomata and grow inter-cellulary, limited by the leaf veins resulting in an angular lesion shape. Germination of fungal spores is essentially a process during which the normal metabolic and physiological activity is restored after dormancy. This involves spore transformation from a dormant state of low metabolic activity done of high metabolic activities (Singh *et al.,* 2014). Infection and sporulation occur in a broad temperature range, from 10 to 33°C, rain or high humidity, alternating with dry times (Keller *et al.,* 2015). The disease is favoured by intermittent dry-wet and warm-cool weather (Sartorato, 2002). Angular Leaf Spot epidemics are usually observed relatively late in the crop cycle typically about the flowering stage. Lesion multiplication and extension on the foliage lead to defoliation, a prime mechanism leading to reduced physiological performance of the canopy (Allorent and Savary, 2005) Spread is by airborne spores released from the spots on the leaves. Spread over long distances occurs on seed. The fungus is splashed in rain from the infected seed to leaves. The fungus survives between plantings in the remains of the crop, on volunteer plants, and on seed, where it can survive for at least 12 months. The wet periods allow spore germination, infection and production on the spots; dry periods allow spread of the spores in the wind.

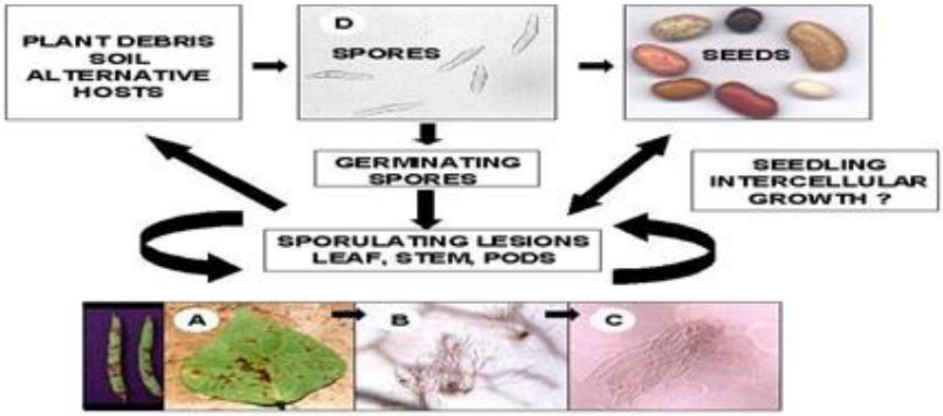


Figure 1: Angular leaf spot disease cycle. Courtesy of (Allorent and Savary, 2005)

2.4.6. Symptoms and signs

The disease affects all of the plant's green components, including the leaves, petioles, stems, and pods, causing a variety of symptoms. Angular dark brown lesions on leaves are the most common sign. The veins and veinlets separate spots that start on the underside of the leaf. There are no colourful boundaries on the lesions, which are grey at first and brown subsequently. This disease is distinguished from the blotch produced by *Cercospora cruenta* and other leaf diseases by the absence of colour in the leaf and the remarkable angularity of the spots. Lesions on main leaves are rounder and bigger than those on trifoliate leaves, and they form concentric rings. Lesions may cover large areas of the leaf causing chlorosis that leads to premature plant defoliation. The disease can cause significant loss in common bean yield.

Figure 2: Angular leaf spot lesions on bean pods and leaf – arrows indicate the lesions (David *et al.*, 2014.)

2.4.7. Epidemiology

The pathogen infects leaf tissue by entering stomata and advancing intracellularly in the mesophyll and palisade parenchyma. Within nine days after infection, the fungus develops

intracellularly throughout necrotic lesions. By 9-12 days stromata develop in the sub stomatal cavity and sporulation may then occur during periods (24-48 hours) of continuous moisture (Cardona- Alvarez, *et al.,* 1956). Moisture is probably the most important factor governing the development of ALS epidemics and is a prerequisite for infection synnemata formation, and sporulation.

2.4.8. Environmental factors

The range of temperatures where spore germination of *Pseudocercospora* is possible to be very wide (5–33^{o}C), and also the range of optimum temperature for spore germination lies between 18 and 24°C (Sharma & Sohi 1980; Sindhan & Bose 1980b) and 24°C and alternate periods of high and low relative humidity favour the development of epidemics of this disease (Cardona-Alvarez 1956; Sindhan & Bose 1980b; Inglis & Hagedorn 1986; Sartorato 1988). Infection was reported to decrease above and below 24°C, ceasing above 36 °C and below 5 °C (Sindhan & Bose 1980b; Verma & Sharma 1984). Cardona Alvarez (1956) observed no disease at 32 *ac.* Chlorosis and defoliation developed most rapidly at 24°C, and at a slower rate at 20, 28 and 16°C. Buruchara (1983) and Verma & Sharma (1984) confirmed the retardation of chlorosis and defoliation at low temperatures (16 0c. Defoliation occurred after ten days at 24°C, 12 days at 20 °c and 28°C, and 19 days at 16^{o}*c* (Cardona-Alvarez 1956).

Similarly, Monda *et al.* (2001) reported spore germination in *Pseudocercospora* to be strongly dependent on moisture. They observed that spore germination on the leaf surface occurs only when the leaf surface is wet, and that it happens within three days of spore deposition. At 24 ^{0}C, the pathogen requires a 5-7-day incubation time, which can be prolonged to 15 days in lower circumstances. Radiation appears to have little effect on spore germination. According to, infection might develop after a period of 48-72 hours under favorable circumstances. To allow for effective infection and subsequent synnmata development, high relative humidity, rainfall, or precipitation periods are required. Gupta *et al*. (1998) also found that disease growth was aided by epidemiological factors such as leaf wetness for 12 hours and a temperature of 25°C. General agreement exists among authors that adequate moisture is a critical requirement for the successful infection of the host and sporulation of the pathogen. Although a few lesions did develop on inoculated plants dried immediately after inoculation, Cardona-Alvarez (1956) found that an initial period of exposure to high humidity (optimum 95-100 %) was a prerequisite for infection.

These findings were supported by those of Sindhan & Bose (1980b) who placed the minimum RH at 85.7 %, with an optimum of between 90.2 and 100 %.

There is considerable difference of opinion as regards the time for which inoculated plants should be exposed to high humidity. A minimum period of three hours in a dew chamber was reported by Cardona-Alvarez (1956) to be sufficient for infection to take place, the severity of infection increasing up to 24 hours. Llanos (1957) reported that increasing degrees of infection were obtained after 16, 24 and 40 hours at RH > 95 %, whereas Brock (1951) found that at least three days were necessary for satisfactory disease development. Llanos (1957) reported that light does not influence conidium germination. However, found germination to be slightly better in light, although this factor did not have an effect on pathogenicity. Cardona-Alvarez (1956) studied the effect of light intensity on disease development and reported that different light intensities had almost no effect on incubation period and defoliation. However, necrosis was more severe on plants exposed to medium shading, and initial symptoms were more pronounced on uncovered than covered plants. Exposure to different day lengths also had a minimal effect on incubation period. The highest disease severity was obtained with a 12-hour photoperiod, and the lowest with photoperiods of 16 and of four hours (Cardona-Alvarez 1956).

2.5. Disease Development

2.5.1. Infection process

Under humid conditions, conidia can germinate within three hours. Bipolar germination is most common but lateral germination with 3-4 germ tubes has also been observed (Cardona-Alvarez 1956). Srinivasan (1953) reported that germination took place after 6-8 hours and that germ tubes anastomosed freely. Cardona-Alvarez (1956) studied host-parasite relations by means of light microscopy. Germination took place on the plant surface, and the germ tube penetrated the leaf or other aerial parts through the stomata. Penetration was completed within two days under optimal conditions. Mycelium then developed in the substomatal cavity, and after four days had colonised the intercellular spaces between the spongy parenchyma. Chloroplasts showed signs of degradation three days after inoculation, followed closely by necrosis of guard cells and adjacent mesophyll cells, disintegration of the spongy parenchyma and finally of the abaxial epidermis. After nine days the fungus became intracellular in the necrotic and neighbouring tissue, and its growth was delimited by the vascular bundles. Stromata developed if) the substomatal cavities and were fully formed 12 days after infection, when infected tissue collapsed and

lesions became macroscopically visible. Synnemata formed only when humidity remained high (Cardona-Alvarez 1956). Where sufficient moisture was present they appeared 14 days after inoculation (Srinivasan 1953). Lesions are reported to gradually increase in size for several days after their appearance (Correa & Saettler 1987). This aspect is also discussed under the section on temperature requirements.

2.5.2. Incubation period

Incubation period is defined as 'the time interval between inoculation and the appearance of disease symptoms', and refers to the appearance of lesions and not necessarily the start of sporulation. Considerable variation exists in reports referring to the duration of the incubation period, from 10-12 days (Brock 1951; Correa & Saettler 1987),12 days (Srinivasan 1953), 12-14 days (Anonymous 1978), 9-16 days (during different months) (Sharma & Sohi 1980) to 6-15 days (Wagara *et al.* 1995). Schwartz *et al.* (1982) reported that symptoms appeared in the field 14 days after inoculation. According to Cardona-Alvarez (1956), temperature influenced incubation period, which may explain the above differences. Incubation period varied from 12-15 days at 16°C, nine days at 20 °C and ten days at 20 and 28°C, with no disease development at 32 ^{o}C. A similar tendency was reported by Buruchara (1983), with incubation period varying from 5-16 days. Incubation period also varies among cultivars (Buruchara *et al.*, 1988). It therefore appears that although this parameter may provide valuable information on pathotype differences, it cannot be easily employed except under naturally uniform or highly-controlled conditions.

2.5.3. Survival and dissemination of pathogen

Wind-blustered particles of diseased soil, wind-blown and rain splashed spores, water, and air currents all contribute to the spread of angular leaf spot disease within and between fields. Seed, agricultural waste, volunteer crops, and off-season bean crops were all identified as key sources of *P. griseola* inoculum. Infested seed, on the other hand, is thought to be the major source of infection. The fungus remained alive in seeds for more than a year as latent mycelium and played a key role in disease start and transmission in new areas. Demonstrated that the pathogen contaminated seeds from both the outside and the inside. After the infection destroy the host cells, stroma forms, allowing the pathogen to remain dormant in the infected plant tissue until favourable conditions return (Monda *et al.*, 2001). The fungus may survive for eight months on host debris, and the surviving inoculum can infect a new crop. The pathogen survived in infected plant debris from one

season to the next, remaining alive in plant debris for more than 10 months under field circumstances. Under laboratory circumstances, the conidia remained alive in plant waste for six months and eight months, respectively.

2.6. Management of Common Bean Angular Leaf Spot

2.6.1. Cultural practices

The common bean growers should carefully use various management strategies such as crop rotation, crop field sanitation, the use of healthy seeds, resistant and tolerant varieties, stress and wound avoidance, inter-cropping, optimum plant spacing and use of soil amendments that promote soil healthy and plant nutrition. For example, in Canada, overwintering of the disease is not common due to cold winter temperatures, a minimum of three-year crop rotation is recommended. In Ethiopia, intercropping with non-host plants such as maize is common in bean cropping systems (Fininsa, 2001).For instance, integration of intercropping and varietal mixtures can effectively reduce ALS pressure in cropping systems.

2.6.2. Host plant resistance

The use of resistant varieties is the cheapest, easiest, safest, and most effective means of controlling plant diseases (Stenglein *et al.,* 2003). It eliminates losses from diseases and avoids the contamination of the environment with toxic chemicals that would otherwise be used to control plant diseases. Varieties resistant to ALS are available and three countries represent 57.2 % of the resistant germplasm: Peru (14.3 %), Mexico (28.6 %) and Democratic Republic of Congo (DRC) (14.3 %) (Garcia *et al.,* 2006). Regionally and locally, resistant/tolerant varieties to ALS are being developed.

2.6.3. Biological control

Biological control is the reduction of inoculum density or disease producing activities of a pathogen in its active or dormant state, by antagonist, or by mass introduction of one or more antagonists. Use of antagonistic species is environmentally oriented, ecologically and economically sound method as depicted in benefit ratio and showed less environmental risk and toxicity as compared to other conventional disease controlling methods. Now a day's biological control is considered as an important approach of agricultural biotechnology in recent years for controlling many fungal plant pathogens (Zaher *et al.*, 2013, Abada and Eid, 2014). The different mechanism of bio-control of plant pathogens using antagonists may be through competition for space and food or by stimulating host plant by inducing tolerance or resistance to the pathogen, or antibiosis

that means production of low molecular fungi toxic compounds or enzymes (Matar *et al*. 2009). Singh and Zaidi (2002) reported that some bioagent enhanced the growth of some crop species.

2.6.4. Integrated disease management

Varieties combining vertical and horizontal resistance are the most suitable, and actions should be taken to prolong genotypes resistance, such as sanitation. Since pathogen infection decreases seed vigour, germination rates and longevity in storage, healthy and pathogen-free seeds should be able to germinate and give rise to vigorous plants with high yielding capacity; the selection of area free of/or isolated from the pathogen or not suitable for the pathogen; and the application of cultural practices such as efficient weed and disease control, and optimum irrigation and fertilization (Maude, 1996; Singh, 2006). Because the pathogen was present in the field at the beginning of the growing season, even a small portion of infected seeds is sufficient to provide enough inoculum to spread and infect many plants early, thus causing severe losses (Stenglein *et al.,* 2003). Planting in well drained soils contribute to create conditions not favourable to the pathogen, and good soil drainage reduces the number and activity of certain fungal pathogens. There is a cost related to soil drainage, making of ridges or mounds. Removal of previously infected crop debris prevents infection build up (Mwangombe *et al.*, 2007).

2.6.5. Chemical control

Fungicide use in dry common bean production is extremely rare. The use of fungicides to control ALS disease is relatively uncommon in eastern and central Africa. But in bean producing regions outside Africa, fungicides such as triazole Propiconazol, triazole Tebuconazole triples and benomyl benzimidazole are regularly used to control ALS (Fernandez *et al.,* 2000). The use of the triazole Tebuconazole triples yield under conditions of high disease pressure. In Ethiopia, use of triadimefon fungicides on a moderately resistant cultivar of common bean reduced ALS epidemics and increased seed yield and yield components compared to susceptible cultivars. Instead of using several fungicides indiscriminately, a substantial use of fungicides can control the disease if used in combination with host resistance (Azmeraw and Hussein, 2017). Fungicides are also typically used since they are effective for fungi diseases, which require accurate disease forecasting.

3. MATERIALS AND METHODS

3.1. Description of the Study Areas

The disease assessments and sample collection were conducted in the Southwest zone of Oromia region during 2022 and 2023 main cropping seasons. The survey encompassed the major common bean growing districts, namely Bako Tibe, Ilu Galan, Gobu Sayo, Bilo Boshe, Didessa and Gechi Southwest Oromia zone, Ethiopia (Fig. 3). The districts vary in their ecological features spanning low, mid and high-land conditions. Annual rainfall and elevation in six districts ranged from 873 to 1683 mm and 1534-1942 m.a.s.l., respectively (Appendix 21). The laboratory and green-house activities were conducted at Jimma University College of agriculture and veterinary medicine during 2024. The experimental field was conducted for two consecutive seasons 22 June in 2022 and 24 June in 2023 during the main cropping at Bako Agricultural Research Center West Shoa Zone of Oromia Regional State, located at 37^0 0"9' E and 09^0 0"6'N with an altitude of 1650 m.a.s.l. and 250 km, to west of Addis Ababa. Bako receives an average annual rainfall 1445mm and mean minimum and maximum temperatures 28.1 ºC and 14.0 ºC, respectively.

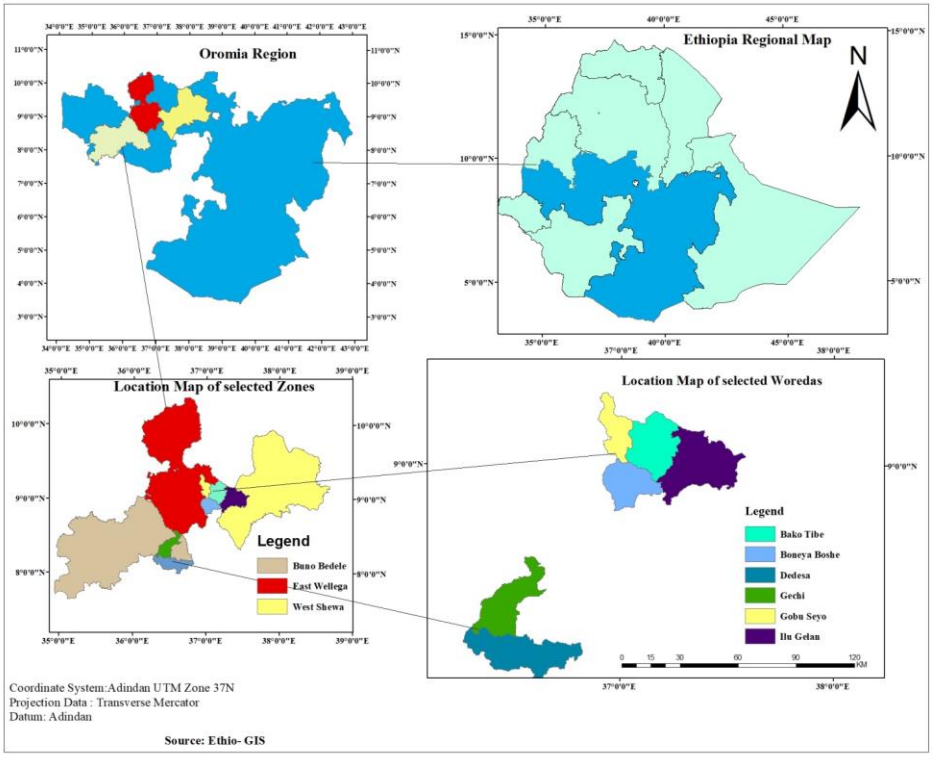


Figure 3: Geographical locations for common bean angular leaf spot (*Pseudocercospora griseola*) survey districts and field experimental sites of study area, in 2022 and 2023 main cropping season

3.2. Sampling Methods

A purposive multistage sampling strategy was employed to select six main common bean growing districts and 24 *Kebeles* within the districts across the study area. The selection of districts and *Kebeles* was carried out in consultation with the Zonal agricultural bureaus and districts agricultural offices, respectively. Within each *Kebeles*, four to six farmers' fields were assessed at intervals of 5 to 8 km along the main and feeder roadsides using random sampling along the pre-planned routes.

3.3. Sampling design and sample size determination

Fields were randomly sampled for the disease assessment during 2022 and 2023 main cropping seasons, which were determined using the Yamane's formula (1967) as follows.

$$\mathbf{n=}\frac{\boldsymbol{N}}{\mathbf{1}+\boldsymbol{N}+(\boldsymbol{e})\mathbf{2}}$$

Where,

n= is sample size, N =is the size of population, E= is the desired level of precision.

N= 3461, e=0.08

Table 1: List of districts, number of kebeles and fields will be covered by the survey

District	Kebele	Total fields	Sampled fields
Bako Tibe	4	755	36
Ilu Galan	4	461	22
Gobu Sayo	4	608	29
Bilo Boshe	4	671	32
Didessa	4	525	25
Gechi	4	440.5	21
Total	24	3461	165

3.4. Assessment of Common Bean Angular Leaf Spot in the Field

Angular leaf spot incidence and severity were evaluated by directly observing symptoms of the disease on common bean plants. The assessment was conducted along the two diagonals (in an ''X'' fashion) using $1m^2$ quadrats at least 8m far apart from each other approximately. In each field, 5 quadrats were systematically assigned to the respective points and common bean plants within the quadrat were counted and recorded as infected and healthy plant. The prevalence of common bean angular leaf spot across the study area

was calculated using a formula described by (Peterson *et al.*, 1948). Similarly, disease incidence (Muthomi *et al*., 2017) and percent severity index of angular leaf spot severity was rated from randomly selected plants per field by scoring ten representative plants for each spaced quadrat using standard scales of 1 to 9 (Pastor-Corrales and Jara, 1995) and Ghosh *et al*. (2009) (Table 2).

$$\text{Disease Prevalence} = \frac{\text{Number of infected fields}}{\text{Total number of field assessed}} \ x100$$

$$\text{Disease incidence} = \frac{number\ of\ diseased\ plants}{total\ number\ of\ plants\ in\ quadrants} \ x100$$

$$\text{PSI (\%)} = \frac{\text{Sum of numerical ratings}}{\text{Totalnumber of plants scored x Maximum score on scale (9)}} x100$$

$$\text{AUDPC} = \sum_{i}^{n-1} \binom{yi + yi + 1}{2} (\text{ti} + 1 - \text{ti})$$

Where: n = represents the total number of assessment times, ti is the time of the ith assessment in days from the first assessment date, and yi is percentage of disease severity at ith assessment.

Table 2: Scales, parts affected and descriptions of scales used to score angular leaf spot severity. Source: Pastor-Corrales *et al.* (1995)

Scale	Plant parts affected by angular leaf spot
1	No visible disease symptoms;
2	The presence of up to 3% leaf lesions;
3	the presence of up to 5% leaf lesions, without sporulation of the pathogen;
4	The presence of sporulating lesions covering 10% of the leaf area
5	The presence of various sporulating lesions from 2 to 3 mm in size, covering 10-15% of the leaf area;
6	Presence of numerous sporulating lesions greater than 3 mm in size, covering 15-20% of the leaf area
7	The presence of numerous sporulating lesions greater than 3 mm in size, covering 20-25% of the leaf area;
8	Presence of numerous sporulating lesions greater than 3 mm in size, covering 25-30% of the leaf area
9	>30% of the leaf or pod surface area is covered by large sporulating and often coalescing lesions. Leaf tissues are generally chlorotic resulting in severe and premature defoliation. Infected pods are often deformed and shriveled and contain a low number of seeds. Abundant sporulating lesions are present on stem and branches.

3.5. Geographical and Agronomic Data

In this regard global positioning system (GPS) instrument was used to determine geographical coordinates (latitude and longitude) and altitude of each inspected field. GPS based survey sheet was prepared to collect information on disease status from each area. Additionally, data on agronomic parameters such as crop growth stage (vegetative, podding, pod filling and maturity) using CIAT (2010) phenology scale and cropping practices, such as sowing date, fertilizer application (fertilized or unfertilized), tillage frequency, crop density (number of plants m^2), preceding crop grown, cropping system (sole cropping or intercropping), weed management practices (poor, intermediate or good), crop variety and seed sources (own seeds or other sources) (Appendix 1) were carefully collected and handled to determine their correlation with disease parameters, such as incidence and severity. Data were collected through interview with growers' and on-site observation of bean fields during the survey periods.

3.6. Infected sample collection

Out of a total of 165 assessed common bean fields, samples were collected from 130 fields where the occurrence of angular leaf spot disease was recorded. Leaf , petiole, pod and seed sample were collected from each quadrant separately (totally 650 samples) placed in paper bags, labeled with the name of the district, *kebeles*, variety, crop growth stage and date of collection written on the paper bag and putting a piece of paper placed inside . The samples were kept in a refrigerator at 4℃ until the assessment was completed. After, assessment and sample collection were finalized; the samples were transported to Jimma university plant pathology laboratory using an icebox and preserved at 4℃ in the refrigerator until isolation and identification were completed.

3.7. Characterization of *Pseudocercospora griseola* Isolates

3.7.1.Isolation of the pathogen *Pseudocercospora griseola* isolates from host tissue

Out of five samples collected from one field, two of the samples were subjected to isolation (purposely one sample from the center quadrat and randomly one from four corners of the field). Isolation of the pathogen from infected leaf, petiole, pod and seeds tissues was done following standard fungal isolation methods under aseptic conditions. Infected leaf, petiole, pod and seeds samples were thoroughly washed with distilled water, cut into 1-2mm pieces with lesion having half healthy and half diseased tissue and surface sterilized with 5% sodium hypochlorite solution for 2 minutes and subsequently rinsed in

three changes of sterilized distilled water, and then placed in between blotting paper to remove excess moisture (Leitich *et al*., 2016), transferred to potato dextrose agar (PDA) plates (9 cm diameter) supplemented with streptomycin to avoid bacterial contaminations and then incubated at 24°C. Five days later, *Pseudocercospora* colonies identified based on the fungus colony characteristics and purified transferred into new PDA plates following the hyphal tip method (Ferniah *et al.,* 2014) and incubated for 14 days to get pure culture of the isolates which were subsequently maintained on PDA slants at 4℃ for further studies.

3.7.2. Macroscopic characterization of *Pseudocercospora* griseola

The macroscopic features of *Pseudocercospora s griseola* isolates were characterized according to Crous *et al*., (2006). Accordingly, the colony colors: (surface and reverse), texture (cottony or fluffy), elevation (flat or raised) and margin (undulated or regular), were visually examined after 14- days- old pure cultures obtained as described in (Section 4.2.2).

3.7.3. Microscopic characterization of *Pseudocercospora* griseola

The conidia of the isolates were mounted on microscopic slide following the method described by Alexopoulos (1962). Mounted conidia were observed, measured and assessed for their length, width, shape of conidia, number of septa and pathogen fruiting structure at 40 magnification using Euromex microscope (Euromex CX43) that connected with a desktop computer. The photographs of the conidia were also captured under this microscope. The sporulation capacity of the isolates was done according to Kumar (2017). Accordingly, a block of 5 mm diameter was excised from the fungal colony using sterilized cork borer and transferred to 5 ml sterile distilled water in a test tube, where it was mixed thoroughly to make a uniform spore suspension. One drop of spore suspension was placed on to a slide; the average spore count was determined by observing three microscopic fields under low magnification of the microscope. Then the isolates were categorized into nil (0), poor (1-10), moderate (11-20), well (21- 30) and excellent (31 and above) sporulation capacity (Kumar, 2017).

3.7.4. Characterization via pathogenicity test

Pathogenicity analysis of the 18 isolates morphologically identified as *P. griseola* was conducted under greenhouse conditions from November to February 2024 at Jimma University College of agriculture and veterinary medicine using Dinkinesh susceptible

common bean variety (Aytenfsu *et al.*, 2019, Tumsa *et al.*, 2015*)* which was provided by Malkasa Agricultural Research Center. Inocula of the individual isolates were prepared on PDA as described in section 3.4.1. From 14 days old cultures, conidia were harvested in 15 ml beaker by adding 10 ml of sterile distilled water (SDW) in each Petri plate. To remove mycelial masses, the suspension was filtered through sterile cheese cloth. Then the final conidial density was adjusted to $2x10^4$spore/ml using a haemocytometer (CIAT, 2015). One drop of Tween 20 were added per 100 ml of inoculum and mixed thoroughly before inoculation to prevent inoculum spilling and to stick on leaf surfaces and inoculation was performed following the standard inoculation technique (Pastor-Corrales *et al*., 1998).

Accordingly, leaves of three-week-old seedlings, raised in the greenhouse (Leitich *et al.*, 2016) in a plastic pots using sterilized top soil, sand and manure with the ratio of (2:1:1), were inoculated by spraying on the upper and lower side of primary trifoliate leaves with 5 ml of finally adjusted spore concentration until run off (Wagara *et al.*, 2004; Kumar *et al.*, 2017; Meso *et al*., 2019). The control common bean plants were inoculated with sterilized distilled water for the same period of time. All inoculated plants were individually tagged and covered with transparent polyethylene bags for 48 hours separately to maintain humidity, which facilitates pathogen to infection (Narasimha and Srinivas, 2012) and arranged in a complete randomized design (CRD).

Disease severity assessment was conducted at one-week intervals, specifically at 7, 14, 21, 28 days after inoculation (Pandey *et. al.*, 2003) using the 1-9 disease scoring scale described by (Schoonhoven and pastor-Corrales, (1987), where 1, plants with no visible disease symptoms; 3, presence of a few small non-sporulating lesions that cover approximately 2% of the leaf surface; 5, plants with several small lesions with limited sporulation and covering approximately 5% of leaf surface; 7, plants with abundant and generally large sporulating lesions covering approximately 10% of leaf surface and associated with chlorosis and necrosis; 9, 25% or more of leaf surface with large sporulating and often coalescing lesions, frequently associated with chlorosis resulting in severe and premature defoliation (Schoonhoven and pastor-Corrales,1987). To further confirm the pathogenesity of each isolate, the pathogen was re- isolated from diseased plants was performed. Based on the recorded disease severity index recorded the isolates identified as the most virulent was selected for testing the reaction of varieties to the

disease were worked out by using a formula described by Pandey *et al*. (2021b) (section 3.2).

3.8. Evaluation of host resistance against *Pseudocercospora griseola* isolate

The evaluation of common bean varieties for disease reaction was conducted at Jimma University College of agriculture and veterinary medicine from January to March 2024 under greenhouse conditions. Two common bean varieties were used Dinkinesh as (susceptible) and Ser, 125 as (resistance) checks (Aytenfsu *et al.*, 2019 and Tumsa *et al.*, 2015). Sterilized seeds of 12 common bean varieties, (Table 3) were sown in a plastic pot containing sterilized soil prepared from topsoil, compost and sandy soil with a ratio of 2:1:1 in the greenhouse. The treatments were arranged in Complete Randomized Design (CRD) with 3 replications. One pot per replication with 1-2 plants per pot was used for each of the varieties for inoculation (Table 3).

Table 3: General information on released common bean varieties used in testing their reaction to virulent isolate of BtDdpg2 and in the experiment

No	Varieties	Year of Release	Seed color	Seed source	Yield (t ha-^{1})	Reaction to disease
1	Dinkinesh	2006	Red	MARC/EIAR	2.5-3.0	Susceptable
2	Awash1	1990	White	MARC/EIAR	2.0	Susceptable
3	Mexican-142	1973	White	MARC/EIAR	1.7	Susceptable
4	Waju	1994	White	MARC/EIAR	2.1-25	M/resistance
5	Awash Malka	1998	White	MARC/EIAR	2.8	M/resistance
6	Gobersha	2007	Red Speckled	HU	2.0-2.2	M/resistance
7	Dame	2008	Red Speckled	MARC/EIAR	1.9-2.0	Susceptable
8	Nasir	2003	Red	MARC/EIAR	2.03	M/resistance
9	Ser-125	2014	Red	MARC/EIAR	3.5	Resistance
10	Ser 119	2014	Red	MARC/EIAR	3.3	Resistance
11	Loko	2009	Large white	MARC/EIAR	1.63	M/susceptible
12	Gabisa	2012	Brown	MARC/EIAR	1.8-2.1	M/resistance

Maintainer: Source: Melkassa Agricultural Research Center (MARC), Haramaya University and Bako Agricultural Research Center (BARC), Reaction of varieties to disease sourced from MoARD, (2005).

Aggressive isolate benefited in the pathogenicity test was used for testing resistant reaction under greenhouse condition. Then, inocula of the selected isolate (BtDdpg2) were prepared using the same procedure used for the pathogenicity test inocula preparation (section 3.7.4). Inoculation was done on 21 days -old seedlings using the spray method until runoff, using hand sprayer. Similarly, control plants were sprayed with sterilized distilled water. All inoculated plants were immediately covered with transparent plastic bag for 48 hours post-inoculation to maintain humidity (Narasimha and Srinivas, 2012). Disease severity assessment was done every week intervals at 7, 14, 21, 28, days after inoculation (CIAT) using a 0-9 disease rating scale developed by Wheeler (1969). The reaction class of varieties to the disease was determined based on the percent severity index (PSI) values following Lohith *et al*. (2010) (Table 3). Finally, Percent Severity Index (PDI) and area under the disease progress curve (AUDPC) were calculated out using formulas described in (section 3.4.4).

3.9. Evaluation of Fungicide on Angular Leaf Spot of Common Bean Variety under Field Conditions

3.9.1. Experimental materials

Four common bean varieties were used as treatments. The varieties were Mexican-142 (G-11239), which is susceptable, Awash 1 (Exrico-23) and Waju, which is moderately susceptable, and Awash Malka (PAN-182), which is moderately resistant. All of them were navy (small white) which are primarily used for commercial (canning) purpose (Tumsa *et al.,* 2015). They were released from Melkassa Agricultural Research Center, Ethiopia and grown across bean growing areas of the country (Table 3).

3.9.2. Fungicides

Two systemic fungicides Natura 250 EW (Tebuconazole) and Jaba 250 EC (Propiconazol) were used singly in the same spray to test their efficacy against common bean angular leaf spot disease with their recommended dose. Jaba 250 EC and Natura 250 EW fungicides were applied at the rate of 0.5 L/ha for each fungicide. Spraying of fungicides was started when the first symptoms of the disease appeared and continued according to spray schedule designated for each treatment (Table 4). Control plots were kept unsprayed during the experiment. Spraying of the fungicides was performed using knapsack sprayers with 250 and 200 liters of water per hectare for each fungicide respectively. During application, plastic sheet was used to separate the plot being sprayed from the neighboring plots to prevent inter-plot interference due to spray drift.

Table 4: Fungicides used for CBALS disease management source (Shukla 2009, Rashid 2018)

Commercial Name	Active Ingredient	Dose/ha	Water volume(L)/ha	Mode Of Action	Time of spray
Natura 250 EW	Tebuconazole 250g/L	0.5L	250	Systemic Foliar spray	Disease onset
Jaba 250 EC	Propiconazol 250g/L	0.5L	200	Systemic Foliar spray	Disease onset

3.9.3. Experimental designed

The experiment was laid down with randomized complete block design (RCBD) in a factorial arrangement using four cultivars, two fungicides and one control with three replications. Total area allocated for the experiment was 37.8 m x 15 m (555.75 m2). A total of 36 treatments combinations including the control were used. For each treatment of fungicides only one cultivar was used as a control. Six rows plot of 2.4x4m (9.6 m2) and Spacing between blocks measured 1.5 m and between adjacent plots 1 m respectively, were used. Spacing between rows were 0.4 m, and between plants within a row was 0.1 m. Bean planting was done on 17 June during 2022 and 19 June during 2023 main cropping season at Bako agricultural research center on plots free of common bean for the last three years. Planting was done at the rate of two seeds per hill and thinned to one plant per hill 15 days after planting (DAP) to insure 240 plants per plot. Fertilizer and other agronomic practices were applied and practiced as recommended (100 kg ha- 1 DAP) during planting.

3.9.4. Disease assessement

Disease incidence and severity were recorded on 10 pre-tagged plants from the middle four rows of each plot at an interval of seven days starting from one week after the appearance of the disease symptom. Five assessments were done during the evaluation period for disease severity and incidence in both years. Disease severity scores were then converted into percentage severity index (PSI) with the same procedure to section 3.4.

The area under disease progress curve (AUDPC) and growth curve models were developed for the disease progress data. AUDPC-values were calculated for each plot using the formula stated by (Campbell and Madden 1990; Vander plank, 2013) (section 3.4).

3.9.5. Assessment of crop growth, yield and yield components

Observations on the following yield attributes will be made from each plot in each replication.

Plant height (cm): The plant heights of ten randomly taken plants from each of the four middle rows were measured from the ground level to the tip of the plant at physiological maturity and expressed as an average of heights of ten plants per plot.

Number of pods per plant*:* The number of pods per plant was counted from ten randomly taken plants from the middle four rows and expressed as an average for each plot.

Number of seeds per plant: It was determined by multiplying the number of pods per plant and number of seeds per pod.

Hundred Seed weight (g): The 100 seed weight was measured in grams by using electronic seed counter machine followed by automatically measuring the seed weight after moisture content were adjusted to12% (AACC, 2000).

Grain yield (t/ha): The yield was recorded from the middle four rows for each treatment and converted to yield ton per hectare.

Adjusted yield (Adj.Y): The adjusted yield was the average yield adjusted downward by 10% to reflect the difference between experimental yield and farmers' yield.

Adj.Y. = Av.Y – (Av.Y*0.1); where, Av.Y = average common bean yield and Adj.Y = adjusted common bean yield.

Sale revenue/gross benefit (GB): It was computed by multiplying field gate price per kilogram from the local/nearest market with adjusted yield. GB = Adj.Y*field gate price. **Total Cost (TC) =** mean current prices of Natura and Jaba (1700 and 1450 ETB/l respectively), water (0.5 ETB/l), wage for fungicide application (200 ETB/person) and soap for cleaning (65 ETB/piece) were considered per hectare. Their prices were based on price during planting in 2022 and 2023.

Net profit (NP): It was calculated by subtracting the total costs of fungicides from the total gross benefit for each treatment. NP = Gross benefit – Total cost.

Marginal Cost (MC) = change in costs between treatments

Marginal Benefit (MB) = change in benefits between treatments

Marginal rate of return (MRR): It measures the increase in net return associated with each additional unit of cost (marginal cost) and it was calculated as follow:

$MRR = \Delta NI/\Delta IC$

Where, MRR = marginal rate of returns, ΔNI = change in net income compared with control and ΔIC = change in input cost compared with control.

3.10. Data Analysis

Based on the nature of the activities done and collected data, different statistical analysis procedures and techniques were used. For survey study, to explain and determine the dependent and independent variables with respect to the most required characteristics, such as mean, range, and standard error were analyzed using two stages nested design procedure of SAS 9.3 statistical software over districts, altitude range and variety. Means separation was done using the LSD test at significance levels of ($P<0.05$). The correlation of disease incidence and severity with altitude, previous crop, weeding frequency and tillage frequency was computed using the Pearson correlation procedure of SAS 9.3 statistical software was done according to (Payne *et al.,* 2011). Multiple regression analysis was carried out to determine the relationship of incidence and severity of the disease with the independent variables using SAS 9.3 (SAS, 2016). Nested design model used in analyzing the field assessment data is described as follows:

$Yjk= \mu+ tj+\beta j (\kappa) +\varepsilon\iota (jk)$

Where: *yjk* is the common bean angular leaf spot disease intensity whereas peasant association *k* is nested within district *j,* μ is the overall mean, τj is the effect of the *jth* district, $\beta k (j)$ is the effect of the *kth* peasant association within the *jth* district, and $\varepsilon l (ijk)$ is the error term.

Analysis of variance for percent severity index (PSI) and AUDPC data of pathogenicity test, varieties reaction evaluation and field experiment were analyzed using the GLM procedure of SAS version 9.3 statistical software (SAS, 2016). Treatment Mean separation among varieties was performed using Duncan's Multiple Range Test (DMRT) at 5% probability level (Gomez and Gomez, 1984). A disease infection rate of inoculated isolates and an infection rate of the disease across the varieties were determined by SAS version 9.3 statistical software (SAS, 2016). Similarly, a disease infection rate of field experiment activity was determined by SAS version 9.3 statistical software (SAS, 2016).

Relations of AUDPC, disease progress rate with yield and yield related parameters were examined through correlation analysis. Logistic [ln(y/(1–y))] (Van der Plank, 1963) and Gompertz [–ln(–ln(y))] (Berger, 1981) models were evaluated to determine the disease

progress rates from the linear regression of disease severities versus days after planting (DAP) for each varieties. Coefficient of determination (R2) and standard error (SE) were used to select the fitness and magnitude of the tested models (Campbell and Madden, 1990). Then the appropriate model (Gompertz) was used to determine the disease progress rate (r) and the intercept of the curve (Appendix 4). Data had better fitted to Gompertz than logistic model. Therefore, rate of increase in angular leaf spot were estimated and compared using the Gompertz model.

3.10.1. Partial budget analysis

The cost and benefit of each treatment was estimated from the marginal rate of return (MRR) that was computed by considering the variable cost available in the respective treatment. Variable costs included chemical costs and labor expenses for application of fungicides both for foliar application. The yield and economic data were collected to compare advantages of foliar application in different treatments. Economic data encompassed input cost that varied, including cost for chemicals and labour during production time. Based on the data obtained, cost-benefit analysis was performed using partial budget analysis, which is a method of organizing data and information about the cost and benefits of various agricultural alternatives (CIMMYT, 1988). Before marginal analyses were carried out, dominance analysis was conducted for the treatments. A dominance analysis was thus carried out by first listing the treatments in order of increasing costs that varied. Any treatment that has net benefits that are less than or equal to those of a treatment with lower costs that varied is dominated and it was eliminated from further consideration (CIMMYT, 1988).

3.10.2. Relative yield loss

Yield loss is the reduction of crop yield due to angular leaf spot and it was measured as percentage of yield reduction from unsprayed plots compared with maximum chemical protected plot using the following formula:

$$\text{RYL (\%)} = \frac{Y1-Y2}{Y1} X100$$

Where, RYL= relative yield loss (reduction of the parameters yield and yield components)

Y1 = mean of the respective parameter on maximum Protected plot, and

Y2 = mean of the respective parameter in other treatments and /or unprotected plot.

4. RESULTS AND DISCUSSION

4.1. Distribution of Common Bean Angular Leaf Spot in southwest Ethiopia

The assessment result revealed that, the disease was prevalent in six assessed districts with different prevalence levels. Combined analysis of disease incidence and severity data revealed non significant difference between 2022 and 2023 main cropping season and therefore data of both years were pooled together and presented. Two years overall mean of disease prevalence recorded was 94.4% in six districts (Table 5). The disease prevalence was scored 100% at Bako Tibe, Bilo Boshe, and Gobu Sayo districts while 93.3%, 90%, and 80% at Didessa, Ilu Galan and Gechi districts, respectively. There were significant ($p<0.05$) differences in disease incidence and severity among districts. The disease intensity varied from slight to severe infection depending on the variability of the variety grown, tillage frequency, and seed source, previous history of the farm, plant population, cropping system, crop pattern, and growth stage, weeding frequency and sowing date difference farmers were used in their fields. The overall mean values of disease incidence (69.4%) and severity (73.1%) were recorded in all assessed location. Statistically, there was no significant difference ($p<0.05$) in disease intensity recorded during the field survey between the two years in the study area. However, a significant difference ($p<0.05$) was observed among the districts.

The highest disease incidences were recorded at Bako Tibe, Bilo Boshe and Gobu Sayo with the mean values of 82.8%, 74.8% and 71.2%, respectively whereas the lowest disease incidence was recorded at Ilu Galan, Gechi and Didessa with mean value of (57.9%), (61.1%) and (68.3%), respectively. Similarly, the highest disease severities were recorded at Bako Tibe, Bilo Boshe (88.0%), (79.7%) and Gobu Sayo (78.2%) while the lowest was at Gechi, Ilu Galan and Didessa with 57.2%, 64.8% and 69.7% (Table 5). The result indicates that there were variations in common bean angular leaf spot prevalence, incidence and severity among study areas this could be due to the altitude ranges and agronomic practices. Bako Tibe and Bilo Boshe districts have the lowest altitude range and rainfall compared to the other districts in this study. Rendering to the study, common bean angular leaf spot development varied from place to place depending on altitudes, variety's reaction, and agronomic practices. The study was in line with the report of Gudero *et al.,* (2019) who stated that altitude ranges (1500-2000 m.a.sl) showed higher probability of association with angular leaf spot mean severity than farms at high altitudes

respectively. This means the highest prevalence and intensity of the disease was recorded from the lowland and midland altitude ranges. In line with the present result Saettler (1991) reported that the disease is prevalent at low to mid-altitudes, where warm temperature, high relative humidity and rainfall favor rapid progress of the disease.

The disease was widely distributed at Tulu Sangota, Sadan Kite, Dambi Dima, Jawis, Eba, Bachara Oda Gibe, Ongobo Makanisa and Ongobo Dambi *kebeles* with mean disease incidences of 85.7%, 84.5%, 82.9%, 81.2%, 78.8%, 78.2%, and 76.8%, respectively. The lowest disease incidence was recorded at Jato, Sibabiche, Galamaya, Dirki, Seko, Mine and GambellaTare kebeles of Ilu Galan, Gachi and Gobu Sayo with the mean incidence 53.2%, 53.3%, 58.5%, 59.1, 59.3%, 59.4%, and 60.3%, respectively.

The highest mean disease severity was recorded in Dambi Dima, Tulu Sangota, Ongobo Makanisa, Eba, Dirki, and Ongobo Dambi, followed by Sibabiche, Chafe Konchi, and Sadan kite with mean values of 97.5 %, 95.4%, 91.2%, 89.9%, 84.9%, 84.8%, 84.4%, 81.1% and 81% in the same order while the lowest disease severity was recorded at Galamaya, Jato, Saso, Seko, Gobe and Sombo Kejo with mean values of 30.2%, 34.4%, 46.0%, 48.4%, 55.5%, and 60.9%, respectively. This study showed that similar trends regarding to common bean angular leaf spot incidence and severities at different localities in lowland, midland and highlands of southwest Oromia Zones. The lowest mean values of disease incidence and severities were recorded in *kebeles* located at higher altitudes while the highest values when compared to areas located in lower and mid altitudes. This result indicated that, the ALS was more sever and prefer midaltitude to lower altitude agroecological areas. The result is in agreement with the survey conducted in Kenya reported by Mwang ‘ombe’ *et al.* (2007) who reported angular leaf spot incidence and severity increased in area at low and mid altitude, while less in area above 2000 m.a.s.l. Statistically, there was a significant difference ($p<0.05$) among *Kebeles* in disease intensity. The differences in a disease amount among *Kebeles* and across the locations might be due to variety reaction and pathogen potential to cause disease. The result is in line with the reports of Ahmad *et al.* (2014).

Angular leaf spot was also found severe in moderately to highly weed infested bean farms assessed. A remarkable observation during field assessment was that fields infested by *Guizotia scarba, Stellaria media (L.), Agratum conyzoides, Galinsoga parviflora, Biden pilosa, and Biden Pachylom* weeds showed the highest disease intensity relative to

infestation- free fields and those fields infested by grass family weeds species. Many of the weed species recorded were destructive competitors for available soil nutrients, space, light and moisture that would later reduce crop strength and make the crop susceptible to infection (Habtu *et al*., 1996; Belet *et al*. 2013; Yimer *et al*., 2018). High weed density could also increase relative humidity and warmth of the microclimate under the crop canopy, favoring the onset, infection and development of ALS (Stenglein *et al.,* 2003; Gupta *et al.,* 2005; Adikshita, 2012; Ddamulira *et al.,* 2014). Therefore, this could be another reason for the difference in disease intensity among *kebeles* since infestation of weed was limited on some *kebeles*. The study is consistent with previous results, Eshetu, *et al.* (2013) stated that highly weed infested field's increased ALS severity, on average, by 20.52% compared to weed free fields.

Table 5: Common bean angular leaf spot prevalence, incidence, and severity across different *kebeles* and districts in southwest zones of Oromia, in 2022 and 2023 main cropping season.

Name of Districts	*Name of Kebeles*	Prevalence (%)	Disease severity (%)	Disease incidence (%)
			Mean ±SE	Mean ±SE
Bako Tibe	Bachara Oda Gibe	100	78.2^{cdef} ±4.4	78.2 ^{ab} ±4.9
	Dambi Dima	100	97.5 ^{a}±6.7	82.9 ^{ab}±5.4
	Sadan Kite	100	81.0 ^{cde}±4.9	84.3 ^{ab}±2.7
	Tulu Sangota	100	95.4 ^{ab}±2.6	85.7 ^{a}±2.6
	Mean	100	88.0	82.8
Ilu Galan	Jato	80	34.4 ^{j}± 9.2	53.2 d±9.7
	Dirki	100	84.8 ^{abcde}±10.3	59.1 ^{cd}±6.1
	Gobe	80	55.5 ^{hi}±7.5	65.6 ^{abcd}±5.7
	Sibabiche	100	84.5 ^{abcde} ± 12.2	53.8 ^{d}±9.5
	Mean	90	64.8	57.9
Gobu Sayo	Ongobo Maka	100	91.2^{abc}±6.9	77.1 ^{abc}±6.6
	Ongobo Dambi	100	84.9 ^{abcde}±4.0	76.8 ^{abc}±2.5
	Sombo Kejo	100	60.9^{ghi}±6.5	70.7 ^{abcd}±4.7
	Gambella Tare	100	75.8 ^{defg}±3.7	60.3^{cd}±4.4
	Mean	100	78.2	71.2
Bilo Boshe	Jawis	100	82.1 ^{bcde}±3.8	81.2 ^{ab}±3.2
	Eba	100	89.9^{abcd}±1.9	78.8 ^{abc}±3.1
	Koye Konchi	100	65.8^{fgh}±5.6	68.59 ^{abcd}±2.2
	Chafe Konchi	100	81.1^{bcde}±6.09	70.69 ^{abcd}±2.6
	Mean	100	79.7	74.8
Didessa	Goro	100	78.9 ^{cdef}±8.5	71.19 ^{abcd} ±7.3
	Saso	100	46.0^{ij}±5.5	66.5 ^{bcd}±7.1
	Gashe	100	78.7 ^{cdef} ±4.6	64.2 ^{bcd}±2.6
	Sobo	85	75.1^{defg}±9.3	71.29 ^{abcd}±8.3
	Mean	96.3	69.7	68.3
Gechi	Galamaya	80	30.2^{j}±9.4	58.5 ^{cd}±11.2
	Gixo	85	72.1^{efgh}±10.4	66.9 ^{abcd} ±12.1
	Seko	80	48.4 ^{ij}±11.7	59.3 ^{cd}±11.3
	Mine	75	77.9 ^{cdef}±11.1	59.4 ^{cd}±9.6
	Mean	80	57.2	61.1
	Over all mean	94.4	73.01	69.4
	LSD (0.05)		16.1	18.9

Mean values in a column with different letters are significant at $p<0.05$; LSD = least significant difference, SE= Standard error.

4.1.1. Prevalence and intensity of angular leaf spot by common bean varieties

Most of the farmers in the study area were involved in common bean production. They commonly grow available local varieties obtained from the markets and varieties released by research center of the country. In the study area, seven common bean varieties namely; Nasir, Loko, Gabisa, Dame, Anger, local and Waju were intensely cultivated by farmers. Of this Dame was the most frequent variety 39(23.5%) followed by Nasir 37(22.4%) and Angar 30(18.2%). There were significant (0.05%) differences among the common bean varieties in common bean angular leaf spot prevalence at Bako Tibe, Ilu Galan, Gobu Sayo, Bilo Boshe, Didessa and Gechi districts (Fig. 4). The highest disease prevalence of common bean angular leaf spot was recorded from fields covered by Dame, Local, Waju and Loko varieties in the study area with the mean values of (100%), (100%), (92.9%), (92 %) respectively while (83.3%), (80%), (75.7%) recorded from Gabisa, Anger and Nasir varieties.

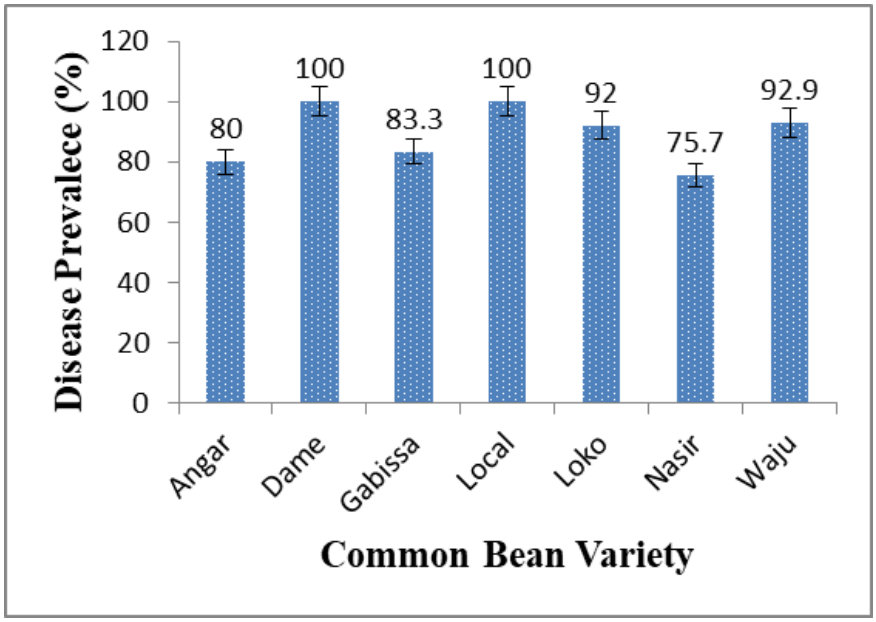


Figure 4: Disease prevalence across common bean varieties in the southwest zone of Oromia during 2022 and 2023 main cropping season.

There was a significant difference ($p<0.05$) in disease incidence and severity among the varieties grown in the study area. The highest disease incidence was recorded from Dame, Loko and Local varieties with the mean values of 88.7%, 82.2% and 79.1 %, respectively. The lowest disease incidence of 35.7% was recorded from Nasir variety followed by Angar

common bean varieties 57.1%. Similarly, the highest disease severity was recorded from Dame, Local and Loko varieties with the mean values of 92.8%, 84.9% and 81.0 %, varieties. The lowest disease severity was recorded from Nasir and Angar common bean varieties with the mean values of 43.4% and 68.1%, respectively (Fig. 5).

Although the performances of common bean varieties varied from location to location based on altitudes, angular leaf spot scored almost on all commercial varieties during the survey in low, mid and highlands of southwest zones of Oromia. Of the commercial variety Dame and Loko was showed susceptible reaction to angular leaf spot in southwest Oromia zones. Similarly, previous findings indicated, Dame common bean varieties were showed susceptible reaction to angular leaf spot disease across the southwest of Ethiopia (Gudaro *et al.*, 2019). This might be due to Variability of angular leaf spot intensity across the locations mainly associated with resistance reaction of varieties, pathogen virulence, geographical locations, weather variables and agronomic practices prevailing across the locations. Similar assessments were conducted in different countries and reported the presence of disease variability across surveyed fields in Congo Kijana *et al.*, 2017) and Ethiopia (Gudaro *et al.*, 2019).

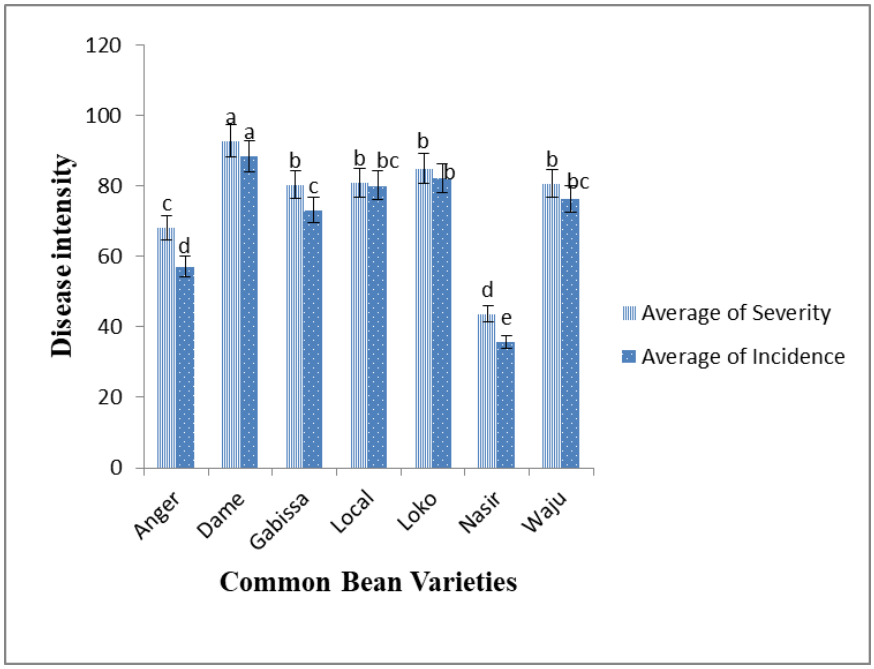


Figure 5**:** Disease intensity across common bean varieties in the southwest zone of Oromia, 2022 and 2023. . Bars with a different letter for respective disease parameters are significantly different at (*p <0.05*)

4.1.2. Occurrence of common bean angular leaf spot by growth stages

From 165 common bean fields, 13, 50, 59 and 43 were assessed at Vegetative, pod-forming, pod-filling, and maturity growth stages, respectively. In similar, angular leaf spot was recorded from 8, 43, 57 and 43 of common bean fields inspected in the same order growth stages. The result showed that angular leaf spot intensity was significantly ($p<0.05$) different between those growth stages (Table 6). The maximum mean disease incidence was recorded in pod-filling growth stage (84.7%) followed by maturity stage (71.3%) which was significantly varied. However, the lowest mean values of disease incidence (51.7%), (37.1%) were recorded at pod-forming and vegetative growth stage, respectively. Similarly, the highest mean values of disease severity was recorded from the pod-filling growth stage (89.4%) followed by maturity stage (77.8%) which was significantly varied. However, the lowest mean disease severity (59.9) and (40.9) was scored at pod-forming and vegetative growth stage respectively. The study aligns with the reports of Aytenfsu *et al. (*2019a), who specified that the highest disease severity (86.56%) was observed at the pod-filling stage compared to other growth stages. If the conditions are conducive for ALS development, it may coalesce, that leads in premature defoliation (Saettler, 1991) (Table 6).

In general, the result showed that angular leaf spot intensity inclination increased with increasing of crop growth stages. This result is in line with Kijana *et al*. (2017) who reported the highest intensity of angular leaf spot was scored at pod-filling and maturity stages of the crop. These results similarly the reported highly significant difference between growth stages (Lenne, 1991; Chaerani and Voorrips 2006). However, once the plant is infected with the disease, it may damage the growth stages then, after losing green pigment of the leaf it became stable Ayitenfsu *et al*. (2019). This could be due to the decline of nutrient supply from the infected tissues (Baily *et al.*, 2013).

Table 6: Intensity of common bean angular leaf spot by growth stages in southwest Ethiopia, during 2022 and 2023 main cropping seasons

	Disease Incidence (%)	Disease Severity (%)
Growth stage	Mean±SE	Mean±SE
Vegetative	49.9 [c]±2.5	40.9 [d]± 4.1
Pod forming	65.1 [bc]±2.9	55.1 [c]± 2.8
Pod filling	84.8[a]±0.9	89.7 [a]± 0.80
Maturity	53.7 [c]±3.84	77.2 [b]± 1.76
LSD (0.05)	16.02	6.71

Mean values with the same letter within a column did not significantly different at ($p< 0.01$), LSD = least significant difference

4.1.3. Effect of agronomic practices on distribution and intensity of common bean angular leaf spot

Agronomic practices, Planting date showed significant ($p <0.05$) effect on incidence and severity of angular leaf spot. The highest mean disease incidence (85.1%) and severity (89.7%) was scored on fields sown early June than fields sown July and august (69.5%, 43.9%) and (75.9%, 50.7%), respectively (Karaye *et al*., 2017). Common bean angular leaf spot was might start from early stage of the crop. Late sowing might be not conducive to the disease. This result agree with previous findings Essubalew *et al*. (2015) who stated that early bean sowing increased ALS incidence in which early planting expose plants for long period of rainfall, leaf wetness, pathogen and high humidity. According to Habtu *et al.* (1996), sowing date had a clear effect on disease epidemics. Similarly, Celetti *et al.* (2006) reported ALS spreads and develops rapidly if production conditions of moderate temperature, prolonged periods of wet weather or high humidity alternates with warm weather (Table 7).

The frequency of tillage affect significantly ($p <0.05$) the incidence and severity of common bean angular leaf spot (Table 7). However, three times plowing showed the lowest angular leaf spot incidence and severity compared to the two times tillage frequency. Increased frequency of plowing is expected to minimize the angular leaf spot intensity through its effects on weeds and volunteer plants. This could be concerned with the disturbance of overwintering inoculums and alternative hosts that might be the source of primary inoculum before planting the main crop. This result was in line with the information of Wasaya *et al.*

(2019), Krupinsky *et al.* (2002) and Karavina *et al.* (2011) who reported that, tillage and debris elimination helps to reduce disease occurrence and soil-related constraints by reducing the number of primary inoculums in the fields. Imposing the farm fields for maximum tillage frequency helps to reduce soil penetration resistance, reduce soil bulk density, increases soil moisture preservation capacity, encourage root-soil contact, and suppress the weed growth (Rashidi *et al.*, 2018), which have a profound contribution to enhancing the strength of plants to defend the diseases.

Weed population had influence on the intensity of common bean angular leaf spot. The highest disease incidence and severity were recorded from the weedy fields with a mean of 81.8% and 86.8%, respectively. This agrees with the reports by Eshetu, *et al.* (2013) highly weed infested fields increased ALS severity, on average, by 20.52% compared to weed free fields. Angular leaf spot increased with high weed population density. The reason why disease was more intense in weedy farm could be due to increased humidity and cool temperature facilitated by the dense canopy of weeds. The weedy canopy can increase microclimatic like moisture which might favor for germination and initiation of angular leaf spot disease. This result was concurrent with Yimer *et al.* (2018) who stated, weather factors such as moisture and temperature are critical factors for the development of angular leaf spot.

The common weed types observed during the survey were *Guizotia scarba*, *Agratum conyzoides,* and *Galinsoga parviflora*, *Stellaria media* (L.), *Biden Pachylom, Snowdenia polystachya, Amaranthus hybridus, Datura stramonium, Commelina bengnalensis, Biden Pilosa, Ipomea ariocarpa, and Polygnom nepalensi Meisn.* Even if there was significant difference ($p<0.05$) statistically among fields infested by weed to a different extent, the highest ALS intensity was recorded particularly from fields highly infested by *Guizotia scarba* weed. Accordingly, from Bako district, most of the fields in Tulu sangota, Bachara Oda Gibe and Dambi Dima *Kebeles* and from Didessa district, some of the fields in Sobo, and Saso *Kebeles* has been shown more severe ALS than *Guizotia scarba, Biden Pilosa and Agratum conyzoides* weed-free fields in other *kebeles* assessed during the investigation. This observation proves the fact many of the weed species recorded were aggressive competitors

for available soil nutrients, space, light and moisture that would later reduce crop vigor and make the crop prone to infection (Belet *et al.*, 2013; Yimer *et al.*, 2018).

Another prominent agronomic factor affecting the intensity of angular leaf spot disease addressed in the present investigation was crop rotation. Result of the analysis indicated that, the preceding crops such as maize, teff, common bean, soybean, sweet potato and hot pepper, were contributed in different amounts to the occurrence and intensity of common bean angular leaf spot disease. From the assessed fields, the highest disease incidence was recorded from fields previously planted by common bean with the extent of 84.5% followed by soybean (82.9%). This finding was in agreement with reports of Cardona-Alvarez (1956) who reported that angular leaf spot is pathogenic to common, lima bean and soybean. Stenglein *et al* (2003) identified crop rotation with different grains and growing common bean after three to four years on the same field helps to reduce the problem of ALS disease. Therefore, variation in disease intensity among fields preceded by different crops could be due to the host alternativeness difference of the crops to the pathogen. Generally, the current investigation confirmed the significant importance of debris elimination and crop rotation to minimize the risks of ALS severity properly (Sartorato 2002; Stenglein *et al.* 2003; Abuley *et al.*, 2019).

Table 7: Effect of agronomic practices on common bean angular leaf spot disease during 2022 and 2023 in Western Oromia, under rain fed cropping system

Agronomic practices	Variable class	Disease incidence (%)	Disease severity (%)
		Mean± SE	Mean ±SE
Planting date	June	85.1[a]±1.1	89.7[a]±0.84
	July	69.5[b]±2.1	75.9[b]±1.5
	August	43.9[c]±2.4	50.7[c]±2.6
	LSD (0.05)	5.31	11.31
Tillage frequency	Two times	82.0[a]±1.2	86.2[a]±1.1
	Three times	49.2 [b]±2.2	57.6[b]±2.3
	LSD (0.05)	22.10	19.67
Weed infestation level	Low	51.2 [c]±2.7	57.5[c]±2.6
	Medium	67.3 [b]±3.3	74.7[b]±2.8
	High	81.8 [a]±1.5	86.8[a]±1.3
	LSD (0.05)	13.31	8.97
Previous crop	Maize	55.3 [b]±2.8	61.9 [b]±3.9
	Teff	59.6 [b]±3.7	68.9 b±2.5
	Common bean	84.5 [a]±1.4	88.4 a±1.4
	Papper	59.8 [b]±6.6	65.7 [b]±5.9
	Soybean	82.2 [a]±1.6	88.1 [a]±1.4
	Sweet potato	31.4[c]±2.0	36.2c±1.7
	LSD (0.05)	14.9	19.2

Mean values with the same letter within a column did not significantly differ at p <0.05; LSD = least significant difference; DI is disease incidence; DS is disease severity; Weed infestation was recorded as low; medium and high.

Regression analysis revealed that 81.3% of the variability of common bean angular leaf spot incidence and 77.8% of the variability of field severity were explained by the six explanatory variables (Table 8). However, altitude, tillage frequency, weed frequency, plant density, weed density, and growth stage were showed a significant effect on disease intensity. The result indicated that plant density and crop growth stage affected the development of common bean ALS Saettler *et al*. (1991). Regression results indicated that among the explanatory variables plant density highly significantly ALS disease incidence and severity by 3.01 % and 5.94%, respectively. This result might be associated with microclimate conditions created by plant population around plant canopy that could be an encouragement for the disease development.

Similarly, an increase in crop growth stage increases the angular leaf spot disease incidence and severity by 4.22 and 5.81 respectively. Regression analysis showed that as altitude decrease by one meter common bean ALS disease incidence and severity increases by -2.34% and -5.02%, respectively. In another way, the regression analysis indicated an increase of tillage frequency and weeding frequency decreases the angular leaf spot disease incidence and severity by -8.81 %, -2.47% and -3.10 %, -0.56%, respectively (Samuel *et al.,* 2008b; Eshetu *et al.,* 2013).. The result is in line with the present study conducted by Saettler *et al*. (1991) who stated that, an increase in plant density, weed density and plant growth stage increases ALS disease incidence and severity.

The crop residuals and alternative hosts (i.e. volunteer plants and weeds) in that field might help as a primary source of inoculum for the succeeding crop could be disturbed and reduced by increases of tillage frequency before planting. From variables regressed for disease intensity plant density, weed density and growth stage were positively affected disease intensity of common bean angular leaf spot disease (Samuel *et al.,* 2008b; Eshetu *et al.,* 2013). Conversely, altitude, tillage frequency and weeding frequency has been negatively affected the disease intensity of common bean angular leaf spot disease. Also, altitude, tillage frequency, and weed infestation variables were showed a significant effect on the disease intensity (Stenglein *et al.,* 2003, Mwangombe *et al.,* 2007). Based on this regression analysis, from quantified variables associated with the development of the common bean angular leaf spot altitude, tillage frequency and weeding frequency take place during growing common bean were the most influential variables in explaining the variability of common bean angular leaf spot intensity. The result indicated this agronomic factor could have effect on common bean angular leaf spot development (Njingulula, 2014; Kijana *et al.,* 2017).

Table 8: Multiple regressions for common bean angular leaf spot incidence and severity on independent variables in the south western of Oromia, 2022 and 2023 under main cropping system

Independent Variables	Disease incidence		Disease severity	
	Coefficients	P-value	Coefficients	P-value
Intercept	8.41	-	7.57	-
Altitude(M)	-2.34	0.0203	-5.02	<.0001
Tillage frequency	-2.47	0.0147	-0.56	<.0001
Weeding frequency	-8.81	<.0001	-3.10	0.0023
Plant density	3.01	0.0031	5.94	<.0001
Weed density	1.08	0.2826	0.68	0.5003
Growth stage	4.22	<.0001	5.81	<.0001
R^2	81.25%		77.77%	
AdjR^2	80.05%		76.92%	
Pr>F	<.0001		<.0001	

4.1.4. Correlations among angular leaf spot disease parameters and other factors

In the current study, linear correlation analysis indicated that there was a highly significant ($P<0.001$) and strongly positive correlation ($r = 0.88$) between disease incidence and severity of common bean angular leaf spot disease. There were negative correlations between angular leaf spot incidence ($r= -0.59$) and severity ($r=-0.64$) with altitude (Table 9). The result was in line with the reports of Gudaro *et al.,* (2018) who stated that, altitude has a significant and negative correlation with the intensity of angular leaf spot disease. The prevailing high relative humidity and warm temperature in the low to mid altitude favor development of angular leaf spot. There was highly significant ($P < 0.001$) and strongly negative relationships between disease incidence ($r =-0.76$) and disease severity ($r =-0.70$) with tillage frequency (Table 9). The result is in line with the present study conducted by Gudero *et al*., (2018) who stated that, Low ploughing frequency might boost the buildup of primary inoculum from bean debris, which are responsible for primary infection and development of ALS. Imposing the farm fields for maximum tillage frequency helps to reduce soil penetration resistance, reduce soil bulk density; increases soil moisture preservation capacity, encourage root-soil contact, and suppress the weed growth (Rashidi *et al.*, 1991), which have a profound contribution to enhancing the strength of plants to defend the diseases.

Table 9: Pearson correlation analysis to assess the relationship between disease intensity and altitude and other factors

	TF	WF	ALT	DI	DS
TF	1				
WF	0.68**	1			
Alt	0.47**	0.57**	1		
DI	-0.76**	-0.83**	-0.59**	1	
DS	-0.70**	-0.71**	-0.64**	0.88**	1

*Significant level at p<0.05 and **Significant level at p<0.001.Alt- altitude, TF-tillage frequency, WF- weeding frequency, DI- disease incidence, DS- disease severity.

4.2. Characterization of *Pseudocercospora griseola* Isolates

4.2.1. Isolation and identification of *Pseudocercospora griseola* isolates

Based on morphological (microscopic) characteristics described by Crous *et al*. (2006) and Meso *et al.* (2019), all isolates identified as *P.griseola* isolates were categorized into 18 *isolates* (Table 10) based on their order of isolation frequency (Fig. 6). The result was in agreement with work of, Leitich *et al*. (2016); Ayitenfsu *et al.* (2019) and Mekuanint *et al*. (2022) that indicated and identified the presence of *p. griseola* isolates from common bean crop in Ethiopia. Similarly, Ddamulira (2015) reported that 42 isolates of *P. griseola* isolates were collected from different bean growing areas of western Kenya and characterized into six isolates (63:11, 30:26, 33:23, 63:7, 31:10 and 63:63) by use of 12 differential cultivars. Likewise Rezen *et al.* (2018) reported that the existence of 21 PG isolates among the 39 isolates occurring in Ethiopia and most of the isolates were highly pathogenic to common bean and caused the highest disease severity. Result of the current study indicated presence of different isolates of angular leaf spot among the isolates identified based on their morphological characteristics. Some reports indicated that, angular leaf spot were pathogenic to lima bean (P. lunatus L.) (Cardona-Alvarez, 1956), scarlet runner bean (Brock, 1951), Urd bean (Golato and Meossi, 1972), tepary bean, Pea (Chupp, 1925) and Cowpea, considered soybean but this has not been confirmed.

In the present study, simultaneous presences of *P. griseola* isolates in one host sample and morphologically (macroscopic) varied isolates of the same group of isolates were isolated from fields where disease occurrence was recorded. *P. griseola* isolates obtained from the same geographic locations varied in their pathogens confirming presence of isolates

variability identified in Ethiopian isolates. However, colony color, texture, margin, Elevation and pigmentation was the macroscopic character that has been showed variation among the isolates of the same group of isolates isolated from one field. This result proves the ability of *P. griseola* isolates to maintain their morphological variations within and among fields to adapt to environmental changes (Rezen *et al.*, 2018). The co-occurrence of BbKkpg2 with BbKkpg3 was isolated from assessed fields on a single necrotic spot.

4.2.2. Isolation frequency of *Pseudocercospora griseola* isolate

Frequency of isolation of *P. griseola* isolates was significantly varied, from BtSkpg4 and BtBogpg5 were the most frequently isolated isolates with the frequency of 39(11.5%), and 41(12.1%) respectively followed by DiSopg1, GsOdpg3 and DiGapg2 with the frequency of 21(5.9), 21(6.2) and 20(6.2). Whereas the lowest frequently isolated isolates were IgDipg1, GeGipg5, BbKkpg2and IgGopg1 (4.1%), (4.1%), (4.7%) and (5.0%) respectively (Fig.6). This finding was in line with the report of Meso *et al.* (2019) who stated that different frequency of *P. griseola* isolates from common bean samples in Kenya.

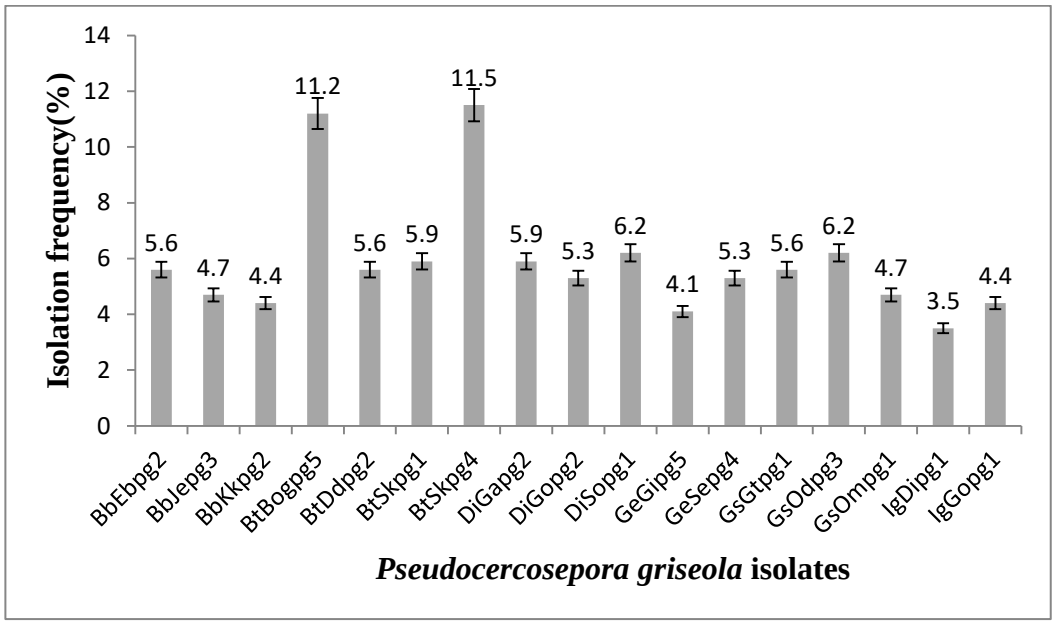


Figure 6: Isolation frequency of identified *Pseudocercospora griseola* isolates

From characterized sample 10, 5, 4 and 3 BtSkpg1 were isolated from leaf, petiole, pod, and seed during isolates identification in the order of mentioned. Similarly, 20, 9, 7 and 5 BtBogpg5, 13, 13, 7 and 4 BtSKpg4, 11, 6, 4 and 2, GsOdpg3, 8, 9, 2 and 2, DiGapg2 were

isolated from leaf, petiole, pod and seed respectively. Two dominant isolates BtBogpg5 and BtSkpg4 were frequently isolated from samples collected from Bako Tibe than the five districts. However, BtSkpg1 and BbKkpg2 were not isolated from samples collected from Ilu Galan district. Similarly IgDipg1and DiSopg1 was not isolated from samples collected from Gobu Sayo and Bilo Boshe districts, respectively (Table 10, Fig. 7).

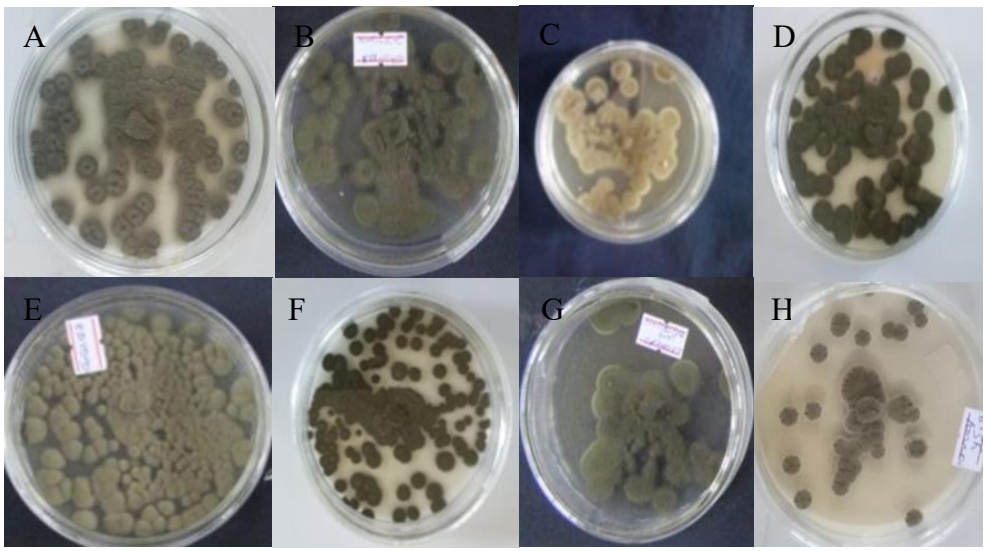


Figure 7**:** Isolates, (A&B), (C&D), (E&F), and (G&H) are front side colony identified from leaf, petiole, pod, and seed sample, respectively

Table 10: Distribution of *P. griseola* isolates in six common bean-producing districts in south west Oromia, Ethiopia in 2022 and 2023 main cropping season

P.griseola isolates	Total no oi	Number of isolate from each plant tissue				Districts					
		Leaf	Petiole	pod	Seed	Bako Tibe	Ilu Galan	Gobu Sayo	Bilo Boshe	Didessa	Gechi
BtSkpg1	22	10	5	4	3	7(31.8)	-	4(18.2)	2(9.1)	4(18.2)	5(22.7)
BtDdpg2	20	8	6	4	2	8(40)	4(20)	2(10)	3(15)	1(5)	2(10)
BtBogpg5	41	20	9	7	5	12(29)	6(14)	8(18.6)	5(12)	6(14)	4(9.3)
BtSkpg4	39	11	17	7	4	9(23)	8(20)	6(14)	6(14)	5(12.2)	5(12.2)
BbKkpg2	17	9	4	3	1	5(29.4)	3(18)	2(12)	3(17)	1(5.9)	3(17)
IgDipg1	14	6	5	2	1	3(21.4)	-	4(29)	3(21)	2(14.3)	2(14.3)
GsOdpg3	20	11	6	4	2	5(25)	3(15)	3(13)	4(17)	3(13)	2(9)
GsGtpg1	21	8	9	2	2	6(29)	3(14)	4(19.1)	2(9.5)	2(9.5)	4(19.5)
GsOmpg1	18	8	7	3	1	4(22.2)	2(11)	2(11)	4(21)	4(21)	2(10.5)
IgGopg1	16	11	4	1	2	4(25)	4(25)	-	3(17)	3(16.7)	2(11)
BbKkpg3	22	13	4	3	2	7(31)	2(9)	5(23)	4(18)	2(9)	2(9)
BbJepg3	18	7	6	2	3	3(16.6)	4(22)	2(11)	3(17)	3(16.6)	3(16.6)
DiSopg1	22	13	6	2	1	8(36)	3(14)	4(18)	-	2(9)	5(23)
DiGopg2	19	9	4	3	3	4(21)	6(32)	3(16)	2(11)	2(11)	2(11)
DiGapg2	21	8	9	2	2	5(24)	6(29)	4(19)	3(14)	2(9.5)	1(4.8)
GeGipg5	14	5	5	3	1	5(36)	1(7)	1(7)	2(14)	3(21)	2(14)
GeSepg4	18	9	4	3	2	5(28)	3(16)	2(11)	1(6)	4(22)	3(16)
GeSepg2	10	5	2	2	1	2(20)	2(20)	1(10)	2(20)	2(20)	1(10)

Values in parenthesis are shown frequency percentage in the districts; - = show the races is not isolated from samples of that district

4.3. Morphological and Cultural Characteristics of *Pseudocercospora griseola* Isolates

Out of 650 angular leaf spot samples collected from 130 common bean fields during 2022 and 2023 cropping seasons across three zones of southwest Oromia, a total of 340 purified isolates were recovered. Based on the similarity of colony appearance on PDA and conidial characters, all the isolates were grouped into 18 *P. griseola* isolates (Table 10 Fig. 7 and 8).

4.3.1. Macroscopic characterization of *Pseudocercospora griseola* isolates

The cultural characteristics of *P. griseola* isolates showed variation in colony color, margin, elevations and textures (Table 11, Fig. 8). Eight different types of upper side colony color were obtained from the 18 representative *P. griseola* isolates evaluated. Most (50.0%) of the isolates had upper side gray colony color on PDA media. These gray colony colors also varied from light-gray to gray, and blue gray to dark gray. This result agrees with that of (Buruchara 1983) who reported that some isolates produce light-grey mycelium, differing from the

characteristic dark-grey of the majority of isolates. Charcoal, smoke, hunter green and army green upper side colony colors were also observed on the other isolates. On the other hand, isolates had dark-gray, dark-green, dark, smoke, ever green, cream, light gray and charcoal colors when viewed on the reverse side of the plates (Table 11). This finding in agreement with the result of Meso (2019) reported the presence of variation in pigment intensity and color among *P.griseola* isolates. The isolates indicated visible variation in texture, colony margin and elevation when grown on PDA.

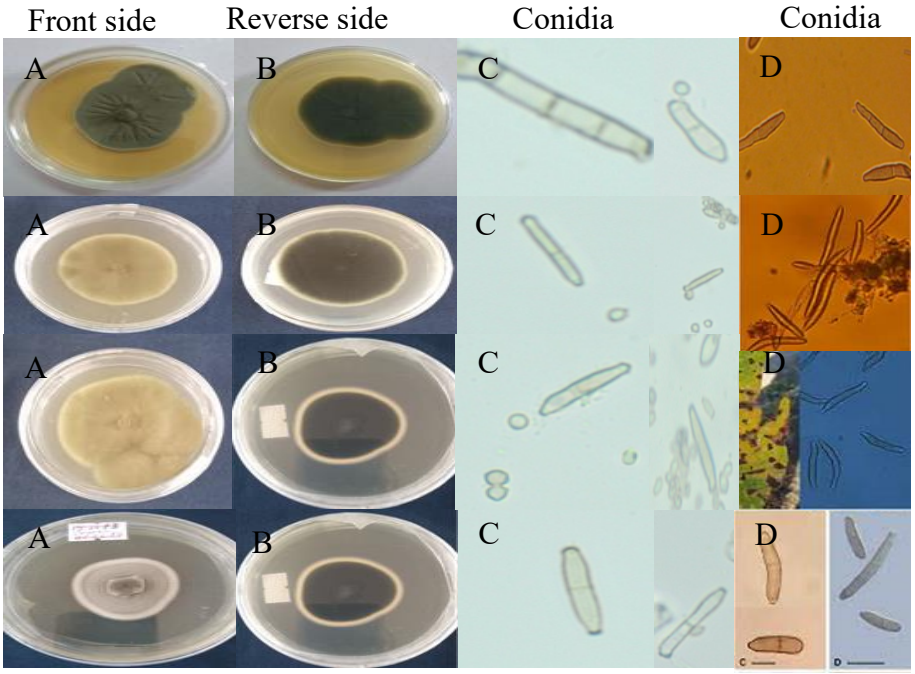


Figure 8: Isolated *P. griseola* from samples collected across southwest Oromia, during the 2022 and 2023 main cropping season. A-are above side colony, B- are reverse side colony, C-Conidia of the respective *P. griseola*; D- reference conidia sourced.

From the 18 *P. griseola* isolates, 50% of the isolates had smooth colony margins and only 38.9% and 11.1% of the isolates had undulated and irregular colony margins. The isolates also showed variations in colony elevations among the study area. 61% of isolates had raised colony elevation, while the remaining 39% isolates were characterized by flat colony elevation. Colony textures observed among isolates were cottony and fluffy types. Cottony and velvety texture was distinguished in 50% and 12 isolates, while 38% isolates showed fluffy texture (Table 11, Fig. 8). These variations in colony margin, elevations and textures

clearly showed that how much this pathogen was variable in different common bean growing areas of southwest, Ethiopia.

Table 11: Cultural characteristics of *P. griseola* isolates in PDA media

Isolates	Colony color		Colony texture	Margin	Elevation
	Upper Side	Reverse side			
BtSkpg1	Gray	Dark gray	Cottony	Smooth	Raised
BtDdpg2	Army green	Dark green	Fluffy	Smooth	Flat
BtBogpg5	Charcoal	Dark	Fluffy	Smooth	Raised
BtSkpg4	Army green	Charcoal	Fluffy	Undulated	Flat
IgGopg1	Gray	Smoke	Fluffy	Smooth	Flat
IgDipg1	Smoke	Dark dray	Cottony	Irregular	Raised
GsOdpg3	Light gray	Dark gray	Cottony	Undulated	Raised
GsGtpg1	Hunter green	Dark gray	Cotton y	Smooth	Raised
GsOmpg1	Gray	Dark gray	Fluffy	Smooth	Flat
BbKkpg2	Army green	Dark gray	Cottony	Smooth	Raised
BbKkpg3	Army green	charcoal	Cottony	Undulated	Raised
BbJepg3	Light gray	dark gray	Cottony	Undulated	Raised
DiSopg1	Hunter green	Ever green	Velvet	Undulated	Flat
DiGopg2	Gray	Dark gray	Cottony	Smooth	Raised
DiGapg2	Smoke	Dark gray	Cottony	Undulated	Raised
GeGipg5	Light gray	Cream	Fluffy	Irregular	Raised
GeSepg4	Dark gray	Light gray	Velvet	Undulated	Flat
GeSepg2	Blue gray	Gray	Fluffy	Smooth	Flat

Bt, Ig, Gs, Bb, Di and Ge = Isolates collected from Bako Tibe, Ilu Galan, Gobu Sayo, Bilo Boshe, Didessa and Gechi districts of different *kebeles*, respectively. Names of *kebeles* in listed representative isolates include: SK = Sadan kite, Dd = Dambi dima, Ts =Tulu Sangota, Bog= Bachara Oda Gibe, Go=Gobe, Di = Dirki, Od= Ongobo Dambi, Gt= Gambella tare, Om= Ongobo Makanisa, Kk= Koye konchi, Eb= Eba, Je= Jawis, So= Sobo, Go= Goro, Ga= Gashe, Se = Seko, Gi= Gixo.

4.3.2. Microscopic characterization of *Pseudocercospora griseola* isolates

Conidial shape, length, width, number of septa of the conidia and mycelia morphology was used as a means of characterizing ALS isolates. Majority (47.1%) and (35.3%) of *P. griseola* isolates infecting common bean had cylindrical and fusiform shaped macro and micro conidia respectively, while some isolates had variable macro and micro conidial shapes ranging from attachment scars (23.5%), Pseudo septate (11.7), Linear (11.7), to Elliptical (5.9%) and Fusoid (17.6%), ovate (17.6%), linear (5.9%), Allantoid (5.9%), to Subglobose (5.9%) shapes respectively, (Table 12, Fig. 8). Similarly, microscopic features were also reported by Kumar

et al., (2006) and Meso *et al.* (2019), who found that the macro-conidia in *P. griseola* were fusoid, thin-walled, relatively cylindrical, elliptical in shape were, double-walled, unicellular with the widest part in the middle and pointed at both ends. Variations in number of septation in the macroconidia were also observed. Average number of septa most frequently varied from 0 to 5. The most frequent conidial septation observed in most of the isolates were in the range of 0 to 1 (*i.e.*, 4 isolates), 1 to 3 (9 isolates) and 1 to 5 conidial septation in 5 isolates (Table 12). The variations could implied that *P. griseola* have different isolates that can cause angular leaf spot on common bean in southwest Ethiopia. Differences in conidial sizes were also revealed by *P. griseola* isolates when grown on PDA at 24 ˚C.

The length and width of conidia were ranged from 21.3 to 32.3µm and 3.1 to 4.7µm, respectively. The highest (25.7 µm) mean conidial length was recorded from isolate GeGipg5, followed by BtSkpg1 (25.40 µm) and BtSkpg4 (23.9 µm). The lowest (15.9 µm) conidial length was recorded from isolate IgDipg1. On the other hand, the widest conidial width (4.7 µm) was measured on BbEbpg2 isolate, followed by GeGipg5 (4.3 µm) and GeSepg4 (4.2 µm). On the contrary, the thinnest conidial width (2.6 and 3.1 µm) was measured on BtTspg5 and IgDipg1 isolates, respectively. Generally, there were many variations in sizes and shapes of conidia among *P. griseola* isolates tested. This finding was in line with the report of (Crous *et al.* 2006; Meso *et al.* 2019; Gudero *et al.*, 2019) who stated that significant variability in septation, length and width of the conidia among isolates. Similarly earlier reports indicated that conidia of *P. griseola* vary widely in number of septa and even conidial size (Deighton, 1977 and Buruchara, 1983) but no further experiments were conducted to relate these variations to pathogenicity, virulence or parasitic fitness.

The morphological variations among isolates could depend on variations with common bean varieties and weather conditions where the crop was grown. The results clearly showed that there was variation among *P. griseola* isolates under different geographic areas of common bean production. Also, isolates of *P. griseola* isolates were good in their sporulation capacity after 14 days of incubation. The poor and excellent sporulation capacity was recorded from DiGopg2 and GeSepg2 isolates, respectively. This result was concurrent with Kumar *et al.* (2019) who reported the occurrence of a significant difference in sporulation capacity among *P. griseola* isolates.

Table 12: Conidial dimension, Number of septa, Sporulation capacity and shape of *P. griseola* isolates grown on potato dextrose agar incubated at 24 ◦C for 14 days

Isolate	Dimension of conidia (mean ± SD)							
	Conidial Length (µm)		Conidial Width (µm)		Conidial shape		Nos	SC
	Mean	Range	Mean	Range	Micro	Macro		
BtSkpg1	25.4±1.3	23.9-27.9	4.1±0.02	4.0-4.1	Fusiform	Cylinderical	1-3	Excellent
BtDdpg2	19.2±1.7	16.3-22.1	3.6±0.5	3.1-4.7	Elliptical	Cylinderical	1-5	Excellent
BtBogpg5	19.5±5.4	13.3-30.3	3.9±0.1	3.8-4.0	Fusoid	Cylinderical	0-4	Moderate
BtSkpg4	23.9±3.4	19.8-30.8	2.6±0.3	2.1-2.9	Ovate	Attachment scars	1-2	Moderate
IgGopg1	16.6±1.2	14.3-18.3	3.5±0.2	3.3-3.8	Linear	Attachment scars	0-2	Excellent
IgDipg1	15.9±0.9	14.0-17.0	3.1±0.12	2.9-3.2	Fusoid	Pseudo septate	1-6	Good
GsOdpg3	23.7±2.0	20.3-27.5	4.0±0.3	3.3-4.4	Fusiform	Cylinderical	0	Poor
GsGtpg1	18.9±2.6	14.3-23.3	3.5±0.1	3.2-3.7	Allantoid	Elliptical	2-4	Moderate
GsOmpg1	19.0±3.9	13.5-26.8	4.1±0.14	3.9-4.4	Fusiform	Cylinderical	0	Excellent
BbKkpg2	20.1±5.1	13.3-29.9	3.6±0.3	3.0-4.0	Fusiform	Linear	0	Good
BbKkpg3	18.0±0.7	16.7-19.1	4.7±0.4	3.9-5.1	Fusiform	Cylinderical	1-6	Excellent
BbJepg3	19.5±0.7	17.1-22.3	3.5±0.3	3.2-4.0	Ovate	Linear	0-3	Moderate
DiSopg1	17.9±1.2	15.8-20.1	3.4±0.9	2.5-5.1	Fusoid	Pseudo septate	1-5	Excellent
DiGopg2	19.3±1.1	17.3-21.2	3.9±0.37	3.2-4.3	Subglobose	Cylinderical	1-3	Poor
DiGapg2	17.9±1.2	15.8-20.1	3.4±0.9	2.5-5.1	Ovate	Attachment scars	0	Excellent
GeGipg5	25.7±3.4	21.3-32.3	4.3±0.1	4.1-4.3	Linear	Cylinderical	1-5	Moderate
GeSepg4	19.7±0.7	18.3-21.0	4.2±0.3	3.7-4.7	Fusiform	Attachment scars	1-5	Moderate
GeSepg2	17.6±0.6	16.7-19.1	3.1±0.12	2.9-3.2	Fusiform	Pseudo septate	1-3	Good

Nos= number of spore, SC= Sporulation capacity, *1-10 spore per microscopic field (Poor), *11-20 spore per microscopic field (moderate), *21-30 spore per microscopic field (good) *>30 spores per microscopic field (excellent), according to Bais *et al.* (2019).

4.3.3. Characterization of *Pseudocercospora griseola* isolates via pathogenicity test

Most of the inoculated isolates have been shown angular leaf spot symptom on the susceptible host seedlings of Dinkinesh common bean variety (Table 13; Fig 9). Also there was a significant difference ($p<0.05$) in the disease severity index among inoculated isolates (Appendix 5). In case of appearance of symptoms, plants inoculated by BtDdpg2, BtSkpg4 and IgJapg1 isolate were the earliest to develop disease symptom followed by one of the isolates from BtSkpg1 isolates. Most of the isolates incubate after six days of inoculation while, the others take ten days to incubate on host tissue. The finding was in line with the reports of Kumar (2017) who stated that angular leaf spot symptoms can be observed starting from seven days after inoculation under controlled conditions.

The result of this study was in in line with previous reports indicated angular leaf spot isolates have a significant variation in their incubation period, from 10-12 days (Brock 1951; Correa & Saettler 1987),12 days (Srinivasan 1953), 12-14 days (Anonymous 1978), 9-16 days (during different months) (Sharma & Sohi 1980) to 6-15 days (Wagara *et al.* 1995). Schwartz *et al.* (1982) reported that symptoms appeared in the field 14 days after inoculation. The finding was in line with the reports of Kumar (2017) who stated that angular leaf spot symptoms can be observed starting from 14-15 days after inoculation under controlled conditions.

Percent disease index and AUDPC of inoculated *Pseudocercospora griseola* isolates indicated a significant variation among inoculated isolates (Table 14). BtDdpg2 isolates was most aggressive with highest percent disease index 94.4% recorded at 28 days after inoculation. Similarly, the AUDPC recorded from plants inoculated by isolates of BtDdpg2 was the highest and (Table 13), followed by isolates of BtSkpg4. Similarly, Aytenfsu, Terefe and Ayana, (2019a) reported a significant difference among *Pseudocercospora griseola* in virulence level and disease progress rate under greenhouse conditions.

The result of this study indicated isolates of DiGopg2 have been shown the lowest percent disease index and AUDPC mean value which was almost nonsignificant from control plants at 7 DAI. Plants inoculated with DiGopg2 isolate were shown very slight (9.8%) symptoms on the senescent lower leaves. This indicates this isolate were non-pathogenic to common bean crop.

Analysis of disease progress rate has been shown a significant rate of infection for some of the inoculated isolates and non-significant for the others. Temporal progression of infection rate in plants inoculated by DiGopg2 and BbEbpg3 isolates was slower by 2.33 times from the rate of infection by the most aggressive isolate (BtDdpg2).

In another way, this virulent isolate was around 1.84 times faster than isolates of DiGopg2. Generally, the rate of angular leaf spot disease infection was significantly faster on plants inoculated by aggressive isolates (BtDdpg2) (Table 13).

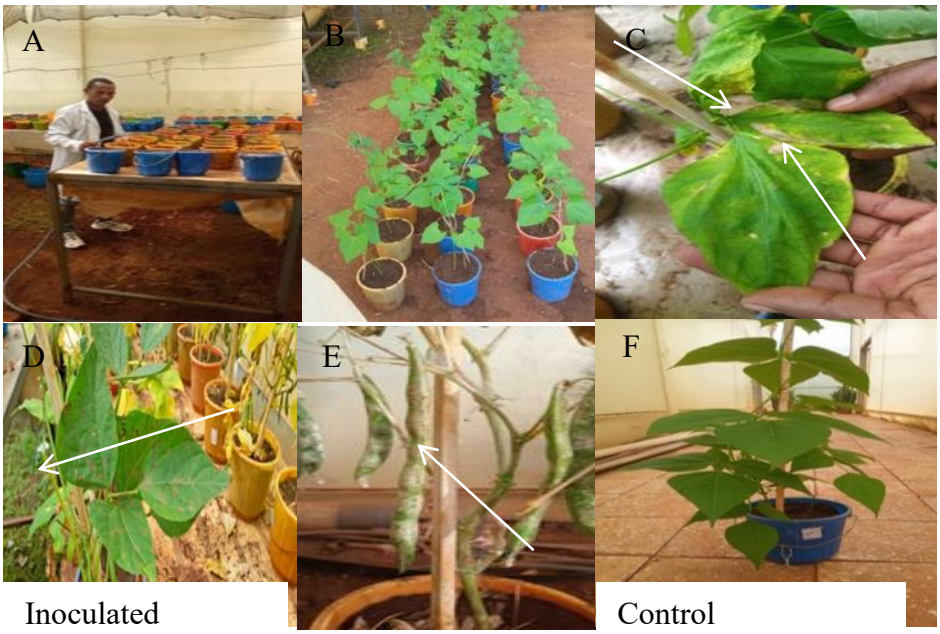


Figure 9: Pictures showing seedling to vegetative growth stage for inoculation (A-B), common bean angular leaf spot disease symptoms on leaf and pod taken from glasshouse study during pathogenicity test (C-E) and variation of the inoculated plant from sterilized

Table 13: Efficiency of *P.griseola* isolates to infect common bean (Dinknesh variety) and establish disease under greenhouse conditions, 2023 (preliminary test of pathogenicity)

Isolates	Severity (%) of ALS at different days after inoculation						
	7DAI	14DAI	21DAI	28DAI	AUDPC	R	R^2 (%)
BtDdpg2	31.6^{ab}	46.2^{a}	54.3^{b}	94.4^{a}	1237.3^{a}	0.158^{a}	88.9
BtSkpg1	23.9^{bcd}	33.3^{b}	41.7^{cd}	64.1^{c}	833.6^{bc}	0.080^{cd}	83.0
BtSkpg4	35.9^{a}	51.1^{a}	62.9^{a}	89.6^{a}	1144.6^{a}	0.131^{a}	82.4
Ijatopg1	24.1^{bc}	37.0^{b}	47.4^{bc}	79.1^{b}	952.3^{b}	0.117^{ab}	85.7
BtBogpg5	20.9^{cde}	28.4^{bcd}	33.1^{fg}	51.8^{e}	684.6^{cde}	0.064^{d}	77.5
IgDipg1	21.6^{bcde}	33.2^{b}	42.4^{cd}	55.5^{ce}	799.2^{c}	0.074^{cd}	74.5
GsOdpg3	22.2^{bcde}	33.9^{b}	41.3^{cd}	56.1^{c}	800.9^{c}	0.073^{cd}	77.3
GsGtpg1	14.2^{cdefg}	32.6^{bc}	37.2^{cde}	59.6^{c}	746.7^{c}	0.075^{cd}	89.7
GsOmpg1	15.6^{cdefg}	16.7^{ef}	25.9^{ef}	45.2^{ef}	510.6^{g}	0.074^{cd}	77.8
BbKkpg2	19.7^{cdefg}	28.3^{bcd}	35.7^{de}	57.3^{c}	718.5^{cd}	0.082^{cd}	81.2
BbEbpg3	17.3^{cdefg}	22.8^{def}	28.9^{e}	37.8^{h}	555.1^{g}	0.061^{d}	53.7
BbJepg3	12.6^{efg}	15.4^{f}	32.6^{de}	49.4^{ef}	552.8^{g}	0.098^{cd}	85.2
DiSopg1	11.6^{fg}	21.1^{def}	31.6^{de}	44.9^{f}	564.9^{ef}	0.090^{cd}	92.2
DiGopg2	9.8^{g}	14.8^{f}	17.2^{f}	29.6^{h}	361.7^{h}	0.061^{d}	88.8
DiGapg2	10.9^{fg}	23.2^{edf}	28.6^{e}	38.9^{h}	536.8^{ef}	0.039^{f}	64.5
GeGipg5	11.6^{efg}	19.0^{ef}	29.8^{e}	39.4^{gh}	520.6^{f}	0.077^{cde}	92.5
GeSepg4	13.4^{defg}	24.4^{cde}	31.6^{ed}	43.4^{fgh}	589.0^{def}	0.077^{cde}	58.3
CO	0.00h	0.00^{g}	3.7^{g}	12.9i	5.44^{i}	0.19	98.0
CV (%)	31.5	13.9	11.8	10.3	7.4	29.1	-
LSD (0.05)	10.5	6.4	7.0	9.5	158.1	0.05	-

Mean values in a column with different letters are significant at $p < 0.01$; AUDPC = area under disease progress curve; DAI = days after inoculation; LSD = least significant difference.

4.3.4. Evaluation of Common Bean Varieties for their Reaction against *Pseudocercospora griseola* isolate under greenhouse condition

4.3.4.1. Angular leaf spot severity

Reaction of 12 released common bean varieties to the aggressive isolate (BtDdpg2) was studied under greenhouse conditions after the selection of one aggressive isolate based on the pathogenicity test result. The result indicated that there was a highly significant difference ($P<0.001$) among tested common bean varieties in disease severity (Table 14; Appendix 4). Based on the mean of percent disease index, all of the tested varieties were categorized into five resistance reaction classes. Ser125, Ser119 and Gobersha common bean variety has been indicated the lowest mean of percent disease index across the observation dates and significantly different from all other common bean varieties. Accordingly, the three varieties were indicated a resistant reaction to the disease. The highest percent disease index (98.4%), (96.4%) was recorded from susceptable check Dinkinesh and Mexican-142 varieties followed by (88.1%), (87.7%) Awash1 and Dame common bean varieties at final date of assessment. Interestingly, in agreement with this result, Gudero and Aytenfsu *et al*. (2019) who reported that Dinkinesh and Mexican- 142 common bean varieties were highly susceptible to angular leaf spot disease under both field and green-house conditions. In another way, loko common bean varieties were moderately susceptible to the disease. While, Waju, Nasir, Awash Malka and Gabisa varieties were showed intermediate to the ALS. The pathogen takes 5-7-day to incubate on the susceptable host. The days of the occurrence of the disease symptom was varied across the tested varieties. Artificial inoculation of common bean varieties using one isolates of PG resulted in typical symptoms and development of the ALS, which took only 10 to 14 DAI to develop. Disease symptom was observed ten days after inoculation on Mexican-142, Awash 1 and Dinkinesh varieties. However, the disease symptom was observed on all of the varieties after 14 days post-inoculation in a different extent of severity. Terna *et al.* (2017) reported incidence of the disease after inoculation of the pathogen was significantly different among the varieties.

4.3.4.2. Angular leaf spot AUDPC

Analysis of variance of AUDPC showed significant ($p < 0.001$) variations among the varieties tested for ALS AUDPC under green-house condition. The highest (3050.9%-days) AUDPC value was obtained from the variety Dinkinesh susceptable (check) followed by Mexican-142 (2805.0 %-days) and Awash1 (25658 %-days). However, significantly different from Gabisa, Awash Malka and Nasir variety. Both Dinkinesh and Mexican-142 varieties has been shown a highly susceptible reaction to the disease. Whenever Loko variety were shown a susceptible reaction to the disease. On the contrary, the lowest AUDPC values were computed for the Varieties Ser125 (532.3 %-days), Ser119 (781.6 %-days) and Gobersha (955.8 %-days) followed by Nasir (1483.6 %-days), Awash Malka (1505.8 %-days) and Gabisa (1679.7%-days) which showed moderately resistant at Jimma in green-house (Table 14). However, the AUDPC value of Nasir variety was less than the AUDPC value of Loko common bean variety that has shown susceptible reaction based on PDI at 49 days after inoculation.

4.3.4.3. Angular leaf spot progression rate (r)

Disease progress rates of ALS severity are shown in (Table 14). The computed disease progress rates showed significant ($p<0.001$) variations among different host-pathogen interactions. Angular leaf spot progressed at rate of more than 0.04 unit day-1 in all varieties, except the resistant check Ser125, Ser119 and Gobersha. Progression of disease infection rate was faster on (0.163 unit day^{-1}) susceptable check Dinkinesh common bean variety, followed by (0.016 unit day^{-1}) Mexican-142 varieties. The progression rate of the disease infection was relatively slower (0.025 unit day^{-1}) on Ser125, (0.028 units day^{-1}) Ser119, and (0.039 unit day^{-1}) Gobersha followed by (0.04 unit day^{-1}) Awash Malka, (0.049 unit day^{-1}) Nasir and (0.048 unit day^{-1}) Gabisa common bean varieties, respectively. In another way, an infection rate of the disease has never been shown a significant difference among the observation dates on Loko and Waju common bean varieties. Generally, the disease infection rate was faster on varieties classified under a highly susceptible and susceptible class of resistance reaction for the disease. Identification and evaluating common bean varieties for their reaction to angular leaf spot is pre requisite to a disease resistance-breeding. The use of resistant variety is valuable not only to reduce the losses due to diseases but also to minimize the toxicity due to application of fungicides (Parey *et al.*, 2013; Manu *et al.*, 2014). The most practical method to control angular leaf spot is the use of resistant varieties which would also be acceptable from

a commercial and breeding perspective. The results of present study agree with previous work done by Aytenfsu *et al.* (2019b) who reported that Ser125 was resistant by joining compatible integrated management options and Dinkinesh and Mexican-142 were reported as susceptible variety. The recent work by Aytenfsu *et al.*, (2019b) also showed that among 12 cultivars screened for resistance against *P. griseola*, none was found fully resistant; only two cultivar (Ser125 and Ser119) has been found resistant with angular disease severity of 11.11% and 22.22%.

Table 14: Response of common bean varieties to *Pseudocercospora griseola* infection under green-house conditions

Variety	Percent disease index (%)									
	7DAI	14DAI	21DAI	28DAI	35DAI	42DAI	49DAI	AUDPC	Rate	RC
Dinkinesh	34.5^{a}	55.7^{a}	62.5^{a}	71.5^{a}	85.2^{a}	97.9^{a}	98.4^{a}	3050.9^{a}	0.163^{a}	HS
Mexican-142	28.4^{bc}	39.8^{c}	54.3^{b}	63.8^{bc}	81.5^{ab}	94.5^{ab}	96.4^{ab}	2805.0^{a}	0.116^{ab}	HS
Awash 1	24.7^{c}	37.0^{c}	46.5^{bc}	53.9^{de}	69.7^{c}	86.8^{c}	88.1^{b}	2452.9^{c}	0.08^{bcd}	S
Dame	24.7^{c}	36.7^{c}	43.9^{c}	68.2^{ab}	75.9^{b}	85.5^{c}	87.7^{b}	2565.8^{c}	0.08^{bcd}	S
Loko	10.5^{cd}	26.7^{d}	41.2^{c}	50.4^{de}	63.7^{cd}	81.7^{c}	83.5^{b}	2060.8^{d}	0.09^{cde}	MS
Gabisa	16.0^{def}	24.4^{d}	31.5^{d}	38.9^{f}	44.4^{e}	58.8^{e}	62.5^{d}	1679.7^{e}	0.049^{de}	MR
Awash Malka	13.6^{f}	24.6^{d}	29.2^{d}	33.0^{f}	39.1^{e}	54.2^{e}	56.4^{de}	1505.8^{f}	0.04^{de}	MR
Waju	10.5^{cd}	28.6^{d}	43.4^{c}	47.5^{e}	57.0^{d}	76.8^{d}	78.4^{c}	1812.1^{c}	0.05^{de}	MR
Nasir	14.8^{ef}	19.3^{e}	27.4^{d}	34.9^{f}	41.5^{e}	53.8^{e}	55.2^{e}	1483.6^{f}	0.048^{de}	MR
Gobersha	10.7^{f}	13.7^{e}	16.4^{e}	16.6^{e}	23.3^{f}	27.8^{f}	29.4^{f}	955.8^{g}	0.039^{bc}	R
Ser 119	9.7^{g}	12.7^{f}	15.1^{e}	17.8^{g}	21.9^{f}	25.6^{f}	27.4^{f}	781.6^{g}	0.028^{e}	R
Ser125	4.8^{h}	8.5^{f}	11.6^{e}	12.4^{gh}	14.5^{g}	17.3^{g}	17.7^{g}	532.3^{h}	0.025^{e}	R
CV (%)	13.41	9.41	13.69	9.77	6.78	6.17	5.84	4.89	31.52	-
LSD (0.05)	3.86	4.71	8.37	8.02	6.10	6.78	7.61	141.1	0.043	-
R^2 (%)	96.23	98.10	95.46	97.45	98.80	98.83	98.92	99.41	82.57	-

Mean values with different letters are significant at $p < 0.01$; AUDPC = area under disease progress curve; CV= Coefficient of variation; LSD = least significant difference; RC= resistance class; R= resistant; MR= moderately resistant; MS= moderately susceptible; S= susceptible; HS= highly susceptible

4.4. Effect of Fungicidal Spray on Incidence and Severity of Common Bean Angular Leaf Spot

4.4.1. Disease incidence

Combined analyses of disease parameters, growth, grain yield and yield components data were showed significant variation between cropping seasons. Therefore, results were separately presented for disease, growth, yield and yield components for each cropping season (Table 15). Analysis of variance revealed that interaction effects of cultivars and fungicides does not showed significant difference ($P<0.01$) in disease incidence of common bean ALS however, cultivars and fungicides as main factor showed highly significant difference in both years. Incidence data was showed significant difference ($P<0.01$) among common bean varieties at all dates of assessment in both years ($p<0.01$) (Appendix 7 and 8). Incidence recorded did not exceed 22.7% in Awash Melka, but reached up to 36.4% in Mexican-142 and 34.2% in Awash-1 at initial date of assessment (55 DAP) during 2022 main cropping season.

During 2022 main cropping season at initial date of assessment, incidence was reduced by 20.2%, 36.7% and 48.9% in Awash Melka over Waju, Awash1 and Mexican-142 varieties, respectively. Similarly, reduction in ALS incidence by 7.6%, 12.3% and 17.3% in Awash Melka was compared with Waju, Awash1 and Mexican-142 varieties at final date of assessment (Table 15). Significant variation was measured between Awash-1 and Mexican-142 in ALS incidence both at initial and final date of assessment during 2023 main cropping season. The significant difference observed among cultivars, indicated that the common bean epidemic level varies among cultivars. This report was in line with the report of Tivoli *et al.,* (1992) and Rhaïem *et al.,* (2002), who stated that, disease resistance level shown by some genotypes in the field could be broken under certain environmental conditions, which may make these varieties susceptible.

Effect of chemical foliar spray showed significant variation on ALS incidence at all dates of assessment ($p <0.01$) during 2022 and 2023 main cropping season. Application of Natura, and Jaba reduced disease incidence by 28.6% and 11.3% at 55 DAP and 21.5% and 18.3% at 83 DAP during 2022 main cropping season as compared to unsprayed plot, respectively. Similarly, application of Natura, and Jaba reduced disease incidence by 36.1% and 14.0% at

55 DAP and 18.4% and 9.8% at 83 DAP during 2023 main cropping season as compared to unsprayed plots, respectively. In both years, on the initial and final assessment date the highest and significantly different disease incidence was observed on unsprayed control plots. Effects of interactions of the main treatments did not show significant variation, at all dates of assessments during 2022 and 2023 main cropping season except, at 83 DAP ($p<0.01$) during 2022 (Appendix 7 & 8). Similarly, in 2023 main cropping season interaction of variety with fungicide foliar sprays was non-significant at all dates of assessment (Appendix 7 and 8).

Table 15: Effect of common bean varieties and fungicides on incidence of angular leaf spot during 2022 and 2023 main cropping season

	Mean disease incidence (%)			
	During 2022 cropping season		During 2023 cropping season	
Treatments	55DAP	83DAP	55DAP	83DAP
Awash Malka	22.7^{c}	79.4^{d}	22.9^{d}	77.6^{d}
Waju	29.1^{b}	87.5^{c}	28.7^{c}	84.0^{c}
Awash 1	34.2^{ab}	93.7^{b}	36.2^{b}	88.4^{b}
Mexican-142	36.4^{a}	97.3^{a}	44.9^{a}	93.8^{a}
CV (%)	15.5	3.6	12.4	2.5
LSD (0.05)	4.6	2.9	4.0	2.2
Fungicide				
Natura	25.2^{c}	74.8^{C}	26.7^{c}	75.0^{c}
Jaba	31.3^{b}	77.9^{b}	31.0^{b}	82.9^{b}
Control	35.3^{a}	95.3^{a}	41.8^{a}	91.9^{a}
CV (%)	15.4	3.4	11.4	9.6
LSD (0.05)	4.2	2.6	3.7	1.8

Values in the column with the different letter represent significant variation; CV = coefficient of variance, Initial incidence assessment at 55, Final incidence assessments at 83, DAP= Days after planting

4.4.2. Severity of common bean angular leaf spot disease

The interaction of varieties and fungicide foliar sprays were showed significant difference ($p<0.05$) in both years on disease severity at initial and final dates of assessment (appendix 9 and 10). Higher disease severity was scored from unsprayed plots of variety Mexican-142 (81.7%), (87.8%) Awash1, (78.1%), (78.9%) and Waju (70.8%), (72.0%) at the final assessment date (83 days after sowing) of 2022 and 2023 main cropping season respectively. The PSI of common bean angular leaf spot was lower 10.4% and 11.9% on Awash Malka variety sprayed with Natura at initial assessment date in 2022 and 2023 main cropping season, respectively. Similarly, the mean value of unsprayed plot of these varieties was showed

reducing PSI of common bean angular leaf spot at final date of disease assessment than other varieties.

The percentage severity index of common bean angular leaf spot was significantly reduced on sprayed plot than unsprayed in both years. From unsprayed plot, PSI of common bean angular leaf spot was higher on variety Mexican-142 and Awash1whereas lower value of PSI was scored from variety Awash Malka followed by Waju during 2022 and 2023 main cropping season at initial and final date of assessment. The use of Natura foliar spray reduced PSI of common bean angular leaf spot by 62.0%, 43.8% and 9.9%, 39.5% on sprayed Awash Malka varieties in their order over unsprayed plot of these varieties at initial and final date of assessment during 2022 and 2023 main cropping season respectively. Correspondingly, the use of Natura and Jaba foliar spray reduced PSI of common bean angular leaf spot by 41.7%, 28.7% and 27.5%, 15.0% on sprayed Waju varieties in their order over unsprayed plot of these varieties at final date of assessment during 2022 and 2023 main cropping season respectively (Table 16 and 17).

Similarly, Natura and Jaba foliar fungicides in combination with variety Awash1 decreased PSI of common bean angular leaf spot by 35.6%, 31.1% and 26.9%, 11.1% in that order over unsprayed plot of these varieties at final date of severity assessment during 2022 and 2023 main cropping season respectively. Also in two years Natura and Jaba foliar spray in combination with variety Mexican-142 decreased PSI of common bean angular leaf spot by 28.8%, 5.4% and 27.4%, 11.9% in that order over unsprayed plot of these varieties at final date of severity assessment during 2022 and 2023 main cropping season respectively. The plot subjected to foliar spray was reduced the common bean ALS diseases severity in all varieties at initial and final dates of assessment as compared to unsprayed plot in both years at Bako agricultural research center. Generally, Natura foliar spray on Awash Malka variety had significant effect in reduction of PSI of common bean ALS disease in both years. This might be due to the chemical application of Natura foliar spray effectiveness in controlling common bean ALS and the resistance of the variety. This finding was similar to the reports of (Sharma and Sohi, 1978), who reported that, foliar use of fungicides such as Thiovit, Dithane M-45, Zincocap, wettable sulphur, and Bordeaux combination has been shown to lower disease severity and yield loss. Similarly, Giroto, (1974), Fortugno *et al.,* (1974) and Bhat

(2002) reported that foliar treatment of fungicides such as Derosal, Saprol and triforine has been shown to minimise the severity of angular leaf spot disease and boost yield. As reported by Fikire *et al.* (2011) management of angular leaf spot on beans is effective by spraying Benomyl at 7-day intervals.

Table 16: Effect of common bean varieties under foliar applications of Natura and Jaba on percentage severity index of angular leaf spot during 2022 cropping season at BARC

Varieties	Mean disease severity (%)							
	55DAP during 2022 cropping season				83DAP during 2022 cropping season			
	Fungicides				Fungicides			
	Natura	Jaba	Control	Mean	Natura	Jaba	Control	Mean
Awash Malka	10.4^{i}	11.3^{i}	27.4^{c}	16.37	35.5^{i}	39.7^{h}	63.2^{d}	46.1
Waju	14.0^{h}	16.7^{fg}	29.9^{b}	20.2	41.3^{h}	50.5^{g}	70.8^{c}	54.2
Awash 1	15.1^{gh}	20.2^{e}	25.5^{cd}	20.3	50.8^{g}	54.4^{f}	78.9^{b}	61.4
Mexican-142	17.6^{f}	24.8^{d}	34.1^{a}	25.5	58.2^{e}	77.2^{b}	81.7^{a}	72.3
Mean	14.28	18.3	29.2	20.6	46.5	55. 5	73.7	58.5
CV (%)				6.58				2.37
LSD (%)				2.29				2.35

Initial disease severity from which PSI obtained was scored at 55 DAP during 2022 cropping season, Final disease severity from which PSI obtained was scored at 83 DAPS during 2022 cropping season. CV=coefficient of variance, BARC=Bako agricultural research center.

Table 17 : Effect of common bean varieties under foliar applications of Natura and Jaba on percentage severity index of angular leaf spot during 2023 cropping season at BARC

Varieties	Mean disease severity (%)							
	55DAP during 2023 cropping season				83DAP during 2023 cropping season			
	Fungicides				Fungicides			
	Natura	Jaba	Control	Mean	Natura	Jaba	Control	Mean
Awash Malka	11.9^{h}	18.7^{de}	13.2^{gh}	14.61	41.3^{j}	49.5^{i}	68.3^{d}	53.03
Waju	16.0^{de}	19.3^{d}	17.6^{ef}	17.6	52.2^{h}	61.2^{f}	72.0^{c}	61.8
Awash 1	16.2^{de}	22.2^{c}	27.2^{a}	21.1	57.1^{g}	69.4^{d}	78.1^{b}	68.2
Mexican-142	14.1^{g}	23.4^{c}	25.0^{b}	20.8	63.7^{e}	77.3^{b}	87.8^{a}	76.3
Mean	14.55	20.9	20.8	18.7	53.6	64.4	76.6	64.8
CV (%)				4.46				2.20
LSD (%)				1.5				3.71

Initial disease severity from which PSI obtained was scored at 55 DAP during 2023 cropping season, Final disease severity from which PSI obtained was scored at 83 DAPS during 2023 cropping season. CV=coefficient of variance, BARC=Bako agricultural research center.

4.4.3. Disease progress rate

Disease progress rate, which was obtained from disease severity, significantly variable among varieties in both main cropping season ($p<0.05$) (Appendix 11). Analysis of variance (ANOVA) revealed that cultivars and fungicide spray as main factor and their interaction showed highly significant difference ($P<0.01$) in disease progress rate of common bean ALS (Appendix 11). In this study, the lowest disease progress rate (0.026 unit/ day) and the highest (0.062 unit/ day) were obtained from Awash Malka variety sprayed with Natura and unsprayed Mexican-142 variety, respectively (Table 18). However, the disease progress rate obtained from Waju variety of Natura (0.027 unit/ day) and Jaba (0.029 unit/ day) sprayed plots had no significant difference between them statistically but, showed significance difference with unsprayed (0.041 unit/ day) plots. Similarly, on Awash1 variety disease progress rate of (0.03 unit/ day), (0.032 unit/ day) and (0.055 unit/ day) were recorded from Natura, Jaba and unsprayed plots, respectively. Likewise, on variety Mexican-142 the lowest (0.039 unit/ day) disease progress rate were recorded from the plots sprayed with Natura and showed significant variations from plots received Jaba (0.056 unit/ day) and the unsprayed (0.062 unit/ day). Generally, disease progress rate recorded from Awash Malka variety was much lower than the disease progress rate of other variety corresponding to spraying fungicide.

Similarly, in 2023 main cropping season, analysis of variance (ANOVA) revealed that interaction effects of cultivars and fungicides sprays showed significant variations on disease progress rate (Appendix 11). The lowest disease progress rate (0.037 unit/ day) and the highest (0.056 unit/ day) were recorded from Waju cultivar sprayed with Natura fungicide and Mexican-142 cultivar sprayed with Jaba fungicide, respectively. Similarly, on Awash Malka cultivar the lowest disease progress rate (0.029 unit/ day) was recorded from sprayed plot with Natura fungicide. While the lowest (0.037 unit/ day) disease progress rate was recorded from untreated control plots of the same varieties. However on Awash 1 varieties, the lowest (0.03 unit/ day) disease progress rate was recorded on plots received Natura fungicide spray. On this variety (Awash1), sprayed plots of Natura and Jaba did not show significant variations from unsprayed control plots of Awash Malka (0.037 units/ day) except unsprayed plot of Waju. Among unsprayed control plots the highest (0.074 unit/ day day) and the lowest (0.037 unit/ day) disease progress rate were recorded on Mexican-142 and Awash Malka cultivars in

the order mentioned (Table 18). This might be due to the higher disease pressure associated with the variation in favorable environmental condition and the varieties used.

Table 18: Disease progress rate (r) of angular leaf spot of common bean varieties under foliar application of Jaba and Natura in2022 and 2023 at BARC

Treatments	DPR (unit /day) at BARC 2022				DPR (unit /day) at BARC 2023			
Varieties	Fungicides				Fungicides			
	Natura	Jaba	Control	Mean	Natura	Jaba	Control	Mean
Awash Malka	0.026^{g}	0.029^{fg}	0.037^{cde}	0.031	0.029^{g}	0.031f$_{g}$	0.054^{b}	0.038
Waju	0.027^{cde}	0.029^{fg}	0.041^{c}	0.033	0.037^{e}	0.041^{cde}	0.055^{b}	0.045
Awash 1	0.03^{de}	0.032^{efg}	0.055^{b}	0.039	0.040^{de}	0.047^{c}	0.057^{b}	0.048
Mexican-142	0.039^{cd}	0.056^{ab}	0.062^{a}	0.053	0.045^{cd}	0.056^{b}	0.074^{a}	0.059
Mean	0.031	0.037	0.049	0.039	0.038	0.044	0.06	0.048
CV (%)				9.17				6.86
LSD (0.05)				0.011				0.0054
P –Value				<.0001				0.0022

BARC = Bako Agricultural Research Center, DPR= Disease progress rate, CV = Coefficient of variance

4.4.4. Disease progress curve (DPC)

In 2022, angular leaf spot progression was lower for all varieties sprayed with Nature followed with Jaba, while it was highly progressed on unsprayed plots (Fig.10). Similarly, in 2023 application of Natura on all varieties reduced angular leaf spot progression (Fig. 11). Whereas it was highly progressed on unsprayed plots. The disease was progressed increasingly and attained closely sigmoid shape in most Control check varieties and susceptible check variety (Fig. 10 and11).

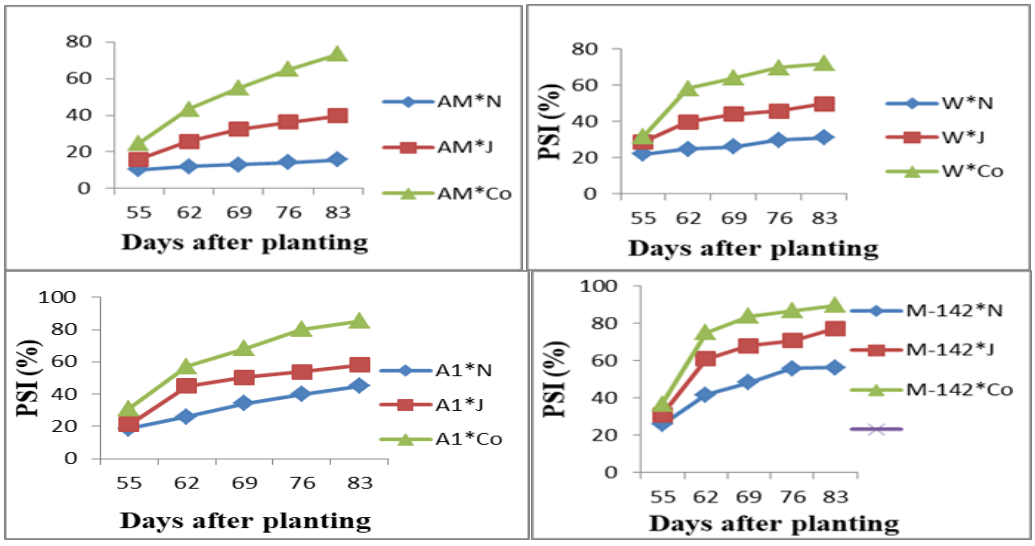


Figure 10**:** Disease progress curve of common bean angular leaf spot (percentage severity index (PSI)) on common bean varieties under foliar applications of N =Natura, J=Jaba, AM =Awash Melka, W= Waju, A1 = Awash-1, M-142 = Mexican-142 during 2022 at BARC.

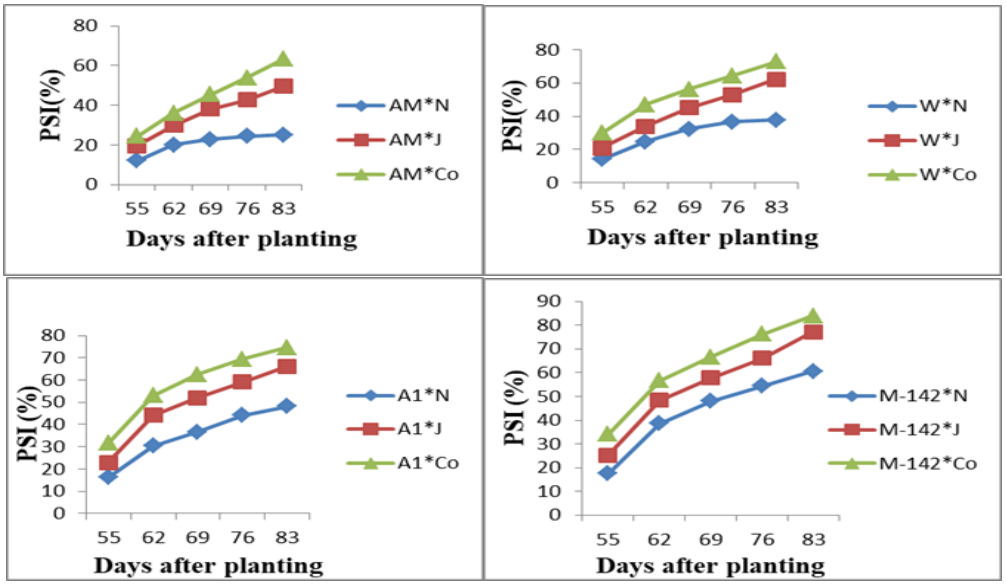


Figure11**:** Disease progress curve of common bean angular leaf spot (percentage severity index (PSI)) on common bean varieties under foliar applications of N =Natura, J=Jaba, AM = Awash Melka, W= Waju, A1 = Awash-1, M-142 = Mexican-142 during 2023 at BARC.

4.4.5. Area under disease progress curve (AUDPC)

Analysis of variance revealed that cultivars and fungicides as main factor showed highly significant difference however, their interaction not showed significant difference (P<0.01) in AUDPC of common bean ALS in both years. Analysis of variance for the area under disease progress curve (AUDPC) values showed significant difference among varieties (p <0.01) in both years. Lower AUDPC value was calculated from Awash Melka (943.1%-days) as compared with waju (1176.6%-days), Awash-1 (1374.4%-days) and Mexican-142 (1520.4%-days) in 2022 main cropping season (Table 19). Similarly, AUDPC was lower for Awash Melka (1037.6%-days) followed by waju (1300.4% -days), and higher for Awash1 (1419.9%-days) and Mexican-142 (1723.6%-days) in 2023 main cropping season. The overall mean (1253.2%-days) AUDPC value in the 2022 main cropping season was lower than in 2023 (1370.3%-days).

During 2022 and 2023 main cropping season area under disease progress curve had shown highly significant difference (p <0.01) both for Natura and Jaba sprayed plots. In 2022 main cropping season foliar chemical sprayed plots with Natura have lower AUDPC value (993.4%-days) followed by Jaba foliar sprays (1186.2%-days) than unsprayed plot (1581.2%-days) (Appendix 11). Likewise, in 2023 main cropping season the highest AUDPC (1685.8

%-days) was valued for unsprayed control. However, the lowest AUDPC (1099.28 %-days) was estimated on common bean plots treated with Natura 0. 5L/ha which was significantly different from Jaba with rates of 0.5L/ha (1326.05%-days) and unsprayed plots (Table19). This finding was similar to the report of Belachew (2016), who reported that, three times spray of systemic fungicides has been recorded highly effective in reducing area under disease progress curve of faba bean gall disease. Similarly, study was in agreement with the reports of Akpa *et al.* (1993), who reported that seeds treated with tetramethyl thiuram disulfide and sodium hypochlorite (NaOCl) had significantly lower seedling blight compared with unprotected as in the control. Wulita *et al* (2015) reported that application of fungicide on fababean gal disease reduces disease intensity. From the result obtained, it was confirmed that the overall disease development was significantly influenced by the varieties used, fungicide spray as well as the type of fungicides. The data showed highly significant differences ($P<0.01$) among treatments.

Table 19: The AUDPC values of the CBALS disease on varieties and fungicide in both years

Treatment	AUDPC (%-days) 2022	AUDPC (%-days) 2023
Awash Malka	943.1[d]	1037.6[d]
Waju	1176.5[c]	1300.4[c]
Awash1	1374.4[b]	1419.9[b]
Mexican-142	1520.4[a]	1723.6[a]
Over all mean	1253.6	1370.3
CV (%)	6.65	6.00
LSD(0.5)	88.20	86.99
Fungicides		
Natura	993.4[c]	1099.28[c]
Jaba	1186.2[b]	1326.05[b]
Control	1581.2[a]	1685.8[a]
CV (%)	6.6	7.5
LSD (0.5)	74.13	73.11

AUDPC: Area under disease progress curve, Means with the same letters are not significantly different.

4.4.6. Yield and yield components

4.4.6.1. Seed yield of common bean

Interaction effect of varieties and fungicides spray showed significant variations in producing seed yield in both years (Appendix 12 and 13). In 2022 main cropping season the highest mean seed yield (3.7 t ha-^{1}) was recorded on Awash Malka varieties sprayed with Natura fungicide and showed significant variations from plots of this varieties sprayed with Jaba (3.4 t ha-^{1}). The least mean seed yield (1.8 t ha-^{1}) was recorded from unsprayed plots of varieties Mexican-142 (Appendix 15). In this year on varieties Mexican-142, sprayed with Natura gave (2.4t ha-^{1}) mean grain seeds which was significantly differed from unsprayed plots. Also on Waju varieties, the highest (3.2 t ha-^{1}) mean grain yield was obtained on sprayed plots with Natura fungicide than unsprayed plots (2.3t ha-^{1}) (Table 20).

Similarly during 2023 main cropping season, the highest grain yield of (3.8 t ha^{-1}) was obtained on Awash Malka varieties from plots sprayed with Natura fungicide. Furthermore, the next highest (3.5 kg ha^{-1}) grain yield was obtained on Awash Malka varieties sprayed Jaba fungicide. On Waju cultivar, the highest (3.3 t ha^{-1}) and (2.9 t ha^{-1}) was obtained on Natura and Jaba sprayed plots of each respectively. But on Awash1 varieties, the highest (2.8 t ha-^{1}) and the lowest (2.3 t ha-^{1}) grain yield was recorded on plots sprayed Natura fungicide and unsprayed plots respectively. In this year on unsprayed plots, the least (2.3 t ha-^{1}) and (1.9 t ha-^{1}) grain yield was obtained on Awash1 and Mexican-142 varieties in the order mentioned. This least yield in moderately susceptible and highly susceptible cultivars could be due to high initial inoculum of disease in both cultivars and its persistence for prolonged period (Table 21).

4.4.6.2. Yield components

Analysis of variance (ANOVA) revealed that fungicide spray, varieties as a main factor and their interaction showed significant variations ($P<0.05$) on the plant height, number pod per plant, seed per plant and seed per pod during 2022 and 2023 main cropping season (Appendix 12 and 13) in study area.

4.4.6.3. Plant height

Results indicated that there was a significant ($p<0.05$) difference in plant height during 2022 among the common bean varieties Awash Malka (78 cm), Waju (102.1 cm), Awash1 (65.4)

and Mexican-142(83.6) sprayed with Natura. But, Awash Malka and Awash1 varieties sprayed with Jaba were statistically on par in their plant heights.

Regarding 2023 main cropping season, significant variation was observed among common bean varieties on plant height and comparatively the tallest (86.0%) and shortest (58.9%) plant height were recorded on Waju and Awash1 sprayed with Natura and un sprayed plot respectively. This might be due to the higher disease pressure on unsprayed control plots than on the treated plots. This report was in line with the report of Tumsa *et al.* (2015), who stated that the CBB significantly reduced the height of the common bean crop. Also, this study is in agreement with the finding of DBARC (2015), which reported that the faba bean gall significantly reduced the height of the faba bean crop.

4.4.6.4. Seed per plant

During 2022, the highest number of seed per plant (142.1) and the lowest (38.2) were obtained from Awash Malka variety sprayed with Natura fungicide and unsprayed Mexican-142 variety, respectively. In this year on Awash1 variety, the lowest (43.0) and the highest seed per plant (94.6) were recorded on plots sprayed with Natura fungicide and unsprayed plot, respectively. On Waju and Awash Malka variety the lowest seed per plant were recorded on unsprayed plots. Among the control plots of each variety the highest seed per plant (75.9) and the lowest (38.2) were obtained from Awash Malka and Mexican-142 variety (Appendix 15). Whereas, during 2023 main cropping season the highest number of seed per plant (140.1) was obtained on Awash Malka variety sprayed Natura fungicide and lowest (54.3), was obtained from Awash1 variety sprayed Jaba fungicide (Appendix 16). On Waju variety, the highest and the lowest seed per plant (105.6, 59.5) were recorded from plots sprayed Natura fungicide and Jaba in that order.

4.4.6.5. Pod per plant

During 2022 main cropping season the highest and significantly different number of pod per plant (30.6) was recorded on Awash Malka variety sprayed with Natura fungicide followed by (21.0) Waju variety sprayed Natura fungicides. The least mean pod per plant (7.6) was obtained from unsprayed Mexican-142 variety. This may be due to the ALS infection was higher at pod filling and reduces the number of pods through plant infection then cause

defoliation. This report was in line with the report of Sharma *et al.,* (1980) reported that pod infection had direct effect on seed yield and indicated that the pod development stage is the most vulnerable stage of common beans for quick disease progress. Similarly in 2023 main cropping season also, among the unsprayed plots, Awash1 variety recorded the lowest pod per plant (7.0) than others. On Awash Malka variety, the highest and the least numbers of pod per plant (30.6, 14.4) was obtained from plots sprayed Natura and unsprayed plot, respectively.

4.4.6.6. Hundred Seed weight

Analysis of variance (ANOVA) revealed that cultivars, fungicide spray as main factor and their interaction showed highly significant difference ($P<0.01$) in hundred seed weight of common bean during 2022 and 2023 main cropping season (Appendix 12 and 13). In this study, the highest HSW (34.87g) and the least (13.22g) were obtained from Waju variety sprayed with Natura and Awash1 variety sprayed with Jaba, respectively (Appendix 15and 16). However, the HSW obtained from Waju variety of Natura (34.9), Jaba (34.6) sprayed and unsprayed (32.8g) plots had no significant difference between them. Likewise, on variety Mexican-142 the highest (15.7 g) hundred seed mass were recorded from the plots sprayed with Natura but it didn't show significant variations from plots received Jaba (13.2g) and the unsprayed (14.1g). Similarly, on Awash1 variety a HSW of 19.3g, 15.8g and 13.2g were recorded from Natura, Jaba and unsprayed plots, respectively. Generally, HSW recorded from Waju variety was much higher than the weight of other variety corresponding to spraying fungicide (Table 20 and 21).

Similarly, in 2023 main cropping season, analysis of variance (ANOVA) revealed that interaction effects of cultivars and fungicides sprays showed significant variations on HSW (Appendix 12 and 13). The highest HSW (35.9g) and the lowest (13.6 g) were recorded from Waju cultivar sprayed with Natura fungicide and Mexican-142 cultivar sprayed with Jaba fungicide, respectively. Similarly, on Awash Malka cultivar the highest HSW (20.1 g) was recorded from sprayed plot with Natura fungicide. While the lowest (16.7 g) hundred seed weight was recorded from untreated control plots of the same varieties. However, on Awash 1 varieties, the highest (19.7) hundred seed weight was recorded on plots received Natura fungicide spray. On this variety (Awash1), sprayed plots of Natura and Jaba did not show significant variations from unsprayed control plots of Awash Malka (16.7g) and Mexican-142

(14.5g) except unsprayed plot of Waju. Among unsprayed control plots the highest (34.2 g) and the lowest (14.1 g) hundred seed weight (HSW) were recorded on Waju and Awash1 cultivars in the order mentioned. This might be due to the higher disease pressure associated with the environmental condition and the varieties used in both years.

Table 20: Effect of common bean varieties with fungicide foliar spray on percentage severity index at Bako research center under field condition in 2022 main cropping season

	Plant height			Pod/ plant			Seed/ plant			Hundred S/weight			Y(t ha-^{1})		
Varieties	Fungicides			Fungicides			Fungicides			Fungicides			Fungicides		
	N	J	C	N	J	C	N	J	C	N	J	C	N	J	C
A/Malka	78.0^{cd}	61.1^{ef}	64.1^{def}	26.8^{a}	18.4^{c}	15.1^{d}	142.6^{b}	119.8^{b}	75.9^{e}	20.8^{b}	18.1^{bc}	16.3^{cde}	3.7^{a}	3.4^{b}	2.4^{ef}
Waju	102.1^{a}	87.4^{abc}	95.4^{ab}	21.0^{b}	15.2^{d}	11.3^{ef}	123.9^{a}	87.2^{d}	50.9^{g}	34.9^{a}	34.6^{a}	32.8^{a}	3.2^{b}	2.9^{c}	2.3^{efg}
Awash 1	65.4^{def}	63.1^{f}	49.9^{ef}	15.7^{d}	12.5^{e}	8.7^{fg}	94.6^{bc}	74.9^{e}	43.0^{h}	19.3^{bc}	15.8^{cde}	13.7^{e}	2.7^{cd}	2.5^{de}	2.2^{fg}
Mex-142	83.6^{bc}	76.6^{cde}	74.9^{cde}	9.7^{fg}	13.3^{de}	7.6^{g}	83.7^{cde}	68.2^{f}	38.2^{h}	15.7^{cde}	13.2^{e}	14.1^{de}	2.4^{ef}	2.1^{g}	1.8^{h}
Mean	82.3	68.8	74.4	18.3	14.9	10.7	111.2	87.5	52	22.7	20.4	19.2	3.1	2.7	2.2
CV (%)			12.9			10.2			4.8			11.9			5.7
LSD (0.05)			16.4			2.5			6.8			4.2			0.3

N=Natura, J=Jaba, C=Control, CV=Coefficient of variance, LSD= LSD= Least significant difference

Table 21: Effect of common bean varieties with fungicide foliar spray on percentage severity index at Bako agricultural research center under field condition in 2023 main cropping season

	Plant height			Pod/ plant			Seed/ plant			Hundred S/weight			Y(t ha-^{1})		
Varieties	Fungicides			Fungicides			Fungicides			Fungicides			Fungicides		
	N	J	C	N	J	C	N	J	C	N	J	C	N	J	C
A/Malka	72.9^{a}	75.5^{bc}	60.1^{d}	30.6^{a}	19.9bc	14.6cd	140.1^{a}	114.7^{ab}	76.9^{c}	20.13^{b}	18.43^{bc}	16.73^{bcd}	3.8^{a}	3.5^{b}	2.5^{fg}
Waju	86.0^{bc}	70.4^{c}	58.7^{d}	21.0^{b}	15.6bcd	10.9de	105.6^{b}	59.5^{cde}	59.1^{cde}	35.93^{a}	33.13^{a}	34.23^{a}	3.3^{bc}	2.9^{cd}	2.4^{fgh}
Awash 1	58.9^{d}	53.9^{d}	42.4^{e}	14.4^{cd}	11.1de	7.0b	71.8^{cd}	54.3^{cde}	36.0^{e}	19.67^{b}	16.13^{bcd}	14.13^{d}	2.8^{de}	2.6^{ef}	2.3^{gh}
Mex-142	81.1^{ab}	75.1^{bc}	70.6^{c}	13.3^{d}	11.9de	10.0de	68.7^{cd}	59.2^{cde}	47.5^{de}	16.06^{bcd}	13.60^{d}	14.47^{cd}	2.5^{fg}	2.2^{h}	1.9^{i}
Mean	74.7	68.7	58.0	19.8	14.6	10.6	96.6	71.9	54.9	22.9	20.3	19.9	3.2	2.8	2.3
CV (%)			8.7			22.5			20.5			11.7			6.3
LSD (0.05)			9.8			5.7			25.9			4.2			0.3

N=Natura, J=Jaba, C=Control, CV=Coefficient of variance, LSD= LSD= Least significant difference

4.4.6.7. Association of disease parameters with growth, common bean seed yield and yield components.

Association of disease progress rate and area under disease progress curve with common bean yield and yield parameters were estimated using a simple linear regression model. Area under disease progress curve was highly and negatively associated with all recorded common bean yield and yield contributing parameters. During 2022 main cropping season yield and area under disease progress curve were negatively and significantly ($p< 0.05$) correlated (r = -0.89**). It was also negatively and highly significantly ($p< 0.001$) correlated with yield contributing parameters. On the other hand, disease progress rate was negatively and highly associated with the common bean yield (r=-0.893**) and the most yield contributing parameters such as branch per plant (r=-0.257**) and pod per plant (r=-0.606**) in 2023 main cropping season (Table 22).

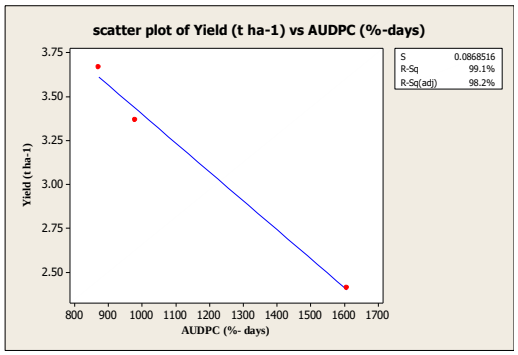
Concerning 2023 main cropping season (Table 23) trial site, area under disease progress curve and disease progress rate were negatively and highly significantly ($p<0.001$) associated with common bean yield and yield components. However, hundred seed weight was not significantly ($p<0.05$) important with other yield parameters despite it correlated negatively. In addition, disease progress rate and area under disease progress curve revealed statistically insignificant ($p<0.05$) difference with hundred seed weight and number of seed per pod in spite of their negative correlations. On the other hand, area under disease progress curve, disease progress rate (r) and plant height were associated negatively.

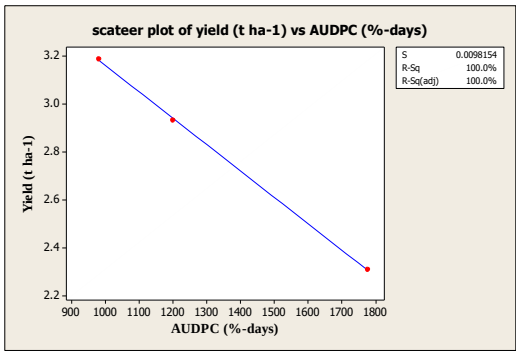
Table 22: Coefficient of correlation (r) between growth and yield and disease parameters in common bean at BARC during 2022 main cropping season

Parameter	PH	BPP	PPP	SPP	SPP	HSW	TSY	AUDPC	DPC
PH	1.00								
BPP	0.532**	1.00							
PPP	0.561**	0.591**	1.00						
SPP	0.513**	0.628**	0.808**	1.00					
SPP	0.546**	0.615**	0.696**	0.749**	1.00				
TSW	0.079	-0.225	0.236	0.165	0.173	1.00			
TSY	0.385*	0.564**	0.782**	0.776**	0.644**	0.328*	1.00		
AUDPC	-0.504**	-0.504**	-0.795**	-0.788**	-0.618**	-0.326*	-0.89**	1.00	
DPR	-0.272	-0.257	-0.606**	-0.584**	-0.423*	-490**	-0.819**	0.901**	1.00

PH = plant height (cm), BPP = branch per plant (No), PPP = pod per plant (No), SPP = seed per plant (No), SPP = seed per pod (No), total seed yield (t ha-1), AUDPC = area under disease progress curve (%-days) and DPR = disease progress rate (unit day-1). * = significant at <0.05 and ** = highly significant at <0.001 probability level.

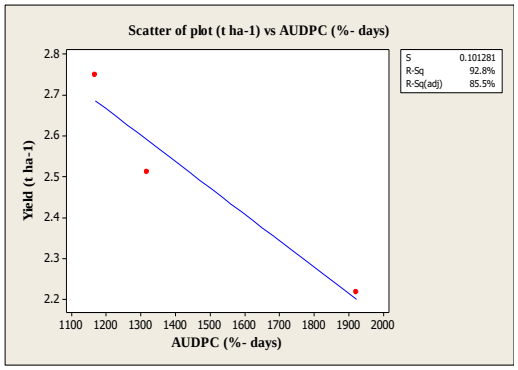
Linear regression of the AUDPC was used for predicting the yield loss in common bean due to angular leaf spot (Fig.12); because AUDPC linear regression better indicated the relationship of yield loss and the disease than the other disease parameters linear regression. The area under disease progress curve (AUDPC) is a very appropriate summary of plant disease epidemics that incorporates initial intensity, the rate parameter, and the duration of the epidemic which determines final disease intensity.

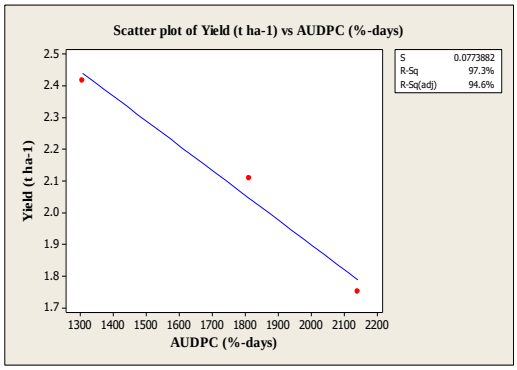




Y= 5.043 - 0.001644X, P= 0.060

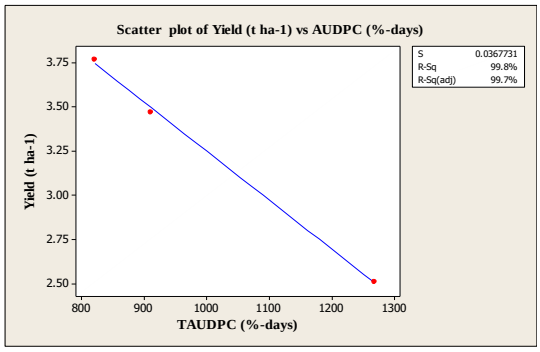
Y = 4.257 - 0.001098X, P=0.010



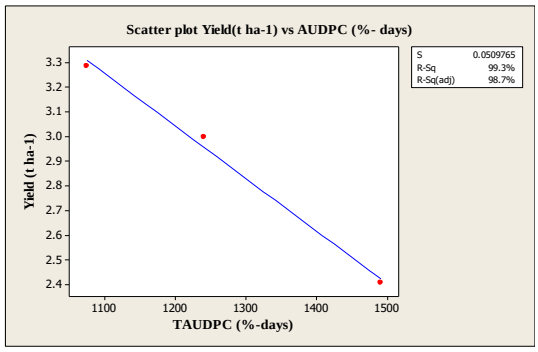


Y = 3.437 - 0.000643X, P= 0.173

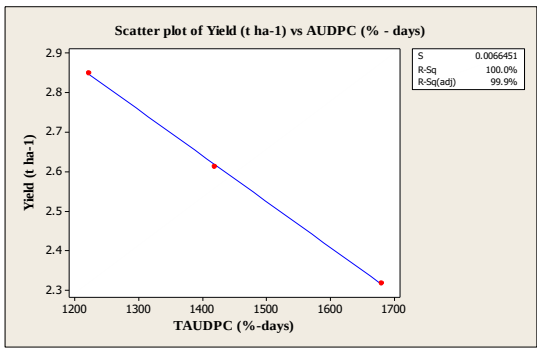
Y = 3.458 - 0.000779X, P=0.105



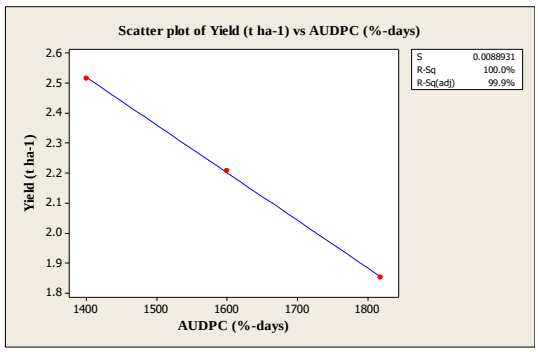
Y= 6.021 - 0.002771X, P=0.025



Y = 5.590 - 0.002123X, P=0.05



Y = 4.263 - 0.001159X, P=0.011



Y= 4.744 - 0.001588X, P =0.012

Figure 12: Linear regression relating AUDPC of common bean angular leaf spot with total common bean yield (t ha-1), during 2022 and 2023main Cropping season.

Table 23: Coefficient of correlation (r) between growth and yield and disease parameters in common bean at BARC during 2023 main cropping season

Parameter	PH	BPP	PPP	SPP	SPP	TSW	TSY	AUDPC	DPR
PH	1.00								
BPP	0.532**	1.00							
PPP	0.561**	0.591**	1.00						
SPP	0.513**	0.629**	0.808**	1.00					
SPP	0.546**	0.615**	0.696**	0.749**	1.00				
TSW	0.079	-0.225	0.236	0.165	0.173	1.00			
TSY	0.385**	0.564**	0.782**	0.776**	0.644 **	0.328*	1.00		
AUDPC	-0.504**	-0.504**	-0.795**	-0.788**	-0.618**	-0.326	-0.893**	1.00	
DPR	-0.381*	-0.522**	-0.667**	-0.722**	-0.613*	-0.294	-0.868***	0.907**	1.00

PH = plant height (cm), BPP = branch per plant (no), PPP = pod per plant (No), SPP = seed per plant, SPP = seed per pod, total seed yield (t ha-1), AUDPC = area under disease progress curve (%-days) and DPR = disease progress rate (unit day-1). * = significant at <0.05 and ** = highly significant at <0.001 probability level.

4.4.6.8. Relative yield loss assessment

Yield losses were computed relative to the average yield of plots with maximum protected against the disease i.e. the plots treated with Natura and Jaba foliar fungicide applications of common bean varieties in both years. The computed relative yield losses showed prominent differences among plots treated with Natura and Jaba fungicide applications in both 2022 and 2023 main cropping season (Appendix 18). During 2022 and 2023 main cropping season the computed relative yield losses showed prominent differences among treatments. Yield losses were reduced in Awash Malka with Natura spray fungicide (10.5%), (10.8%) compared to Awash Malka unsprayed plot (22.1%) (29.2%), this corresponds to the gain of additional yield (0.9 and 0.6 tons/ha) over unsprayed plot in Awash Malka in both years, respectively. This finding was in line with the work of Conneret *et al.* (2001) who reported that application of the foliar fungicide could reduce losses in seed yield and quality from bean anthracnose disease. About 0.7 and 0.4 tons/ha additional yield was obtained in Waju Jaba sprayed compared with Awash-1 Jaba sprayed in both years, respectively. The highest yield loss was observed in Mexican- 142 unsprayed plot (42.6%, 35.1%) followed by Awash-1 unsprayed plot (31.8%, 28.5%) during 2022 and 2023 main cropping season respectively. This high yield loss in moderately susceptible and highly susceptible varieties could be due to high initial inoculum of disease in both varieties and its persistence for prolonged period. This report was in line with the report of Tesfaye (1997) who specified that, severity of bean anthracnose and its effect on yield of common bean and found that high disease severity ranging between 17.2 to 76.6 % resulted in mean yield loss of 67.2%. Similarly, Sharma *et al.* (1980) reported that pod infection had direct effect on seed yield and indicated that the pod development stage is the most vulnerable stage of common beans for quick disease progress. Similarly, Sartorato *et al.* (1998) reported yield losses due to anthracnose in susceptible cultivars vary from 38-100 % under different situations. In Ethiopia the disease caused 50-60% crop loss (Golato and Meossi, 1972).

The least yield loss was obtained from Awash Malka Natura and Jaba sprayed (Appendix 18) in both years. This could be due to genetic resistance of Awash Malka variety to the virulence of pathogen and fungicides. In Awsah-1 sprayed with Jaba, yield loss was reduced by 11.9%, 10.7% compared with unsprayed (31.8%, 28.2%) and in Mexican-142 sprayed with Jaba, yield loss was reduced by 12.7%, 12.5% compared with Mexican-142 unsprayed (42.6%,

35.1%) in both years respectively. Pyndji (1991) who reported that 43.9 % yield loss in French bean was due to anthracnose infection, and found that pod infection had direct effect on seed yield, however, the extent of losses varied with severity level. The present study indicated that the maximum relative yield loss was recorded from susceptible varieties Awash-1 and Mexican-142 unsprayed plots than the remaining cultivars treated with two different fungicide spray in both season.

4.4.6.9. Cost - benefit analysis

Economic analysis for common bean angular leaf spot management was performed using net returns (CIMMYT, 1988) to determine their profitability for the management of common bean angular leaf spot. It is a very useful technique to determine the costs and benefits of a new technology compared to the traditional one. The bean yields, sales, costs sustained due to use of the fungicide and the net benefit relative to the benefits gained from unsprayed plots were computed. But, yield in kilogram per hectare, and net returns in Birr per hectare from common bean angular leaf spot management varied among disease control treatments. Variation in net benefit was obtained among varieties ($p < 0.01$) in both years. The two years mean partial budget analysis depicted the highest (ETB 41,235ha-1, ETB 33,385 ha-1) marginal benefit from Awash Malka plots sprayed with Natura and Jaba foliar fungicide followed by Waju and Awash-1 varieties sprayed with Natura and Jaba resulted marginal benefits of ETB 25,035 and 18,985 ha-1 respectively. In addition, the marginal rates of return were calculated for the significant treatments under dominant analysis for comparison of the treatment cost/benefit of the treatments (Table 24).

For the variety Awash Melka plots sprayed with Natura exhibited that for every one ETB incurred or invested on foliar fungicide additional ETB 12.8 was obtained in return, followed by Waju ETB 7.3 from plots sprayed with Natura fungicide. Generally, Awash Malka with Natura, followed by Waju with Natura foliar fungicide resulted in a higher marginal rate of return than the other two common bean varieties, i.e. Awash1 and Mexican 142 (Table 24).

Table 24: Two years mean Partial budget analysis of common bean angular leaf spot management through host resistance, and alone application of fungicides at Bako agricultural research center, southwest Ethiopia.

Treatment	Fungicide	Adjusted yield (t ha-1)	[1]Sale price (ETB kg-1)	[2]Sale revenue (ETB)	[3]Total input cost (ETB)	[4]Marginal cost (ETB)	[5]Net profit (ETB)	[6]Marginal Benefit	7Marginal rate of return (%) =6/4
Awash Malka	Control	2.4	36	86400	7150	0.00	79250	0.00	
	Jaba	3.4	36	122400	9765	2615	112635	33385	1276.7
	Natura	3.75	36	135000	14515	7350	120485	41235	165.26
Waju	Control	2.3	36	82800	7150	0.00	75650	0.00	D
	Jaba	2.95	36	106200	9765	2615	94635	18985	D
	Natura	3.2	36	115200	14515	7350	100685	25035	D
Awash1	Control	2.2	36	79200	7150	0.00	72050	0.00	D
	Jaba	2.55	36	91800	9765	2615	82035	9985	D
	Natura	2.85	36	102600	14515	7350	86285	14235	D
Mexican -142	Control	1.8	36	64800	7150	0.00	57650	0.00	D
	Jaba	2.15	36	77400	9765	2615	67635	9985	D
	Natura	2.45	36	88200	14515	7350	73685	16035	D

Note: Numbers written in columns of marginal rate of return (MRR) were treatments that showed significant differences in dominance analysis; average market price of bean ETB 36 kg-1

5. CONCLUSION AND RECOMMENDATION

The common bean (*Phaseolus vulgaris* L.) is the most important grain that is directly consumed in the human diet, corresponding to half of the grain legumes consumed in the world. However, its production is affected by many biotic and abiotic factors. Among the biotic factors fungi diseases angular leaf spot caused by *Pseudocercospora griseola* has been the most common and causes qualitative and quantitate yield losses. The present study was conducted in order to assess the distribution and importance of angular leaf spot of common bean and factors affecting disease intensity in the southwest of Ethiopia. Furthermore, isolation, identification and characterization of *Pseudocercospora griseola* isolates based on morphological and pathogenicity factors have been conducted. Evaluation of reaction of common bean varieties to the disease was conducted under glasshouse condition. Besides, the effect of integrated management of common bean angular leaf spot (*Pseudocercospora griseola*) through host resistance and chemical applications on epidemics of this disease is investigated under field condition.

From the field survey results, highest angular leaf spot severity was recorded in Bako Tibe district and lowest angular leaf spot severity was recorded in Gechi district. The variation of disease intensity might be associated with several agronomic practices (the seed source, weeding frequency, crop rotation, altitudes, variety, cropping system, sowing date and growth stage, tillage frequency) before sowing has showed significant contributions in the distribution and intensity of angular leaf spot disease in the study area. Regarding the diversity *P. griseola* isolates in the study area, based on cultural and morphological characteristics, 18 isolates were identified as common bean *Pseudocercospora griseola*. The study on the pathogenicity of *P. griseola* isolates also revealed most isolates are pathogenic to the susceptible common bean Dinkinesh variety, of course with different level of aggressiveness as evidenced by the variation on the effect on leaf and intensity of pod. In this regard, Bako Tibe (Dambi Dima) was identified as the source of the most pathogenic isolate BtDdpg2 which caused100% angular leaf spot incidence. Evaluation of varieties reaction study also identified potential varieties that can be used in future researches to combat this disease through developing resistance genotypes.

In the present study field trial was conducted to evaluate the effects of fungicide sprays on incidence and severity of common bean under field conditions during 2022 and 2023 main cropping season, with natural infection at Bako agricultural research center.

From the result, Natura significantly reduced the disease; cost benefit analysis indicated that application of Natura fungicide gave the highest net profit and marginal rate of return. There for Natura fungicide is recommended for the producers to manage angular leaf spot; when Natura is not available on the market Jaba is used as an optional of the disease management.

In conclusion, the present study showed that angular leaf spot of common bean is becoming an important treat in the production of common bean in the southwest of Ethiopia. It was also found that several factors related to pathogen characteristics and cultural practices influence positively or negatively the intensity of the disease in the study area. Furthermore, this study confirms the presence of variation in isolates of *Pseudocercospora griseola* with respect to cultural, morphological and pathogenic characteristics. The disease management study also identified potential common bean variety that can be used in future studies focusing of disease resistance. The observed significant variation in fungicide application efficacy also gives a hope of combating this disease. Finally, isolate BtDdpg2, identified as the most pathogenic isolate that can be recommended to be used in screening common bean for resistance reaction against ALS. Bean variety Ser125, Ser119, and Gobersha and Nasir, Gabisa and Awash Malka are recommended for further varietal development research in common bean disease resistance breeding program, as a source of resistant and moderately resistant to disease respectively. Common bean angular leaf spot management using host resistance with supplemental fungicides found promising. Further studies on fungicides dose and screening of varieties at favorable areas and fungicide needed. From the result Natura significantly reduced the disease; cost benefit analysis indicated that application of Natura fungicide gave the highest net profit and marginal rate of return. Therefore, Natura fungicide is recommended for the producers to manage angular leaf spot; when Natura is not available on the market Jaba is used as optional. The efficacy and economic validity of these methods should be verified under multi-location field studies.

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7. APPENDICES

Appendix 1: A questionnaire for assessment of common bean angular leaf spot in major common bean growing districts Western zone of Oromia region

1. Demographic information
1.1. Surveyors name: _____1.2. Farmers name:_____
1.3. Age: ____1.4. Sex: _____ 1.5. Education level_____1.6. Marital status: _____
1.7. Date of Assessment: _____1.8. Variety: _____ 1.9. Seed source_____
2. Site information
a. Region: _____Zone: _____Woreda: _____ peasant association: _____ Village name: _____ Altitude: _____Latitude:_____ Longitude: _____
b. Annual temperature :_____ c. Rainfall: _____ d. Humidity: _____
3.Farm information
a. Preceding crop _____b. Previous history of the farm _____c. Soil type and color _____d. Field area size_____d. Type of cropping system _____
4. Survey site: a. Farmer field _____b. Research station _____ c. Private Farm_____
5. Crop growth stage:
a. Vegetative_____ b. pod forming _____ c. pod filling _____ d. Maturity _____
6. Angular management practice that has been taken
a. Fungicide _____ b. Cultural practice _____
c. Host plant resistance _____ d. Others _____
7. Plant density: high _____ medium _____ low_____
8. Crop stand: good _____bad _____fair_____
9. Are fertilizer applied? Yes _____ No_____
If yes, what was the rate applied and frequency?
a. Dap _____kg/ha b. Urea _____kg/ha
c. FYM _____kg/ha d. Compost _____kg/ha,
10. Agronomic practice that has been manipulated
a. Cultivation frequency _____
b. Weed controlling method: - hand weeding _____ herbicide _____
c. Frequency of weeding _____
d. Weed management: good _____ bad _____ fair_____

Appendix 2: Summary of linear regression statistics used in evaluation of two growth models for appropriateness for describing disease progress of common bean angular leaf spot with two different chemicals Natura and Jaba tested at BARC, during 2022 and 2023 main cropping season

Chemicals	Varieties		2022 main cropping season				2023 main cropping season			
		Model	Intercept	Rate	SE of slop	R2	Intercept	Rate	SE of slop	R2
Jaba	Awash Malka	Logit	-4.78	0.06	0.007	83	-4.15	0.05	0.004	91
		Gompit	-2.26	0.03	0.003	86	-2.14	0.03	0.003	91
Control	Mexican-142	Logit	-4.46	0.07	0.008	88	-5.56	0.09	0.015	75
		Gompit	-3.09	0.06	0.006	88	-3.88	0.07	0.011	79
Control	Awash1	Logit	-5.03	0.08	0.010	82	-4.74	0.07	0.009	85
		Gompit	-3.33	0.06	0.007	85	-3.12	0.06	0.006	87
Jaba	Mexican-142	Logit	-5.14	0.08	0.007	90	-4.76	0.08	0.012	75
		Gompit	-3.34	0.06	0.005	91	-3.02	0.05	0.008	79
Natura	Awash1	Logit	-4.51	0.06	0.007	83	-5.44	0.07	0.010	82
		Gompit	-2.32	0.03	0.004	87	-3.03	0.05	0.006	85
Control	Awash Malka	Logit	-3.92	0.05	0.002	98	-6.10	0.09	0.010	84
		Gompit	-2.30	0.04	0.001	98	-3.50	0.06	0.005	60
Jaba	Waju	Logit	-4.13	0.05	0.007	79	-4.67	0.06	0.007	87
		Gompit	-2.12	0.03	0.004	83	-2.64	0.04	0.004	89
Jaba	Awash1	Logit	-3.54	0.05	0.009	67	-4.71	0.07	0.008	86
		Gompit	-1.85	0.03	0.005	72	-2.84	0.05	0.005	87
Control	Waju	Logit	-3.85	0.06	0.004	93	-5.28	0.08	0.013	75
		Gompit	-2.39	0.04	0.003	94	-3.17	0.05	0.008	80
Natura	Awash Malka	Logit	-4.69	0.05	0.006	83	-4.90	0.06	0.006	88
		Gompit	-2.14	0.03	0.003	86	-2.35	0.03	0.003	89
Natura	Mexican-142	Logit	-4.63	0.04	0.007	85	-4.91	0.07	0.010	79
		Gompit	-2.54	0.04	0.004	89	-2.79	0.04	0.006	83
Natura	Waju	Logit	-4.11	0.05	0.008	76	-4.99	0.06	0.007	85
		Gompit	-1.97	0.03	0.004		-2.58	0.04	0.004	87

BARC = Bako Agricultural Research Center

R2= Coefficient of determination

Appendix 3: ANOVA table of disease severity and AUDPC mean squares for ALS pathogenecity test at Jimma University College of agriculture and veterinary medicine during 2024.

		Disease severity				
Source of variation	DF	7DAI	14DAI	21DAI	28DAI	AUDPC
Model	16	225.38**	446.08**	590.35**	1602.95**	212713.3**
Treatments/Isolate	14	236.6**	508.75**	670.9**	1602.95**	275196.9
Replication	2	4.32*	7.5 ns	26.64ns	7.58ns	1149.1
Error	28	33.9	14.8	17.7	32.2	2729.8
CV (%)		31.2	13.9	11.8	10.4	12.2

CV = Coefficient of variance; ***Very highly significant (P < 0.001); **highly significant (P < 0.01); *Significant (P < 0.05), NS = Non- significant; R2 = coefficient of determination; DAP = Days after planting

Appendix 4: ANOVA table of disease severity and AUDPC mean squares for common bean varieties.

		Disease severity						
Source of variation	DF	7DAI	14DAI	21DAI	28DAI	35DAI	42DAI	AUDPC
Model	14	247.39**	608.48**	851.16**	1151.04**	1785.97**	2258.81	2114330.6 **
Replication	2	1.88	0.948	15.01	4.92	16.37	1.03897	2093.8
Isolate	1	1106.53**	2231.22**	4225.28**	4778.96**	7690.90**	10809.18	8067200.5 **
Variety	11	226.66**	565.02**	734.13**	1092.21**	1739.37**	2102.12	1957203.6 **
Error	24	4.53	6.86	23.59	17.56	12.56	15.57	6487.1

** Significant at p < 0.01; AUDPC = Area under disease progress curve; ANOVA= Analysis of variance; DAI = days after inoculation; DF= Degree of freedom.

Appendix 5: ANOVA table for common bean angular leaf spot incidence at different days after planting (DAP) at BARC during 2022 cropping season

	Mean square				
Sources	55 DAP	62 DAP	69 DAP	76 DAP	83DAP
Variety	333.2**	155.6ns	266.4**	280.2**	538.7**
Chemical	311.6**	707.9**	1739.4 **	1561.2**	353.3**
Variety *Chemical	44.4ns	58.2ns	63.6ns	42.3ns	45.4**
Error	22.5	67.5	31.9	19.4	9.4
CV (%)	15.5	16.5	9.4	6.7	3.4
R^2	80.1	63.7	87.5	91.5	92.3

CV = Coefficient of variance; ***Very highly significant (P < 0.001); **highly significant (P < 0.01); *Significant (P < 0.05) ns = Non- significant; R2 = coefficient of determination; DAP = Days after planting; BARC = Bako Agricultural Research Center

Appendix 6: ANOVA table for common bean angular leaf spot incidence at different days after planting (DAP) at BARC during 2023 cropping season

	Mean square				
Sources	55 DAP	62 DAP	69 DAP	76 DAP	83DAP
Variety	817.8**	1895**	1320.6**	869.9**	425.3***
Chemical	732.2**	1143.5**	859.1 **	489.3**	509.0***
Variety *Chemical	21.3ns	58.2ns	99.3ns	100.1ns	8.5ns
Error	**16.9**	**71.9**	**84.1**	**66.2**	**4.5**
CV (%)	**12.4**	**16.5**	**16.2**	**12.9**	**2.5**
R^2	**92.1**	**84.2**	**77.3**	**74.7**	**95.9**

CV = Coefficient of variance; **highly significant (P < 0.01); *Significant (P < 0.05) ns = Non- significant; R2 = coefficient of determination; DAP = Days after planting; BARC = Bako Agricultural Research Center

Appendix 7: ANOVA table for common bean angular leaf spot percentage severity index (PSI) at different days after planting (DAP) at BARC during 2022 cropping season

		Mean square				
Source	Df	55 DAP	62 DAP	69 DAP	76 DAP	83 DAP
Variety	3	126.9**	769.71**	788.24***	939.31**	1115.96***
Chemical	2	714.3**	999.7**	1439.20***	1694.90**	2302.46***
Variety*Chemical	6	18.9**	20.05**	21.64ns	42.84ns	72.18***
Variety*Chemical*year	6	896.3*	1065.7*	1786.9**	2023.1**	2212.5**
Error	22	1.84	1.63	24.95	23.68	1.92
CV (%)		6.56	3.21	10.62	9.23	2.37
R^2 (%)		97.89	99.19	90.07	92.7	99.49

CV = Coefficient of variance; **highly significant (P < 0.01); *Significant (P < 0.05) ns = Non- significant; R2 = coefficient of determination; DAP = Days after planting; BARC = Bako Agricultural Research Center

Appendix 8: ANOVA table for common bean angular leaf spot percentage severity index (PSI) at different days after planting (DAP) at BARC during 2023 cropping season

		Mean square				
Source	Df	55 DAP	62 DAP	69 DAP	76 DAP	83 DAP
Variety	3	118.89**	1359.80**	1126.76**	1041.83**	868.62**
Chemical	2	139.88**	1849.81**	1414.93**	1721.20**	1583.87**
Variety*Chemical	6	19.65**	28.24*	51.27ns	12.5ns	18.51**
Variety*Chemical*year	6	196.3**	1961.7*	1553.9**	2124.1**	2133.5**
Error	22	0.71	10.98	24.07	28.97	2.04
CV (%)		4.46	7.49	9.48	9.28	2.20
R^2 (%)		97.9	97.1	92.57	91.46	99.24

CV = Coefficient of variance; **highly significant (P < 0.01); *Significant (P < 0.05) ns = Non- significant; R2 = coefficient of determination; DAP = Days after planting; BARC = Bako Agricultural Research Center

Appendix 9: Mean squares of analysis of variance (ANOVA) for disease progress rate and AUDPC in BARC, West Shoa, Ethiopia, during 2022 and 2023 cropping seasons

		Mean Square			
		2022 cropping season	2022 cropping season	2023 cropping season	2023 cropping season
Source	DF	AUDPC	Rate (unit/day)	AUDPC	Rate (unit/day)
Variety	3	564458.5**	0.00088849**	728744.0**	0.00061034***
chemical	2	1077553.2**	0.000954***	1049742.0**	0.00147479**
Chemical*Variety	6	14302.5ns	0.00008267***	12o81.8ns	0.00005203***
Error	22	6953.2	0.000013	6763.2	0.0001033
CV (%)		6.6	9.2	6.0	6.9
R^2 (%)		96.3	94.8	96.7	95.7

Df = Degree of freedom; AUDPC = area under disease progress curve; DPR= Disease progress rate; CV = Coefficient of variance; R_2= Coefficient of determination; * = Significance difference at ($P < 0.05$); ** = Significance difference at ($P < 0.01$); BARC = Bako Agricultural Research Center

Appendix 10: ANOVA table for yield and yield components during 2022 main cropping season at BARC

		Mean square						
Source	Df	PH	BPP	PPP	SPP	SPP	HSW	TY(t-ha-^{1})
Variety	3	2199.9**	3.2**	168.9**	4310**	11.14**	73079**	1.8**
Chemical	2	490.5**	13.7**	222.8**	10715**	4.3**	3002.5**	2.16**
Variety* Chemical	6	46.3**	2.5**	6.7**	144.5**	0.35**	588.7ns	0.09**
Error	22	93.5	0.51	2.2	16.1	0.10	606	0.799
CV		12.9	11.2	10.2	4.8	6.1	11.8	5.7
R^2		78.9	83.5	95.3	99.0	95.2	94.5	95.4

DF = Degree of freedom; CV= Coefficient of variance; PH = Plant height; BPP = Branch per plant; PPP = Pod per plant; SPP= Seed per plant; SPP = Seed per pod, HSW = Hundred seed weight; TY = Total yield; R2 = Coefficient of determination; ** = Significance difference at ($P < 0.01$); NS = Non significant difference; BARC = Bako Agricultural Research Center

Appendix 11: ANOVA table for yield and yield components during 2023 main cropping season at BARC

		Mean square						
Treatment	Df	PH	BPP	PPP	SPP	SPP	HSW	TY(t-ha-^{1})
Variety	3	1074.1**	3.2**	225.0**	5931.**	5.55**	7367.2**	1.8**
Chemical	2	866.1**	13.7**	260.4**	5264.8	1.72**	2443.8*	2.2**
Variety* Chemical	6	43.6**	2.5**	23.3**	402.0**	0.7**	545.0**	0.095**
Error	22	34.1	0.51	11.4	235.0	0.25	611.2	0.03
CV		8.7	11.2	22.5	20.6	9.4	11.7	6.3
R^2		87.5	83.5	84.2	86.2	81.9	94.5	94.1

DF = Degree of freedom; PH = Plant height; BPP = Branch per plant; PPP = Pod per plant; SPP= Seed per plant; SPP = Seed per pod; HSW = Hundred seed weight; TY = Total yield; CV= Coefficient of variance; R2 = Coefficient of determination; ** = Significance difference at ($P < 0.01$); NS = Non significant difference; BARC = Bako Agricultural Research Center

Appendix12: Mean incidence of angular leaf spot on common beans at all days of assessment during 2022 cropping season at different days after planting (DAP) at BARC

Treatment	55DAP	62DAP	69DAP	76DAP	83DAP
Awash Malka +N	16.7	44.8	46.3	51.0	71.6
Awash Malka +J	22.8	42.6	48.7	53.7	75.1
Awash Malka +C	28.7	47.9	64.9	72.0	91.3
Waju+N	21.6	45.7	59.0	63.7	84.4
Waju+J	31.3	43.2	48.0	54.3	84.3
Waju +C	34.3	56.0	69.8	76.3	93.7
Awash 1+N	28.3	49.3	63.7	68.7	88.3
Awash 1+J	31.3	43.0	48.8	54.0	94.3
Awash 1+C	43.0	61.1	78.0	81.3	96.7
Mexican-142+N	34.2	47.6	58.2	68.0	94.7
Mexican-142+J	39.7	47.7	56.7	63.7	97.7
Mexican-142+C	35.3	69.3	81.7	84.7	99.6
LSD(0.05)	Ns	Ns	ns	ns	Ns

LSD= Least significance difference; BARC= Bako Agricultural Research Center;

DAP= Days after planting

Appendix 13: Mean incidence of angular leaf spot on common beans at all days of assessment during 2023 cropping season at different days after planting (DAP) at BARC

Treatment	55DAP	62DAP	69DAP	76DAP	83DAP
Awash Malka +N	17.7	25.0	33.3	49.6	71.0
Awash Malka +J	21.0	37.0	42.3	51.0	80.3
Awash Malka +C	30.0	42.3	50.3	55.7	81.3
Waju+N	24.3	37.0	48.7	53.7	77.0
Waju+J	26.7	48.7	58.0	66.3	84.7
Waju +C	35.0	52.7	57.7	57.7	90.3
Awash 1+N	30.0	49.0	54.7	57.7	81.7
Awash 1+J	33.7	48.7	50.7	63.7	87.3
Awash 1+C	45.0	67.7	70.0	69.0	96.3
Mexican-142+N	34.7	54.0	56.7	60.0	86.3
Mexican-142+J	42.7	73	74.7	82.6	95.3
Mexican-142+C	57.3	80.3	83.00	84.0	99.7
LSD(0.05)	Ns	Ns	ns	ns	ns

BARC= Bako Agricultural Research Center

DAP= Days after planting

Appendix 14: Mean severity index of angular leaf spot on common beans at all days of assessment during 2022 cropping season at different days after planting (DAP) at BARC

Treatment	55DAP	62DAP	69DAP	76DAP	83DAP
Awash Malka +N	10.4^{i}	22.3^{g}	27.7	31.9	35.5^{i}
Awash Malka +J	11.3^{i}	24.4^{g}	32.3	36.3	39.7^{h}
Awash Malka +C	27.4^{c}	35.8^{e}	45.4	61.0	63.2.3^{d}
Waju+N	14.0^{h}	30.7^{f}	35.0	40.3	41.3^{h}
Waju+J	16.7^{fg}	36.0^{e}	43.1	45.4	50.5^{g}
Waju +C	29.9^{b}	47.4^{b}	54.3	69.7	70.8^{c}
Awash 1+N	15.1^{gh}	34.3^{e}	40.9	45.3	50.8^{g}
Awash 1+J	20.2^{e}	44.9^{c}	49.7	50.3	54.4^{f}
Awash 1+C	25.5^{cd}	58.3^{a}	68.9	75.7	78.9^{b}
Mexican-142+N	17.6^{f}	38.6^{d}	45.7	53.1	58.2^{e}
Mexican-142+J	24.8^{d}	48.3^{b}	55.2	65.9	77.3^{b}
Mexican-142+C	34.1^{a}	56.7^{a}	67.1	74.3	81.7^{a}
CV (%)	6.58	3.21	10.62	9.23	2.37
LSD (0.05)	2.29	2.16	ns	ns	2.35
P value	0.001	0.001	0.53	0.14	0.001

BARC= Bako Agricultural Research Center, DAP= Days after planting, CV= Coefficient of variance, LSD= Least significance difference

Appendix 15: Mean severity index of angular leaf spot on common beans at all days of assessment during 2023 cropping season at different days after planting (DAP) at BARC

Treatment	55DAP	62DAP	69DAP	76DAP	83DAP
Awash Malka +N	11.9^{h}	22.5^{g}	30.1	35.8	41.3^{j}
Awash Malka +J	18.7^{de}	25.7^{fg}	34.2	37.6	49.5^{i}
Awash Malka +C	13.2g^{h}	43.3^{c}	52.6	61.0	68.3^{d}
Waju+N	16.0d^{e}	30.8^{ef}	37.4	44.6	52.2^{h}
Waju+J	19.3^{d}	37.5^{d}	46.0	53.3	61.2^{f}
Waju +C	17.6^{ef}	55.7^{b}	64.0	69.6	72.0^{c}
Awash 1+N	16.2^{de}	34.0^{de}	47.6	51.7	57.1^{g}
Awash 1+J	22.2^{c}	44.3^{c}	50.2	57.9	69.4^{d}
Awash 1+C	27.2^{a}	56.3^{b}	59.9	71.4	78.1^{b}
Mexican-142+N	14.1^{g}	44.7^{c}	52.7	59.0	63.7^{e}
Mexican-142+J	23.4^{c}	61.0^{b}	68.5	70.8	77.3^{b}
Mexican-142+C	25.0^{b}	75.0^{a}	77.1	82.5	87.8^{a}
CV (%)	4.46	7.49	9.48	9.28	2.20
LSD (0.05)	1.5	5.41	ns	ns	3.7
P Value	<0.001	0.048	0.090	0.53	<0.001

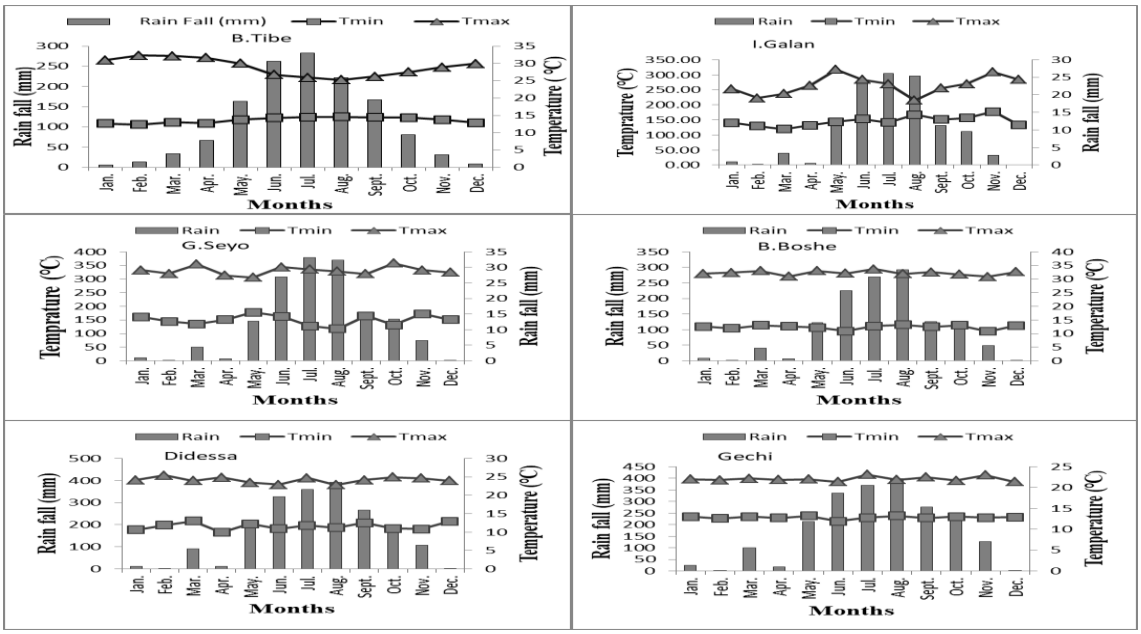
BARC= Bako Agricultural Research Center; DAP= Days after planting; CV= Coefficient of variance; LSD= Least significance difference

Appendix 16: Relative yield loss of common bean due to ALS (*P. griseola*) as influenced by common bean variety and fungicide application during 2022 and 2023 at BARC

Treatment	Fungicide	Y(t ha-^{1})	2022		2023
			RYL (%)	Y(t ha-^{1})	RYL (%)
Awash Malka	Natura	3.8	0.00	3.7	0.00
	Jaba	3.4	10.5	3.3	10.8
	Control	2.3	22.1	2.4	29.2
Waju	Natura	3.2	0.00	3.2	0.0
	Jaba	3.1	3.3	2.9	9.4
	Control	2.2	30.3	2.3	21.4
Awash1	Natura	3.1	0.00	2.8	0.0
	Jaba	2.7	11.9	2.5	10.7
	Control	2.1	31.8	2.2	28.2
Mexican -142	Natura	2.6	0.00	2.4	0.00
	Jaba	2.3	12.7	2.1	12.5
	Control	1.8	42.6	1.7	35.1

Y = common bean yield (t ha-1), RYL = relative yield loss in percentage

Appendix 17: Summary of primary weather factors that affects angular leaf spot epidemics in six districts, southwest, Ethiopia during the 2022 and 2023 main cropping seasons.



Appendix 18: List of districts and weather conditions of the study areas.

Districts	Altitude Range (m)	Longitude and Latitude	AARF(mm)	Temp. ^{o}C	
				Mean Max	Mean Min
Bako Tibe	1600-1768	36^{0}0'9"E and 09^{0}0'6"N	1156-1445	28.1	14.0
Ilu Galan	1505-1812	37^{0}19'49"E and 08^{0}59'5"N	800-1451	21.7	12.0
Gobu Sayo	1200-1960	37^{0}0'7"E and 09^{0} 0'9"N	1350-2000	31.0	15.0
Bilo Boshe	1669-1762	37^{0}0'0"E and 08^{0}54'0"N	800-1250	33.0	13.0
Didessa	1450-2250	36^{0}047'0"E and 08^{0}013'0"N	948-1969	24.7	11.9
Gechi	1787-2100	36^{0}34'0"E and 08^{0}16'60"N	989-2080	22.0	13.0

NK=Number of kebele, NF=Number of field, AARF =Annual average rain fall (mm), T. Max =Temperature Maximum and Min.= Temperature Minimum (°C); Source: (Bako, Bedele research center and Nekemt Meteorological Agency Office).

Appendix 19: Pictures showing interviewing farmers (A-C), symptoms of the disease in the farmers' fields (D-E), sample collection (F-G) laboratory and glasshouse activities (H-O) and field test (P-R).