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Prevalence, Characterization, and Integrated Management of Finger Millet [Eleusine Coracana (L) Gaertn] Blast [Magnaporthe Grisea (Hebert) Barr] in Western Amhara, Ethiopia

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BAHIR DAR UNIVERSITY
COLLEGE OF AGRICULTURE AND ENVIRONMENTAL
SCIENCES
DEPARTMENT OF PLANT SCIENCES
PLANT PATHOLOGY Ph.D. PROGRAM

PREVALENCE, CHARACTERIZATION, AND
INTEGRATED MANAGEMENT OF FINGER
MILLET [*Eleusine coracana* (L) Gaertn] BLAST
[*Magnaporthe grisea* (Hebert) Barr] IN WESTERN
AMHARA, ETHIOPIA

Ph.D. Dissertation

By

Melkamu Andargie Dagnew

November 2025

Bahir Dar, Ethiopia

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Gaertn] Blast [*Magnaporthe grisea* (Hebert) Barr] in
western Amhara, Ethiopia**

Ph. D. Dissertation

By

Melkamu Andargie Dagnew

Submitted to the Department of Plant Sciences, Bahir Dar University
in Partial Fulfillment of the Requirements for the Degree of Doctor
of Philosophy (Ph.D.) in Plant Pathology

Advisory Board Members:

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November 2025

Bahir Dar, Ethiopia

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DISSERTATION APPROVAL SHEET

As member of the Board of Examiners of the **Doctor of Philosophy (Ph.D.)** Dissertation open defense examination, we have read, and evaluated this dissertation prepared by **Mr. Melkamu Andargie Dagnew**, and examined the candidate entitled "**Prevalence, Characterization, and Integrated Management of Finger Millet [*Eleusine coracana* (L) Gaertn] Blast [*Magnaporthe grisea* (Hebert) Barr] in western Amhara, Ethiopia**". We hereby certify that the dissertation is accepted for fulfilling the requirements for the award of the Degree of Doctor of Physiology (Ph.D) in Plant Pathology.

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DECLARATION

This is to certify that this **Prevalence, Characterization, and Integrated Management of Finger Millet [*Eleusine coracana* (L.) Gaertn] Blast [*Magnaporthe grisea* (Hebert) Barr] in Western Amhara, Ethiopia**” submitted in partial fulfillment of the requirements for the award of the degree of Doctor of Philosophy in "**Plant Pathology**" to the Department Graduate Program Council of Plant Science, Graduate Program of College of Agriculture and Environmental Sciences, Bahir Dar University by **Mr. Melkamu Andargie** (ID. No. BDU1301221) is an authentic work carried out by him under our supervision. The matter embodied in this dissertation work has not been submitted earlier for an award of any degree to the best of our knowledge and belief. The materials obtained from other sources are duly acknowledged in the dissertation.

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DEDICATION

To my late brothers, and sister: Kabe Andargie, Maru Andargie, and Tadila Andargie, for giving me with passion, and love.

ABBREVIATIONS AND ACRONYMS

AdARC	Adet Agricultural Research Center
AUDPC	Area Under Disease Progress Curve
BDU	Bahir Dar University
BMV	Biomass Yield
CBD	Complete Block Design
CIMMYT	International Maize and Wheat Improvement Center
CSA	Central Statistical Agency
DAPG	Diacetylphloroglucinol
DAS	Days after Sowing
DH	Days to Heading
DM	Days to Physiological Maturity
DMRT	Duncan's Multiple Range Test
DPM	Days to Physiological Maturity
EIAR	Ethiopian Institute of Agricultural Research
FAOSTAT	Food and Agriculture Organization Corporate Statistical Database
FL	Finger Length
FMBD	Finger Millet Blast Disease
FSSC	Finote Selam Research Sub- Center
FTC	Farmer Training Center
GPS	Geographical Positioning System
GY	Grain Yield
HAUDPC	Head Area Under Disease Progress Curve
HBI	Head Blast Incidence
HBS	Head Blast Severity
HBI	Head Blast Incidence
HI	Harvest Index
HSA	Host Seed Agar
HSR	Hypersensitive Response
INDIASTAT	Socio-Economic Statistical Information about India
IPGR	International Board for Plant Genetic Resources
IRRI	International Rice Research Institute
LAUDPC	Leaf Area Under Disease Progress Curve
LBI	Leaf Blast Incidence
LBS	Leaf Blast Severity
Mg	<i>Magnaporthe grisea</i>
MLOS	Mycoplasma like Organisms
MoANR	Ministry of Agriculture and Natural Resources
MR	Moderately Resistance
MS	Moderately Susceptible
MSE	Means Square Error
MSV	Mean Severity Value
NAUDPC	Neck Area Under Disease Progress Curve

NBI	Neck Blast Incidence
NB-LRR	Nucleotide-binding leucine-rich repeat (NB-LRR) proteins
NBS	Neck Blast Severity
NEP	Number of Ear per Plant
NHB	Neck and Head blast
NFE	Number of Finger per Ear
NPS	Nitrogen-Phosphorus-Sulfur fertilizer
NTP	Number of Tillers per Plant
OMA	Oat Meal Agar
PAMPs	Pathogen-Associated Molecular Patterns
PDA	Potato Dextrose Agar
PDI	Percent Disease Index
PH	Plant Height
PRRS	Pathogenic Transmembrane Pattern Recognition Receptors
RCBD	Randomized Complete Block Design
SAR	Systemic Acquired Resistance
SAS	Statistical Analysis System
SC	Suspension Concentrate
SEM	Standard Error of the Mean
SPSS	Statistical Package for Social Sciences
St. Check	Standard check
TRT	Treatment
UPGMA	Unweighted Pair Group Method with Arithmetic Mean
WAMSC	Western Amhara Meteorological Services Centre
WP	Wettable Powder

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[*Eleusine coracana* (L) Gaertn] BLAST [*Magnaporthe grisea*
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GENERAL ABSTRACT

Finger millet is an important cereal crop grown in Ethiopia, including in the study area. However, the production and productivity of the crop is limited by biotic and abiotic factors. Among the biotic factors, blast disease caused by the fungal pathogen, *Magnaporthe grisea* is severely limiting the yield of the crop. This study was conducted to investigate the intensity of blast disease on finger millet, and identifying effective management options in Western Amhara. Field surveys carried out in 2022 and 2023 revealed 100% prevalence, with incidence and severity levels varying from 15.21% to 58.26% and 18.24% to 86.98% respectively. The highest incidence and severity were observed in Semien Achefer (56.54%), and in Jabi Tehnan (65.38%) districts respectively. While the lowest values recorded in Dangila district. These differences might be attributed due to variations in agro-climatic conditions, farming practices, and/or the susceptibility of finger millet varieties. Semi-structured questionnaires were used to survey farmers' local knowledge, and management strategies. Although many farmers had observed blast symptoms for almost a decade, 46.8% were

unaware of its causes or how it spreads, while only 33.2% associated it with susceptible varieties. Farmers use different indigenous management methods including burning crop residues (39.3%) and decreasing nitrogen fertilizer use (11.6%), but only 0.4% reported using fungicides. Key challenges to effective disease management included a lack of awareness, a low perceived level of risk, and limited access to effective control measures. During the 2022 rainy season, blast-infected finger millet samples (leaf, neck and finger) were collected from the study areas, isolated and characterized in the laboratory. The findings revealed significant morphological and physiological diversity among pathogen isolates. The best growth was observed at 30°C with a pH of 6.5, while oatmeal agar was the most suitable culture medium. In addition, 64 finger millet genotypes were evaluated under epiphytic conditions at two research sites (Adet and Finote Selam) using simple lattice design. The level of resistance varied between locations and among genotypes. G14, G31, G60, G16, G35, and G32 consistently exhibited resistance, whereas G7, G14 and a local check were found to be high-yielders. An integrated field experiment was conducted to examine the combined effects of four varieties (Bako-09, Tessema, Necho and a local check) and three fungicides (Hexaconazole + R Tricyclazole, Trifloxystrobin 100 g /l + Tebuconazole 200 g/l and Propiconazole), arranged in factorial randomized complete block design (RCBD). The findings revealed that Bako-09, treated with Hexaconazole + R Tricyclazole, showed the least disease severity and achieved the highest yield (3045.1 kg/ha), with an economic return of 13,479. Use of Bako-09, high-yielding local varieties together Hexaconazole + R Tricyclazole, and strengthening extension services to improve farmer awareness on disease identification and management are recommended to increase finger millet production in west Amhara and similar agro-ecological zones of Ethiopia.

Keywords: Awareness, Fungicides, Genotypes, Incidence, Resistance, Variability

Chapter 1. GENERAL INTRODUCTION

1.1 Back-ground and Justification

Finger millet (*Eleusine coracana* L. (Gaertn)) is considered as one of the oldest cereals, with its wild ancestor identified in Axum, Ethiopia, around 3000 B.C.(Prabhu and Meenakshi, 2013). Finger millet is classified within the Poaceae family (previously known as Graminae), under the Chloridoideae subfamily, belonging to the Eleusine genus, and identified as *Eleusine coracana* (L.) Gaertn (Mirza and Marla, 2019; Sood *et al.*, 2022). The cultivated form, *E. coracana* subsp. *coracana*, is believed to have been domesticated over 5,000 years ago from its wild relative, *E. coracana* subsp. *africana* ($2n = 4x = 36$), primarily in the highland regions extending from Ethiopia to Uganda (Sood and Babu, 2016; Joshi *et al.*, 2021). This wild subspecies arose from natural hybridization between the diploid species *E. indica* (AA genome) and an unidentified B-genome contributor (Neves *et al.*, 2005). Following its origins in East Africa, cultivated finger millet reach into the lowland areas of Africa and was introduced into India around 1000 B.C. via sea trade (Hilu *et al.*, 1979; Winchell *et al.*, 2018), with India currently recognized as a secondary center of genetic diversity (Dida *et al.*, 2008).

Finger millet is primarily cultivated in tropical and subtropical regions, especially in arid and semi-arid areas with scarce rainfall. It demonstrates a high degree of adaptability to various agro-climatic environments (Gupta *et al.*, 2017; Mukherjee *et al.*, 2025). Mainly grown in the semi-arid areas of Africa and India, and has a vital role during times of extreme drought (Kotschi, 2006; Assefa Awol *et al.*, 2013). Its adaptability and suitability for low-input agricultural practices, making it preferable for subsistence farmers (Nirmalakumari and Ulaganathan, 2016). Its rich nutritional profile and excellent shelf-life, supports in improving food security (Mukarumbwa and Mushunje, 2010; Dida *et al.*, 2021).

Finger millet is cultivated on approximately 4.5 million hectares worldwide, with annually production of around 3.7 million tons of grain globally where 2.5 and 1.2 million tons are produced in Africa and India, respectively (FAOSTAT, 2022). Even though finger millet accounts only an estimated 12.5% of the global millet cultivation area, it is an essential crop across more than 25 countries in Africa and Asia (Bora, 2013; Kumar *et al.*, 2016). Between 55% and 60% of global finger millet production comes from Africa, especially from Eastern African countries including Ethiopia (Oduori and Kanyenji, 2005; Orr *et al.*, 2016).

Ethiopia is recognized as a center of origin, and genetic diversity for numerous crop species, including finger millet, due to its diverse altitudes, various climate conditions, different soil types, and sufficient annual rainfall (Kassahun Tesfaye and Solomon Mengistu, 2017). In Ethiopia, finger millet is the sixth most important cereal after tef, wheat, maize, sorghum and barley (Temesgen Jerjero *et al.*, 2022).

In 2023/2024, roughly 445,000 hectares of land were allocated for finger millet farming, yielding around 125,000 metric tons (CSA, 2024). Nonetheless, there is a 2% decrease in yield over the last five years, with an average yield of 2.47 t/ha compared to the potential yield of the crop up to 6 t/ha under optimal conditions (Dagnachew Lule *et al.*, 2014; CSA, 2018). While in the Amhara Regional State, it is slightly higher at 2.54 tons per hectare and in the West Gojam Zone, it reaches 2.58 tons per hectare (CSA, 2021). However, these figures are still considered low in comparison to the potential yield, which ranges from 4 to 5 tons per hectare (Kebede Dessalegn *et al.*, 2019).

Finger millet possesses natural resilience and a rich nutritional profile, making it an essential climate-smart crop to tackle food and nutritional insecurity in regions prone to drought, providing a sustainable alternative to traditional, resource-heavy cereals (Pinca, 2024). Despite its resilience, finger millet cultivation is limited by various both biotic and abiotic factors (Saha *et al.*,

2016). Among the biotic factors, blast disease caused by *Magnaporthe grisea* (Hebert) Barr (anamorph: *Pyricularia grisea*) is the major one affecting growth and grain yield in finger millet, and other important cereals such as rice and wheat (Klaubauf *et al.*, 2014; Chung *et al.*, 2020). *Magnaporthe grisea* is a heterothallic filamentous ascomycete fungus belonging to the Pyricularia family (Qi *et al.*, 2019).

Blast disease is prevalent in Africa and Asia; it is widely distributed in all finger millet producing areas in Kenya (Mbinda *et al.*, 2021), and Ethiopia (Getachew Gashaw *et al.*, 2014). The disease hindering plant growth and leading to yield losses ranging from 20–50% (Odeph *et al.*, 2020). Yield losses in East Africa is exceeding 80% (Pagliaccia *et al.*, 2018), and can cause up to 100% losses on susceptible genotypes (Kihoro *et al.*, 2013). Finger millet is infected by blast at all growth stages, from seedling to pre flowering, panicle production and grain filling (Ranganatha *et al.*, 2022; Arya *et al.*, 2026). This fungus is recognized as a highly diverse, and rapidly evolving pathogen, characterized by numerous physiological races (Panda *et al.*, 2017).

The fungus produces conidia that are translucent, two-septate, slightly darker in shade, and measure $20\text{--}22 \times 10\text{--}12 \mu\text{m}$. These conidia have an obclavate shape that narrows to the apex (Devi and Sharma, 2010). The dispersal of conidia is mainly through seed (Tanaka *et al.*, 2009), in addition to direct contact between plants or rain splash (Talbot, 2003; Chen *et al.*, 2013).

Blast disease infection occur when a three-celled conidia attaches on a leaf surface (Muimba-Kankolongo, 2018). Conidia utilize adhesive materials that are released from the tip of the spore when it is hydrated, attach to the surface of the host leaf. The spore then firmly bonds to the hydrophobic surface of the plant, facilitating its germination. Consequently, germ tubes develop, and changed into melanized appressoria. By generating turgor pressure through the accumulation of compatible solutes, such as glycerol, and the secretion of enzymes that degrade the cell wall, a fully formed appressorium exerts pressure on the leaf

cuticle, penetrate the epidermal cells and invade the host tissue (Marcel *et al.*, 2010; Mentlak *et al.*, 2012; Pan *et al.*, 2019). Then the pathogen spreads to adjacent cells through plasmodesmata without altering the host cell walls (Galhano and Talbot, 2011). After entering the plant cells, the pathogen initially undergoes a biotrophic growth phase, where the fungus derives nutrients from living cells followed by a necrotrophic growth phase, in which it feeds on dead cells and where it produces asexual conidia to infect additional plant tissues (Park *et al.*, 2009; Fernandez and Orth, 2018) (Fig. 1. 1). Under optimal conditions of high humidity, the fungus generates a large quantity of spores from infected lesions, causing rapid disease spread to adjacent plants through wind and water droplets (Mentlak *et al.*, 2012).

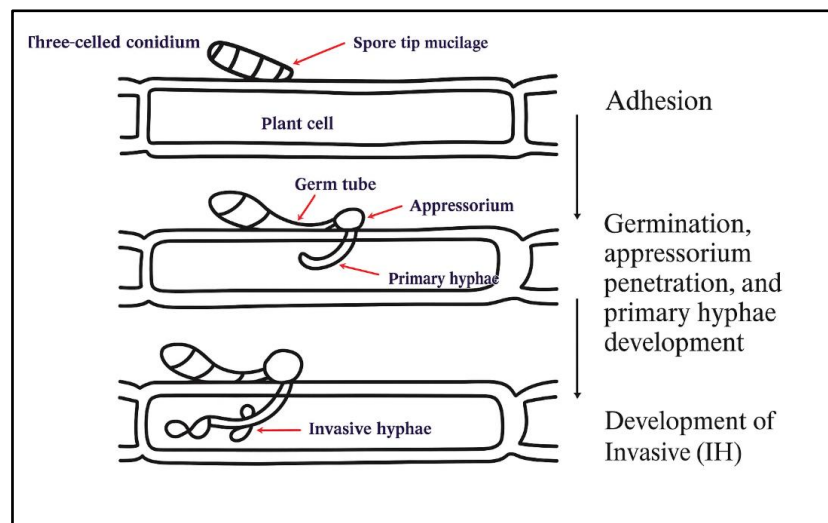


Figure 1.1. A diagrammatic representation of the infection cycle of *M. grisea*

Source: Mbinda and Masaki (2021)

The symptoms of finger millet blast are characterized by black lesions on the inflorescence and diamond-shaped, greyish-white lesions on the leaves bordered with brown (Holt, 2000). Initially, small gray or brownish spots formed on the leaves. These tiny lesions eventually develop into diamond-shaped lesions with a greyish-white center, measuring about 1 to 5 cm in length and 0.5 cm in width within 2 to 3 days post-infection (Figure 1. 2). Factors, such as the age of the plant, environmental conditions, and the degree of host resistance, significantly influence the development of blast lesions (Shittu, 2018). A notable decrease in

finger length, seed weight, the number of seeds per finger, and overall grain yield can occur when head blast attacks (Mgonja *et al.*, 2013).

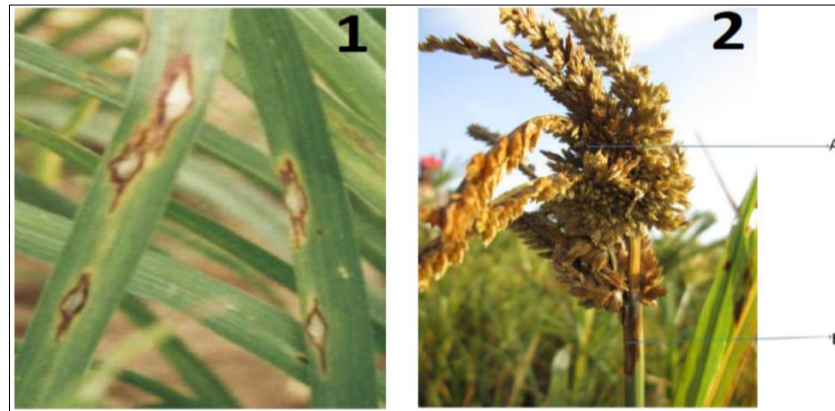


Figure 1.2. The symptoms of blast disease in finger millet caused by *M. grisea*: Leaf blast (1), head (finger) blast (A), and neck blast (B).

Source: Shittu (2018)

Both phenotypic and genotypic variability in *P. grisea* have been widely reported. Host specificity is recognized as a major basis of pathogenic variation. Molecular studies show that *P. grisea* consists of genetically diverse isolate groups (Levy *et al.*, 1993; Motlagh *et al.*, 2015). Variation may arise through heterokaryosis, changes in chromosome number, chromosome anomalies or genomic rearrangements (Khadka *et al.*, 2013). Parasexual recombination also contributes to variability (Zeiglar, 1998). Sexual recombination has been shown to influence population structure (Kumar *et al.*, 1999). Pathogenic variability in finger millet isolates is further reported by Jayo *et al.* (2021); Das *et al.* (2023), as physiological heterothallism.

Finger millet plants exhibited multiple defense responses against blast disease. Plants that were infected exhibited deposition of callose and an accumulation of components that strengthen the cell wall, including callose and proteins that cross-link to enhance wall integrity and impede the progress of pathogens. Elevated levels of salicylic acid (SA) and jasmonic acid (JA) were observed, and an analysis of MKK1/2 transcripts corroborated the critical role of Mitogen-Activated Protein Kinase (MAPK) signaling in managing *M. grisea* infection. The interplay between phytohormones, the expression of defense-related genes,

and enzymatic responses further confirmed the activation of resistance mechanisms. These results emphasize the importance of SA-mediated signaling as a fundamental process that boosts the synthesis of inducible proteins and limits pathogen infiltration (Patil *et al.*, 2020). Furthermore, defenses at the morphological, anatomical, and biochemical levels, including decreased leaf area and angle, a reduced number of stomata, a thicker epidermis and cuticle, fewer chlorenchymatous strands, increased phenolic content, and diminished levels of total and reducing sugars, were linked to resistance against blast. These characteristics can be utilized as reliable selection criteria for breeding finger millet genotypes that are resistant (Jain and Yadava, 2006).

Blast pathogen identification involves serological tests and morphological evaluations; however, these techniques require specialized expertise, and often suffer from both sensitivity and specificity issues (Hasan *et al.*, 2016). To overcome these challenges, molecular techniques, especially polymerase chain reaction (PCR), should be implemented for more accurate pathogen identification. The molecular identification of fungal species largely depends on the amplification, and sequencing of the internal transcribed spacer (ITS) region within the fungal genome, which displays significant variability among different populations of the same species (Mior *et al.*, 2017). Additionally, utilizing species-specific primers for the amplification of fungal DNA, is considered the most reliable approach due to its high specificity for the target pathogen (Gowrisri *et al.*, 2019).

To manage finger millet blast, implementing cultural practices such appropriate planting dates, using certified seeds, rotating crops, keeping proper spacing, and managing nitrogen and silicon levels effectively, field hygiene and optimal water use (Lenne *et al.*, 2007; Mgonja *et al.*, 2013; Mbinda and Masaki, 2021). Blast control strategies in East African farmers, includes adjusting planting dates, using fertilizers and quality seeds (Finckh, 2008; Obilo *et al.*, 2012; Sood and Babu, 2016). Proper application of organic and inorganic fertilizers have been demonstrated to reduce the occurrence of blast (Dass *et al.*, 2013; Das,

2017), while appropriately managed seed rates and spacing along with regular weeding, limit alternative hosts (Lenné and Thomas, 2006; Oduori, 2008). Intercropping with legume crops is another method, as it improves nitrogen fixation (Adipala *et al.*, 1994; Ghosh, 2004).

Fungicides are widely used to control blast disease in crops including finger millet (Pooja and Katoch, 2014; Mbinda and Masaki, 2021). Systemic fungicides, such as tricyclazole, propiconazole and carbendazim, beside with their combinations, including carbendazim + mancozeb have shown high effectiveness when applied as seed treatments or foliar sprays (Nagaraja *et al.*, 2007; Ghazanfar *et al.*, 2009; Miah *et al.*, 2017). Field studies have indicated that propiconazole, tricyclazole, tebuconazole + trifloxystrobin and newer formulations like metominostrobin can significantly reduce leaf, neck and finger blast, leading to improved yields (Bhat *et al.*, 2012; Sharma *et al.*, 2018; Patro *et al.*, 2020). Fungicides work by disrupting fungal processes, including mitosis, respiration and melanin synthesis (Kunova *et al.*, 2013; Kunova *et al.*, 2014). However, their efficacy can be affected by factors like formulation, application method and pathogen resistance (Zhang *et al.*, 2009; Castroagudín *et al.*, 2015; Shittu, 2018).

Biological control has emerged as a promising, eco-friendly and cost-effective alternative for managing plant diseases including blast (Sekar *et al.*, 2018; Patil and Kumudini, 2019; Lahlali *et al.*, 2022; Poonacha *et al.*, 2023). Biological control functions through mechanisms such as competition, antibiosis, mycoparasitism, hypervirulence and induced resistance (Singh *et al.*, 2016; Law *et al.*, 2017; Negi *et al.*, 2017). Beyond disease management, bio-inoculants improve plant growth, increasing root and shoot growth, flowering, and maturation (Singh *et al.*, 2016; Tamreihao *et al.*, 2016; Negi *et al.*, 2017; Amruta *et al.*, 2018). Despite these benefits, environmental factors may limit biocontrol efficacy and the risk of pathogen resistance (Suprpta, 2012; Gopalakrishnan *et al.*, 2014).

Developing finger millet varieties that are resistant to blast is a cost-effective strategy for addressing blast disease, especially in subsistence farming systems (Janni *et al.*, 2008). Numerous screening studies have revealed promising blast resistant genotypes: Babu *et al.* (2013) reported 66 blast resistant accessions. Manyasa *et al.* (2019) noted that East African accessions (G18, G43, and G67) were resistant at all stages of blast, with some achieving yields exceeding 20 t/ha. Upamanya *et al.* (2019) found VR 1117 to possess broad resistance. Improved varieties like IE4795 and IE5066, developed through traditional breeding techniques, integrate durable blast resistance with favorable agronomic traits, thereby reducing reliance on fungicides (Mbinda and Masaki, 2021). These resistant lines are vital resources for breeding programs improving finger millet resilience and yields. Ghimire *et al.* (2022) also reported that identified resistance finger millet genotypes, supporting breeding programs aimed at improving disease resistance.

A range of management strategies including resistant varieties, adjusting planting dates, intercropping, fungicides and biocontrol have been working with varying degrees of success (Lenne *et al.*, 2007). Nevertheless, these methods are not often used by resource-limited farmers due to unaffordable costs, access or limited efficacy against the highly adaptable pathogen like blast. The acceptance of these strategies also relies on farmers' knowledge, and access to sustainable and affordable alternatives (Valencia *et al.*, 2015). Gaining an understanding of farmers' views on blast disease, its effects and methods of control is crucial for creating successful, and participatory interventions (Mbinda *et al.*, 2021).

A successful and sustainable strategy for controlling blast disease necessitates a comprehensive approach that integrates chemical methods, biological control, the use of resistant breeding lines and cultivars, evaluation of pathogen diversity and virulence, forecasting of disease, race mapping, and consideration of the impact of wild crop species and weeds on disease outbreaks. These strategies should be enhanced by proper agronomic practices, including the removal of crop residues, crop and land rotation, avoidance of broadcasting seeds and

double cropping, effective water management, and addressing factors that limit yield. A management strategy that implements chemicals solely based on observed crop damage and anticipated yield and economic losses is crucial for enduring blast control and for bolstering finger millet cultivation to enhance global food security (Asibi *et al.*, 2019). Despite this, there is a scarce of localized research and adaptable management strategies focused specifically on Ethiopia, including the selected study area. In particular, the scarcity of epidemiological data on *M. grisea* populations and the lack of resistant varieties tailored to the different agroecological zones hinder effective disease management. Therefore, this research intends to fill this significant gap by conducting surveillance of finger millet blast disease in Northwestern Amhara to ascertain the current status of the disease and its contributing factors, isolating and characterizing local *M. grisea* strains, exploring farmers' knowledge and management practices, and evaluating effective control strategies that emphasize resistance in host plants along with the combined use of resistant varieties and fungicides.

1.2 Statement of the Problem

Finger millet is a highly nutritious crop that is adaptable to climate changes and has cultural importance, particularly in Ethiopia. It is crucial for improving food security and supporting rural populations. However, regardless of its significance, research and funding for finger millet have been minimal in comparison to major staple crops. There is a lack of basic information on finger millet blast management in different regions of Ethiopia, including in the western Amhara sub-region. This problem is especially persistent in Ethiopia in general and in the Amhara region in particular, where there is a lack of epidemiological data and effective blast management strategies. Therefore, it is pertinent to fill some of the research gaps through surveillance of the disease with associated risk factors, isolation and characterization of the pathogen, screening of breeding finger millet lines for resistance and high yield as well as evaluating integrated management practices that combine resistant varieties with

fungicide use. In addition, considering the diversity in farmers' practices across regions influenced by varying agro-ecological and socio-economic contexts, this study aimed to evaluate farmers' knowledge, and perceptions of finger millet blast disease in North western Amhara, Ethiopia. Addressing these challenges will improve finger millet production systems in Ethiopia; assist in national development and food security goals, and back global efforts to promote underutilized, climate-resilient crops that are crucial for sustainable agriculture.

1.3 Objectives of the Study

1.3.1 General objective

To develop a sustainable and integrated management strategy for finger millet blast disease through comprehensive assessment of distribution, pathogen characterization, evaluation of farmer practices, and identification of effective control measures to improve the productivity and resilience of finger millet cultivation in western Amhara and similar agroecologies.

1.3.2 Specific objectives

1. To assess the occurrence, distribution and severity levels of finger millet blast across selected districts;
2. To evaluate the knowledge, and management practices of smallholder farmers about finger millet blast disease;
3. To identify the *Magnaporthe grisea* pathogen from infected finger millet samples by using cultural and morphological techniques;
4. To evaluate finger millet genotypes for resistance to *Magnaporthe grisea* under field conditions; and
5. To determine the combined effects of finger millet varieties and fungicides on reducing blast disease severity and improving yield

1.4 Significance of the Study

This study is significant as it addresses the knowledge gaps regarding perceptions of farmers' and management strategies, the distribution of the disease in the study areas, and the biological properties of the pathogen.

Understanding the distribution, characteristics and management of this pathogen is essential for protecting food security, and the livelihoods of smallholder farmers who rely on finger millet for both food and income.

1.5 Description of the Study Areas

The research was undertaken at Yilmana Densa, Jabi Tehnan, Dangila, Semien Achefer, Takusa and West Dembiya districts, situated within the West Gojam, North Gojam, Awi and Central Gondar Administrative zones of the Amhara region, Ethiopia (Appendix 1.1). In northwestern Amhara, smallholder farmers predominantly engage in mixed farming systems that integrate crop cultivation with livestock husbandry. Despite limited access to external inputs and modern agricultural technologies, traditional farming practices in the region frequently incorporate techniques such as crop rotation and intercropping. These approaches facilitate nutrient cycling and contribute to sustainable pest management by improving ecological processes, thereby maintaining soil fertility while minimizing dependence on external resources (Muoni, 2019; Genanew Agitew *et al.*, 2024). The area is divided into three primary agro-ecological zones: high altitude (>2500 m.a.s.l) accounting for 25%, mid-altitude (1500–2500 m.a.s.l) making up 44% and low altitude (<1500 m.a.s.l) representing 31%. The average annual temperature varies between 15 and 30°C (Habtamu Ayalew *et al.*, 2023). The main crops grown include maize, teff, finger millet, wheat, chickpea, beans, Niger seed, and cabbage. It is one of the food-insecure regions in the country due to various agronomic, environmental, and socioeconomic challenges (Bayuh Belay and Melaku Wale, 2019).

1.6 Compilation of the Dissertation

This dissertation is comprised of eight chapters. Chapter one provides the background and justification for the study, the problem statement, objectives and expected contributions of the research, and organization of the dissertation. Chapter two summarizes the materials and methods of the study, including the research design, study location, data collection techniques, and experimental procedures. Chapters' three to seven consist of individual manuscripts developed

from independent research activities. Each manuscript includes an abstract, an introduction or background, the results, and a discussion that interprets the findings in line with the existing literature and final conclusions drawn from the study. These chapters represent the main scientific contributions of the dissertation and are formatted appropriately for submission to peer-reviewed journals. Finally, Chapter eight presents a detailed summary of the entire research project, focusing on the key findings to provide integrated insights, and offers practical recommendations for future research, policy, or practice in the field.

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Chapter 2. OCCURRENCE, DISTRIBUTION AND INTENSITY OF FINGER MILLET BLAST IN WESTERN AMHARA, ETHIOPIA

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Abstract

Blast disease significantly hampers finger millet production, and causing considerable yield reductions. This research aimed at assessing the prevalence and intensity of blast disease in the major finger millet-growing districts of Northwestern Amhara. Field surveys were conducted in 2022 and 2023 cropping seasons across 270 farmer fields in five districts using purposive sampling, guided by a field manual and a scoring scale of 0–9 for leaf blast and 0–5 for neck and finger blast. Blast disease was detected in every district that was surveyed, with variations in incidence and severity based on agro-climatic factors, farming systems, agronomic methods, and the restricted implementation of management strategies. Incidence rates ranged from 15.21% to 58.26%, with Semien Achefer showed the highest mean incidence (56.54%) and Dangila the lowest (17.69%). The overall mean incidence across districts was 33.54%. Disease severity ranged from 18.24% to 86.98%. The highest mean severity occurred in Jabi Tehnan district (65.38%), while the lowest was recorded in Dangila district (36.16%). The overall mean severity across districts was 51.50%. Blast disease was detected in every district assessed, with variations in

incidence and severity due to differences in agro-climatic conditions, farming systems, agronomic practices, and the restricted application of management strategies. The results revealed the need for immediate measures to establish effective management strategies for blast control to improve finger millet production and productivity.

Keywords: Blast disease, Disease management, Finger millet, Incidence, Severity

2.1 Introduction

Finger millet (*Elusine coracana* L. Gaertn) is an important cereal crop growing in various developing countries, especially in Africa and India, where it is a primary food source for subsistence and food-insecure communities (Zerihun Tadele, 2016). It holds particular significance for smallholder farmers who cultivate it in arid, semi-arid and marginal areas under unfavorable agro-ecological conditions (Sab *et al.*, 2018).

In Ethiopia, finger millet is mainly growing by subsistence farmers. It is integral to traditional dietary practices, and used to make porridge, bread, *injera* (often mixed with teff), and local drinks like *Areki* and *Tela*. Its straw is also utilized for animal fodder, roofing, and weaving (Merkuz Abera and Fentahun Tesafa, 2016). However, finger millet production in Ethiopia is currently about 2.47 t/ha below its potential yield of 6 t/ha which has been recorded in research and on-farm trials (Bekele Anbessa *et al.*, 2016). Various biotic and abiotic factors contribute to this yield gap, with blast disease being the most significant biotic constraint (Zigale Semahegn *et al.*, 2021). The disease is caused by *M. grisea* (Hebert) Barr (anamorph: *P. grisea* (Cooke) Sacc) (Das *et al.*, 2021). Worldwide, blast continues to be the primary biotic threat to finger millet yield, and reported in African and Asian countries including India (Babu *et al.*, 2014; Das *et al.*, 2021; Dida *et al.*, 2021). The disease resulting in considerable yield reductions (Babu, 2011). The disease also affects rice (*Oryza sativa* L.), and was first recorded over 3,000 years ago in Asia and has expanded globally (Odeph *et al.*, 2020). It affects various parts of the plant leaves, neck and ear at different

growth stages, and is primarily transmitted through seeds. The pathogen survives in infected crop residues, and becomes active during the rainy season (Manandhar *et al.*, 2016). Conditions such as temperatures ranging from 22°C to 30°C and relative humidity above 70% increase its development and dissemination (Singh *et al.*, 2018; Ghimire *et al.*, 2022).

Effective farming and agronomic techniques such as timely planting, moderate planting density, row cropping, practicing crop rotation, and managing residue and weeds, along with the use of resistant varieties and specific biocontrols or fungicides, greatly reduce finger millet blast by decreasing pathogen inoculum, altering the microclimate of the canopy, and improving the resistance of the host. (Mbinda *et al.*, 2021).

In Ethiopia, the disease has been reported in major finger millet-producing areas, including East Wollega (35–68.3% incidence, 18–35.8% severity), West Wollega (45–76.7%, 22.5–50%), Metekel (10–75%, 0–25%), Awi (20–65%, 5–27%), and West Gojam (37–95%, 5–69%) (Getachew Gashaw *et al.*, 2014). It also reported in Assosa and Kamashi zones of the Benishangul-Gumuz region, with a 34.13% disease severity index (Minyahil Kebede and Assefa Gidesa, 2017). Reports indicate that disease incidence and severity reaching 57.9% and 23.7% respectively, and the losses attributed to blast have been reported to vary between 10.1% and 41.4% (Getachew Gashaw *et al.*, 2014). The disease is also reported in key finger millet-producing areas of Amhara region, which includes Central Gondar, North Achefer, South Gondar and causing significant yield losses (Fentie Molla, 2012; Wossen Tarekegne *et al.*, 2019; Misganaw Anteneh and Endayen Melaku, 2021). However, the present status of the disease is unknown due to lack of reliable information regarding its distribution, prevalence, and severity, which impedes precise evaluation and efficient management. Therefore, this study aimed at assessing the occurrence, distribution and severity of finger millet blast disease and associated risk factors in the main production areas of Northwestern Amhara, Ethiopia.

2.2 Materials and Methods

2.2.1 Study area, sampling and survey methodology

The survey was carried out in the main growing seasons of 2022 and 2023 (September to November) across four administrative zones in Amhara region: West Gojam, North Gojam, Awi and Central Gondar (Figure 2.1). These Administrative zones include the districts of Jabi Tehnan, Dangila, Semien Achefer, Takusa and West Dembiya selected purposively based on the disease report, and the potential finger millet producing districts in the region. The surveyed kebeles (five from Semien Achefer, four from Jabi Tehnan, Takusa, and Dangila, and three from West Dembiya) within these districts were selected by extension agents based on their history of finger millet cultivation, and disease report over the previous three to five years. A total of 270 farmer fields (158 in 2022 and 112 in 2023) from 5-10 farms from each kebele were accessed, with a smaller number of farms during 2023 due to security issues. The sampled fields were distributed across the districts, depended on the availability of finger millet farming: Semien Achefer had more number of fields assessed (70), followed by Jabi Tehnan (58), Takusa (58), Dangila (48), and West Dembiya (36).

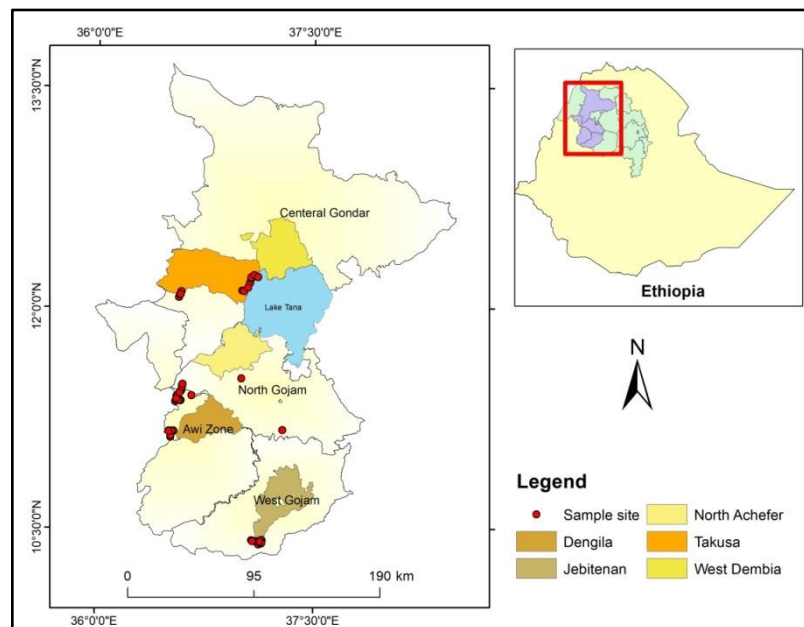


Figure 2.1. Map of the sampling points in the survey districts

Disease assessment was conducted using the diagonal transects method. A diagonal transect walk in 'X' layout was used to access the disease in finger millet field following the procedure outlined by Lin *et al.* (1979). A quadrant measuring 0.5 m × 0.5 m was used, and five quadrants were assessed from each field. In every quadrant, the total number of plants and the number of infected plants were recorded (Figure 2.2).



Figure 2.2. Collection of disease and related data on the farmers' fields

2.2.2 Data collection

Using a color-printed diseased plant guide, five plants were randomly selected from each quadrant, and evaluated for blast symptoms and the level of damage. The severity of the disease was rated on a scale of 0 to 9 for leaf blast (Appendix Figure 2.1) and 0 to 5 for neck and finger blasts (Appendix Figure 2.2), with slight modifications to the method established by Babu *et al.* (2013). The prevalence of the disease was determined by calculating the ratio of fields exhibiting blast symptoms to the total number of fields surveyed, using the formula of Mounde *et al.* (2008).

$$\text{Disease prevalence (\%)} = \frac{\text{Number of fields affected}}{\text{Total number of fields assessed}} \times 100 \dots\dots\dots(i)$$

The rate of finger millet blast disease was determined by counting the number of infected plants and expressing it as a percentage of the total plants evaluated. This calculation followed the standard formula of Teng and James (2002).

$$\text{Disease incidence} = \frac{\text{Number of diseased plants}}{\text{Total number of inspected plants}} \times 100 \dots\dots\dots(ii)$$

The severity scores for finger millet blast disease were transformed into a percentage severity index (PSI) using the formula of Magar *et al.* (2015) as demonstrated below:

$$\text{PSI} = \frac{\text{Sum of individual disease ratings}}{\text{No.of observations assessed} \times \text{maximum disease rating}} \times 100 \dots\dots\dots(iii)$$

Weather data, such as average monthly rainfall, relative humidity, and both maximum and minimum temperatures for the growing seasons of 2022 and 2023, were obtained from the Western Amhara Meteorological Services Center (WAMSC, 2023). The meteorological data are shown in Table 2.1.

Table 2.1. Mean monthly temperature (°C), relative humidity (%), and rainfall (mm) across districts in 2022 and 2023

Districts	Temperature											
	May		June		July		Aug.		Sep		Oct	
	2022		2022		2022		2022		2022		2022	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
Jabi Tehnan	27.5	14.3	27.8	13.9	25.5	13.7	26.2	14.3	27.6	14.3	30.7	13.8
S. Achefer	28.7	14	30.3	17.9	22.3	12.2	22	12.2	27.4	10.1	24.6	14.2
Dangila	27.4	12.4	23.9	12.4	21.2	13.1	21.4	13	23	12	23.2	11.3
Takusa	26.8	8.3	27.8	9.5	23.7	9.3	24	9.1	26.2	9.3	26.8	9.6
W. Dembiya	28.7	8.5	28.9	10.3	24.9	10.6	25	10.3	27.4	10.1	27.4	10
	2023		2023		2023		2023		2023		2023	
	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min
Jabi Tehnan	27	13.7	27	13.6	27.6	13.7	25.7	13.6	26.4	13.5	28.2	13.4
S. Achefer	25.7	13.3	23.4	12.2	22	11.7	23.2	12.8	24.4	14.1	23.2	13.7
Dangila	23.9	13.0	21.2	13.3	21.4	12.7	23.0	12.5	22.8	11.7	22.9	11
Takusa	27.3	7.8	26.2	7.4	23.4	7.6	26.7	7.2	27.4	7.1	26.8	6.7
W. Dembiya	28.2	8.1	27	7.6	24.6	8.1	27.5	7.4	28.2	7.5	27.7	7.4
Relative Humidity (RH %)												
	May		June		July		Aug		Sep		Oct	
	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023
Jabi Tehnan	42.94	40.68	65.94	63.28	80.25	76.43	80.62	77.04	75.56	72.46	70.12	58.29
S. Achefer	40.25	38.43	61.49	61.82	72.24	68.14	74.21	75.02	70.65	68.23	64.21	54.13
Dangila	41.00	46.00	63.00	64.00	74.00	66.00	71.00	69.00	63.00	65.00	59.00	52.00
Takusa	35.52	33.43	56.94	56.28	67.42	63.41	69.12	70.2	65.56	63.32	59.12	49.31
W. Dembiya	37.49	35.86	60.49	58.82	75.52	71.34	75.26	72.4	70.65	67.64	65.21	53.92
Rain Fall												
	May		June		July		Aug		Sep		Oct	
	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023	2022	2023
Jabi Tehnan	230	211	279	275	445.7	425.5	193	191	161	143	120	112
S. Achefer	21.5	82.6	141	176	324	243.8	180	254	97.4	210	95	97

Dangila	61.4	95.6	306	357	322	479	284	360	215	327	197	201
Takusa	58.7	74.8	72	178	138	210.7	154	187	85	97	29	57.3
W. Dembiya	60.2	78.2	199	185	193	231.3	273	199	97.4	101	54.9	65.5

S. Achefer- Semien Achefer, W. Dembiya- West Dembiya

During the survey, data on planting methods, crop growth stage, field histories, sowing dates, seed type, farm, and agronomic management practices were noted. Data on geographic coordinates (latitude and longitude) and altitudes of the fields were recorded using GPS (Trex Legend GPS system, Garmin technology). Additionally, observations were made regarding other common diseases, and insect pests present.

2.2.3 Statistical analysis

The collected data were analyzed using SPSS Version 23 to evaluate variations in disease occurrence and severity rates among different locations, types of diseases and growing seasons in finger millet. When significant differences were identified, Turkey's Honestly Significant Difference (HSD) test was used for separating the means.

2.3 Results and Discussion

2.3.1 Agronomic practices involved in finger millet cultivation

The results revealed presence of significant variations in farming and agronomic practices among different districts. In Takusa and West Dembiya, a majority of farmers (77.59% and 75.00%, respectively) have small plots measuring between 0.15 and 0.25 hectares, whereas medium-sized farms (between 0.3 and 0.5 hectares) are more prevalent in North Achefer (62.86%) and Dangila (47.92%). The types of soil differ by district: Nitosols are the primary soil type in Jabi Tehnan and North Achefer, while in Takusa, Leptosols, and Dangila and West Dembiya are dominated by Vertisol. Cereal-cereal crop cultivation is common, particularly in Jabi Tehnan (86.21%) and Semien Achefer (75.71%) (Appendix Table 2.1). In addition, there is a shortage of managing crop residues, the practice of sole cropping, and dependence on local seeds are common in all districts. Planting mainly takes place from mid-June to early July, although some farmers

in Jabi Tehnan and Semien Achefer practicing late planting and this late planting. The use of fertilizers is most prevalent in Semien Achefer (84.29%), followed by Jabi Tehnan (79.31%) and Dangila (77.08%), while West Dembiya (55.56%) and Takusa (51.72%) exhibit the lowest usage. Most fields had seeds sown in a broadcast pattern (Appendix Table 2.1). Asibi *et al.* (2019) highlighted that successful management of blast disease requires a combination of improved farming practices, such as removing crop residues, rotating crops and land, avoiding broadcasting and double cropping, optimizing water use, and handling factors that limit yield.

Moderate planting densities are found in Semien Achefer, Jabi Tehnan, and Dangila whereas Takusa and West Dembiya showed lower planting densities. Weeding activity is more common in Takusa and West Dembiya, where overall field management is mostly better in West Dembiya and these might be the possible factors for less disease incidence and severity in the districts of Takusa and West Dembiya relative to Jabi Tehnan, and North Achefer Districts. The application of fungicides remains low across all districts (Appendix Table 2.1).

Agronomic practices play a crucial role in influencing the occurrence of finger millet blast across various districts. In Jabi Tehnan, most farmers engage in cereal-cereal rotations using local varieties, along with poor residue management (Appendix Table 2.1). Similarly, in Semien Achefer, insufficient residue management and high plant density may supported in the spread of the disease. These issues likely lead to magnify inoculum persistence and weakened host resistance (Oduori, 2008; Onyango, 2016). Conversely, crop rotation aids in disturbing the cycle of diseases by planting non-host crops in the intervals between growing seasons, thus breaking the continuity of pathogens (Kato, 2001)

In contrast, Takusa and West Dembiya demonstrated more effective farming and agronomic practices. In Takusa, 37.93% of plots were rotated with various crops, and half of the fields saw improved management, leading to lower disease

levels. The frequent weeding practices in West Dembiya (with 25% of plots weeded three times) altered microclimates, and eliminate alternate hosts, resulting in a decreased incidence of the disease (Appendix Table 2.1). These districts also benefited from improved residue management and crop rotations. Some farmers in Takusa and West Dembiya adopted better management practices such as timely weeding, suitable crop rotation, proper plant spacing and improving soil fertility with organic fertilizers prior to planting. Such practices may lead to a significant reduction in disease severity. Effective farm management involving these strategies can lower disease infection rates and improve yields (Meena *et al.*, 2017).

The adoption of improved seed varieties is another vital factor. In Jabi Tehnan and Semien Achefer, 86.21% and 84.29% of farmers, respectively, opted for farmer's varieties, whereas Dangila and West Dembiya relatively had a higher utilization of improved varieties (16.67%) (Appendix Table 2.1), which might be the reason for moderating disease levels in these districts. Breeding programs that develop cultivars resistant to specific races of *M. grisea* are essential for sustainable and effective blast management (Tian *et al.*, 2022). Moreover, residue management had a notable effect on disease severity. In Jabi Tehnan, the lack of adequate residue clearing might facilitated the persistence of fungal inoculum; increase the disease, while Takusa and West Dembiya, which practiced better residue management, may the possible reason for lower disease incidence. Variations could indicate differences in access to inputs, financial limitations, extension services, and agronomic practices. Another factor that may contribute to the elevated incidence and severity of disease in Jabi Tehnan and Semein Achefer is the high plant density, which increased humidity conducive to blast epidemics and enables the spread of pathogen spores. A combination of practices, including crop rotation, residue clearance, and the use of resistant varieties, is critical for effective disease control (Manandhar *et al.*, 2016; Mbinda *et al.*, 2021).

The main aim of intercropping is to supplement the utilization of resources, which includes canopy architecture, root systems, nutrient absorption and overall resource synergy (Ma *et al.*, 2023). Nevertheless, this method can present challenges, as thick vegetation might elevate relative humidity, creating an environment conducive to blast epidemics (Daryanto *et al.*, 2020). Increased plant density is likely to increase disease spread, particularly for blast caused by *M. grisea* (Gautam *et al.*, 2013). So maintaining proper plant density is essential to reduce the spread of pathogen inoculum. Finger millet is especially vulnerable to blast disease under certain microclimatic conditions, such as increased humidity resulting from dense tree canopies or intercrops like brassica, as noted by (Getachew Gashaw *et al.*, 2014). In Kenya, farmers commonly practice intercropping finger millet with various cereals and pulses (like maize, beans and cowpeas), fruits (including mangoes, oranges, guavas, and pawpaw), and tubers (such as cassava and sweet potatoes) as a result reported less disease intensity (Mbinda *et al.*, 2021).

2.3.2 Blast disease occurrence and distribution

As shown figure 2.3, the symptoms of finger millet blast disease were recorded as black lesions on the inflorescence, and diamond-shaped, greyish-white lesions on the leaves bordered with brown were used as a guide for blast disease identification during assessment (Holt, 2000). Finger millet crop showed disease symptoms typical of blast, such as gray, diamond-shaped spots with brown edges on the leaves, black spots on the panicles (neck) and nearby tissues and a black or rusty discoloration on the fingers (Holt, 2000).



Figure 2.3. Symptoms of blast disease affecting the leaf, neck, and head areas of finger millet (Images taken during the survey by the authors at Finote Selam and Semien Achefer, 2022)

Table 2.2 demonstrates a high and consistent pattern of finger millet blast disease throughout study districts. Every surveyed *kebele* within the administrative districts of West Gojam, Awi and Central Gondar (including Takusa and West Dembiya districts) reported a 100% incidence in both 2022 and 2023 (Table 2. 2). The distribution of finger millet blast varied among different farms and districts, displaying two primary patterns: dense and sparse. The areas of West and North Gojam (Jabi Tehnan and Semien Achefer) experienced a high level of blast infestation, whereas Awi and Central Gondar (Dangila, Takusa, and West Dembiya) exhibited a comparatively low distribution. These differences likely reflect variations in farming practices, agronomic management, and local agro-climatic conditions.

Table 2.2. Finger millet blast disease occurrence in the surveyed districts and kebeles in 2022 and 2023 growing seasons

Administrative zones	District	Kebele	No of farms surveyed		Blast Occurrence	% blast disease Prevalence
			2022	2023		
West Gojam	Jabi Tehnan	Abasem zeguaye	10	7	+	100
		Bakel-Abater	7	5	+	100
		Mankussa abedgoma	7	5	+	100
North Gojam	Semien Achefer	Zabatsion	10	7	+	100
		Amebeshen	7	5	+	100
		Liben	10	7	+	100
		Denbola	10	7	+	100
		Sankera	7	5	+	100
Awi	Dangila	Kunzla	7	5	+	100
		Bata Berayeta	7	5	+	100
		Zeguda kidanemeheret	7	5	+	100
		Gunderi	7	5	+	100
		Gerarege Teklehayemanote	7	5	+	100
Central Gondar	Takusa	Chach	7	5	+	100
		Mekonta	10	7	+	100
		Ayibga	7	5	+	100
	West Dembiya	Kurabas	10	7	+	100
		Guarhie	7	5	+	100
		Sankisa	7	5	+	100
		Narchecha	7	5	+	100
Sun-total			158	112		
Total			270			100

The widespread occurrence, affecting all 270 surveyed farms over the two years, emphasizes the endemic nature of the disease in the area. Despite significant variations in agro-climatic conditions, particularly altitude ranging from lowland regions likes Takusa (1789 m a.s.l.) to highland kebeles such as Gunderi in Awi (2186 m a.s.l.) (Appendix Table 2.1) disease incidence was noted at all locations. This indicates that the blast pathogen can adapt remarkably to various

environmental conditions, creating a considerable obstacle for effective disease control. As noted by Bekele Anbessa *et al.* (2016), finger millet can grow at altitudes ranged from sea level up to 2400 meters, thus making these districts suitable for its cultivation. Additionally, the presence of the disease across different geographic coordinates, ranging from southern kebeles in West Gojam (e.g., Abasem Zeguaye at approximately 10°39'N) to northern areas of Central Gondar (e.g., Ayibga and Kurabas above 12°N) (Appendix Table 2.1), highlights its widespread distribution throughout the regions where finger millet is cultivated.

2.3.3 Distribution of blast across districts

Jabi Tehnan and Semien Achefer exhibited the highest rates of disease occurrence, at 39.47% and 39.94% respectively, while Dangila had the lowest incidence at 21.27%. Takusa and West Dembiya showed intermediate levels of disease incidence (Figure 2.4; Appendix Table 3.2). There was an overall decline in incidence from 2022 to 2023, particularly in Jabi Tehnan, where leaf blast reduced from 32.19% to 28.73% and head blast declined from 55.29% to 46.39%; conversely, Semien Achefer experienced an increase in leaf blast from 30.56% to 35.25%. Throughout the different districts and years, head blast consistently had the highest incidence, followed by neck blast, with leaf blast reporting the lowest levels. Jemal Tola and Tesfaye Gudisa (2021) found that Pawe experienced the highest average incidence (63.64%) and severity (26.61% in panicle and 25.91% in leaf blast) than Metekel, implying that differences in cultivars, agricultural practices, agro-ecological factors, and differential gene expressions during seedling and maturity crop stages can affect the intensity of the disease, varying from mild to severe.

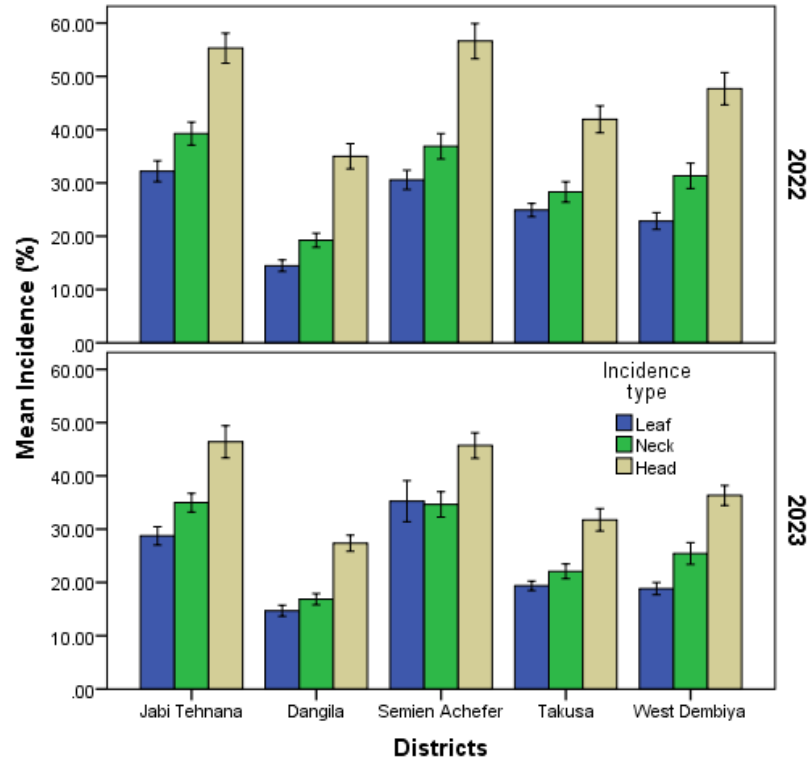


Figure 2.4. Mean Incidence of finger millet blast disease (leaf, neck, and head types) across five districts in 2022 and 2023

The severity of the disease showed the same trend: Jabi Tehnan had the highest average severity of 65.41%, followed by Semien Achefer (60.87%), and Dangila reported the least severity of 36.16%, while Takusa and West Dembiya showed moderate severity levels (Figure 2.5; Appendix Table 2.3). Generally, severity decreased from 2022 to 2023 cropping year, for example, neck blast in Jabi Tehnan dropped from 81.84% to 65.71%, and in Takusa from 61.54% to 45.71%; however, changes in Semien Achefer were varied by plant parts. Across all districts and years, head blast was the most severe disease, followed by neck blast, while leaf blast remained the least severe. This might be due to poor agronomic practices in the districts of Jabi Tehnan, and Semein Achefer, and suitable weather condition favors the spreading and infectivity of the blast pathogen. Mebratu Gebremariam *et al.* (2015), reported such differences based on the agro-ecological conditions.

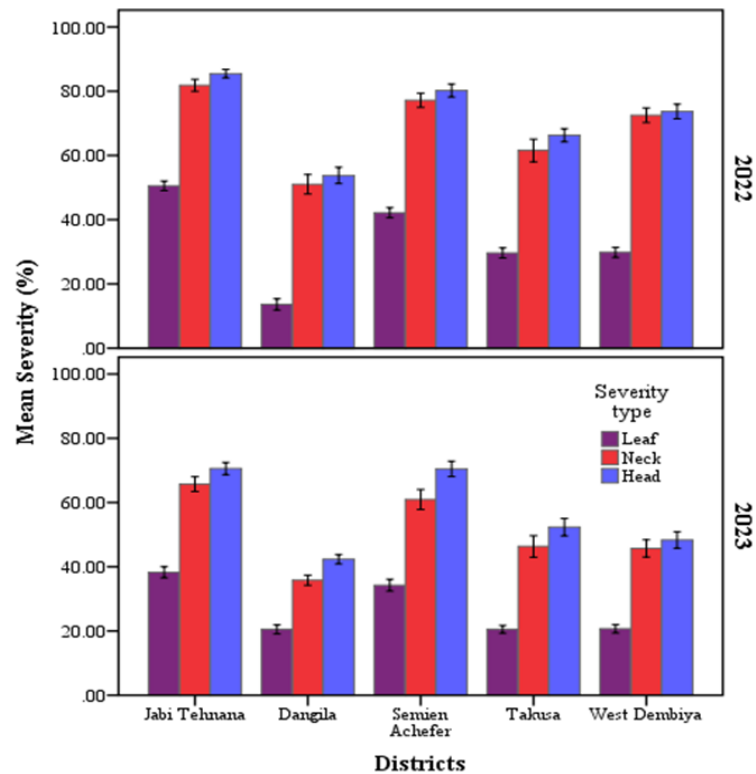


Figure 2.5. Mean severity of finger millet blast disease (leaf, neck, and head types) across five districts in 2022 and 2023

The incidence and severity of blast exhibited notable variation among districts, kebeles and years. For leaf blast, the incidence varied from 12.60% (at Bataberayeta, Dangila, 2023) to 36.95% (at Mankussa Abedgoma, Jabi Tehnan, 2022). Neck blast reached its highest level of 46.63% (at Abasem Zeguaye, 2022) and the lowest of 16.03% at Bataberayeta during 2023. The severity of head blast ranged from 23.76% (at Ayibga, Takusa, 2023) to 67.08% (at Amebeshen, Semien Achefer, 2022) (Table 2.3). This might be due to inappropriate agronomic practices and the weather conditions suitable for blast epidemics. Similar results are also reported by Odeph et al. (2020) in the disease assessment reports of Kenya.

Table 2.3. Mean incidence of finger millet blast disease across locations in 2022 and 2023

Incidence type (Mean±SE)								
District	Kebele	Leaf		Neck		Head		Mean±SE
		2022	2023	2022	2023	2022	2023	
Jabi	M. abedgoma	36.95 ^a ±1.69	31.29 ^b ±2.01	42.36 ^{abc} ±1.93	35.57 ^b ±1.01	52.25 ^{a-d} ±2.37	40.74 ^{b-f} ±1.88	40.58±1.97
Tehnan	Zabatsion	35.38 ^{ab} ±1.61	31.97 ^b ±1.6	32.84 ^{cde} ±1.61	30.29 ^{b-e} ±1.03	50.23 ^{bce} ±2.12	41.31 ^{b-f} ±2.92	44.30±2.55
	Baker Abater	29.96 ^{ab} ±1.73	26.77 ^{bc} ±1.18	35.19 ^{b-e} ±1.72	33.52 ^{bc} ±1.90	57.25 ^{abc} ±3.27	53.43 ^a ±3.49	39.15±1.67
	A. zeguaye	26.50 ^{c-f} ±1.18	24.71 ^{bcd} ±1.37	46.63 ^a ±1.69	40.79 ^a ±1.67	61.47 ^{ab} ±3.01	49.63 ^{ab} ±2.25	34.50±1.70
Semien	Amebeshen	25.96 ^{def} ±0.69	26.96 ^{bc} ±0.71	35.88 ^{b-e} ±1.85	31.71 ^{bcd} ±2.13	67.08 ^a ±1.69	44.89 ^{a-d} ±1.85	38.75±1.67
Achefer	Denbola	34.40 ^{abc} ±2.82	43.00 ^a ±3.60	43.23 ^{ab} ±2.91	40.79 ^a ±1.21	56.16 ^{abc} ±3.94	47.26 ^{ab} ±2.04	44.14±2.75
	Liben	34.10 ^{a-d} ±1.09	33.53 ^b ±1.18	37.61 ^{a-d} ±1.60	33.28 ^{bc} ±1.18	55.18 ^{abc} ±3.13	45.34 ^{a-d} ±1.18	39.84±1.56
	Sankera	28.49 ^{b-e} ±1.10	30.63 ^b ±1.20	30.94 ^{def} ±2.22	27.33 ^{c-f} ±1.54	47.74 ^{bce} ±1.97	43.87 ^{a-e} ±2.08	35.61±1.69
	Kunzla	27.23 ^{c-f} ±0.89	28.79 ^{bc} ±0.95	33.41 ^{b-e} ±2.04	29.52 ^{b-e} ±1.84	57.41 ^{abc} ±1.83	44.38 ^{a-d} ±1.97	37.18±1.68
Takusa	Ayibga	26.84 ^{c-f} ±1.81	19.83 ^{c-f} ±1.24	20.52 ^{ghi} ±1.10	17.07 ^{gh} ±0.68	31.62 ^{fg} ±1.55	23.76 ⁱ ±1.30	23.27±1.28
	Chach	23.56 ^{efg} ±1.15	17.96 ^{c-f} ±0.80	34.17 ^{b-e} ±1.68	26.53 ^{def} ±1.40	51.19 ^{bce} ±1.95	37.82 ^{c-g} ±1.62	31.87±1.43
	Kurabas	26.92 ^{c-f} ±0.94	19.79 ^{c-f} ±0.69	27.96 ^{d-h} ±1.14	21.01 ^{fgh} ±0.83	38.72 ^{d-g} ±2.03	30.99 ^{f-i} ±2.00	27.57±1.27
	Mekonta	23.39 ^{efg} ±0.96	19.93 ^{c-f} ±0.71	29.66 ^{d-g} ±1.81	23.73 ^{efg} ±1.16	44.49 ^{c-f} ±2.00	34.44 ^{d-h} ±1.47	29.27±1.35
West	Guarhie	26.70 ^{c-f} ±1.20	20.55 ^{c-f} ±0.91	40.86 ^{abc} ±1.27	31.29 ^{bcd} ±1.00	46.74 ^{cde} ±1.70	36.53 ^{d-g} ±1.21	33.79±1.22
Dembiya	Narchecha	22.85 ^{efg} ±1.28	18.70 ^{c-f} ±1.03	26.24 ^{e-i} ±1.06	20.86 ^{fgh} ±0.93	43.90 ^{c-f} ±2.25	34.26 ^{e-i} ±1.80	27.80±1.39
	Sankisa	18.96 ^{fgh} ±0.69	16.38 ^{def} ±0.39	26.91 ^{e-i} ±0.84	21.22 ^{fgh} ±0.59	52.40 ^{a-d} ±3.23	38.09 ^{c-g} ±1.90	28.99±1.27
Dangila	Bataberayeta	13.33 ^h ±0.7	12.60 ^f ±0.62	18.32 ^{hi} ±1.26	16.03 ^h ±0.92	37.98 ^{efg} ±2.16	28.55 ^{ghi} ±1.45	21.14±1.19
	G.T. hyemanote	13.47 ^h ±0.76	13.73 ^f ±0.82	18.18 ^{hi} ±1.16	16.42 ^{gh} ±0.90	33.15 ^{efg} ±1.67	26.57 ^{ghi} ±1.26	20.48±1.07
	Gunderi	13.61 ^h ±0.82	16.60 ^{def} ±0.71	18.04 ⁱ ±1.05	17.72 ^{gh} ±0.92	28.32 ^g ±1.08	24.59 ^{hi} ±1.06	19.81±0.94
	Z. K. meheret	16.47 ^{gh} ±1.03	14.85 ^{ef} ±1.04	21.38 ^{f-i} ±0.91	16.80 ^h ±0.88	38.72 ^{d-g} ±1.48	28.95 ^{ghi} ±1.08	22.86±1.07
	Mean±SE	25.80±1.25	23.67±1.97	31.60±1.54	26.97±1.17	47.86±2.27	38.03±1.81	32.4±1.55

M.Abdegoma - Mankussa abedgoma, A. zeguaye - Abasem zeguaye, G.T. hyemanote - Gerarege Teklehayemanote, Z. K. meheret - Zeguda kidanemeheret. Means with the same letter in a column shows there are no significant differences

In terms of disease severity, Mankussa Abedgoma (Jabi Tehnan) was among the most affected *kebeles*, with leaf blast severity of 52.89% and a neck blast severity of 89.76% in 2022. The highest head blast severity (89.44%) was observed in Denbola (Semien Achefer) in the same year (Table 2.4).

In contrast, the lowest severity levels were noted in kebeles such as Chach (Takusa) and Bataberayeta (Dangila) with leaf blast severity of 18.67% and 19.85%, and neck blast severity of 33.33% in Bataberayeta and 33.33% in Zeguda Kidanemeheret (Dangila), respectively (Table 2.4).

Table 2.4. Mean Severity of finger millet blast disease across study localities in 2022 and 2023

Severity type (Mean±SE)								
District	Kebele	Leaf		Neck		Head		Mean±SE
		2022	2023	2022	2023	2022	2023	
Jabi Tehnan	M. abedgoma	52.89 ^a ±1.30	36.89 ^{ab} ±1.81	89.76 ^a ±1.18	69.60 ^a ±2.00	84.32 ^{abc} ±0.73	76.20 ^a ±1.49	68.51±1.26
	Zabatsion	49.78 ^{ab} ±1.25	40.89 ^a ±1.61	77.76 ^{bcd} ±2.16	62.13 ^{ab} ±3.22	86.56 ^{abc} ±1.36	68.80 ^{abc} ±1.62	63.22±1.75
	Baker Abater	47.02 ^{abc} ±1.55	36.44 ^{ab} ±1.61	78.08 ^{bcd} ±1.43	62.60 ^{ab} ±1.70	88.48 ^{ab} ±1.50	69.40 ^{abc} ±1.77	61.02±1.43
	A. zeguaye	52.53 ^a ±1.63	39.400 ^a ±1.49	81.76 ^{abc} ±1.60	68.27 ^a ±2.08	82.56 ^{abc} ±1.22	66.40 ^{bc} ±1.98	62.04±1.53
Semien Achefer	Amebeshen	38.75 ^{de} ±1.07	33.78 ^{ab} ±1.21	67.36 ^c ±2.00	52.53 ^{bc} ±2.37	81.12 ^{bc} ±1.07	74.13 ^{ab} ±1.91	57.95±1.61
	Denbola	45.95 ^{a-d} ±0.77	36.98 ^{ab} ±1.40	85.60 ^{ab} ±1.03	68.48 ^a ±1.89	89.44 ^a ±0.95	72.96 ^{ab} ±1.57	66.57±1.27
	Liben	41.11 ^{cde} ±1.60	33.66 ^{ab} ±1.06	79.40 ^{bc} ±2.18	59.27 ^{ab} ±1.06	82.60 ^{abc} ±1.06	69.92 ^{abc} ±1.06	60.99±1.34
	Sankera	42.65 ^{b-e} ±2.22	30.22 ^b ±1.56	76.80 ^{b-e} ±1.74	56.80 ^{bc} ±2.22	68.16 ^{de} ±1.85	62.67 ^{cd} ±1.82	56.22±1.90
	Kunzla	40.07 ^{cde} ±1.65	32.00 ^{ab} ±1.39	72.08 ^{de} ±1.87	54.57 ^{bc} ±2.29	74.64 ^d ±1.46	68.40 ^{abc} ±1.87	57.09±1.76
Takusa	Ayibga	30.82 ^{fg} ±1.44	20.00 ^c ±1.44	48.00 ^{fg} ±3.02	36.00 ^{fg} ±2.68	60.53 ^{ef} ±1.70	42.93 ^{fg} ±3.12	39.71±2.23
	Chach	24.59 ^g ±1.03	18.67 ^c ±1.01	74.40 ^{cde} ±1.50	52.00 ^{bcd} ±1.70	72.00 ^d ±1.51	54.93 ^{de} ±1.85	49.43±1.43
	Kurabas	36.89 ^{ef} ±1.04	22.82 ^c ±1.25	75.20 ^{cde} ±1.71	56.00 ^{bc} ±1.83	67.20 ^{de} ±1.71	60.53 ^{cd} ±1.60	50.29±1.52
	Mekonta	27.56 ^g ±1.16	20.54 ^c ±0.98	53.76 ^{fg} ±2.01	41.33 ^{d-g} ±3.96	65.76 ^{de} ±1.95	50.93 ^{ef} ±1.81	43.31±1.98
West Dembiya	Guarhie	31.11 ^{fg} ±1.13	20.00 ^c ±0.94	79.20 ^{bc} ±1.80	48.00 ^{cde} ±2.44	80.00 ^c ±1.56	49.87 ^{ef} ±1.45	51.36±1.55
	Narchecha	29.78 ^{fg} ±1.18	20.67 ^c ±1.00	69.33 ^{de} ±1.39	46.80 ^{c-f} ±1.69	70.40 ^d ±1.65	48.80 ^{ef} ±2.65	47.63±1.59
	Sankisa	28.59 ^g ±1.69	21.78 ^c ±1.44	69.07 ^{de} ±1.38	41.20 ^{d-g} ±1.79	70.67 ^d ±1.59	45.60 ^{fg} ±2.75	46.15±1.77
Dangila	Bataberayeta	10.67 ^h ±0.97	19.85 ^c ±1.00	50.93 ^{fg} ±1.48	33.33 ^a ±0.84	50.67 ^g ±2.26	39.20 ^a ±1.05	34.11±1.32
	G.T. hyemanote	12.30±1.23	20.30±1.06	48.00±2.4	30.95±0.95	52.80±2.21	41.29±0.94	35.54±1.45
	Gunderi	16.29 ^h ±1.65	20.74 ^c ±1.12	45.07 ^g ±3.32	40.80 ^{efg} ±0.97	54.93 ^{fg} ±2.15	44.00 ^{fg} ±1.35	36.97±1.76
	Z. kidanemeheret	13.93 ^h ±1.49	20.89 ^c ±1.55	57.07 ^f ±1.81	33.33 ^a ±1.15	55.73 ^{fg} ±2.01	43.73 ^{fg} ±0.83	37.45±1.47
	Mean±SE	33.33±1.34	27.08±3.47	68.77±1.85	51.58±1.92	71.79±1.58	56.96±1.71	51.83±1.59

Means with the same letter in a column shows there is no significant difference

Bataberayeta consistently showed low incidence and severity for all types of blast disease, making it one of the least affected kebeles. Over the years, the districts of Jabi Tehnan and Semien Achefer contained the most severely affected kebeles, while Dangila experienced the lowest disease levels. These variations likely reflect differences in agro-climatic conditions, susceptibility of crop variety and agronomic management practices. The prevalence and severity of finger millet blast differed among various fields and locations, affected by unique geographical and environmental factors. Specifically, the disease was more widespread during the 2022 growing season compared to 2023, primarily due to more favorable environmental conditions (temperature, rainfall, and relative humidity) for blast epidemics in some districts in 2022. The increased occurrence and severity of the disease in the mid-altitude districts of Jabi Tehnan and Semien Achefer can be attributed to poor agronomic practices of farmers including using susceptible varieties, late sowing, high plant density, poor crop rotation and less weeding activities together with less disease management activities and climatic related factors such as higher temperatures, increased rainfall and elevated humidity, which are more pronounced in these districts. Previous findings by Odeph et al. (2020), Oduori (2008), and Getachew Gashaw et al. (2014) revealed the wide distribution of the disease in areas such as Busia, Teso, Kisii, East and West Wollega, Metekel, Awi and West Gojam. Additionally, Owere (2013) indicated that finger millet blast is endemic in all regions that cultivate finger millet in Uganda, with the severity of the disease varying according to local climatic conditions. Zhang *et al.* (2016) further highlighted that blast disease is prevalent globally, impacting over 85 countries, with finger millet and rice as the primary hosts of the blast causing pathogen *M. grisea*. Finger millet blast exhibited notable variation in its prevalence across various farms, areas and districts, leading to its division into two main categories: widely distributed and less dispersed. The disease was more prevalent in the West Gojam, and North Gojam zones, especially in the Jabi Tehnan and Semien Achefer districts, in contrast to the Awi and Central Gondar

zones (which include Dangila, Takusa and West Dembiya districts), where its spread was limited. Onyango (2016); Jemal Tola and Tesfaye Gudisa (2021) indicated that the distribution of blast disease is largely determined by favorable ecological conditions, such as consistent and well-distributed rainfall.

In the districts of Jabi Tehnan and Semien Achefer, situated at elevations ranging from approximately 1947 to 1950 meters and 1981 to 1990 meters above sea level, the average temperatures throughout the growing seasons were recorded at 28.64°C in 2022 and 27.15°C in 2023 for Jabi Tehnan, and 25.71°C in 2022 and 24.07°C respectively. The elevated temperatures and humidity in these districts may create conducive conditions for the blast pathogen, that maintains a constant availability of blast spores in the air throughout the year, promoting the disease's development (Onyango, 2016).

Moreover, many finger millet fields in the districts of Jabi Tehnan and Semein Achefer are bordered by tall indigenous trees, which increase humidity levels and limit sunlight, raising microclimatic conditions that are favorable for the blast pathogen (Getachew Gashaw et al., 2014).

The patterns observed in western Ethiopia align with findings from other regions where finger millet is cultivated. In western Kenya, the occurrence of blast disease was notably high in important finger millet growing areas, influenced by factors such as rainfall, altitude, planting density, intercropping and farming methods. Farmers in these areas showed lack of knowledge regarding the identification, transmission and management of the disease, highlighting the need for targeted education and tailored management approaches for different agroecological regions (Mbinda et al., 2021). In a similar vein, Odeph et al. (2020) noted yield losses between 20% and 50% in Kenya, with total crop failure in severe instances. In Uganda, Owere (2013) found that blast disease was widespread, with its severity influenced by local climatic conditions. These results emphasize the broad impact of the disease and underline the necessity for management strategies tailored to specific districts, particularly those heavily

impacted such as Jabi Tehnan and Semien Achefer. The origins of the finger millet blast pathogen may play a role in the expanding prevalence of the disease in the surveyed areas. In sub-Saharan Africa, populations of *M. grisea* have infected both rice and finger millet, displaying unique genetic variations, mating-type distributions, reproductive statuses and host compatibilities (Odeph et al., 2020). These variations reflect the varied histories and agricultural methods of these crops throughout East Africa (Takan et al., 2012).

Shittu (2018) has reported that genetic variation, influences the frequency of *M. grisea* isolates. The research indicated that gene flow between rice and other hosts of *M. grisea* is linked to the presence of such elements, providing crucial insights into the population dynamics of the pathogen. Furthermore, studies on the genetics of the finger millet blast fungus have demonstrated that *M. grisea* populations associated with finger millet from Japan, Nepal, India and several West African countries consistently harbor the *grh* element (Viji et al., 2000; Tanaka et al., 2007). The genetic diversity and adaptability of *M. grisea* are essential for its widespread presence and the varying intensity of finger millet blast disease.

PCR analysis has indicated that certain native blast populations in East Africa are genetically different from Asian strains, particularly in their absence of the *grh* repeat element that is found in the latter. Most isolates from East Africa lack this element, implying that the pathogen may have been imported from other areas, possibly via the cross-border transfer of finger millet seeds. This is further supported by the observation that *M. grisea* isolates containing the *grh* repeat element are more recent arrivals (Takan et al., 2012; Shittu, 2018). The movement of seeds and spore dispersal via wind across regions like Ethiopia, Kenya and Uganda underscores the need to understand both the genetic makeup of the pathogen and the influence of human activities on influential the epidemiology of the disease. The existence of certain haplotypes in various regions of Kenya and Uganda provides further support to this concept (Lenne et al., 2007).

The incidence of the disease is significantly higher in locations such as Jabi Tehnan, Siemen Achefer, and West Dembiya, which are in closer proximity to areas like Wollega, Benishangula and Sudan. This closeness implies that human actions, including seed exchange and wind-based spore dispersal, play a major role in the spread of the disease. Moreover, practices such as buying seeds from local markets or borrowing them from neighbors may facilitate the spread of the disease, both within the survey region and in other parts of Ethiopia.

Despite the high prevalence and devastating nature of blast disease, lack of disease management practices like inappropriate fungicide use was noted in many districts. This deficiency may be due to broader challenges, including limited awareness and access to control measures, small farmers in East Africa (Onyango, 2016). Constraints in resources and knowledge regarding available management options further limit the use of fungicides for economically significant diseases like blast (Odeh, 2023). The observed inappropriate fungicide application and lack of effective disease management practices in the evaluated districts highlights the pressing need for raising awareness and improved access to resources. Poor crop and weed management aggravates the problem. For instance, in Dangila, 81.25% of farmers reported weeding only once, permitting weeds to compete with finger millet and possibly harbor the disease. Weeds also increase plant density, and hinder airflow, increasing disease pressure (Kumar *et al.*, 2025). This underscores the necessity for comprehensive IDM strategies that involve resistant varieties, maintaining planting population (density), timely planting, non-host crop rotations (such as legumes), proper residue management, proper weeding and fungicide application (Gupta *et al.*, 2017). Additionally, it is crucial to educate farmers on disease management techniques to promote the adoption of sustainable disease management strategies and achieve long-term disease control across various districts (Mbinda *et al.*, 2021).

2.4 Conclusion and Recommendations

Finger millet blast disease has been detected across districts at various severity levels. The districts with the highest occurrences were Jabi Tehnan and Siemen Achefer may due to favorable agro climatic factors for the disease epidemics and poor farming and agronomic practices, while the lowest severity levels were noted in West Dembiya, Takusa, and Dangila districts. The incidence of the disease ranged from 15.21% to 56.28% and severity 36.75 to 86.98% respectively. This level of disease severity is very high and calls for the urgent need to increase efforts in developing and implementing sustainable management strategies. Additionally, consistent monitoring of finger millet blast is essential to help farmers providing timely recommendations for management practices. This study establishes a foundation for prioritizing research and policy initiatives directed at controlling finger millet blast. To sustain the livelihoods of subsistence farmers in the study area, and similar agro ecological zones, a holistic approach to disease management that incorporates resistant varieties and suitable agronomic practices is required. During the field evaluation, multiple insect pests and other ailments were noted. Consequently, additional research is required to evaluate, recognize, and effectively control these pests and diseases.

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Chapter 3. CHARACTERIZATION OF *Magnaporthe grisea* ISOLATES CAUSING FINGER MILLET BLAST IN WESTERN AMHARA, ETHIOPIA

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Abstract

Finger millet (*Eleusine coracana* L. (Gaertn) is an essential cereal crop cultivated in Ethiopia including in the study area, appreciated for its nutritional value and drought resistance. Nevertheless, Finger Millet Blast disease caused by *Magnaporthe grisea* is significantly reducing its yield and yield components. This research aimed to characterize *Magnaporthe grisea* isolates obtained from diseased plant samples collected from key finger millet farming areas in Northwest Amhara. During field assessments, infected plant samples were collected, air-dried, and individually packaged for pathogen isolation and characterization. Cultural and morphological data were analyzed using SPSS to ensure objective comparison and accurate interpretation of isolate differences. About 19 *Magnaporthe grisea* isolates were selected based on their morphological and growth traits. Of the four-culture media tested oatmeal agar promoted the best mycelial growth and sporulation, followed by host seed agar. Most isolates demonstrated optimal growth at a temperature of 30 °C and a pH of 6.5 and in the presence of dextrose and NaNO₃. Pathogenicity varied widely, with Mg83 displaying the highest disease severity and Mg96 the lowest. These

results help for understanding the biology of *Magnaporthe grisea*, and facilitate the development of future management approaches of the disease.

Key words: Culture, Morphology, Mycelium, Nutrition, Pathogenicity, Sporulation

3.1 Introduction

Finger millet (*Eleusine coracana* (L) Gaertn) is a major food grain crop for millions of people in Africa and India (Shinggu *et al.*, 2016). It is the most extensively grown millet in the world after foxtail millet (*Setaria italica*) and pearl millet (*Pennisetum glaucum*) (Upadhyaya *et al.*, 2007). Additionally, it is one of the most important plant genetic resources for farmers living on dry, infertile and marginal soils in terms of agriculture and food security (Odeny *et al.*, 2020). Finger millet has been cultivated for approximately 5,000 years in the highlands of East Africa, particularly in Ethiopia and western Uganda (Goron and Raizada, 2015). As an allotetraploid ($2n = 4x = 36$), it possesses high genetic variability, with thousands of accessions conserved worldwide (Kasule *et al.*, 2024).

The most economically important finger millet disease is blast, which is caused by the fungus *Magnaporthe grisea* (Anamorph; *Pyricularia grisea* (Herbert) Barr) (Mgonja *et al.*, 2007). Since finger millet is grown in semi-arid highland environments that favour blast disease under suitable humidity and temperature conditions (Mgonja *et al.*, 2013). The disease was initially reported in Asia over 3,000 years ago, and it has since spread worldwide, and host spot areas for the disease includes India and African countries including Kenya, and Ethiopia (Odeph *et al.*, 2020). Blast might result in yield losses of 50% in finger millet and 30% in rice (Prajapati *et al.*, 2013).

Magnaporthe grisea, exhibits strong indications of co-evolution within East Africa, and pathogen populations in Kenya and Uganda show extensive genetic diversity, with numerous haplotypes and nearly balanced mating-type, suggesting frequent sexual reproduction instead of clonal growth (Takan *et al.*,

2012). A study involving over 300 isolates identified approximately 243 distinct haplotypes, most of which are unique, with very few containing the “grasshopper” element typical of Asian lineages, supporting local diversification (Mgonja et al., 2007). Patterns in effector genes also demonstrate regional variations: Ethiopian isolates typically contain PWL1 and PWL2, while the majority of Kenyan and Ugandan isolates do not (Takan et al., 2012). Functional research indicates that variations in these effectors can influence host specificity (Masaki *et al.*, 2023). The high genetic diversity and on-going evolution of *M. grisea* underscore the importance of systematically characterizing both millet germplasm and pathogen populations to aid in the development of durable blast-resistant breeding strategies.

The overall study of morphological and cultural characteristics of *M. grisea* has revealed that the optimal growth conditions are 28 °C and at a pH of 6.5 on potato dextrose agar, and demonstrates improved growth with sodium nitrate-based media (Aakash *et al.*, 2024). The pathogenicity test could perform to confirm whether the pathogen isolates are the cause of finger millet blast, as well as to assess the virulence of the pathogen and varietal susceptibility. Research conducted in Ethiopia, such as Mebratu Gebremariam *et al.* (2015) on rice, and Getachew Gashaw *et al.* (2014) on finger millet has indicated that phenotypic variability among isolates related with differences in altitude, temperature, and humidity, coinciding with observed disease severity in fields. Cultural and morphological traits including colony structure, conidial size, sporulation, and in vitro growth are known to differ among isolates (Aneja, 2005). In addition, considering the high diversity and adaptability of *M. grisea* populations, as well as the suitable conditions for blast epidemics in Ethiopia, characterization of pathogen isolates is crucial to understanding its pathogenicity, diversity, evolution and to identify the most virulent isolates using various growth media, pH and temperature ranges, nutrient sources, and pathogenesis (Shanmugapackiam *et al.*, 2019). Thus the aim of this study is to characterize *M.*

grisea isolates that were collected from various finger millet growing districts of the Amhara region.

3.2 Materials and Methods

3.2.1 Description of the study areas

Disease plant samples were collected in three administrative zones: Viz. West Gojam, North Gojam, Awi and Central Gondar (Table 2.2). Samples were collected from September to November of 2022 during the main growing season. The sampling locations are found at altitudes ranging from 1789 to 2207 meters above sea level (m.a.s.l), between 10°39'41.4" and 12°09'05.2" North and 036°41'27.1" and 037°34'36.0" East (Appendix Table 3.1). The research area experiences rainfall ranging from 38.9mm to 1600mm. The average lowest and maximum temperatures of the research area ranged from 9°C to 34.4°C (Appendix Figure 2.2). The region is known for its mixed crop-livestock system, wherein finger millet is the main cereal crop grown with other cereals.

3.2.2 Collection of diseased plant samples

During the 2022 main rainy season, blast-infected tissue samples (leaf, neck and finger) of finger millet were obtained from sampling sites in the Amhara region of Ethiopia (Figure 2.2), during vegetative and physiological maturity stages. Sampling sites also included "hot spot" areas where the disease occurs frequently. For further analyses, samples were placed in individual bags, air-dried and kept at 4°C (Puri and Kumar, 2018).

3.2.3 Isolation and identification of *Magnaporthe grisea*

The pathogen isolation was performed following a normal tissue isolation procedure of Tuite (1969). To reduce surface pollutants, diseased plant tissues were cut from the edge of the affected region, split open longitudinally with a surgical blade and rinsed in tap water for two minutes to remove surface contaminants. After sterilizing the surface for a minute with 70% ethanol, it was cleaned three times with sterile distilled water to get rid of any remaining surface impurities and finally it was dried using sterilized filter paper (Aneja,

2007). In order to prevent the growth of undesirable bacterial contamination, the surface-sterilized tissues were immediately placed onto potato dextrose agar (PDA) supplemented with 60 mg/l Neuromycine sulphate obtained from Bahir Dar university, postgraduate microbiology researchers (Tredway *et al.*, 2003). Then, the Petri plates were incubated for 10 to 15 days at $27\pm1^{\circ}\text{C}$ in the dark until mycelia and conidia appeared. The isolates were purified by sub-culturing on PDA and kept on PDA slants at 4°C for later use. Based on their geographic origin (Gojam, Awi and Gondar) and isolate type (leaf, neck and finger portions of finger millet), 19 well-grown isolates were chosen from the total isolates (Table 3.1) and used for thorough cultural, morphological, physiological and biochemical characterization (Getachew Gashaw *et al.*, 2014). The selected *M. grisea* isolates were subculture on PDA slants and maintained at $27\pm1^{\circ}\text{C}$ for duration of 15 days. For future research, these isolates were refreshed periodically and kept in a refrigerator at 4°C (Bhojya, 2013; Gupta *et al.*, 2020).

3.2.4 Characterization of isolates and mycelial growth

The morphology of the mycelium and conidia (spore form, septation, color and growth pattern) were used to characterize the isolates of *M. grisea* (Rayner, 1970; Barnett and Hunter, 1998). Four media were used to study the growth characteristics of the isolates: Richards's agar (Oxoid), Potato dextrose agar, Oatmeal agar (OMA), and Host seed extract agar + 2% sucrose (HAS). For 15 minutes, all of the media were sterilized at 121°C . Each of the sterile Petri plates was filled with twenty to twenty-five milliliters of the respective medium. Fungal blocks of four mm in diameter from the mycelial mat were cut from the isolates of a 10-day pure culture margin and placed in the middle of Petri dishes containing all of the respective media. All the treatments were replicated three times. The centers of the fungal block and cross lines were made using permanent board markers on the lower underside of the plate. To prevent contamination, each plate was wrapped with Parafilm tape and incubated at $27 \pm 1^{\circ}\text{C}$. Ten days after incubation, the radial growth of the colony, growth rate and colony color were observed (Getachew Gashaw *et al.*, 2014). In addition, the

growth characteristics of the isolates including surface texture, pigmentation, mycelium color, color of the metabolite produced in the media and mycelial growth patterns (aerial, subdued and submerged or combination) and appearance (ringed, sectored, uniform, rough and smooth) were recorded (Babu, 2011). The colony diameter of each isolate on the Petri plates was measured in millimeters in two directions every two days using a transparent ruler. The measurements were taken and recorded on the tenth day of incubation. Additionally, the sporulation rate and margin types were recorded (Barnett and Hunter, 1998). Using lactophenol cotton blue mount procedures, sporulation was observed under a microscope starting five days after incubation and continuing every two days until thirty days following inoculation. An entire loop of culture was put on a sterile slide, thoroughly mixed with lactophenol, and covered with a cover slip. Next, the sporulation rate of each isolate on various medium was evaluated using 40X microscopic counts (Excellent >30; Good, 20-30; Fair, 10-20; Poor <10 and Nil-0) (Aneja, 2007).

Conidial characteristics served as the basis for morphological characterization. *M. grisea* isolates was cultured on PDA and incubated for ten days at $27\pm 1^{\circ}\text{C}$. The physical characters of each isolate including color, shape and size (length and width), were measured, and the number of septation on each conidia was counted under a microscope. Barnett and Hunter (1998) key manual was used to identify the isolates based growth characteristics. Under a light microscope, the spores on slides were examined following staining with lactophenol cotton blue. As stated by Meena (2007), ocular and stage micrometers were used to measure the size of conidia. To display the typical spore shape of the *M. grisea* isolates, images were obtained using smart phone fitted with 50 mega pixel camera (Muluadam Berhan *et al.*, 2024).

3.2.5 Physiological characterization of isolates

At various temperatures, the growth of *M. grisea* isolates was investigated. An inoculation of 30g malt extract +2.0g Dipotassium hydrogen phosphate +1.0g Ammonium chloride +15.0ml 1N Citric acid +12g Agar +1000ml Distilled

water was applied to a 4mm mycelial disc cut from a margin of an actively growing culture. The inoculation was then incubated in the dark for 10 days at five different temperature ranges (15, 20, 25, 30 and 35°C) replicated three times. Following the procedures of Gupta et al. (2020), the colony diameters of each isolate on plates were measured and the rate of sporulation was noted.

To examine the impact of pH on the growth of the pathogen, A 4 mm diameter mycelial disc inoculum was removed from the edge of a 10-day-old culture of the isolates cultured on PDA and added to 250 ml flasks containing 90 ml of potato dextrose broth (PDB). The pH of PDB was adjusted by 0.5 units, ranging from 4 to 7 using 1N HCl and 1N NaOH and using Vogel (1951) approach, dihydrogen phosphate citric acid buffer was used to set the medium to the appropriate pH. All the treatments were replicated three times and inoculated medium was incubated at $27 \pm 1^\circ\text{C}$. After 14-days incubation, the mycelial mats were extracted and collected from the filtrate using pre-weighed Whatman No. 42 filter paper. The adhering salts were removed by washing the mats with distilled water three times. After 48 hours of oven drying at 65°C , the dry weight of each isolate was measured using an electronic scale. The mycelial dry weight per culture was calculated by subtracting the weight of filter paper from the weight of filter paper plus mycelial mat (Meena, 2007).

3.2.6 Biochemical characterization of isolates

The ability of the isolates to use nitrogen and carbohydrates was examined using Richards's basal medium [Sucrose ($\text{C}_{12}\text{H}_{22}\text{O}_{11}$) 50.00 g, Potassium dihydrogen phosphate (KH_2PO_4) 5.00g, Potassium nitrate (KNO_3) 10.00g, Magnesium sulphate ($\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$) 2.50 g, Ferric chloride ($\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$) 0.02g, agar 20.0g and distilled water (to make up) 1000ml] (Ainsworth, 1981), by substituted the carbon sources with 50.0g of each of the following: fructose, sucrose, maltose and Dextrose, and the nitrogen sources with 10.0g of each of the following: KNO_3 , NaNO_3 , L-arginine monohydrochloride and L-glycine (Getachew Gashaw et al., 2014). After being thoroughly dissolved, all the carbon and nitrogen sources were sterilized for 15 minutes at 121°C . Four mm mycelial

discs were cut from the periphery of a pure 10 days old culture using a sterile cork borer. The discs were then inoculated into Petri plates that contained prepared and sterilized medium, and the plates were incubated at $27 \pm 1^\circ\text{C}$ for 10 days. The colony diameter of the tested isolates on a plate was measured (Getachew Gashaw et al., 2014).

3.2.7 Pathogenicity test

To assess the pathogenicity of *M. grisea* isolates, an open-field study was conducted in August at the Department of Biology, Bahir Dar University, using the susceptible finger millet variety Boneya obtained from Adet Agricultural Research Center (AdARC), during the time when disease occurrences in the farmers field (Srivastava *et al.*, 2014; Ashrafi *et al.*, 2021).

Prior to planting, the seeds were soaked three times in sterilized distilled water (SDW) to eliminate surface-contaminated microorganisms, after being surface sterilized for five minutes with a 2% sodium hypochlorite solution (Duggar and Davis, 1919). The seeds were planted in 15 cm diameter plastic pots containing 3.5 kg of soil replicated three times. The pots were then kept in a completely randomized design (CRD), and each pot was watered with 200 ml of tap water early in the morning at three days interval. To maintain 10 plants per pot, seedlings were thinned at the one-leaf stage (Babu, 2011). Six mm mycelial discs of each isolate were taken from a 7-day-old culture of *M. grisea* that was maintained at $27 \pm 1^\circ\text{C}$ on OMA medium. To obtain mass multiplication of spores for inoculation, each isolate was grown for 15 days at $27 \pm 1^\circ\text{C}$ on OMA medium. After 10 milliliters of distilled water were added to the plates, the fungal growth which contained mycelium and conidia was scraped off using a sterile spatula. To release the conidia into the water, 30 ml spore suspension of each isolate was added to a 100 ml conical flask and well mixed by vortexing. The harvested spores were filtered through a double-layer muslin cloth, and the concentration was adjusted to 1×10^{-5} conidia/ml. Just before the inoculation, Tween 80 (0.2%) was added to the solution as an adjuvant, and the inoculum was sprayed on the leaves of 15-day-old pot-grown seedlings using a hand-operated atomizer to

artificially inoculate them. To prevent the spores from being dislodged, the inoculated plants were allowed to partially dry for 30 minutes, while the control group consisted of seedlings that were sprayed with water. After seven days of spraying, the leaf blast severity of each isolate was recorded using a progressive 1–9 scale. Re-isolating from the artificially inoculated was done to confirm Koch's postulates (Babu, 2011).

3.2.8 Statistical analysis

The statistical analysis of the growth characteristics of the isolates at various media, temperatures and pH as well as mean comparisons of the isolates based on various parameters were carried out using the one-way ANOVA procedures of SPSS statistical analysis software version 23. Mean comparisons of each treatment were carried out using Turkey's Honestly Significant Difference (HSD) ($\alpha=0.05$).

3.3 Results and Discussion

3.3.1 Isolation of the pathogen

From a total of 966 diseased plant samples collected (Appendix Table 3.1), and 558 cultured in the isolation media (PDA), 376 pure *Magnaporthe grisea* (Mg) isolates were obtained (Appendix Table 3.2). For intensive characterization, nineteen isolates were chosen based on their origin of location, source of plant tissues and the cultural and morphological radial growth characteristics of the test pathogen. The isolates selected are coded as Mg5, Mg8, Mg15, Mg16, Mg27, Mg38, Mg39, Mg68, Mg70, Mg75, Mg83, Mg96, Mg99, Mg109, Mg116, Mg121, Mg140, Mg147, and Mg149 (Table 3.1; Figure 3.1).

Table 3.1. Mg isolates codes along with their respective collection sources

S. No	Isolate code	Source of collection	Plant part	S. No	Isolate code	Source of collection	Plant part
1	Mg5	Zabatsion	Leaf	11	Mg83	Adet	Neck
2	Mg8	Abasem zeguaye	Leaf	12	Mg96	Amebeshen	Head
3	Mg15	Denbola	Leaf	13	Mg99	Sankera	Neck
4	Mg16	Mankussa abedgoma	Leaf	14	Mg109	Abasem zeguaye	Neck
5	Mg27	Baker abater	Leaf	15	Mg116	Dangila	Head
6	Mg38	Liben	Leaf	16	Mg121	Dangila	Neck
7	Mg39	Sankera	Head	17	Mg140	Mekonta	Head
8	Mg68	Zabatsion	Head	18	Mg147	Sankisa	Neck
9	Mg70	Sankera	Neck	19	Mg149	Kurabas	Neck
10	Mg75	Guarhie	Leaf				

Mg- *Magnaporthe grisea*

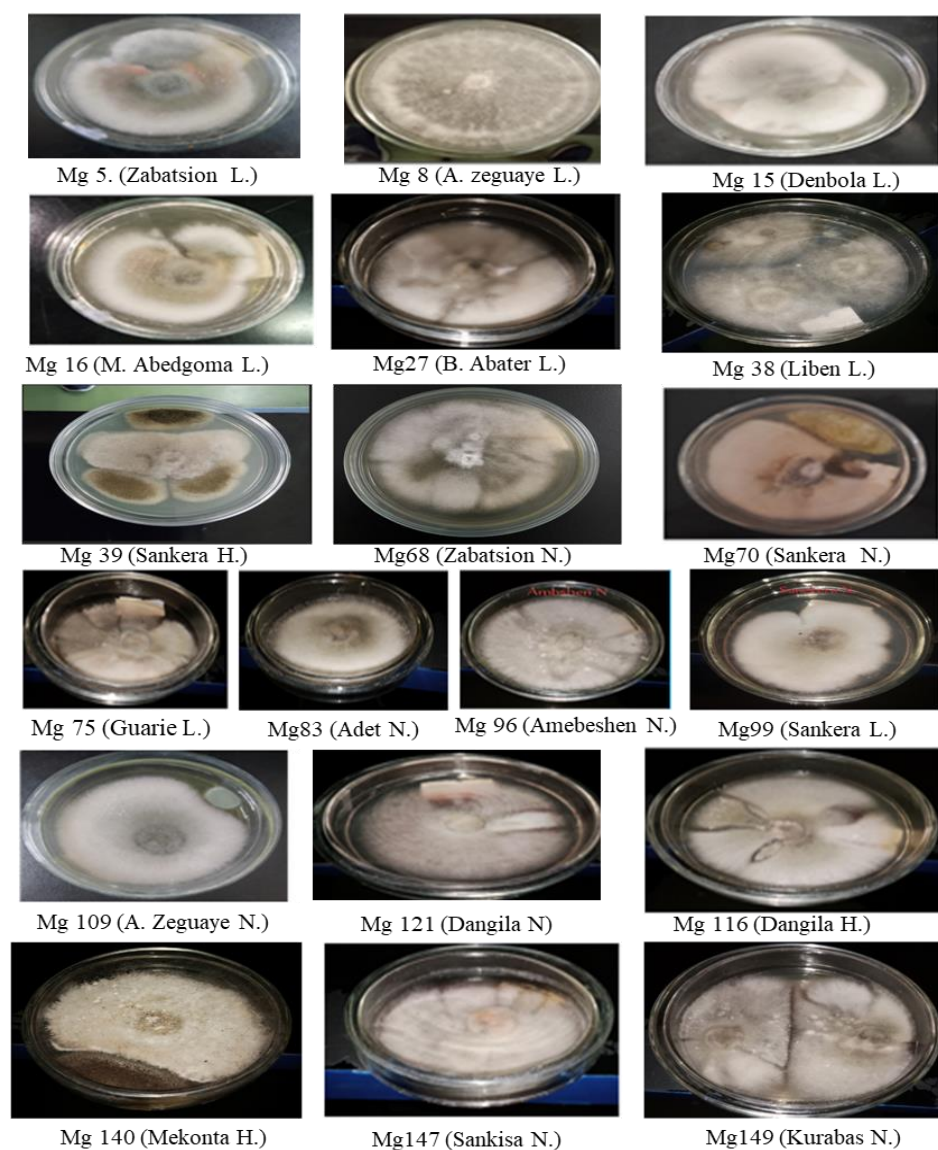


Figure 3.1. Cultural characteristics of the *M. grisea* isolates selected for detail study

3.3.2 Conidial characteristics of the *M. grisea* isolates

The conidial features of the *M. grisea* isolates, summarized in Table 3.2 indicated considerable variability among the isolates regarding septation, shape, size and the colour of both conidial mass and conidiophores.

Table 3.2. Conidial Characteristics of the *M. grisea* Isolates

Isolates	Septation	Shape	Mean Size (μm^2)	Colour
Mg5	3	Obclavate	23.43 ± 4.20 (L) ^b , 9.00 ± 1.20 (W) ^a	Grey conidial mass; light brown conidiophores
Mg8	3	Obclavate	19.73 ± 3.90 (L) ^a , 9.00 ± 1.30 (W) ^a	Greyish-black conidial mass; black conidiophores
Mg15	2	Pyriform	18.57 ± 4.40 (L) ^b , 8.83 ± 1.12 (W) ^a	Pale grey conidial mass; medium brown conidiophores
Mg16	3	Obclavate	20.30 ± 4.00 (L) ^a , 8.90 ± 1.10 (W) ^a	Greyish-white conidial mass; light grey conidiophores
Mg27	3	Obclavate	19.08 ± 3.85 (L) ^a , 8.85 ± 1.10 (W) ^a	Greyish-black conidial mass; black conidiophores
Mg38	2	Pyriform	17.43 ± 4.00 (L) ^b , 8.90 ± 1.10 (W) ^a	Grey conidial mass; dark brown conidiophores
Mg39	3	Obclavate	19.47 ± 3.95 (L) ^a , 9.00 ± 1.30 (W) ^a	Dark grey conidial mass; black conidiophores
Mg68	2	Pyriform	19.60 ± 4.10 (L) ^a , 8.95 ± 1.15 (W) ^a	Whitish-grey conidial mass; medium grey conidiophores
Mg70	3	Obclavate	17.55 ± 4.00 (L) ^b , 8.95 ± 1.15 (W) ^a	Grey conidial mass; dark grey conidiophores
Mg75	2	Pyriform	16.87 ± 3.85 (L) ^b , 7.05 ± 1.25 (W) ^b	Greyish-white conidial mass; light brown conidiophores
Mg83	2	Pyriform	16.38 ± 4.15 (L) ^b , 7.10 ± 1.20 (W) ^b	Whitish-grey conidial mass; light grey conidiophores
Mg96	3	Obclavate	18.78 ± 4.10 (L) ^a , 8.90 ± 1.20 (W) ^a	Pale grey conidial mass; medium brown conidiophores
Mg99	2	Pyriform	17.20 ± 4.80 (L) ^b , 7.15 ± 1.20 (W) ^b	Grey conidial mass; dark brown conidiophores
Mg109	2	Pyriform	23.41 ± 3.82 (L) ^b , 9.13 ± 1.24 (W) ^a	Greyish-white conidial mass; light grey conidiophores
Mg116	3	Obclavate	17.78 ± 4.00 (L) ^a , 8.85 ± 1.13 (W) ^a	Greyish-black conidial mass; dark brown conidiophores
Mg121	2	Pyriform	16.28 ± 4.25 (L) ^b , 7.10 ± 1.15 (W) ^c	Whitish-grey conidial mass; light brown conidiophores
Mg140	3	Obclavate	18.53 ± 4.50 (L) ^b , 8.90 ± 1.30 (W) ^a	Grey conidial mass; dark grey conidiophores
Mg147	2	Pyriform	17.55 ± 3.60 (L) ^b , 9.05 ± 1.15 (W) ^a	Greyish-black conidial mass; dark grey conidiophores
Mg149	2	Pyriform	16.75 ± 3.90 (L) ^b , 7.05 ± 1.20 (W) ^b	Greyish-white conidial mass; light grey conidiophores

The isolates present two categories of septation: 2-septate (like Mg109, Mg121, Mg15, and Mg147) and 3-septate (such as Mg116, Mg140, Mg39, and Mg27) (Figure 3.2).

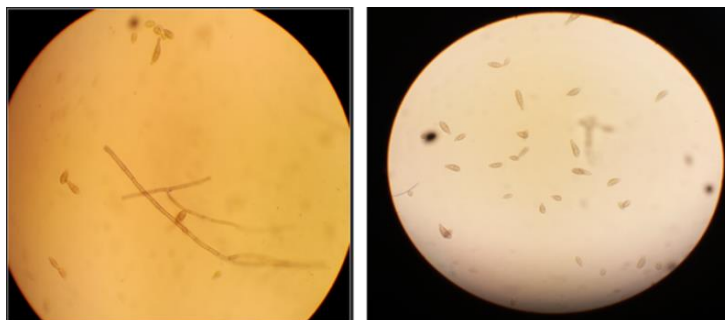


Figure 3.2. Observation of conidia under binocular microscope

This observation aligns with the research conducted in India by Shanmugapackiam et al. (2019), who documented comparable septation patterns in *M. grisea* isolated from finger millet. They identified septation as a crucial characteristic for morphological identification. Adhikari and Sudisha Jogaiah (2020) also indicated the prevalence of 2-septate conidia over 3-septate forms, although both types were present among field isolates of ragi blast in India. This morphological variability is essential for a comprehensive understanding of the taxonomy and pathogenic potential of isolates. In addition, two main shapes were identified: Pyriform observed in isolates such as Mg109, Mg121, Mg83 and Mg149. Obclavate was seen in isolates such as Mg116, Mg140, Mg39, and Mg70 regardless of their origin of disease sample collection. Puri and Kumar (2018) also reported similar morphological diversity, where pyriform conidia were predominant over obclavate. Besides, the average length of conidia varied from 16.28µm (Mg99) to 23.43 µm (Mg109), whereas the width showed less variation, on average 9.00 µm for all isolates. Variations in size within isolates was also reported by Mebratu Gebremariam et al. (2015) who documented lengths ranging from 20 to 26 µm and widths from 8 to 10 µm for *Pyricularia oryzae* isolates in Ethiopia. Notably, Mg140, Mg39, Mg8 and Mg5 displayed longer conidial lengths compared to other isolates. Odeph *et al.* (2021) highlighted similar size ranges in isolates from Kenya. Importantly, longer conidia were associated with increased virulence (Choi *et al.*, 2013).

Moreover, the conidial mass exhibited a colour spectrum from greyish-white (Mg109, Mg75) to greyish-black (Mg116, Mg8 and Mg27). Similarly, the colour of the conidiophores varied, ranging from light grey (Mg16) to black (Mg39, Mg8). These colour variations are consistent with the findings of Mior *et al.* (2017), who observed that conidial pigmentation can differ from light to dark. Furthermore, the observed variability in the pigmentation of conidia and conidiophores is consistent with Palanna (2024) who found that darker pigmentation is the dominant characteristic of most isolates.

3.3.3 Cultural characteristics of isolates on different growth media

The research regarding the blast pathogen *M. grisea* indicated that the four widely used and recommended culture media for the growth of the blast pathogen, including HSA, OMA, PDA and Richard's agar had a significant impact on its morphological characteristics, growth patterns and sporulation rates (Table 3.3).

Table 3.3. Effect of different culture media on colony characters, and sporulation of *M. grisea*, isolates

Isolate	Media	Colony colour	Surface texture	Margin	Pigmentation	Mycelial growth	Growth rate	Sporulation
Mg5	HSA	Grayish white	Velvety	undulate	Black	Combination	Good	Fair
Mg8	HSA	Grey	Cotony	entire	Dark brown	Combination	Good	Fair
Mg15	HSA	Grayish white	Velvety	undulate	Dark brown	Combination	Good	Good
Mg16	HSA	Black	Velvety	filamentous	Light brown	Submerged	Good	Good
Mg27	HSA	Grayish white	Velvety	entire	Black	Flat	Good	Good
Mg38	HSA	Black	Cotony	entire	Black	Aerial	Medium	Fair
Mg39	HSA	Grayish white	Cotony	undulate	Dark brown	Aerial	Good	Good
Mg68	HSA	Grayish white	Cotony	undulate	Black	Aerial	Medium	Poor
Mg70	HSA	Grey	Cotony	undulate	Black	Combination	Good	Excellent
Mg75	HSA	Grayish white	Cotony	entire	Dark brown	Combination	Good	Excellent
Mg83	HSA	Grayish white	Velvety	entire	Dark brown	Aerial	Medium	Poor
Mg96	HSA	Grayish white	Cotony	entire	Black	Aerial	Medium	Good
Mg99	HSA	Grayish white	Velvety	undulate	Light brown	Combination	Good	Good
Mg109	HSA	Dark grey	Fluffy	undulate	Dark brown	Combination	Good	Excellent
Mg121	HSA	Grayish white	Velvety	entire	Black	Combination	Medium	Excellent
Mg116	HSA	Black	Cotony	entire	Black	Combination	Medium	Fair
Mg140	HSA	Grayish white	Cotony	entire	Dark brown	Submerged	Medium	Fair
Mg147	HSA	Grey	Cotony	entire	Black	Aerial	Good	Good
Mg149	HSA	Grayish white	Cotony	entire	Light brown	Flat	Good	Fair
Mg5	OMA	Off white	Velvety	undulate	Dark brown	Combination	Good	Fair
Mg8	OMA	Off white	Fluffy	entire	Dark brown	Combination	Good	Fair
Mg15	OMA	Off white	Velvety	undulate	Dark brown	Combination	Medium	Excellent
Mg16	OMA	Grayish white	Velvety	undulate	Dark brown	Combination	Good	Good
Mg27	OMA	Grayish white	Velvety	entire	Dark brown	Flat	Good	Good
Mg38	OMA	Grayish white	Velvety	entire	Dark brown	Combination	Good	Good
Mg39	OMA	Off white	Fluffy	undulate	Dark brown	Combination	Good	Excellent
Mg68	OMA	Off white	Fluffy	undulate	Dark brown	Combination	Good	Excellent
Mg70	OMA	Off white	Fluffy	undulate	Dark brown	Aerial	Good	Good
Mg75	OMA	Off white	Velvety	entire	Dark brown	Combination	Good	Good
Mg83	OMA	Off white	Fluffy	entire	Dark brown	Combination	Good	Excellent
Mg96	OMA	Off white	Cotony	entire	Dark brown	Aerial	Good	Excellent
Mg99	OMA	Grayish white	Cotony	undulate	Dark brown	Aerial	Good	Fair
Mg109	OMA	Grayish white	Cotony	undulate	Light brown	Aerial	Good	Fair
Mg116	OMA	Grayish white	Fluffy	entire	Light brown	Combination	Good	Good
Mg121	OMA	Off white	Cotony	entire	Light brown	Aerial	Medium	Excellent
Mg140	OMA	Grayish white	Cotony	entire	Brown	Aerial	Good	Excellent
Mg147	OMA	Off white	Fluffy	entire	Dark brown	Aerial	Good	Good
Mg149	OMA	Grayish white	Cotony	entire	Dark brown	Flat	Good	Fair
Mg5	PDA	Grey	Velvety	undulate	Dark brown	Submerged	Medium	Good
Mg8	PDA	Pale grey	Velvety	entire	Dark brown	Submerged	Good	Poor
Mg15	PDA	Grey	Fluffy	undulate	Black	Aerial	Medium	Good
Mg16	PDA	Grey	Cotony	undulate	Black	Aerial	Good	Fair

Mg27	PDA	Grayish white	Velvety	undulate	Black	Flat	Good	Fair
Mg38	PDA	Dark grey	Fluffy	undulate	Dark brown	Aerial	Medium	Poor
Mg39	PDA	Dark grey	Velvety	undulate	Dark brown	Aerial	Medium	Excellent
Mg68	PDA	White	Cottony	undulate	Dark brown	Aerial	Medium	Poor
Mg70	PDA	Dark grey	Cottony	entire	Black	Aerial	Medium	Excellent
Mg75	PDA	Dark grey	Fluffy	undulate	Dark brown	Submerged	Good	Good
Mg83	PDA	Grey	Cottony	entire	Dark brown	Aerial	Medium	Fair
Mg96	PDA	Pale grey	Fluffy	undulate	Black	Flat	Medium	Poor
Mg99	PDA	Dark grey	Velvety	undulate	Dark brown	Aerial	Good	Fair
Mg109	PDA	Grey	Fluffy	entire	Black	Aerial	Medium	Excellent
Mg121	PDA	Grayish white	Cottony	undulate	Black	Aerial	Good	Fair
MG116	PDA	Dark grey	Fluffy	undulate	Light brown	Aerial	Good	Fair
Mg140	PDA	Grey	Cottony	undulate	Black	Aerial	Medium	Fair
Mg147	PDA	Dark grey	Fluffy	undulate	Dark brown	Submerged	Good	Poor
Mg149	PDA	Grayish white	Fluffy	undulate	Brown	Submerged	Medium	Fair
Mg5	R. Agar	Grey	Velvety	Undulate	Light brown	Combination	Medium	Fair
Mg8	R. Agar	Grey	Velvety	Entire	Light brown	Submerged	Medium	Fair
Mg15	R. Agar	Off white	Velvety	Undulate	Dark brown	Combination	Good	Good
Mg16	R. Agar	Grayish white	Velvety	Entire	Dark brown	Submerged	Good	Fair
Mg27	R. Agar	Grayish white	Velvety	Entire	Black	Flat	Good	Fair
Mg38	R. Agar	Black	Fluffy	Undulate	Black	Aerial	Medium	Poor
Mg39	R. Agar	Grayish white	Cottony	Undulate	Dark brown	Combination	Good	Good
Mg68	R. Agar	Off white	Fluffy	Undulate	Light brown	Aerial	Medium	Fair
Mg70	R. Agar	Grey	Cottony	Entire	Black	Aerial	Good	Excellent
Mg75	R. Agar	Grayish white	Fluffy	Entire	Dark brown	Combination	Good	Good
Mg83	R. Agar	Grayish white	Cottony	Entire	Dark brown	Aerial	Medium	Poor
Mg96	R. Agar	Grey	Fluffy	Undulate	Light brown	Flat	Medium	Fair
Mg99	R. Agar	Dark grey	Velvety	Undulate	Light brown	Combination	Medium	Good
Mg109	R. Agar	Grey	Fluffy	Entire	Light brown	Aerial	Medium	Good
Mg121	R. Agar	Grayish white	Cottony	Entire	Dark brown	Aerial	Medium	Fair
MG116	R. Agar	Grayish white	Fluffy	Entire	Dark brown	Combination	Good	Good
Mg140	R. Agar	Grayish white	Cottony	Entire	Dark brown	Aerial	Medium	Fair
Mg147	R. Agar	Grayish white	Fluffy	Entire	Black	Aerial	Good	Fair
Mg149	R. Agar	Grayish white	Fluffy	Entire	Light brown	Submerged	Medium	Fair
R. Agar- Richard's Agar								

In the HSA, most isolates display darker pigmentation, black, dark grey or greyish white, besides noticeable differences in the synthesis of coloured metabolites. On the other hand, on OMA, the colony colour is generally lighter, appearing as greyish or off-white, with a light brown pigmentation in the metabolites produced. On PDA, while some isolates (e.g., Mg109, Mg70 and Mg27) maintain black pigmentation, others exhibited dark brown (e.g., Mg38, Mg99) (Table 3.3). Richard's Agar typically yields intermediate pigmentation, with colonies appearing greyish white or grey and metabolites exhibiting light brown and these results agreed with the reports of Kushmitha *et al.* (2022). Research conducted by Shaw *et al.* (2019) indicated that darker pigmentation on PDA is attributed to an increased production of melanin-like substances in certain *M. grisea* isolates. A decrease in pigmentation when grown on nutrient-

rich media such as OMA and Richard's Agar, which may be associated to reduced metabolic activity induced by stress. The pigmentation of colonies is closely associated with stress conditions and the biosynthesis of melanin, both of which are vital for the virulence of the pathogen (Puri and Kumar, 2018). Media that offer higher carbon/nitrogen ratios, such as HSA and PDA are conducive to pigmentation (Shanmugapackiam et al., 2019).

On HSA, the colonies present two major textures, cottony and velvety, characterized by both aerial and submerged growth forms. In contrast, OMA predominantly features fluffy textures and aerial mycelial growth. On PDA, the isolates typically exhibit cottony textures, with aerial mycelium being prevalent in most isolates. Richard's Agar shows a predominance of fluffy and velvety textures, accompanied by a combination of aerial and submerged growth patterns (Table 3.3). Research by Tracyline *et al.* (2021) indicated that the nutrient composition of the media significantly affects colony texture. Media rich in nutrients, such as OMA and PDA are likely to yield fluffy textures due to increased hyphal growth. Additionally Sahu *et al.* (2018) observed that velvety textures are found in media that facilitate moderate growth rates, such as Richard's Agar.

The surface texture and growth patterns serve as indicators of the physiological adaptations of *M. grisea*. Aerial mycelium is often associated with the potential for sporulation, while submerged growth patterns reflect the availability of nutrients and their diffusion (Shanmugapackiam et al., 2019). The margins of fungal colonies demonstrate significant variability depending on the growth medium utilized. On OMA and Richard's Agar, entire margins are predominantly observed, whereas HSA and PDA tend to exhibit undulate or filamentous margins. Notably, HSA frequently presents sectorized and ringed morphologies, which may indicate growth patterns influenced by environmental stressors, while OMA is characterized by smoother and more consistent appearances (Adhikari and Sudisha Jogaiah, 2020).

Research by Soban Babu *et al.* (2021) indicated the existence of sectorized colonies and nutrient stress in semi-selective media such as HSA. Conversely, the smooth margins on OMA were attributed to a more favorable nutrient environment.

HSA demonstrates a remarkable capacity for promoting sporulation in isolates such as Mg109, Mg75 and Mg70, likely attributable to its specific nutrient composition that induces reproductive stress. OMA also facilitates good to excellent sporulation, particularly in isolates like Mg68 and Mg83. Richard's Agar encourages sporulation in isolates such as Mg15, Mg39 and Mg70, although it does not achieve the consistency observed with HSA or OMA (Table 3.3). Tracyline *et al.* (2021) reported that HSA and OMA favors sporulation due to their well-balanced nutrient profiles. In contrast, PDA supports sporulation in a limited range of isolates (e.g., Mg39 and Mg70) and generally yields moderate sporulation results for others. Shanmugapackiam *et al.* (2019) identified PDA as a not ideal medium for sporulation, that favors vegetative growth over reproductive processes.

Both HSA and OMA yield a variety of growth patterns (including both combination of sporulation and aerial growth) and exhibit favorable growth rates across most isolates. While, PDA favors rapid growth in certain isolates, often leads to suboptimal sporulation (e.g., Mg83, Mg96). Richard's Agar achieves a moderate balance between growth and sporulation (Table 3.3). Sporulation of isolates on OMA media was highly significant in comparison to other media, therefore, it was confirmed that OMA is an ideal media (Vanaraj *et al.*, 2013). The amount of sporulation among isolates vary depending on the source of plant tissue which they were isolated (Ou, 1985).

Soban Babu *et al.* (2021) found that media with low to moderate nutrient levels facilitate a favorable balance between growth and sporulation. In contrast, nutrient-rich media like PDA favor vegetative growth over reproductive processes.

The composition of the culture medium plays a crucial role in influencing the metabolic activities of fungi. There is an inverse correlation between sporulation and mycelial growth rates, which is affected by the availability of nutrients and the influence of environmental conditions (Akter, 2020; Palanna, 2024).

3.3.4 Effect of different culture media on mycelia growth of the pathogen isolates

The growth patterns of the fungal pathogen (*M. grisea*), which causes blast disease, are significantly influenced by the choice of culture media. Each type of culture medium offers distinct nutritional compositions, which in turn influenced growth rates, colony sizes, and the overall morphological characteristics of the fungal isolates. This investigation assessed the growth performance of *M. grisea* isolates across four different culture media: Oatmeal Agar (OMA), Host-Seed Agar (HSA), Potato Dextrose Agar (PDA), and Richard’s Agar (Figure 3.3, Appendix Table 3.2).

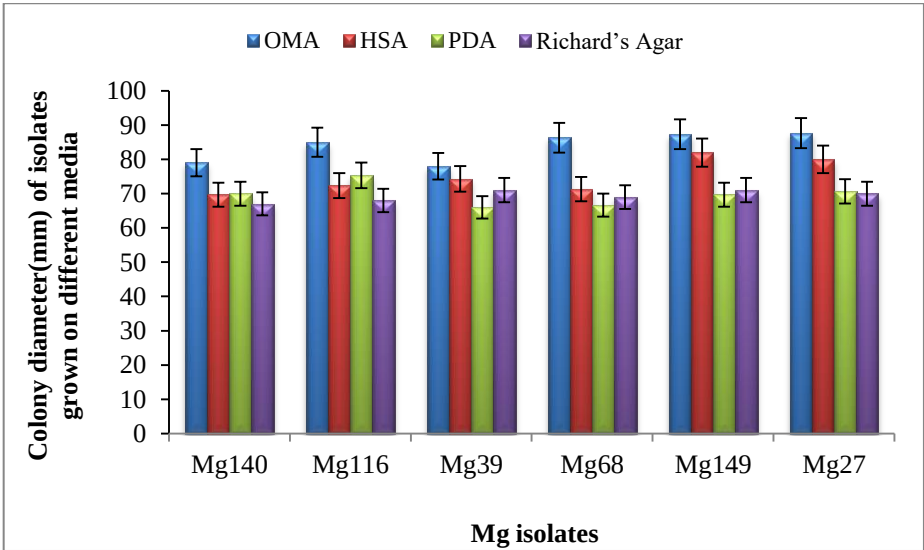


Figure 3.3. Evaluation of different culture media for the mycelial growth of *M. grisea* isolates

Among the four media tested, OMA consistently facilitated the largest colony diameters of most isolates. For example, isolate Mg68 achieved a maximum growth of 86.33 mm, while isolate Mg27 reached 87.67 mm (Figure 3.3, Appendix Table 3.2). Previous studies indicating that OMA carbohydrate-rich growth medium promotes fungal proliferation (Srivastava et al., 2014). HSA

demonstrated similar efficacy for certain isolates (e.g., Mg8, Mg15, Mg5), although it was less effective for others, such as Mg75, which recorded a growth of only 62.33 mm (Figure 3.3, Appendix Table 3.2). PDA resulted in moderate growth levels, likely due to its generic formulation, which is not ideal for *M. grisea* growth. For instance, isolate Mg121 exhibited a smaller colony diameter of 67.00 mm on PDA (Figure 3.3, Appendix Table .2). Richard's Agar providing optimal growth conditions for some isolates (e.g., Mg8 at 80.67 mm) while exhibiting less growth for others (e.g., Mg140 at 71.33 mm). This variability may be due to its nitrogen-rich formulation, which may favor certain isolates over others (Figure 3.3, Appendix Table 3.2).

A significant difference in growth patterns was noted among various isolates across all tested media, indicating that genetic variability may influence nutrient assimilation and adaptability. For instance, isolate Mg8 consistently exhibited larger colony diameters across all media, with a mean measurement of 82.67 mm, whereas Mg140 demonstrated the smallest mean growth at 70.92 mm (Figure 3.3, Appendix Table 3.2). These results align with the research conducted by Tracyline et al. (2021) which identified considerable genetic and phenotypic variability among *M. grisea* isolates.

The average colony diameters varied from 70.92 mm for Mg140 to 82.67 mm for Mg8 (Figure 3.3, Appendix Table 3.2), suggesting media composition, and isolate-specific characteristics interact to affect growth performances. This finding supports the conclusions of Getachew Gashaw et al. (2014), who underlined the relationship between genetic diversity and environmental adaptability in *M. grisea* isolates.

The excellent efficacy of OMA for most isolates indicates its potential as a standard medium for the cultural study of *M. grisea*. While HSA was less effective for certain isolates, it showed benefits for those closely associated to specific hosts (e.g., Mg8 and Mg15). This observation supports earlier research of Odeph et al. (2021) who reported that media designed to mimic host

conditions can improve the growth of pathogens. The moderate performance of PDA across various isolates identified it as a reliable medium for general fungal research, although it may not be the most effective for optimizing growth. The variability in growth observed on Richard's Agar suggests its potential use in studying the impact of nitrogen-rich environments on the physiology of *M. grisea*.

The notable differences in growth across different media and isolates agree with the findings of Babu (2011), underlining the necessity for standardized protocols in cultural and pathogenicity research.

3.3.5 The effect of Temperature on the Mycelial Growth of *M. grisea*

This investigation focused on assessing the impact of various temperatures (15°C, 20°C, 25°C, 30°C, 35°C and 40°C) on the mycelial growth of different isolates, using the mean colony diameters (mm) recorded at different temperature and the result is presented below (Figure 3.4, Appendix Table 3.3). The mycelial growth of isolates is greatly influenced by environmental factors, with temperature being a critical factor. Temperature plays a vital role in regulating metabolic activities, enzymatic functions, and the overall growth dynamics of fungi.

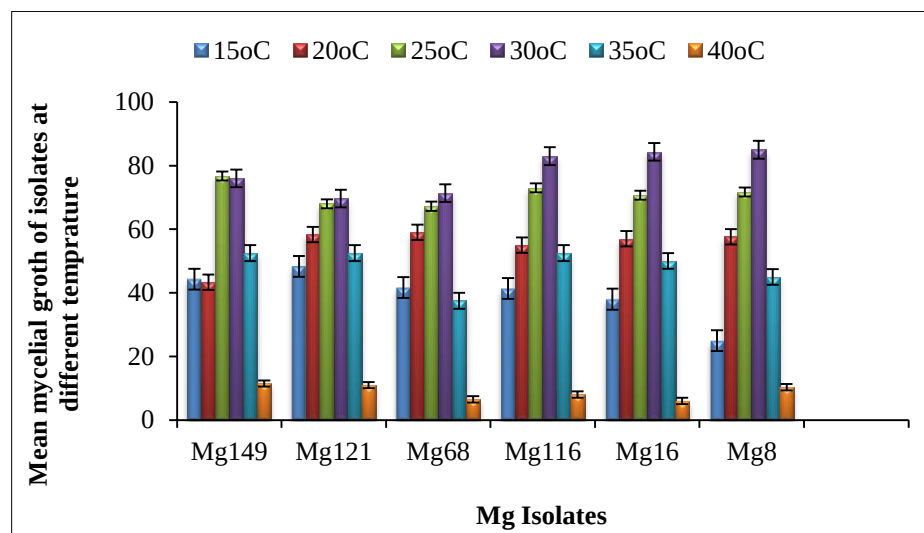


Figure 3.4. Effect of different temperature levels on the mycelial growth of selected *M. grisea* isolates

The findings revealed that the most favorable temperature for mycelial growth of most isolates was 30°C, where a significant increase in colony diameter was observed. For instance, isolate Mg116 demonstrated highest growth at 30°C (83.00 mm), while Mg8 also exhibited vigorous growth (85.00 mm) at this temperature (Figure 3.4, Appendix Table 3.3). This observation supports earlier research, such as Puri and Kumar (2018), which identified 30°C as an optimal growth temperature for *M. grisea*. On the other hand, a marked decline in mycelial growth was recorded at high temperatures (35°C and 40°C) for numerous isolates. Specifically, isolates Mg15 and Mg39 showed a complete break in growth at 40°C (0.00 mm), indicating a critical limit for thermal stress. This reduction aligns with the conclusions of Gupta et al. (2020) who reported that temperature exceeding 30°C is harmful to *M. grisea* growth. Similarly, at 15°C, growth rates were slow, as evidenced by isolates such as Mg38 (29.33 mm) and Mg121 (48.33 mm) (Figure 3.4, Appendix Table 3.3). This observation implies that temperatures below 20°C may not support optimal mycelial growth, a similar pattern reported by Mebratu Gebremariam et al. (2015), who found that *M. grisea* growth is inhibited at lower temperatures.

The growth responses of various isolates to temperature exhibited considerable variability. For instance, isolates such as Mg121 and Mg116 displayed relatively healthy growth at lower to moderate temperatures (20°C and 25°C), while isolates like Mg15 and Mg39 showed weakened or complete growth termination at higher temperatures (Figure 3.4, Appendix Table 3.3). This observed variability reflects the genetic variability present within *M. grisea* isolates, which plays a crucial role in determining their thermotolerance and pathogenicity (Odeph et al., 2021).

3.3.6 The effect of pH on the mycelial growth of *M. grisea* isolates

This study investigates the influence of pH on the dry mycelial growth of *M. grisea* by examining growth across a sort of pH levels ranging from 4 to 10. The results indicated that pH significantly affects the growth dynamics of the

isolates, impacting their mycelial biomass, which is essential for their pathogenicity and environmental adaptability (Figure 3.5, Appendix Table 3.4).

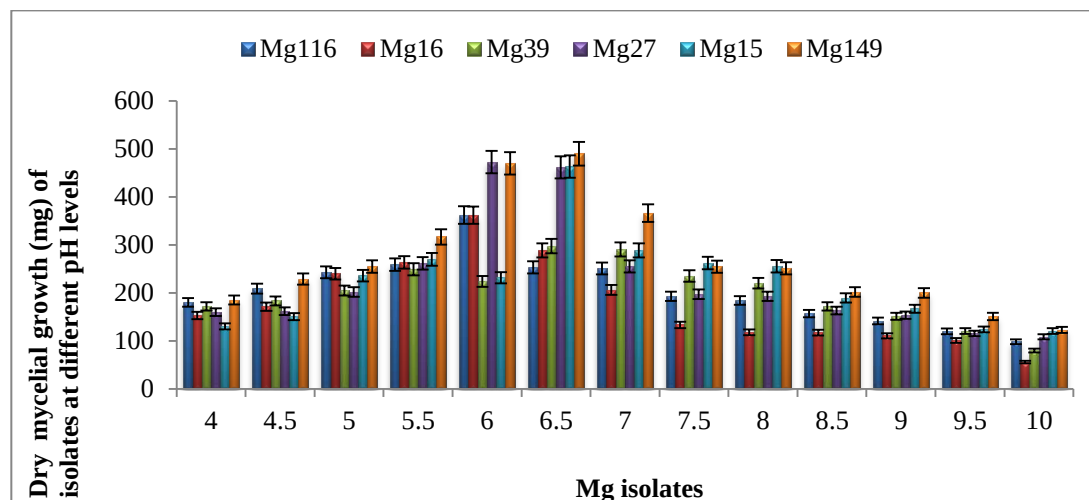


Figure 3.5. Effect of different pH values on dry mycelial weight of selected *M. grisea* isolates

The dry mycelial weight of various *M. grisea* isolates was assessed at ten different pH levels, revealing substantial differences in growth patterns. Of all the isolates, Mg149 showed the greatest average dry mycelial weight (295.95 mg), showing its superior growth potential across the pH spectrum, particularly better in near-neutral to slightly alkaline conditions (maximum at pH 6.5 with 490.00 mg). Followed by Mg68 (269.56 mg) and Mg109 (238.64 mg) that exhibited good growth, particularly at pH 6.5 and 6.0, respectively (Figure 3.5, Appendix Table 3.4), indicating that slightly acidic to neutral pH levels promote optimal fungal biomass production.

In contrast, isolates such as Mg27 (223.51 mg) and Mg16 (178.51 mg) displayed moderate to low growth, with sharp decreases at extreme pH levels (for example, at pH 10: 108.33 mg for Mg27 and 55.67 mg for Mg16), indicating their less adaptability to alkaline conditions. Isolates like Mg116, Mg83 and Mg75 showed moderate average growth (226–241 mg), suggesting greater adaptability though their growth limited at higher pH values (Figure 3.5, Appendix Table 3.4).

Remarkably, pH 6.5 was identified as the most ideal condition for most isolates, helping the highest biomass accumulation, as seen with Mg68 (460.67 mg), Mg15 (463.33 mg), Mg27 (461.67 mg), and Mg149 (490.00 mg). Conversely, both extremely acidic (pH 4.0–4.5) and very alkaline (pH 9.5–10.0) conditions considerably limited growth in nearly all isolates, with several instances reporting values below 150 mg (such as Mg16, Mg109, and Mg99) (Figure 3.5, Appendix Table 3.4).

The results of this investigation align with earlier studies regarding the influence of pH on the growth of *M. grisea*. For instance, Tracyline et al. (2021) indicated that *M. grisea* isolates obtained from Kenya demonstrated optimal growth at pH levels between 5.5 and 6. Moreover, Odeph et al. (2021) identified pH 6 as the most conducive for mycelial development. Additionally, investigations by Yella Goud (2015) indicated that pH can affect the virulence and pathogenic characteristics of *M. grisea*. Given that pH influences nutrient accessibility and enzymatic functions, it is reasonable that isolates best grow at pH levels of 5.5 to 7 may exhibit strong virulence under such conditions, a consideration that is crucial for the formulation of disease management approaches.

3.3.7 Biochemical variability

This study assessed the mycelial growth of *M. grisea* isolates on different carbon sources including dextrose, maltose, D-fructose and sucrose, by measuring the colony diameter and the results presented below (Figure 3.6, Appendix Table 3.5). Among the carbon sources evaluated, Dextrose was found to be the most effective carbon source, promoting superior mycelial growth across most isolates, with the average colony diameter significantly higher than other carbon sources. Maltose and sucrose also supporting considerable growth, although the resulting colony growth was generally smaller compared to those on dextrose. The response to these sugars varied among isolates, with some demonstrating a preference for maltose while others grow better on sucrose. D-fructose was associated with the least growth in most isolates (Figure 3.6, Appendix Table 3.5).

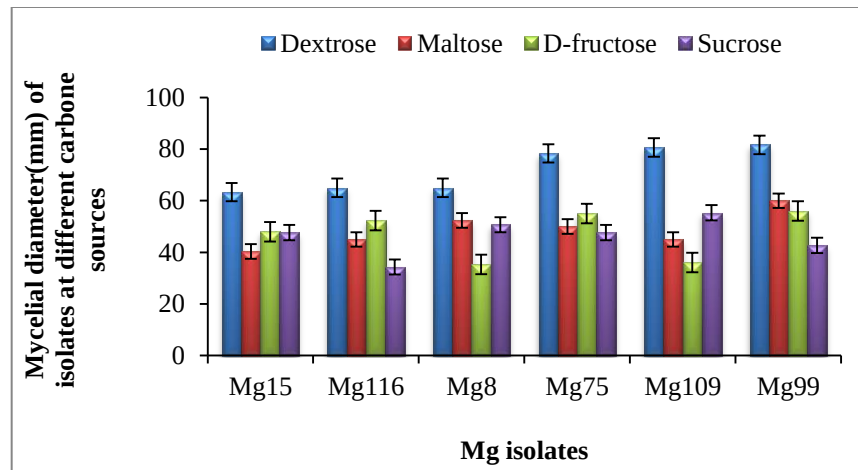


Figure 3.6. Effect of different carbon sources on mycelial growth of selected *M. grisea* isolates

All evaluated isolates exhibited the highest growth on dextrose, which makes it as the most favored carbon source. Isolate Mg99 showed the highest growth on dextrose (81.67 mm), followed by Mg109 (80.67 mm) and Mg75 (78.33 mm), indicating these strains have a strong preference for dextrose. On the other hand, the lowest growth levels varied among isolates and were typically related to sugars like sucrose and D-fructose, which are less efficiently metabolized. For example, Mg68 had the lowest growth on D-fructose (27.33 mm), while other isolates such as Mg116, Mg121, Mg16 and Mg83 displayed minimal growth on sucrose, ranging from 34.33 mm to 36.00 mm (Figure 3.6, Appendix Table 3.5). The general observation indicates that maltose promoted better growth than sucrose or D-fructose for most cases. These results imply that while certain isolates show some metabolic flexibility, dextrose clearly serves as the most effective carbon source. The growth of *M. grisea* isolates is significantly affected by a range of environmental factors, among which the carbon source is basic for fungal growth. Carbon sources are vital sources of energy for the metabolic processes and growth of fungi.

Mebratu Gebremariam et al. (2015) examined the influence of various carbon sources on the growth of *M. grisea*, particularly in relation to blast disease in Ethiopia. The result indicated that dextrose emerged as the most valuable carbon

source for fungal growth, supporting the observation that *M. grisea* strains typically show a preference for glucose, a simple sugar that supplies immediate energy for fungal metabolic processes. Fantaye Ayele (2017) revealed that glucose (dextrose) significantly promoted optimal growth, while sucrose facilitated moderate growth levels. This observation indicates that the carbon source preferences of *M. grisea* isolates from various geographical locations may share similarities, attributable to the fundamental metabolic needs of the fungus. Odeph et al. (2021) focused on the identification and characterization of fungal species associated with *M. grisea* in Kenya. Their research indicated that dextrose and sucrose were the most favorable carbon sources for the mycelial growth of *M. grisea*, while other sugars, including maltose and D-fructose, supported comparatively lower growth rates.

3.3.8 The effect of nitrogen on the growth of *M. grisea* isolates

This investigation employed five distinct nitrogen sources (KNO_3 , NaNO_3 , Peptone, L-arginine, and L-glycine) to evaluate their effects on the mycelial growth of isolates of *M. grisea* (Figure 3.7; Appendix Table 3.6).

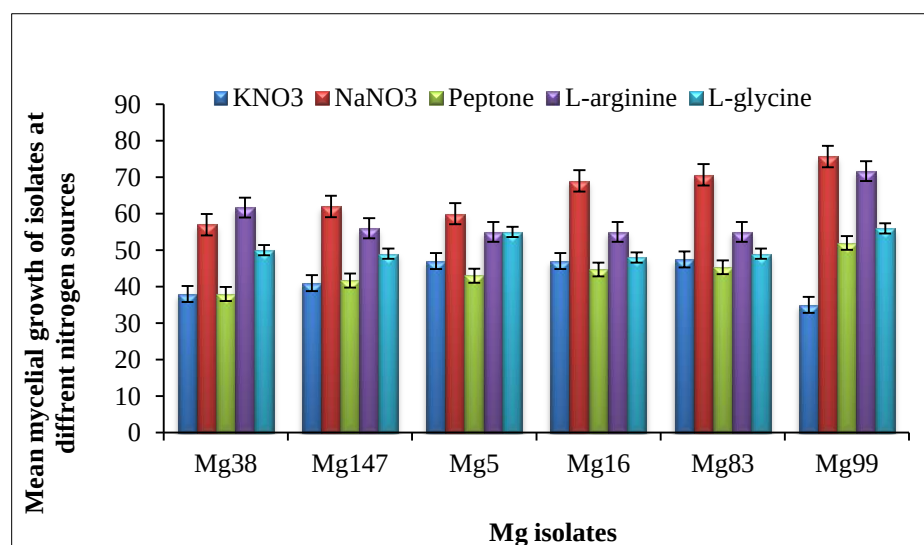


Figure 3.7. Effect of different nitrogen sources on mycelial growth of selected *M. grisea* isolates

The growth patterns of the isolates exhibited considerable variation depending on the nitrogen source utilized. The average diameters of mycelial growth across all nitrogen sources ranged from 44.44 mm to 66.64 mm, with significant

differences observed among different isolates. KNO_3 proved to be the least effective for most isolates, with several isolates demonstrating relatively low growth rates (e.g., Mg99, Mg38, and Mg147, among others). Growth measurements varied from 32.67 mm to 50.00 mm, with Mg5 showed the highest growth under this condition. NaNO_3 nitrogen source generally facilitated improved mycelial growth in comparison to KNO_3 . It resulted in substantial growth for isolates such as Mg99 (75.67 mm), Mg83 (70.67 mm), and Mg16 (69 mm). This indicates that sodium nitrate may offer a more advantageous nitrogen source for *M. grisea* than potassium nitrate due to its bioavailability. As an organic nitrogen source, L-arginine exhibited moderate effects on growth. Growth measurements ranged from 53 mm to 71 mm, with certain isolates, such as Mg99 demonstrating favorable growth of 71 mm. The other amino acid, L-glycine supported a broad spectrum of growth, ranging from 34.67 mm to 56.67 mm across the isolates. Like L-arginine, this nitrogen source proved beneficial for numerous isolates (Figure 3.7; Appendix Table 3.6).

The mycelial growth performance of *M. grisea* is affected by the nitrogen source provided. Nitrogen serves as a crucial nutrient for the growth of fungi, and the specific nitrogen source can significantly influence both the growth rate and the pathogenic characteristics of the organism. The growth patterns identified in this investigation are consistent with various findings documented in the literature. Mebratu Gebremariam et al. (2015) reported that *M. grisea* isolates cultivated on diverse nitrogen sources displayed differing levels of mycelial growth. Similarly, Puri and Kumar (2018) observed that organic nitrogen sources, including peptone and amino acids significantly facilitated the growth of *M. grisea*.

3.3.9 Pathogenicity test

The data presented in the Figure 4.7 and Appendix Table 3.8 illustrates the disease incidence and severity associated with isolates of *M. grisea* on the finger millet variety, Boneya (Appendix Figure 3.1). The measure of disease incidence

and severity serve as critical indicators of the pathogenicity of the *M. grisea* isolates and the vulnerability of the host variety to blast disease.

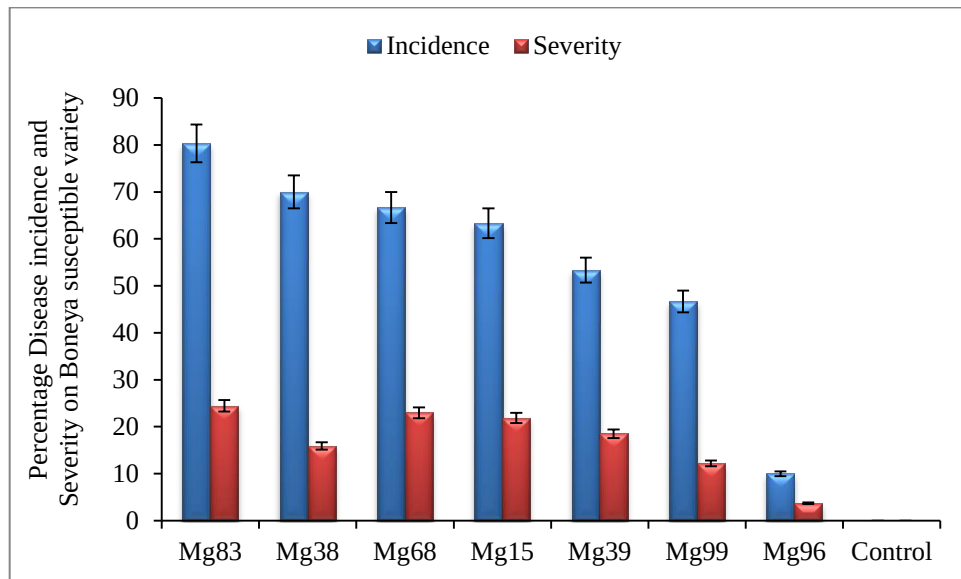


Figure 3.8. Percentage of disease incidence and severity for pathogenicity test on susceptible finger millet variety, Boneya inoculated with selected *M. grisea* isolates

In this investigation, the isolate Mg83 demonstrated the highest disease incidence of 80.33, followed by Mg38 at 70.00 and Mg15 at 63.33 (Figure 3.8, Appendix Table 3.7). These findings suggest the variability of isolates for aggressiveness. The high incidence rates observed in Mg83, Mg38 and Mg15 imply their aggressive infection on the susceptible variety. Conversely, Mg99 exhibited a notably lower disease incidence of 46.67; its aggressiveness may be less compared to Mg83 and Mg38. Notably, Mg96 recorded the lowest incidence at merely 10%, suggesting a reduced virulence level during storage (Figure 3.7, Appendix Table 3.8). These isolates may have lost virulence during storage, as they were virulent in the field at their original collection site. This observation aligns with previous research that has documented variability in the virulence of different *M. grisea* isolates (Getachew Gashaw et al., 2014; Mebratu Gebremariam et al., 2015). Disease severity quantifies the degree or extent of symptoms present on infected plants, generally represented as a percentage of affected plant tissue. The isolate Mg83 caused the highest disease severity (24.45%), and incidence on the infected plants. Isolates Mg38 and

Mg15 also demonstrated considerable severity levels (15.92 and 21.85%, respectively), although they were slightly less severe than Mg83. In contrast, the isolates Mg99 and Mg96 caused relatively low levels of severity, with 12.22% and 3.70% respectively (Appendix Table 3.7). This reduced impact may be attributed to factors such less aggressiveness of the isolate and/or environmental conditions that influence fungal infections. Research conducted by Sahu et al. (2018) reported that *M. grisea* isolates from various regions might have different impacts on finger millet. Shanmugapackiam et al. (2019) and Mior et al. (2017) indicated that the pathogenicity of *M. grisea* isolates is affected by the specific fungal isolate and the variety of the host.

3.4 Conclusion and Recommendations

In this study, *M. grisea* (Mg) isolates revealed significant morphological, physiological and cultural diversity. The conidia showed variability in septation ranging from 2-septate to 3-septate with two distinct shapes (pyriform and obclavate). On the basis of colony, and conidial characteristics, and pathogenicity test, the isolated pathogen was identified as *M. grisea*. Cultural analysis exhibited variations in colony color, texture, margin and pigmentation. The mycelial growth responses to varying temperatures, and pH indicated that 25°C to 30°C was the most favorable range and slightly acidic to neutral conditions (pH 5.5–7) displaying the highest dry mycelial biomass. Differences in carbon source utilization revealed dextrose support best growth across most isolates. D-fructose was the least effective carbon source. Among the nitrogen sources NaNO₃ identified as the most conducive for growth, whereas KNO₃ resulted in reduced growth for most of isolates. In general, these results highlight the considerable physiological and morphological diversity among *M. grisea* isolates, illustrating the ability of the pathogen to adapt to various environmental conditions and nutritional preference. This foundational information is crucial for informing targeted management approaches as well as developing future screening protocols for resistance breeding and fungicide evaluation.

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Chapter 4. ASSESSING THE KNOWLEDGE AND MANAGEMENT PRACTICES OF FARMERS IN FINGER MILLET BLAST FOR DEVELOPING SUSTAINABLE DISEASE MANAGEMENT

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Abstract

Finger millet is an essential food source for millions across Africa and Asia, yet it remains underutilized. The most significant threat to its production is blast disease, caused by the fungus *Magnaporthe grisea*, which results in substantial yield losses. In Ethiopia, many farmers depend on their saved seed, lack of awareness and do not implement management practices due to a lack of knowledge and limited access to effective management techniques. This study was conducted in Northwestern Amhara during 2022 cropping season, to assess farmers' awareness and management practices related to finger millet blast disease using a semi-structured questionnaire. Farmer awareness and practices data collected from four districts, and analyzed using descriptive and chi-square tests revealed that some farmers had been observing disease symptoms for the last nine years, with the highest severity between August and October. About 46.8% were unaware of the cause and mode of transmission, while 33.2% associated it with susceptible varieties. Management strategies reported included burning crop residues (39.3%), decreasing nitrogen fertilizer use (11.6%), and

applying fungicides (0.4%). Barriers to effective disease management included lack of knowledge, low perception of the disease (20.7%), and absence of effective control strategies (12.9%). This research highlights blast disease as a significant challenge to finger millet cultivation and stresses the importance of training farmers to improve their pest identification skills and implement effective management approaches.

Keywords: Blast disease, disease management, farmers' awareness, finger millet, Indigenous knowledge, *Magnaporthe grisea*

4.1 Introduction

Finger millet (*Eleusine coracana* L. Gaertn) is an important food crop in areas prone to drought, where it is primarily cultivated by subsistence farmers under rain-fed conditions (Upadhyaya *et al.*, 2007; Thilakarathna and Raizada, 2015). Its ability to tolerate severe climatic conditions, combined with its high nutritional content, which includes high dietary fiber, iron (Fe), and calcium (Ca), along with its capacity to grow on marginal lands, makes it a crucial crop of food security measures for subsistence farmers in Asia and Africa (Birhanu Ayalew, 2015). Although often regarded as an underutilized and neglected crop, finger millet is widely cultivated throughout the tropical and subtropical regions of Africa, India, Nepal and China, with its origins believed to be in the Ethiopian highlands (Kotschi, 2006). In Ethiopia, finger millet is one of the top cereal crops, ranking sixth in terms of both area cultivated and production, following maize (*Zea mays* L.), teff (*Eragrostis tef* (Zucc.) Trotter), sorghum (*Sorghum bicolor* L.), wheat (*Triticum spp.*), and barley (*Hordeum vulgare* L.) (Amare Seyoum *et al.*, 2019).

Despite its importance, finger millet yield in Ethiopia remains low, primarily due to limited access to improved varieties, inadequate research focus, absence of modern agricultural practices, and sociocultural attitudes that undermine the value of the crop (Zerihun Tadele; Fentie Molla, 2012; Hailegebrail Kinfu *et al.*, 2017). Moreover, factors such as biotic and abiotic stresses, including blast disease, lodging, drought stress, striga infestation, and poor threshing and

milling characteristics, contribute to the production challenges (Mgonja *et al.*, 2007; Saha *et al.*, 2016). Socioeconomic problems, including small land sizes, financial, and restricted access to improved seeds, aggravate the problem (Solomon Admasu and Tegegn Belete, 2020; Adane Gebreyohannes *et al.*, 2021).

Among the biotic challenges, blast disease caused by *Magnaporthe grisea* (anamorph: *Pyricularia grisea*) is recognized as the most critical threat to finger millet globally, leading to significant decreases in yield and grain quality (Ramakrishnan *et al.*, 2016; Gupta *et al.*, 2017).

Farmers possess valuable local knowledge for pest management, yet it is often overlooked (Mendesil *et al.*, 2016). Surveys on farmers' awareness and practices are therefore essential, as they reveal the support required for effective disease identification and prevention. Crop losses can be minimized through appropriate control measures, which depend largely on farmers' knowledge and actions (Midega *et al.*, 2016; Kansiime *et al.*, 2019). Understanding farmers' awareness of a destructive disease such as blast, their control practices, and the constraints they encounter is crucial for shaping research priorities and extension strategies that reflect farmers' needs (Mendesil *et al.*, 2016; Kumela *et al.*, 2019). Additionally, supporting research goals with the realities and needs of farmers promotes higher adoption rates of innovations and increases agricultural productivity. Studies conducted in various countries have examined farmers' awareness and management practices regarding finger millet blast and other crop diseases (Hashim *et al.*, 2018; Houngue *et al.*, 2018; Neindow *et al.*, 2018; Mbinda *et al.*, 2021). Nevertheless, there is a considerable lack of understanding regarding how smallholder farmers view and address blast disease within their communities. In the absence of this data, extension services and research activities may not adequately address the specific challenges encountered by farmers. Thus, this study was conducted to evaluate the knowledge, perceptions, and management practices of smallholder farmers about finger millet blast in Northwestern Amhara. The results are intended to guide the design of context-

specific and farmer-focused extension methods, improve integrated disease management strategies, and ultimately aid in improving the productivity and sustainability of finger millet farming in Ethiopia.

4.2 Materials and Methods

4.2.1 Study areas

A survey was conducted in four administrative zones of western Amhara, specifically in West Gojam (Jabi Tehnan), North Gojam (Semien Achefer), Awi (Dangila), and Central Gondar (Takusa) during the agricultural period from August to November 2022 (Figure 4.1). The survey sites are located between latitudes $10^{\circ}39'41.4''$ and $12^{\circ}24'25.6''$ and longitudes $036^{\circ}41'27.1''$ to $037^{\circ}56'31.38''$, with elevations ranging from 1789 to 2186 meters classified as mid-altitude. In terms of climate, minimum temperatures ranged from 7.29°C to 14.17°C , while maximum temperature between 22.7°C and 28.67°C , and the annual rainfall levels varied from 69.08 to 253.5 mm. This sub-region offers favorable climatic conditions suitable for finger millet farming based on data collected during the survey and displayed in Appendix Figure 4.2.

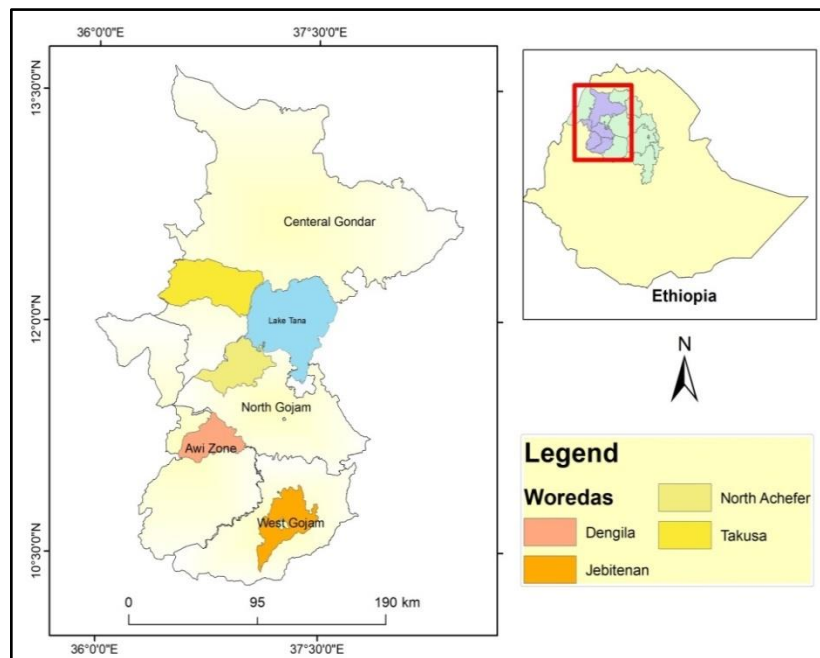


Figure 4.1. Map of sampling districts for assessing farmers' knowledge and management practices

4.2.2 Sampling procedure and sample size determination

Four districts were purposively selected for their finger millet production potential and transport access: Jabi Tehnan (West Gojam) and Semein Achefer (North Gojam), Dangila in Awi, and Takusa (Central Gondar). The selected districts represent the most potential areas for finger millet cultivation, though they have been impacted by blast that led to significant yield losses. A multi-stage sampling method was used; first, kebeles in each district were chosen based on their importance in finger millet production, 12 kebeles (three per district) selected with the help of extension agents. Second, farmers cultivating finger millet in the past three to five years were chosen systematically (every n th farmer) from farmers lists and interviewed (Schreinemachers *et al.*, 2015).

The sample size (n = number of farmers to be interviewed) was determined using the formula suggested by Mghase *et al.* (2010).

$$n = \frac{Z^2 P(1 - P)}{Q^2}$$

Where, n = required sample size, Z = confidence level at 95% (standard value of 1.96), p = estimated proportion of an attribute, estimated at 75% based on available number of farmers who experiencing finger millet cultivation in the area for the past three to five years and the Q = margin of error at 5% (standard value of 0.05). Therefore, the number of farmers interviewed was determined as shown below:

$$n = \frac{Z^2 P(1-P)}{Q^2} = (1.96)^2(0.75)(1-0.75)/(0.05)^2 = 288.12 \approx 288$$

A total of 288 samples, consisting of 258 males and 30 females with at least 22 - 24 participants chosen from each kebele were chosen in Jabi Tehnan, Dangila, Semien Achefer and Takusa districts.

4.2.3 Methods of data collection

A semi-structured questionnaire (Appendix Table 4.1) was employed to carry out a survey in the selected study districts to assess farmers' knowledge and

perception about the disease and the management practices. The agricultural development agents, possessing a college diploma or degree in agriculture, received a concise overview of the study objectives, and the procedures for data collection, along with instructions on how to engage with the farmers. Before the main survey, the questionnaires were piloted with 15 farmers in North Achefer to refine the interview technique, which resulted in the conceptualization of some questions. Using Amharic (the official language mainly spoken by farmers, the researcher and agricultural development personnel conducted face-to-face interviews from September to November 2022, complemented by field visits. Farmers were asked two kinds of questions: closed yes/no questions and open-ended questions, which allowed them to express their views freely. Throughout these interviews, farmers conveyed their viewpoints on production difficulties, their views on finger millet blast, and their management approaches. To evaluate their knowledge of the diseases, the participants were shown a series of colored images showing finger millet plants infected by blast along with various other disease symptoms (Appendix Figure 3.1 and 3.2) assisted by field visit in the nearby farms (Schreinemachers et al., 2015).

The collected data included the socioeconomic characteristics of farmers (age, gender and education levels), as well as trends in finger millet production and the perceptions and knowledge of farmers regarding the blast disease and its management practices. An extensive survey on the disease was conducted to explore the correlation between farmers' knowledge of finger millet blast, and its occurrence and severity in those areas.

4.2.4 Data analysis

The collected quantitative and qualitative data were analyzed using IBM SPSS Statistics 23, with results presented in cross-tabulation tables and descriptive statistics. To evaluate the relationships between variables, contingency chi-square tests ($P \leq 0.05$) were performed. This enabled empirical analysis and description of parameter associations across the four study districts (Hashim et al., 2018).

4.3 Results and Discussion

4.3.1 Household sociodemographic characteristics

About 90.23% of the participants were male, whereas 9.77% were female (Table 4.1). This situation primarily arose from the smaller pool of female farmers registered with the agricultural extension services at the kebele level. A similar trend was noted by Tewodros Mulugeta *et al.* (2024), where from a total of 150 participants, 145 (96.7%) of the participants were males and only 5 (3.3%) were females in research examining farmers' access to agricultural inputs. Their ages ranged from 18 to 75 years. Notable differences were found in the educational backgrounds of the respondents ($\chi^2 = 52.16$; $P = 0.001$) (Table 4.1). According to Mbinda *et al.* (2021), 90% of households that produce finger millet are led by adults, with women comprising 57% of these heads. Similarly, the results of Souleymane *et al.* (2025) revealed a high illiteracy rate among farmers (>50%) and a low participation of women in rice production (mean 9.25%).

Table 4.1. Sociodemographic profiles of respondents in the study area

Variables	Percentage of respondents					df	X ²	P-value
	Dangila (n=72)	Jabi Tehnan (n=72)	N/Achefer (n=72)	Takusa (n=72)	Mean $\pm$ SE			
Age category						18	16.77	0.539
18-20	1.72	0.00	0.00	0.00	0.43 $\pm$ 0.71			
21-30	18.97	11.25	12.5	6.82	12.39 $\pm$ 0.71			
31-40	27.58	33.75	35.23	27.27	30.96 $\pm$ 0.71			
41-50	18.97	30.00	29.55	45.45	31.74 $\pm$ 0.71			
51-60	22.42	16.25	14.77	11.36	16.20 $\pm$ 0.71			
61-70	8.62	7.50	6.82	9.09	8.01 $\pm$ 0.71			
>70	1.72	1.25	1.14	0.00	1.03 $\pm$ 0.71			
Sex						3	4.53	0.021
Female	8.62	10.00	15.91	4.55	9.77 $\pm$ 0.65			
Male	91.38	90.00	84.09	95.45	90.23 $\pm$ 0.44			
Educational level						18	52.16	0.001
Not educated	27.58	26.25	26.14	34.09	28.52 $\pm$ 0.1			
Religious	0.00	10.00	2.27	0.02	3.07 $\pm$ 0.1			
Adult education	50.00	36.25	51.14	40.9	44.58 $\pm$ 0.1			
Primary	12.08	21.25	15.9	11.36	15.15 $\pm$ 0.1			
Secondary	10.34	6.25	4.55	13.63	8.68 $\pm$ 0.1			
Size of FM farm (ha) in 2022						15	59.16	0.001
0.25-0.5	12.28	63.75	9.09	36.36	30.37 $\pm$ 0.02			
0.6-0.75	40.35	20.00	42.05	27.27	32.42 $\pm$ 0.02			
0.8-1	24.56	8.75	35.23	25.00	23.39 $\pm$ 0.02			
1.25-1.5	17.54	7.50	10.23	9.09	11.09 $\pm$ 0.02			
1.75-3	3.51	0.00	3.41	2.27	2.29 $\pm$ 0.02			
>4	1.54	0.00	0.00	0.00	0.39 $\pm$ 0.02			
Years of FM farming						12	28.13	0.019
1-10	29.31	40.00	23.86	50.00	35.79 $\pm$ 0.69			
11-20	27.59	35.00	36.36	18.19	29.28 $\pm$ 0.69			
21-30	29.31	13.75	22.72	20.45	21.56 $\pm$ 0.69			
31-40	12.07	8.75	7.95	11.36	10.03 $\pm$ 0.69			
>40	1.72	2.50	9.09	0.00	3.33 $\pm$ 0.69			

Finger millet varieties used						6	6.34	0.389
Improved	3.45	10.00	5.68	9.09	7.06±0.02			
Local	94.83	90.00	94.32	90.91	92.52±0.02			
Local + Improved	1.72	0.00	0.00	0.00	0.43±0.02			
Source of advice on FM prod						6	21.72	0.010
Agricultural extension workers	31.04	11.25	28.41	27.27	24.49±0.11			
Experienced farmers	62.07	88.75	70.45	72.73	73.50±0.11			
Own	6.89	0.00	1.14	0.00	2.01±0.11			
Training on FM production						6	12.48	0.052
Trained	32.75	30.00	34.09	27.27	31.03±0.04			
Not trained	67.24	70.00	65.91	72.73	68.97±0.04			

Hint: FM= finger millet, prod= production, n=number of samples, DF= degree of freedom, FM= finger millet, χ^2 = Chi-Square test, prodn=production, $P \leq 0.05$ shows there was a significant difference.

As illustrated in Table 4.1, around 44.58% of the participants had adult education, 15.15% had completed elementary education, and 28.52% had no education. According to Mbinda et al. (2021), the overall education levels of participants were low, as only 16% of household leaders in Kisii had received above secondary education, while this figure was 37% in Bungoma region of Kenya.

About 35.79% of the farmers had been involved in finger millet cultivation for a period of 1 to 10 years, with 3.33% having over 40 years of experience in the field, reflecting significant variations in their farming practices ($\chi^2 = 28.12$; $P = 0.02$). The land used for finger millet cultivated ranging from 0.25 to more than 4.00 hectares. There were no significant differences in the types of finger millet seeds used by the farmers ($\chi^2 = 6.34$; $P = 0.38$); however, majority (92.52%) preferred local varieties. Farmers select finger millet varieties based on agronomic, consumption, marketing, and socio-demographic factors. Key considerations include yield, drought and disease tolerance, maturity period, local preferences, and market demand (Ayele Tesfahun *et al.*, 2024). Souleymane *et al.* (2025) reported as maximum years of experience in rice cultivation. Most farmers have limited income and small land holding, practicing substance farming. When asked about the sources from which they received advice regarding finger millet production, the farmers stated that 73.50% shared experience from other farmers, 24.49% from agricultural extension officers, and 31.03% had attended various training sessions on crop production. Significant differences were observed in the information sources across different districts

($\chi^2 = 21.72$; $P = 0.01$) (Table 4.1). Hashim et al. (2018) reported that among the respondents interviewed their ages ranged from 20 to 69 Years. About 89.5% of the respondents completed primary education; however, 3.3% had secondary education. Most of the interviewed farmers have worked on rice production for 3 to 10 years. Their average land unit devoted to rice production ranged from 1 to 2 ha. The majority (92.3%) planted local upland rice varieties, and only 7.7% planted New Rice for Africa (NERICA) an introduced improved variety. The response of interviewed farmers on the sources of advice on rice production activities showed that, 69.6% shared information among themselves, 17.4% received information from agriculture extension officers and 13.0% attended various training on crop production. Mbinda et al. (2021) reported that about 22% of respondents had received training and access to improved seeds.

4.3.2 Constraints in finger millet production

Table 4.2 showed that, 34.74% of participants identified finger millet blast disease (FMBD) as their primary problem. Over the past five to nine years, 30.84% of the surveyed farmers have encountered this disease in their own and their neighbors' farm. The blast disease was common across all surveyed areas and had an adverse impact on crop yields, resulting in considerable production losses. Assessments conducted by the current authors in the study areas showed disease severity ranging from 58.8% to 88.6% (Figure 2.4 & 2.5; Appendix Table 2.2), highlighting a substantial infection problem. Concerning the occurrence of FMBD, substantial differences were found in the fields of their neighbors ($\chi^2 = 16.11$; $P = 0.01$), but not in their own fields ($\chi^2 = 17.3$; $P = 0.99$). About 29.21% of respondents mentioned that high severity of blast disease is typically observed annually in October, with 21.49% reporting from August to October, and 11.44% in September (Table 4.2). This might be due to high Temperature on October and high relative humidity from October to September (Table 2.2; Appendix Figure 1.2) may favor blast disease epidemics.

Table 4.2. Potential limitations to finger millet cultivation and blast disease occurrence in the study districts

Variables	Percentage of respondents					Df	X ²	P-value
	Dangila (n=72)	Jabi Tehnan (n=72)	N/Achefer (n=72)	Takusa (n=72)	Mean ± SE			
FM prodn constraints						15	38.11	0.003
Blast disease	46.55	41.25	1.14	50	34.74±0.11			
Farming practices	15.52	23.75	21.59	0.00	15.22±0.11			
Insect pests	6.89	5.00	4.54	0.00	4.11±0.11			
Lack of access to inputs	1.72	6.25	29.54	43.18	20.17±0.11			
Lack of knowledge	27.59	20.00	13.63	0.00	15.31±0.11			
Weed	1.72	3.75	29.54	6.82	10.46±0.11			
FMBD in the farmer's field						3	17.29	0.992
No	1.72	2.50	2.27	2.27	2.19±0.56			
Yes	98.28	97.50	97.73	97.73	97.81±0.56			
FMBD in other farmers field						6	16.11	0.013
No	3.45	12.50	15.91	13.63	11.37±0.01			
Yes	96.55	87.50	84.09	86.37	88.63±0.01			
Types of blast disease seen						6	40.79	0.001
Head	74.15	42.5	88.63	54.54	64.95±0.07			
Leaf	6.90	2.50	1.14	34.09	11.16±0.07			
Leaf + head	6.90	1.25	0.00	0.00	2.04±0.07			
Leaf + neck	1.72	1.25	0.00	0.00	0.74±0.07			
Leaf + neck + head	1.72	15.00	0.00	0.00	4.18±0.07			
Neck	1.72	16.25	3.41	9.10	7.62±0.07			
Neck + head	5.17	18.75	5.68	0.00	7.40±0.07			
Intensity & level of damage						9	23.04	0.006
High	17.24	16.25	2.27	0.00	8.94±0.04			
Low	27.59	27.50	27.27	29.54	27.97±0.04			
Medium	53.45	50.00	68.18	63.64	58.82±0.04			
Very low	1.72	6.25	2.27	6.82	4.27±0.04			
The first time FMBD occurred in the farmers filed						12	28.12	0.005
10 years a go	13.79	16.25	4.54	18.18	13.19±0.19			
5-9 years a go	36.21	33.75	28.41	25.00	30.84±0.19			
3-4 years a go	24.14	10	39.77	18.18	23.02±0.19			
1-2 years a go	22.41	33.75	21.59	31.82	27.39±0.19			
Do not remember	3.45	6.25	5.68	6.82	5.55±0.19			
Seasons with high FMBD intensity						12	35.61	0.001
August- October	27.58	5.00	37.50	15.91	21.49±0.16			
November	1.72	2.50	2.27	15.91	5.60±0.16			
October	22.41	13.75	42.05	38.63	29.21±0.16			
October and November	0	21.25	9.09	4.55	8.72±0.16			
September	27.59	12.50	3.41	2.27	11.44±0.16			
September and October	18.97	8.75	0	2.27	7.49±0.16			
September- November	0	25.00	3.41	4.55	8.24±0.16			
August and September	0	0	2.27	4.55	1.71±0.16			
Not occurred	1.72	11.25	0	11.36	6.08±0.16			

Note: FM- Finger millet, prodn- production, FMBD- finger millet blast disease

Apart from knowledge gaps, farmers identified high labor costs as a major problem, particularly for activities like weeding and post-harvest processing, which are intensified by the prevalent practice of broadcasting seeds. Other challenges included reliance on low-yielding varieties (Figure 4.2) and the

continuing risk of blast disease (34.7%) (Table 4.3). Despite these difficulties, farmers practice few managing strategies and could recognize the growing signs of blast disease affecting susceptible varieties. According to Mbinda et al. (2021), 94% of the participants recognized blast disease as the primary barrier to finger millet cultivation. Furthermore, 53% noted that the labor-intensive aspects of fieldwork, especially during planting and hand-weeding, posed a challenge, while 38% reported damage caused by birds. The spread of disease may have been increased by informal seed exchanges and changing climatic conditions (Hashim et al., 2018).

4.3.3 Farmers' knowledge on blast disease

About 97.8% of farmers recognized or had awareness about the symptoms of blasts, while only 2.2% of participants had no knowledge or have never seen the disease (Table 4.2). Of the total respondents, 46.88% of participants were unaware of the causes and transmission methods of finger millet blast (Table 4.2). Furthermore, these farmers use different local names to referee the disease. For example, 40% of those surveyed called it Mech, 17.0% Adereke, 15.9% Nafe, and 11.5% Abereke. Additionally, about 21.6% of respondents used different terms in both *Agaw* (a local language spoken by an ethnic group live in Awi zone of Amhara region) and *Amharic* languages, including *Finta*, *Etato*, *Mesha*, *Tilila*, and *Metecho* in *Agaw*, and *Zala Adereke*, *Wage*, *Megasheb*, *Gelab*, and *Korach betelemedo tele* in *Amharic*. There were significant differences ($X^2 = 37.63$; $P = 0.001$) in how farmers understood the finger millet blast disease.

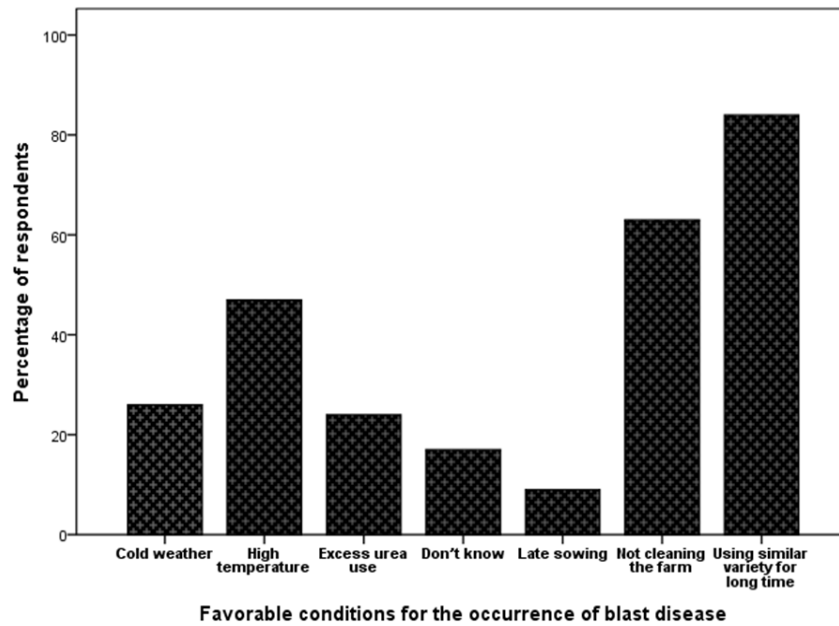


Figure 4.2. Farmers' knowledge of the possible causes of blast disease ($\chi^2=50.32$; $P=0.002$)

A noticeable gap was found in farmers' understanding of how to identify, transmit, and manage finger millet blast. About 46.8% of farmers surveyed had minimal or no knowledge about the origins, symptoms, or management strategies of the disease. Similar findings were reported by Adam *et al.* (2015), revealed that farmers in Tanzania's Lake Victoria Zone were largely unaware of effective management practices for sweet potato diseases. This lack of knowledge may come from limited access to extension services, low levels of education, and minimal exposure to planned agricultural training. On the other hand, Mbinda *et al.* (2021) observed that most farmers in Kenya recognized blast as a significant threat to finger millet production, a difference potentially attributed to higher literacy rates and better agricultural education. Likewise, Zemenu Yemataw *et al.* (2017) highlighted the significance of farmer education in controlling enset bacterial wilt in Ethiopia.

Other diseases observed during field observation include Blight (*Cochliobolus nodulose* Luttr.) (11.2%), Downy mildew (*Sclerospora graminicola* (Sacc.) J. Schröt.) (7.2%), Rust (*Puccinia substrate* var. *substrata*) (6.8%), and both Blight and Rust (5.5%) ($\chi^2 = 37.83$; $P = 0.001$).

4.3.4 Farmers' knowledge of blast epidemic conditions

Significant differences ($X^2 = 50.32$; $P = 0.002$) were observed among farmers concerning the environmental factors, farming, and agronomic practices that are favorable for finger millet blast. When asked about the disease's relationship with other environmental factors, most respondents indicated that the use of susceptible varieties was related to finger millet blast disease epidemics, while a small percentage reported late sowing as a contributing factor (Figure 4.2).

The high occurrence and intensity of blast disease were connected to various agronomic and environmental factors. These included the over-application of nitrogen (urea), the growing of susceptible varieties, inadequate field management, and favorable weather conditions like extended leaf wetness, high humidity, and moderate temperatures between 22°C and 30°C (Appendix Figure 2.2, Table 2.1), which promote the growth and spread of *Magnaporthe grisea*. Previous research has similarly pointed out that favorable climatic conditions and excessive nitrogen contribute to increased disease prevalence and intensity (Singh *et al.*, 2018; Mbinda *et al.*, 2021; Palanna *et al.*, 2021). Excess nitrogen also broadens the leaf surface area, resulting in greater water consumption for photosynthesis and transpiration. In water-scarce conditions, this can worsen water stress in plants, making them more susceptible to fungal diseases like blast (Kumar and Yadav, 2012). Yield instability across all finger millet-growing regions is largely attributed to the frequent breakdown of blast resistance, driven by the crop's susceptibility to rapidly evolving virulent strains of the pathogen (Mbinda and Masaki, 2021). Prolonged rainfall during the heading stage can lead to significant crop losses (Patro and Madhuri, 2014). Symptoms of blast disease were observed to worsen after rainfall indicating the crop's vulnerability to moisture changes. (Bhatt *et al.*, 2011). The disease was consistently reported from August to October, especially worse in October, indicating distinct seasonal disease patterns. Despite the growing severity of the disease over the past five to nine years, only a small number of farmers had adopted proactive

management methods. This may stem from a lack of awareness, and limited available management options.

The pathogen survives across seasons via mycelia and conidia on infected residues and seeds, becoming active in conditions of high humidity (>89% RH) and moderate temperatures (25–28°C, with rapid germination of conidia (Webster, 2000; Poonacha *et al.*, 2023).

4.3.5 Farmer practices for managing finger millet blast

Concerning the blast disease affecting finger millet, a considerable portion of farmers (47.8%) did not implement any controlling strategies, and there were significant variations in management practices ($X^2 = 47.32$, $P = 0.003$) across the districts (Figure 4.3). Farmers have reported various management practices to control finger millet blast disease. About 39.3% of farmers' burn crop residues; 27.4% reduces nitrogen use and 8.9% choose for resistant varieties. Moreover, just 0.4% utilized fungicides (Figure 4.3).

Farmers mentioned the name of pesticides applied for controlling blast diseases includes 2, 4-Dichlorophenoxyacetic acid (2, 4-D) which is actually used for controlling broad leaf weeds in various crops, Ayemeretie (which is also a broad spectrum weedicide), Diazinon (used to control soil and foliage insects and pests on a variety of fruits and vegetables etc.), Agrolanbasine (unknown) and Bravo (fungicide control including blast) which are not recommended for the management of blast disease except Beravo to some extent.

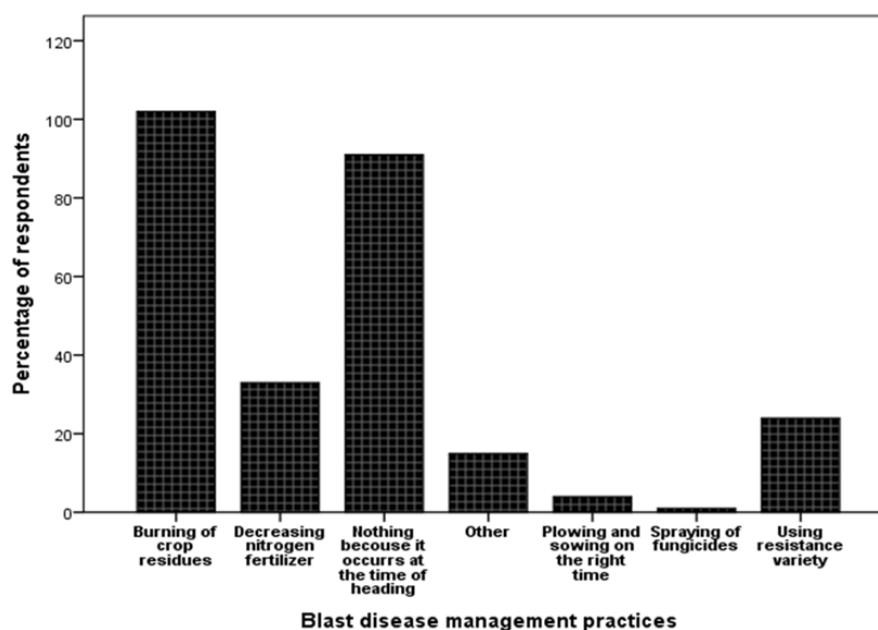


Figure 4.3. Strategies utilized by farmers to control finger millet blast disease ($X^2=47.32$, $P=0.003$)

Table 4.3 indicates that there are four possible reasons for not adopting control measures: a lack of awareness about blast and its management (46.88%), minor crop damage (20.76%), absence of effective control system (12.93%), and the disease being new in the area (2.11%).

Table 4.3. The possible reasons for farmers' opinions on the lack of disease management strategies in the studied districts

Variables	Percentage of respondents					Df	X^2	P-value
	Dangila	Jabi Tehnan	Semien Achefer	Takusa	Mean			
Have no reason	17.24	12.50	3.41	34.09	16.81	15	37.63	0.005
Lack of awareness about blast & its management	56.89	31.25	80.68	18.18	46.88			
No effective blast control mechanism	12.07	23.75	2.27	13.63	12.93			
No fungicide spray because it occurs at heading and maturation	0.00	2.50	0.00	0.00	0.63			
The disease is new for the locality	3.45	5.00	0.00	0.00	2.11			
The level of damage by the disease is low	10.34	25.00	13.62	34.09	20.76			

Limited number of farmers are using pesticides to manage the most prevalent blast disease (finger blast), which occurs during the heading and grain filling stages. The other reason why some farmers do not apply fungicides for head blast is that they express worries that the residual impacts of these chemicals

could harm their health through the food chain. The survey indicated that most farmers depended on local varieties such as Tikur (black), Key (red), Necho (white), and Deke (named after islands in Lake Tana), with just 7.0% opting for improved varieties. This is due to limited access to improved varieties and issues related to high biomass yield, easy for threshing and having good flavor. Improved cultivars available in Ethiopia include Padet, Tadesse, Boneya, Degu, Baruda, Wama, Gute, Bareda, Debatsi, Necho, Tessema, Gudetu, Mecha, Nako-1, Addis-1, Meba, Axum, Diga-1, Urji, Mereb-1, Tekeze-1, Bako-09, Diga-2, and Jabi (MoANR, 2019). However, farmers rely on local cultivars and similar low adoption rates for improved varieties have been observed in other African countries; for example, only 7.7% of farmers in Tanzania used improved varieties for upland rice cultivation (Hashim *et al.*, 2018), while about 25.5% of farmers in Ghana adopted improved varieties for cassava production (Frimpong *et al.*, 2020).

While resistance breeding provides a cost-efficient approach to handle blast by reducing the need for fungicides, many farmers were not aware of the existence of blast-resistant varieties. It is vital to inform farmers about the advantages of these varieties to encourage their adoption (Mbinda and Masaki, 2021). Farmers' inclination toward local varieties is shaped by characteristics such as early maturity, high biomass, simple threshing, and appealing tasty traits. These preferences are supported by findings from Traoré *et al.* (2015) and Wossen Tarekegne *et al.* (2019) which indicated that yield, marketability, and flavor significantly influence varietal choices. However, while farmers believe that local varieties are resistant to disease, they often yield less and lack structural stability (Adane Gebreyohannes *et al.*, 2021). The limited adoption of improved varieties is typically associated with challenges in accessibility and affordability, driving farmers to depend on saved seeds (Hubert *et al.*, 2016). Without modern disease management solutions, farmers rely on traditional methods using cow dung, cattle urine, ash and compost. Although they are cost-effective and eco-friendly, these methods are largely ineffective against the polycyclic nature of blast disease. Similar indigenous techniques were reported by Hasan and Haque

(2014) in the context of vegetable disease management. Burning crop residues was another approach aimed at lowering inoculum levels, although this conflicted with the needs for soil fertility and livestock grazing. Mbinda et al. (2021) also highlighted that farmers employed crop rotation, sanitation, and agrochemicals to combat blast, although the effectiveness of these practices was limited by improper application and low disease awareness (Hashim et al., 2018).

A limited number of farmers reported using pesticides to manage blast disease, with Takusa (61.36%) being the notable exception, while in districts like Dangila (15.52%), Jabitenan (11.25%), and Semien Achefer (2.27%), pesticide use was quite low (Table 4.3). Some farmers were more knowledgeable about applying pesticides for crops such as tomatoes and onions, but they were not well-informed about the types of pesticides or how to handle them properly. This is consistent with the findings of Mendesil et al. (2016), who indicated that a majority of Ethiopian farmers couldn't identify the pesticides used for pest control in peas. In contrast, southern Ethiopia reported that 98% of households utilized pesticides, though 48% were unaware of the specific products employed (Ocho *et al.*, 2016). Souleymane et al. (2025) also reported that only a small proportion (0.87%–2.87%) had used biopesticides for blast control. The persistent problem of blast was also associated with the improper use of pesticides, the application of substandard or counterfeit products, and incorrect dosages issues also highlighted by Ngowi *et al.* (2007), Nonga *et al.* (2011) and Lahr *et al.* (2016). Subsistence farmers, especially in rural Ethiopia, faced systemic problems, such as small land sizes, financial limitations, and inadequate access to modern agricultural inputs including improved seed and information (Bachewe, 2009). However, research showed that providing training to farmers improves their ability to adopt integrated pest management (IPM), leading to a decrease in pesticide dependency and the promotion of environmentally friendly practices (Gautam *et al.*, 2017; Mbinda et al., 2021).

The survey revealed that information on disease management primarily spread through shared themselves, with fellow farmers being the most commonly mentioned source, followed by agricultural extension workers. This observation supports with Owere *et al.* (2014), who stated the significance of knowledge exchange among farmers. Long-term practical learning also played a role in improving knowledge regarding disease identification and management (Traoré *et al.*, 2015). Research has shown that training programs positively influence farmers' attitudes and behaviors related to pest and disease management (Gautam *et al.*, 2017).

4.4 Conclusion and Recommendations

This study confirms that finger millet blast has remained a persistent problem in the study areas for almost a decade. The main factors contributing to its continued presence include low farmer awareness of the disease, reliance on susceptible varieties, and the use of fungicides not recommended for blast control. Although agricultural extension services are the primary source of information, their support has not been sufficient to influence effective disease management. Strengthening farmer knowledge and improving extension capacity are therefore central to addressing the challenges identified in this study. Strengthening these areas would directly support better disease recognition, more appropriate management choices, and ultimately contribute to reducing blast severity in finger millet production.

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Chapter 5. SCREENING OF FINGER MILLET GENOTYPES AGAINST BLAST DISEASE (*Magnaporthe grisea*) UNDER FIELD CONDITIONS IN WESTERN AMHARA, ETHIOPIA

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Abstract

Finger millet is resilience and multipurpose crop mainly cultivated by subsistence farmers in Ethiopia, and other African, and Asian countries. However, the cultivation of the crop is significantly affected by blast disease. This research aimed to evaluate the response of finger millet genotypes to blast disease under natural infestations during the 2022 and 2023 main cropping seasons. A total of 64 finger millet genotypes, including both standard (Jabi) and local checks, were evaluated in a simple lattice design with two replications at the research stations of Adet and Finote Selam. Disease assessments were carried out using 0-9 rating scale on the leaves and 0-5 for the neck and head infections. The results based on mean head blast severity at Adet in 2022, 13 of the tested genotypes were classified as resistant, four as moderately resistant, 17 as moderately susceptible, and 30 as susceptible. In 2023, there were 14 resistant, 11 moderately resistant, 24 moderately susceptible, and 15 susceptible genotypes. The assessment in 2022 at Finote Selam identified three moderately resistant, seven moderately susceptible, 32 susceptible and 22 highly susceptible

genotypes, while in 2023, two moderately resistant, six moderately susceptible, 38 susceptible, and 18 highly susceptible genotypes were recorded. Genotypes G60, G14, G31, G61, G16, G32, and G35 were resistant to all blast stages (leaf, neck, and head). The best performers in yield and agronomic traits were G53, G7, G25, G21, and the local check. The result revealed that utilizing the resistant and moderately resistant genotypes for further resistance breeding programs increases the production and productivity of the crop.

Keywords: Agronomy, Infestation, Lattice, Productivity, Resistance, Yield

5.1 Introduction

Finger millet (*Eleusine coracana* L. Gaertn) is an important cereal food crop for millions of people living in the tropical and subtropical regions of Asia and Africa (Krishna et al., 2020). It is nutritionally superior to rice and wheat due to its large level of dietary fiber, iron, zinc, calcium, phosphorus, potassium, vitamin B and essential amino acids (Singh *et al.*, 2019; Demeke Teklu *et al.*, 2024). Finger millet is the most widely cultivated millet in the world after pearl millet (*Pennisetum glaucum*) and foxtail millet (*Setaria italica*) (Maharajan *et al.*, 2019). It is also one of the essential plant genetic resources for the agriculture and food security of farmers inhabiting infertile and marginal lands (Gupta *et al.*, 2017). Resistance to some pests and diseases, adaption to a varied array of environmental conditions, good production potential, short growing season, little input requirement, tolerating salinity stress and waterlogging make the crop more preferable for human use in the future (Prasad *et al.*, 2020). Finger millet is one of the fundamental food crop in Ethiopia and other parts of Africa and Asia and a beneficial food crop for those with diabetes, heart disease and high blood pressure because of its greater nutritional and medicinal value (Srivastava and Sharma, 2014).

Finger millet is the sixth most important cereal crop in the world after bread wheat (*Triticum aestivum* L), maize (*Zea mays* L), rice (*Oryza sativum* L), barley (*Hordeum vulgare* L), and sorghum (*Sorghum bicolor* L) (Mason *et al.*, 2015). Ethiopia is the second largest producer of finger millet in the world

following India (INDIASTAT, 2020). In Ethiopia, finger millet accounts 4.5% of the total area allocated to cereals each year and contributes about 4% of the total annual cereal grain production in the country (Chekole Nigus and Tebkew Damte, 2018). In 2024, around 445, 000 hectares of land used for production, 125, 000 metric tons were produced with a yield of 2.44 metric tons per hectare with an average reduction of 2% for the last five years (CSA, 2024). The Amhara Region is the main producer of finger millet with 50% share of the country's finger millet area and production (CSA, 2024), however, its production is lower than other cereals.

Regardless of the significant genetic variation in finger millet found in Ethiopia, the yield of the crop is low, on average below 2.4 tons per hectare, in contrast to its potential yield of six tons per hectare. Numerous biotic and abiotic stresses, as well as socioeconomic factors, are the cause of the low finger millet crop productivity in the country (Adane Gebreyohannes *et al.*, 2021). Among the biotic factors, mainly blast disease and insect pests (Demeke Teklu *et al.*, 2024), along with abiotic constraints such as drought stress and socioeconomic factors including limited access to improved varieties, lack of seed access, financial limitations and small land holdings (Adane Gebreyohannes *et al.*, 2021) contribute to this yield gap. Moreover, the productivity of this crop is also limited by a lack of agronomic packages and lodging (Solomon Admasu and Tegegn Belete, 2020).

Finger millet blast caused by *M. grisea* (Hebert) Barr is the most devastating disease affecting finger millet production globally. The pathogen spreads rapidly across all major growing regions, infects different above-ground parts of the plant at all growth stages from seedlings to maturity (Odeph *et al.*, 2021). During high epidemic seasons, blast disease can result in yield losses of up to 100% (Odeph *et al.*, 2020; Dida *et al.*, 2021; Mbinda and Masaki, 2021). In East Africa, the disease has a significant effect on finger millet yields, utilization and market potential (Chung *et al.*, 2020). In Ethiopia, blast disease is recognized as

a major biotic factor affecting finger millet productivity, leading to considerable yield reductions (Zigale Semahegn *et al.*, 2021).

A variety of management strategies have been implemented to manage blast disease, such as cultural practices, fungicide applications, biocontrol agents, botanicals and host plant resistance (Odeph *et al.*, 2020). Of these, host resistance is the most effective, sustainable, and economically feasible approach, particularly for farmers with limited resources (Pathania *et al.*, 2021). Babu *et al.* (2013) evaluated 80 finger millet accessions for blast resistance under field, and greenhouse conditions; and 66 showed combined resistance to leaf, neck, and finger blast. Manyasa *et al.* (2019) also screened 81 East African accessions, identifying three resistant to all blast stages, while others showed partial resistance. Twelve moderately resistant accessions yielded over 20 t/ha. Similarly, Wekesa *et al.* (2019) tested 100 genotypes over two seasons, finding early maturing types more susceptible and six highly resistant. In addition, Ganesha *et al.* (2018) evaluated 14 varieties, and found twelve immune under field conditions. Bal *et al.* (2020) screened 33 genotypes; none of them was resistant to blast or brown spot, though some showed moderate resistance to leaf blast.

Use of resistant genotypes can minimize fungicide need and reduce production costs (Mbinda and Masaki, 2021). However, resistance is mainly controlled by major genes, which are susceptible to breakdown over time (Wang *et al.*, 2017). This highlights the need for persistent efforts to develop high-yielder varieties with durable genetic resistance to blast (Bhatta *et al.*, 2017; Manyasa *et al.*, 2019). In addition, there is a lack of research on screening of resistant finger millet genotypes under the agroecological conditions of Ethiopia. Screening resistant genotypes to blast and assessing their yield potential is a vital step for developing improved varieties that can increase production and sustain finger millet cultivation in Amhara and similar agroecologies. Therefore, this study aimed to identify finger millet genotypes exhibiting resistance to blast disease, thereby providing essential genetic resources for future breeding initiatives.

5.2 Materials and Methods

5.2.1 Description of the study areas

The study was carried out at Adet Agricultural Research Center (AdARC) and Finote Selam Research Substations (FSSC) (Figure 5.1), located in the Yilmana Densa, and Jabi Tehnan districts respectively during 2022 and 2023. Adet is situated at an altitude of 2220 meters above sea level, between latitudes of 11°17'21.1"N and longitudes of 37°28'45.2"E. Minimum and maximum temperatures are 11.0 and 26.8°C respectively, and the mean annual precipitation is 1,372 mm and the soil type of AdARC is Nitosols (Fekremariam Mihretie *et al.*, 2020). Major crops grown in the area are teff, maize, wheat, barley, faba bean, finger millet and pea (Yechale Mengie *et al.*, 2021).

Finote Selam is located within the Amhara National Regional State, located 376 kilometers from the capital city of Addis Ababa, and 176 kilometers to the southeast of Bahir Dar, the principal city of the Amhara Region, in the northwestern part of Ethiopia. Its geographical coordinates are 10°41'23" north latitude and 37°15'35" east longitude (Ayele Semachew *et al.*, 2018). The average annual rainfall is 1250 mm. The elevation of Finote Selam varies between 1500 and 2300 meters above sea level. The lowest and maximum temperatures are 14 and 32°C, respectively. According to the FAO soil classification system, the predominant soil type in Finote Selam is classified as Nitosol, with a soil pH of 5.3 (Tewodros Mulugeta *et al.*, 2024). The area cultivates a variety of cereals, including maize, wheat, sorghum, teff, finger millet, and barley. Haricot beans are the main legume grown, while red pepper is a major spice crop, indicating the strong potential of the region for spice production (Tewodros Mulugeta *et al.*, 2024).

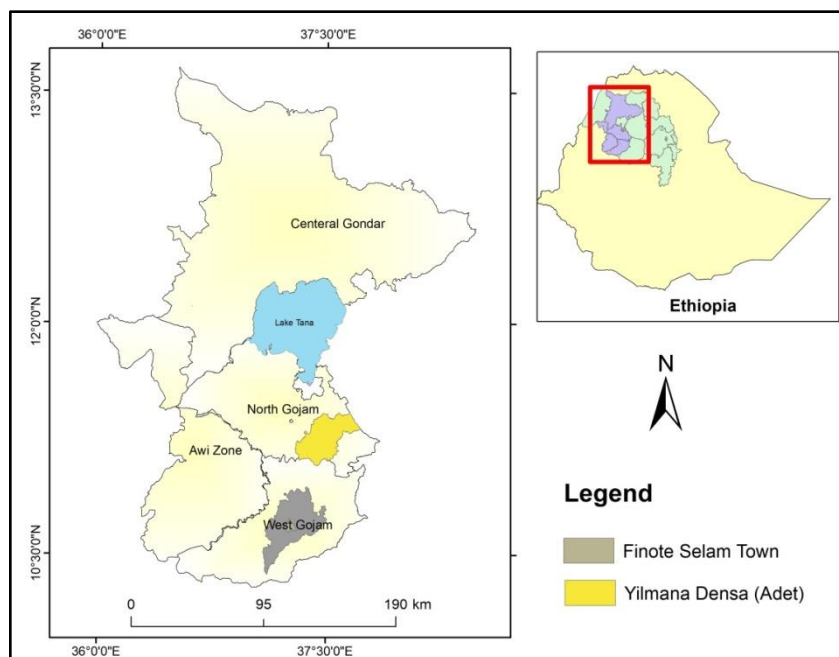


Figure 5.1 Map of the study area at AdARC (Site-1) and FSSC (Site -2)

5.2.2 Experimental materials, and design

The experiment included 62 germplasm (breeding lines) along with Jabi-blast resistant as a standard and one local check. The genotypes were obtained from the Ethiopian Agricultural Research Institute (Adet Agricultural Research Centre), and listed below with their pedigrees (Table 5.1).

Table 5.1. Codes of finger millet genotypes

Genotype	Pedigree	Genotype	Pedigree	Genotype	Pedigree	Genotype	Pedigree
1	P*N-P#17	17	P*N-P#31	33	D*N-P#18	49	N*G-P#34
2	N*W-P#1	18	N*P-P#17	34	W*N-P#P1-1	50	N*B-P#5
3	W*N-P#5	19	N*G-P#30	35	N*T-P#17	51	W*N-P#8
4	W*N-P#3	20	N*T-P#19	36	N*D-P#1	52	W*N-P#6-2
5	N*G-P#18	21	N*G-P#35	37	N*T-P#16	53	N*G-P#22
6	N*P-P#8	22	N*T-P#4	38	N*T-P#21	54	N*G-P#26
7	N*B-P#19	23	N*P-P#10	39	N*G-P#33	55	N*G-P#20-2
8	W*N-P#1-2	24	N*T-P#20	40	B*N-P#25	56	N*G-P#11
9	N*T-P#7	25	P*N-P#5	41	P*N-P#35	57	N*G-P#10
10	D*N-P#7	26	N*P-P#24	42	W*N-P#11-1	58	N*G-P#8
11	N*T-P#25	27	N*B-P#6	43	N*T-P#28	59	N*G-P#30-1
12	N*T-P#2	28	N*G-P#1	44	B*N-P#1	60	N*W-P#4
13	N*T-P#12	29	P*N-P#32	45	N*P-P#9	61	W*N-P#6-3
14	P*N-P#13	30	N*G-P#20-1	46	N*G-P#32	62	B*N-P#10
15	N*T-P#22	31	N*G-P#31	47	P*N-P#30-2	63	St. check (Jabi)
16	N*B-P#7	32	N*P-P#4	48	P*N-P#27	64	Local check

Simple lattice design (8x8) with two replications was employed with a plot size of 4 rows of 2m length and 1.2 m width with a plot area of 2m x1.2m, and the space between blocks, replications, plots and rows were 1m, 1.5m, 0.5m and 0.3m respectively. A seeding rate of 15 kg ha⁻¹ seed was applied, with hand-drilling at intervals of 15cm on June 30/2022 for both Adet and Finote Selam and July 13/2023 at Adet and July 20/2023 at Finote Selam experimental sites respectively. The rates at which fertilizers applied were 50 kg ha⁻¹ for urea and 121 kg ha⁻¹ for NPS. Half urea and all NPS were applied during sowing, and half urea was applied at tillering growth stage. Other agronomic practices were applied as recommended for the crop.

5.2.3 Data collection

Disease assessment for the leaf blast was done starting from seedling and continued up to the booting stage (scored five times) based on the percent leaf area covered with blast lesions at 10-days interval using a 0–9 scale (Appendix Figure 3.1) following a field guidebook. Whereas finger and neck blast was done at physiological maturity, and recorded as 0 = no incidence, 1 = <5%, 2 = 5–10% infection, 3 = 11–25%, 4 = 26–50%, and 5 = >50% infection on neck, and finger parts (Appendix Figure 3.2) (Bal et al., 2020) with minor modifications. Classification of test genotypes for resistance or susceptibility to blast was done based on disease severity (%), and genotypes were grouped into six categories which include: 0–5% resistance (R), 6–25% moderately resistance (MR), 26–50% slightly susceptible (MS), 51–75% susceptible (S), and >75% as highly susceptible (HS) based on leaf blast severity (Kumari *et al.*, 2022). Similarly for neck and finger blasts, highly resistant (HR) with < 10% disease infection, R as 11–30% infected, MR as 31–40% infected, MS between 40–50%, 51–70% infected as S and 71–100% infection as HS in the neck and head regions (Wekesa et al., 2019).

Disease incidence was calculated by using the number of infected plants and expressed as a percentage of the total number of plants assessed using the formula of Teng and James (2002):

$$\text{Disease incidence (\%)} = \frac{\text{Number of plants infected}}{\text{Total number of plants assessed}} \times 100$$

The percent disease intensity (PDI) was calculated by using the following formula of Miedaner *et al.* (1996):

$$\text{PDI for severity} = \frac{\text{Sum of individual disease ratings}}{\text{No. of observations assessed} \times \text{maximum disease rating}} \times 100$$

The blast disease severity scores that were taken at different times were used to calculate the AUPDC of each genotype using the following formula of Madden *et al.* (2007):

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

Where, x_i is the cumulative disease severity expressed as a proportion at the i^{th} observation; t_i is the time (days after planting) at the i^{th} observation and "n" is the total number of observations.

According to the International Board for Plant Genetic Resources recommendation (Hanson *et al.*, 1985), the following yield and yield-related traits: Physiological Maturity (DM), Plant Height (PH), Number of Tillers per Plant (NTP), Number of Ears per Plant (NEP), and Grain Yield (GY) (kg/ha), among others were measured from 10 randomly selected plants from the two central harvestable rows (Figure 5.2).



Figure 5.2. Photo demonstrating field experiment data collection

5.2.4 Data analysis

Disease data was transformed using arcsine transformation before analysis. ANOVA analysis (F-test) revealed significant differences across treatment means and the error variances as a result separate analysis was performed for each location and year. The data on the finger millet blast disease and phenotypic parameters were subjected to an ANOVA (analysis of variance) using SAS version 9.4 (SAS, 2009) software. Duncan multiple range test (DMRT) was used to separate the means at $p < 0.05$ significance level (Gomez and Gomez, 1984). The analysis of Pearson correlation was used to determine the association between the three types of blast diseases as well as the relationship between each type of disease and various morphological traits (Ojha *et al.*, 2024). Based on their AUDPC values, the resistance levels of the tested genotypes were clustered using the Unweighted Pair Group Method (UPGMA) the Arithmetic Mean (Bhatta *et al.*, 2017).

5.3 Results and Discussion

5.3.1 Yield and yield-related performance of selected genotypes

The analysis of variance showed that there was a significant genotypic variation ($P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$) for disease incidence, severity and on measured agronomic traits. Location (Loc), year, treatment (TRT), and interactions between Loc $\times$ TRT, Loc $\times$ Year, and Loc*Year*TRT had a significant effect for most of the disease and agronomic parameters tested (Table 5.2, Appendix Table 5.2).

Table 5.2. ANOVA for the effect of locations, year, treatments, and their interactions on yield, yield components, and disease parameters

Trait	Mean square										
	DPM	PH	NTP	NEP	GY	LBS	NBS	HBS	LAUDPC	NAUDPC	HAUDPC
Mean	147.41	77.63	3.77	5.39	3084.0	27.47	47.79	53.19	661.24	1413.04	1573.11
SEM(±)	3.12	5.13	0.52	0.72	474.00	7.18	9.02	9.13	248.44	300.47	355.77
Loc	285.01***	3533.3***	33.21** *	0.14 ^{ns}	3700052**	48756***	67804***	61139***	1851395.49** *	6946664.52** *	8068613.99* **
Year	190.13**	12053.2** *	64.13** *	0.01 ^{ns}	106815857* *	365.73 ^{ns}	55.62 ^{ns}	1343.2**	821778.03*	85096.43 ^{ns}	2879428.53* **
Year*Loc	1540.2***	278.19*	13.52**	288.6**	3121099.7*	2345.2***	4230.3***	619.3 ^{ns}	3278032.12**	4125755.59**	593790.47 ^{ns}
TRT(df=63)	58.87***	528.15***	2.08***	3.84***	2260674.2*	271.44***	570.15***	927.99***	330689.14***	761028.37***	1223654.26*
Year*TRT	28.66*	105.51 ^{ns}	0.77*	1.15 ^{ns}	522327 ^{ns}	107.9 ^{ns}	202.3 ^{ns}	111.3 ^{ns}	77695.22 ^{ns}	205315.31 ^{ns}	147301.22 ^{ns}
Loc*TRT	33.75**	45.77 ^{ns}	0.63 ^{ns}	2.13***	5483567 ^{ns}	209.5***	221.1 ^{ns}	357.4***	284148.43***	266691.37*	582559.1***
Loc*Year*	17.99 ^{ns}	53.65 ^{ns}	0.52 ^{ns}	1.11 ^{ns}	158429.7 ^{ns}	76.4 ^{ns}	302.9***	79.3 ^{ns}	52156.51 ^{ns}	278633.05*	99667.76 ^{ns}
Error(df=23)	19.52	52.62	0.54	1.05	448245	103.1	162.73	166.64	123445	180559	253141
CV (%)	3.16	9.83	24.67	23.69	23.87	36.39	36.23	31.29	32.26	30.07	31.98
R ² (%)	0.73	0.85	0.78	0.79	0.79	0.81	0.81	0.81	0.69	0.74	0.73

Significance probability levels: '***' 0.001 '**' 0.01 '*' 0.05; ns- not significant; Loc- location; df- Degree of freedom; TRT- treatment; SEM-standard error of the mean; DM- Days to physiological maturity; PH-Plant height (cm); NTE-Number of tiller per plant; NEP-Number of ear per plant; GY- Grain yield (kg ha⁻¹); LBI- leaf blast incidence; NBI- neck blast incidence; HdBI- head blast incidence; LBS-leaf blast severity (%); NBS-Neck blast severity (%); HBS-Head blast severity (%); LAUDPC; NAUDPC and HAUDPC- leaf, neck and head area under disease progress curve % days respectively; CV- Coefficient of variation and R²- coefficient of determination.

Table 5.3 and Appendix Table 5.3 below illustrate the performance of various genotypes over two years (2022 and 2023) and two locations (Adet and Finote Selam) regarding different growth traits, including days to physiological maturity (DM), plant height (PH), number of tillers per plant (NTP), number of ears per plant (NEP), and grain yield (GY). Significant variations were observed among the genotypes for most traits, highlighting both genetic diversity and the impact of environmental factors.

In terms of DPM, genotypes G5, G14 and the standard check (Jabi) consistently demonstrated high values, greater than 150 days under all conditions. Notably, G56 had DM of 161.5 at Adet during 2023 cropping season, which was significantly matured latter than that of most other genotypes. FL also exhibited considerable variation among genotypes, while G53 had the maximum FL at both Adet and Finote Selam in 2022, and G7 in 2023 cropping seasons. G25 also showed greater potential for high tiller production, especially at Adet (2022) and Finote Selam (2023). In contrast, genotypes such as G10, G56 and the local check displayed shorter PH values, particularly in 2023. NTP revealed significant differences with the local check consistently better than other genotypes, scoring 6.4 at Finote Selam (2022). Regarding the NEP, G21 scored the highest value of 8.6 at Adet (2022). The local check also exhibited strong performance at Finote Selam (2022), achieving a NEP of 7.7 (Table 5.3). Grain yield (GY) exhibited considerable difference among genotypes and environmental conditions. G7 achieved the highest yield at Adet during 2022, with 5208.3 kg ha⁻¹, whereas the local check achieved a maximum GY (5375 kg ha⁻¹) at Finote Selam in the same year. The minimum GY of (1375.0 and 2312.5 kg ha⁻¹) was recorded from the genotypes G13 and G56 respectively during the 2023 cropping season at Finote Selam. The significant differences in GY ($p < 0.05$) at different locations might indicate that environmental factors played a crucial role in influencing GY (Table 5.3). Variation among the test accessions were significant for grain yield, yield related and other agronomic parameters also reported by Dagnachew Lule *et al.* (2014) and Gani and Tunwari (2023).

Table 5.3. Mean performance in yield, yield-related and other agronomic parameters of selected genotypes

Adet										
Genotype	2022					2023				
	NTP	FL	NTP	NEP	GY	DPM	FL	NTP	NEP	GY
G5	151.5 ^a	77.0 ^{g-n}	4.3 ^{g-l}	5.3 ^{ghi}	4970.8 ^{ab}	151.5 ^{a-}	79.3 ^{a-g}	2.9 ^{g-k}	3.5 ^j	4041.7 ^a
G7	144.5 ^c	77.0 ^{g-n}	4.6 ^{d-l}	5.8 ^{d-i}	5208.3 ^a	144.0 ^{d-}	73.6 ^{b-n}	3.1 ^{e-k}	3.9 ^{hij}	3291.7 ^a
G10	146.5 ^a	68.0 ^{lo}	4.5 ^{e-l}	6.3 ^{c-i}	4250.0 ^{a-g}	148.5 ^{a-}	60.9 ^{p-t}	3.3 ^{d-k}	4.4 ^{d-j}	2833.3 ^b
G13	145.5 ^a	78.3 ^{f-n}	6.60	8.0 ^{ab}	3658.3 ^{b-i}	151.0	62.4 ^{k-t}	3.9 ^{b-k}	5.7 ^{b-f}	2166.7 ^e
G14	152.0 ^a	69.4 ^{k-o}	5.3 ^{c-}	6.4 ^{c-h}	4466.7 ^{a-e}	151.0 ^{a-}	73.3 ^{b-o}	5.2 ^{ab}	7.4 ^a	3125.0 ^b
G21	145.5 ^a	66.9 ^{mno}	5.2 ^{f-h}	8.6 ^a	3416.7 ^{c-i}	148.0 ^{a-}	75.3 ^{b-i}	4.6 ^{a-e}	6.7 ^{ab}	3833.3 ^a
G25	142.5 ^e	95.5 ^{a-e}	5.3 ^{c-}	6.3 ^{c-i}	3587.5 ^{b-i}	141.0 ^{ef}	88.6 ^b	3.3 ^{d-k}	4.7 ^{c-j}	2708.3 ^b
G30	142.5 ^e	100.8 ^{ab}	4.4 ^{f-l}	5.9 ^{d-i}	2708.3 ^{hi}	147.5 ^{b-}	88.6 ^a	2.9 ^{g-k}	4.1 ^{f-j}	2583.3 ^c
G53	148.5 ^a	104.0 ^a	4.1 ^{lm}	5.7 ^{d-i}	3125.0 ^{c-i}	143.0 ^{de}	81.9 ^{abc}	3.3 ^{d-k}	4.2 ^{f-j}	2416.7 ^e
G56	148.5 ^a	84.3 ^{c-l}	4.4	5.8 ^{d-i}	2941.7 ^{e-i}	161.5 ^a	57.2 ^{rst}	3.2 ^{e-k}	4.1 ^{f-j}	2375.0 ^e
G60	149.0 ^a	94.0 ^{a-f}	5.3 ^{c-}	7.0 ^{b-f}	3875.0 ^{a-i}	152.0 ^{a-}	83.4 ^{ab}	5.0 ^{abc}	6.3 ^{abc}	3250.0 ^a
St. check	153.5 ^a	69.5 ^{k-o}	4.5 ^{e-l}	6.0 ^{d-i}	4512.5 ^{a-d}	156.0 ^{a-}	61.5 ^{m-t}	3.6 ^{c-k}	4.5 ^{d-j}	4500.0 ^a
Local check	145.5 ^a	77.8 ^{f-n}	5.6 ^{bc}	7.1 ^{b-e}	3937.5 ^{a-i}	145.0 ^{d-}	65.4 ^{h-s}	4.5 ^{a-f}	6.0 ^{a-d}	3583.3 ^c
Mean	145.5	10.07	4.55	6.13	3547.72	147.79	8.73	3.51	4.63	2790.3
CV (%)	2.46	8.88	9.7	10.28	17.45	2.22	8.29	20.66	22.79	22.45
Sig. L. (5%)	*	***	***	**	*	ns	***	**	***	*

Finote Selam										
Genotype	2022					2023				
	DM	FL	NTP	NEP	GY	DM	FL	NTP	NEP	GY
G5	160.5 ^a	84.3 ^{e-q}	4.2 ^{a-i}	5.3 ^{a-g}	5208.3 ^{a-c}	153.5 ^a	90.2 ^{c-f}	3.7 ^{a-}	6.8 ^{a-k}	3750.0 ^b
G7	159.5 ^a	87.9 ^{e-n}	2.8 ^{e-j}	4.8 ^{a-g}	5333.3 ^{ab}	147.5 ^{a-g}	81.6 ^{d-n}	3.9 ^{a-}	8.3 ^{a-e}	3520.8 ^b
G10	158.0 ^a	68.5 ^{q-u}	3.9 ^{b-j}	4.4 ^{c-g}	3708.3 ^{a-k}	148.0 ^{a-g}	73.1 ^{f-s}	2.5 ^{ef}	5.7 ^{b-k}	2833.3 ^c
G13	151.0 ^a	61.5 ^u	4.5 ^{a-i}	5.2 ^{a-g}	2333.3 ^{j-l}	143.0 ^{d-g}	61.4 ^{q-s}	3.0 ^{b-}	6.4 ^{a-k}	1375.0 ⁿ
G14	156.5 ^a	66.5 ^{r-u}	3.9 ^{b-j}	4.7 ^{b-g}	5208.3 ^{ab}	153.0 ^{ab}	80.3 ^{d-p}	3.3 ^{a-}	6.6 ^{a-k}	3791.7 ^b
G21	150.5 ^a	74.6 ^{n-u}	4.3 ^{a-i}	5.6 ^{a-e}	4833.3 ^{a-e}	143.5 ^{c-g}	90.2 ^{c-f}	3.1 ^{b-}	8.0 ^{a-f}	3729.2 ^b
G25	150.5 ^a	104.0 ^{a-}	2.5 ^{f-j}	2.9 ^{e-g}	4416.7 ^{a-h}	143.0 ^{d-g}	102.6 ^{abc}	3.2 ^{a-}	4.4 ^{h-k}	2500.0 ^c
G30	151.5 ^a	111.2 ^a	3.3 ^{d-j}	3.7 ^{d-g}	3375.0 ^{e-l}	150.5 ^{a-e}	94.9 ^{bcd}	3.0 ^{b-}	5.5 ^{b-k}	3500.0 ^b
G53	159.0 ^a	107.4 ^{ab}	3.5 ^{d-j}	3.8 ^{d-g}	3500.0 ^{c-l}	148.5 ^{a-f}	114.7 ^a	3.7 ^{a-}	5.4 ^{c-k}	2416.7 ^d
G56	146.0 ^f	85.1 ^{e-p}	2.7 ^{e-j}	5.8 ^{a-e}	2333.3 ^{ijkl}	145.0 ^{b-g}	70.3 ^{h-s}	3.0 ^{b-}	6.4 ^{a-k}	2312.5 ^f
G60	157.0 ^a	100.2 ^{a-}	4.0 ^{b-j}	6.2 ^{a-d}	3458.3 ^{c-l}	153.5 ^a	80.5 ^{d-o}	4.6 ^{ab}	8.9 ^{ab}	2520.8 ^c
St. check	154.5 ^a	81.5 ^{h-s}	4.3 ^{a-i}	5.0 ^{a-g}	5166.7 ^{a-d}	152.0 ^{ab}	80.3 ^{d-p}	3.7 ^{a-}	6.5 ^{a-k}	5208.3 ^a
Local check	153.0 ^a	83.9 ^{e-q}	6.4 ^a	7.7 ^a	5375.0 ^a	153.0 ^{ab}	77.8 ^{d-q}	4.1 ^{a-}	8.8 ^{abc}	4604.2 ^a
Mean	150.5	9.92	3.71	4.66	3533.85	145.81	10.3	3.33	6.16	2464.1
CV (%)	2.79	8.17	25.4	25.67	20.16	2.22	8.29	ns	22.79	22.45
Sig. L. (5%)	***	***	*	ns	***	***	***	20.6	*	***

Note: G- Genotype, St. Check -Standard check, Sig.L. - Significance level Means along the column with the same letter are not significantly different at 5 % (*), 1 % (**) and 0.1 % (***) probability

5.4 Blast Disease in Selected Finger Millet Genotypes

5.4.1 Leaf blast incidence and severity

The analysis of variance revealed that neck blast incidence and severity showed significant ($p < 0.05$) variation among the genotypes at both locations and years (Table 5. 2). Mean leaf blast severity was higher in the 2022 cropping season (20.69%) than 2023 (14.73%) at Adet. Similarly, average leaf severity was higher in 2022 cropping season (38.53%) than in 2023 (35.94%) at Finote Selam. During the 2022 evaluation at Finote Selam, the percent leaf incidence ranged from 32.18 to 100.00% with a mean of 69.94, and severity ranged from 16.02-55.41% with a mean of 35.94. In the 2023 cropping season, blast incidence ranged from 22.45 – 84.55% with a mean of 58.38, and severity ranged from 6.87 – 57.01% with a mean of 38.53% (Table 5.4, Appendix Table 5.4).

Overall at Adet, among the most resistant (R) genotypes; G14, G31 and G60 showed 0% severity while genotypes G20, G51 and local check were susceptible. At Finote Selam, the most R genotype was G60, while the most S genotypes include G20 and G51. Genotypes G5, G13, G21, G33, G39, G44, G45, G49, G52, G53 and the standard check showed moderate resistance (MR) at both locations. The moderately susceptible (MS) and S genotypes at both locations include G20, G27, G30, G51, G62 and local check (Table 5.4).

Table 5.4. Percent Mean leaf blast incidence, severity and AUDPC of selected genotypes

Genotypes	Adet					
	2022			2023		
	LBI	LBS	LAUDP	LBI	LBS	LAUD PC
G5	52.16 ^{a-d}	25.09 ^{a-d}	1043.8 ^{a-f}	47.33 ^a	21.3 ^{abc}	891.9 ^{a-d}
G13	26.76 ^{a-e}	15.43 ^{a-d}	632.1 ^{a-f}	35.56 ^{abc}	16.22 ^{abc}	658.1 ^{a-d}
G14	0.00 ^e	0.00 ^d	0.00 ^f	0.00 ^c	0.00 ^c	0.00 ^d
G20	70.48 ^a	38.69 ^a	1570.1 ^a	51.17 ^a	25.71 ^{ab}	1088.1 ^{abc}
G21	45.09 ^{a-e}	19.39 ^{a-d}	774.3 ^{a-f}	38.26 ^{abc}	15.58 ^{abc}	605.1 ^{a-d}
G27	64.35 ^{ab}	38.22 ^a	1546.5 ^{ab}	46.32 ^a	24.64 ^{abc}	1029.6 ^{a-d}
G30	51.17 ^{a-d}	27.77 ^{a-d}	1152.6 ^{a-f}	10.07 ^{abc}	3.33 ^{bc}	120.7 ^{bc}
G31	0.00 ^e	0.00 ^d	0.00 ^f	0.00 ^c	0.00 ^c	0.00 ^d
G33	21.91 ^{a-e}	9.65 ^{a-d}	397.2 ^{a-f}	19.18 ^{abc}	8.66 ^{abc}	362.1 ^{a-d}
G35	12.38 ^{cde}	3.03 ^{cd}	75.7 ^{ef}	10.07 ^{abc}	2.83 ^{bc}	70.7 ^{cd}
G39	26.76 ^{a-e}	15.01 ^{a-d}	603.8 ^{a-f}	14.34 ^{abc}	6.79 ^{abc}	268.7 ^{a-d}

G41	24.75 ^{a-e}	6.43 ^{bcd}	160.6 ^{def}	0.00 ^{bc}	0.00 ^c	0.00 ^d
G44	35.26 ^{a-e}	21.09 ^{a-d}	872.0 ^{a-f}	27.88 ^{abc}	14.89 ^{abc}	635.6 ^{a-d}
G45	50.01 ^{a-e}	24.92 ^{a-d}	1043 ^{a-f}	41.08 ^{abc}	18.83 ^{abc}	800.1 ^{a-d}
G49	36.79 ^{a-e}	15.54 ^{a-d}	612.7 ^{a-f}	19.18 ^{abc}	9.44 ^{abc}	387.2 ^{a-d}
G51	65.25 ^{ab}	35.57 ^{ab}	1487.3 ^{abc}	49.79 ^a	27.17 ^{ab}	1149.2 ^{ab}
G52	48.64 ^{a-e}	22.45 ^{a-d}	860.1 ^{a-f}	39.05 ^{abc}	17.99 ^{abc}	683.1 ^{a-d}
G53	41.36 ^{a-e}	19.30 ^{a-d}	724.8 ^{a-f}	31.98 ^{abc}	12.57 ^{abc}	455.1 ^{a-d}
G57	27.76 ^{a-e}	9.94 ^{a-d}	366.9 ^{a-f}	0.00 ^c	0.00 ^c	0.0 ^d
G60	0.0 ^e	0.0 ^d	0.0 ^f	0.00 ^c	0.00 ^c	0.0 ^d
G61	10.07 ^{de}	2.83 ^{cd}	70.7 ^{ef}	34.48 ^{abc}	14.51 ^{abc}	557.4 ^{a-d}
G62	52.36 ^{a-d}	28.02 ^{a-d}	1154.5 ^{a-f}	43.76 ^{abc}	21.38 ^{abc}	870.9 ^{a-d}
Standard Check	25.60 ^{a-e}	13.18 ^{a-d}	543.2 ^{a-f}	19.18 ^{abc}	10.26 ^{abc}	432.5 ^{a-d}
Local check	53.48 ^{a-d}	31.61 ^{abc}	1287.5 ^{a-e}	42.36 ^{abc}	26.23 ^{ab}	1062.7 ^{a-d}
Mean	40.73	20.69	841.45	30.22	14.73	601.29
CV (%)	41.05	42.02	38.13	39.57	27.69	43.78
Significance Level	ns	ns	ns	ns	ns	ns

Finote Selam						
Genotypes	2022			2023		
	LBI	LBS	LAUDP	LBI	LBS	LAUDP
G5	64.15 ^{c-j}	30.06 ^{f-p}	488.9 ^{f-o}	47.33 ^a	21.30 ^{abc}	211.1 ^{nm}
G13	43.32 ^{ijk}	18.92 ^{nop}	225.0 ^o	35.56 ^{abc}	16.22 ^{abc}	305.6 ^{j-n}
G14	58.44 ^{d-k}	31.10 ^{e-p}	405.6 ^{j-o}	0.00 ^c	0.00 ^c	397.2 ^{g-n}
G20	94.97 ^{ab}	50.42 ^{a-d}	927.8 ^{a-d}	51.17 ^a	25.71 ^{ab}	583.3 ^{c-m}
G21	50.01 ^{g-k}	25.48 ^{j-p}	300.0 ^{no}	38.26 ^{abc}	15.58 ^{abc}	283.31 ^{mn}
G27	90.70 ^{abc}	51.05 ^{abc}	961.1 ^{abc}	46.32 ^a	24.64 ^{abc}	1077.8 ^{abc}
G30	65.32 ^{b-j}	36.62 ^{b-n}	530.6 ^{e-o}	10.07 ^{abc}	3.33 ^{bc}	300.0 ^{k-n}
G31	64.35 ^{c-j}	33.36 ^{c-p}	508.3 ^{e-o}	0.00 ^c	0.00 ^c	311.1 ^{j-n}
G33	82.63 ^{a-e}	43.48 ^{a-j}	730.6 ^{b-k}	19.18 ^{abc}	8.66 ^{abc}	288.9 ^{mn}
G35	75.54 ^{a-h}	36.56 ^{b-n}	550.0 ^{e-o}	10.07 ^{abc}	2.83 ^{bc}	863.9 ^{a-h}
G39	80.59 ^{a-f}	41.23 ^{a-l}	669.4 ^{b-m}	14.34 ^{abc}	6.79 ^{abc}	991.7 ^{a-e}
G41	70.50 ^{a-i}	35.69 ^{b-o}	630.6 ^{b-n}	0.00 ^{bc}	0.00 ^c	419.4 ^{g-n}
G44	51.70 ^{f-k}	23.14 ^{l-p}	361.1 ^{k-o}	27.88 ^{abc}	14.89 ^{abc}	966.7 ^{a-f}
G45	70.51 ^{a-i}	34.38 ^{b-o}	483.3 ^{f-o}	41.08 ^{abc}	18.83 ^{abc}	555.6 ^{e-n}
G49	90.75 ^{abc}	48.43 ^{a-e}	866.7 ^{a-e}	19.18 ^{abc}	9.44 ^{abc}	886.1 ^{a-g}
G51	100.00 ^a	55.41 ^a	1136.1 ^a	49.79 ^a	27.17 ^{ab}	1180.6 ^a
G52	48.78 ^{h-k}	22.83 ^{m-p}	261.1 ^{no}	39.05 ^{abc}	17.99 ^{abc}	633.3 ^{c-m}
G53	78.54 ^{a-h}	42.78 ^{a-k}	738.9 ^{b-j}	31.98 ^{abc}	12.57 ^{abc}	394.4 ^{g-n}
G57	71.51 ^{a-i}	37.11 ^{b-m}	513.9 ^{e-o}	0.00 ^c	0.00 ^c	572.2 ^{d-n}
G60	35.26 ^{ijk}	18.47 ^{op}	258.3 ^{no}	0.00 ^c	0.00 ^c	725.0 ^{a-l}
G61	51.97 ^{f-k}	25.18 ^{j-p}	330.6 ^{l-o}	34.48 ^{abc}	14.51 ^{abc}	861.1 ^{a-h}
G62	82.54 ^{a-e}	43.09 ^{a-k}	713.9 ^{b-k}	43.76 ^{abc}	21.38 ^{abc}	1069.4 ^{a-d}
Standard Check (Jabi)	61.19 ^{c-k}	28.38 ^{g-p}	411.1 ^{j-o}	19.18 ^{abc}	10.26 ^{abc}	83.3 ⁿ
Local check	68.47 ^{b-i}	43.44 ^{a-j}	619.4 ^{b-n}	42.36 ^{abc}	26.23 ^{ab}	713.9 ^{a-l}
Mean	69.94	35.94	561.15	58.38	38.53	641.06
CV (%)	19.89	24.76	26.94	32.23	36.96	31.38
Significance Level	**	**	***	**	**	***

5.4.2 Neck and head blast incidence and severity

The neck blast incidence percentage ranged from 0 to 77.54% with a mean of 51.52 at Adet and 40.87–100.00% with a mean of 78.28 at Finote Selam in 2022 cropping season. In 2023 cropping season, the incidence ranged from 0 to 66.42% with a mean of 47.16 at Adet, and 43.76–89.64% with a mean of 68.11 at Finote Selam. While severity ranged from 0 to 51.05% with a mean of 33.74 at Adet, and 37.89–85.82% with a mean of 62.51 at Finote Selam. Over growing seasons, the highest mean neck blast severity was recorded at Finote Selam (56.09%) compared with Adet (38.83%) in 2022, and 62.51% than 33.7% in the 2023 cropping season with some genotypes being more tolerant than the standard check (Jabi) (Table 5.5, Appendix Table 5.5).

Overall, the most R genotypes were G55, G57 G3, and G36 in 2022 cropping season, while in 2023, G14, G32, G60, G35 and G31 at Adet. Whereas at Finote Selam, the most R and MR genotypes were G60, G55, G53, G13, G39 and G5 in 2022, and G6 and G55 in 2023. Similarly, the most MS and S genotypes were G61, G58, G24, G35 and G8 in 2022, and G51, G11, G58, G64 and G9 in 2023 at Adet, while at Finote Selam, the most highly S genotypes were G46, G27 and G51 in 2022 and G24, G51, G49 and G46 in 2023 respectively (Table 5.5).

Differences in resistance or susceptibility among genotypes can be attributed genetic variation, including the presence or absence of resistance genes, variation in biochemical defense responses, and structural differences in plant tissues. However, these inherent genetic traits do not act independently. Environmental conditions particularly high humidity, warm temperatures, extended leaf wetness, and excessive nitrogen availability create favorable conditions for *M. grisea* infection and may weaken the defense mechanisms of certain genotypes. Patro *et al.* (2020); Das *et al.* (2021); Dida *et al.* (2021); Manyasi *et al.* (2022) conducted screening of different genotypes and reported similar results.

Table 5.5. Percent mean of neck blast incidence, severity and AUDPC of selected genotypes

Genotypes	Adet					
	2022			2023		
	NBI	NBS	NAUDPC	NBI	NBS	NAUDPC
G5	38.27 ^{a-f}	44.36 ^{a-d}	1934.3 ^{a-d}	61.19 ^{ab}	45.56 ^{c-a-d}	38.27 ^{a-f}
G6	24.41 ^{b-f}	52.65 ^{abc}	2016.5 ^{a-d}	39.75 ^{a-h}	27.31 ^{a-i}	24.41 ^{b-f}
G8	66.15 ^{abc}	58.71 ^a	2261.2 ^a	57.95 ^{a-d}	43.23 ^{a-e}	66.15 ^{abc}
G9	61.18 ^{a-d}	31.97 ^{a-e}	1355.6 ^{a-g}	66.42 ^a	51.05 ^a	61.18 ^{a-d}
G11	68.47 ^{ab}	39.11 ^{a-d}	1818.5 ^{a-e}	61.19 ^{ab}	47.89 ^{abc}	68.47 ^{ab}
G13	49.30 ^{a-e}	35.42 ^{a-e}	1592.8 ^{a-g}	45.07 ^{a-f}	31.79 ^{a-g}	49.30 ^{a-e}
G24	62.24 ^{abc}	54.81 ^{ab}	2285.4 ^a	57.95 ^{a-d}	42.13 ^{a-e}	62.24 ^{abc}
G27	70.50 ^{ab}	46.40 ^{abc}	2047.5 ^{abc}	61.16 ^{ab}	45.73 ^{a-d}	70.50 ^{ab}
G35	12.38 ^{def}	56.38 ^a	1729.0 ^{a-f}	10.07 ^{hi}	3.84 ^{hi}	12.38 ^{def}
G39	56.73 ^{a-e}	33.69 ^{a-e}	1467.1 ^{a-g}	51.17 ^{a-f}	36.74 ^{a-f}	56.73 ^{a-e}
G46	68.47 ^{ab}	44.26 ^{a-d}	1939.4 ^{a-d}	53.48 ^{a-e}	39.15 ^{a-f}	68.47 ^{ab}
G49	42.22 ^{a-d}	53.94 ^{ab}	1868.7 ^{a-d}	20.58 ^{f-i}	12.98 ^{f-i}	42.22 ^{a-d}
G51	72.53 ^{ab}	50.80 ^{abc}	2166.4 ^{ab}	62.19 ^{ab}	47.26 ^{c-a-d}	72.53 ^{ab}
G53	59.84 ^{a-d}	44.51 ^{a-d}	1926.1 ^{a-d}	52.29 ^{a-e}	37.32 ^{a-f}	59.84 ^{a-d}
G55	64.3 ^{abc}	0.00 ^e	583.1 ^g	52.16 ^{a-e}	37.86 ^{c-a-f}	64.3 ^{abc}
G58	77.54 ^a	54.52 ^{ab}	2296.5 ^a	64.34 ^a	49.45 ^{ab}	77.54 ^a
G60	10.07 ^{ef}	39.94 ^{a-d}	1114.3 ^{bg}	10.07 ^{hi}	3.22 ^{hi}	10.07 ^{ef}
G61	12.38 ^{def}	54.50 ^{ab}	1661.8 ^{a-g}	35.67 ^{a-h}	21.29 ^{c-i}	12.38 ^{def}
G62	59.01 ^{a-d}	45.00 ^{abc}	1928.8 ^{a-d}	57.78 ^{a-d}	38.93 ^{a-f}	59.01 ^{a-d}
Standard check (Jabi)	28.98 ^{a-f}	43.42 ^{a-d}	1499.2 ^{a-g}	23.18 ^{e-i}	17.53 ^{e-i}	28.98 ^{a-f}
Local check	57.78 ^{a-e}	47.08 ^{abc}	2064.7 ^{abc}	57.95 ^{a-d}	50.25 ^{ab}	57.78 ^{a-e}
Mean	51.52	38.83	897.82	47.16	33.74	1426.86
CV (%)	38.19	38.87	27.53	26.84	33.22	32.87
Significance levels	ns	ns	ns	***	***	***
Genotypes	Fenotselam					
G5	51.92 ^{uvw}	33.02 ^{uvw}	645 ^{u-y}	52.29 ^{r-w}	41.79 ^{uv}	670 ^{xy}
G6	78.54 ^{d-s}	57.38 ^{g-q}	1290 ^{f-r}	43.76 ^w	37.89 ^v	590 ^y
G8	91.93 ^{a-k}	73.73 ^{e-f}	1645 ^{c-g}	82.55 ^{a-e}	79.15 ^{a-d}	1965 ^{a-e}
G9	95.22 ^{a-g}	77.07 ^{a-e}	1855 ^{a-e}	68.25 ^{e-q}	64.92 ^{d-o}	1420 ^{g-r}
G11	100.00 ^{abc}	78.68 ^{a-d}	2050 ^{abc}	70.50 ^{e-o}	65.22 ^{d-o}	1410 ^{g-r}
G13	50.89 ^{vw}	32.42 ^{uvw}	595 ^{v-y}	55.67 ^{p-w}	50.92 ^{n-v}	1060 ^{q-y}
G24	90.75 ^{a-l}	74.65 ^{a-h}	1710 ^{b-g}	85.58 ^{a-d}	83.49 ^{abc}	2060 ^{a-d}
G27	95.38 ^a	86.65 ^{ab}	2175 ^{ab}	72.27 ^{d-n}	69.92 ^{b-k}	1625 ^{c-n}
G35	65.87 ^{n-v}	39.63 ^{q-v}	845 ^{q-x}	64.15 ^{h-s}	59.51 ^{g-r}	1235 ^{j-u}
G39	51.92 ^{uvw}	32.44 ^{uvw}	605 ^{v-y}	77.54 ^{a-i}	74.29 ^{a-g}	1800 ^{a-i}
G46	94.05 ^{ab}	80.36 ^{abc}	1920 ^{a-d}	89.64 ^a	85.82 ^a	2230 ^a
G49	88.75 ^{a-m}	65.45 ^{c-n}	1335 ^{f-q}	87.59 ^{ab}	85.35 ^a	2150 ^{ab}
G51	96.19 ^a	89.75 ^a	2220 ^a	86.64 ^{abc}	84.53 ^{ab}	2100 ^{abc}
G53	53.79 ^{t-w}	32.22 ^{uvw}	605 ^{v-y}	63.30 ^{i-t}	53.44 ^{l-u}	1090 ^{p-x}
G55	53.61 ^{t-w}	31.09 ^{vw}	570 ^{wxy}	47.59 ^{vw}	39.81 ^{uv}	730 ^{v-y}
G58	93.78 ^{a-i}	72.61 ^{a-j}	1680 ^{c-g}	75.53 ^{a-k}	69.14 ^{c-l}	1655 ^{c-m}
G60	40.87 ^w	18.50 ^w	215 ^y	54.08 ^{q-w}	47.88 ^{p-v}	850 ^{t-y}
G61	62.01 ^{q-v}	35.92 ^{s-w}	665 ^{u-y}	70.45 ^{e-o}	67.84 ^{d-}	1495 ^{e-q}
G62	76.48 ^{f-s}	54.41 ^{j-s}	1050 ^{k-w}	82.56 ^{a-e}	77.84 ^{a-e}	1825 ^{a-h}
Standard check(Jabi)	67.88 ^{m-v}	39.65 ^{q-v}	810 ^{r-x}	79.54 ^{a-g}	51.49 ^{n-v}	1730 ^{b-j}
Local check	96.23 ^{a-f}	75.91 ^{a-g}	1615 ^{c-i}	75.54 ^{a-k}	69.67 ^{b-k}	1570 ^{e-p}
Mean	78.28	56.09	1219.69	68.11	62.51	1373.44
CV (%)	32.02	36.23	34.94	23.56	26.69	34.26
Significance levels	***	***	***	***	***	***

In 2022 cropping season, the head blast severity was ranged from 0–65.85% (mean of 44.97) as compared to 2023 that was ranged from 0–57.50% (mean of 39.54) at Adet. Whereas at Finote Selam, it ranged from 36.23–99.03% with a mean of 64.63 in 2022 cropping season and it ranged from 34.6– 88.51% with a mean of 63.59 in 2023. Generally, less blast disease severity was recorded at Adet than Finote Selam. Overall, the average mean severity at Finote Selam was higher in 2022 (64.63%) as compared to 2023 (63.59%) but at Adet, it was 44.97 in 2022 and 39.54 in 2023 cropping season (Table 5.6, Appendix Table 5.6).

Based on mean finger millet severity score, the most R genotype was G14 during both 2022 and 2023 at Adet. On the other hand, the most S genotypes were G38, G27 and G11 in 2022 and, G45, G64 and G1 in 2023. Whereas, at Finote Selam, the MR genotypes were G13, G60 and G5 in 2022 cropping season and genotypes G4 and G6 were MR in 2023. The most highly S genotypes were G27, G38 and G51 in 2022 and G51 G64 and G45 in 2023 (Table 6.6). Variation among the test accessions, for leaf blast, neck blast, head blast, and AUDPC reported by Dagnachew Lule et al. (2014). Screening of finger millet by Ojha et al. (2024) also revealed that, the accessions showed wide variation in blast resistance, ranging from highly susceptible to resistant. Leaf blast severity ranged from highly susceptible to resistant, neck blast from resistant to susceptible, and finger blast from resistant to susceptible. This broad variability reflects substantial genetic diversity and provides a valuable resource for breeding stronger, blast-resistant varieties. The variation in genotype performance across the screening locations may reflect the combined influence of genetic resistance and local climatic conditions

Table 5.6. Percent mean of head blast incidence and severity of selected genotypes

Genotypes	Adet					
	2022			2023		
	HdBI	HBS	HAUDPC	HBI	HBS	HAUDPC
G1	80.55 ^{ab}	62.27 ^{abc}	2521.5 ^{abc}	73.53 ^a	57.50 ^a	2316.0 ^a
G4	61.09 ^{a-f}	45.48 ^{a-f}	1822.8 ^{a-f}	45.33 ^{a-g}	30.03 ^{a-j}	1162.2 ^{a-j}
G5	68.44 ^{a-d}	54.31 ^{a-d}	2194.3 ^{a-d}	67.45 ^a	50.43 ^{a-e}	2047.0 ^{a-f}
G6	51.06 ^{a-h}	34.61 ^{a-i}	1451.8 ^{a-j}	20.58 ^{fgh}	13.95 ^{g-j}	575.4 ^{g-j}
G11	83.60 ^a	65.85 ^a	2619.4 ^a	70.40 ^a	54.59 ^{ab}	2200.7 ^{abc}
G13	60.18 ^{a-g}	43.59 ^{a-g}	1789.9 ^{a-g}	55.36 ^{a-f}	41.08 ^{a-h}	1711.1 ^{a-g}
G14	0.00 ⁱ	0.00 ⁱ	0.00 ^j	0.00 ^h	0.00 ^j	0.00 ^j
G27	79.54 ^{ab}	64.12 ^{ab}	2599.6 ^{ab}	66.03 ^{ab}	50.96 ^{a-e}	2038.8 ^{a-f}
G38	81.62 ^{ab}	63.13 ^{ab}	2547.2 ^{abc}	70.45 ^a	54.74 ^{ab}	2188.6 ^{a-d}
G45	77.54 ^{abc}	59.62 ^{a-d}	2418.9 ^{a-d}	73.51 ^a	56.94 ^a	2323.4 ^a
G51	77.52 ^{abc}	59.70 ^{abc}	2412.1 ^{a-d}	66.03 ^{ab}	51.29 ^{a-e}	2062.8 ^{a-e}
G60	14.34 ^{hi}	5.80 ^{hi}	144.9 ^{ij}	12.38 ^{gh}	4.12 ^{ij}	102.9 ^{ij}
G61	16.09 ^{ghi}	7.34 ^{ghi}	263.8 ^{g-j}	49.30 ^{a-f}	29.99 ^{a-j}	1240.7 ^{a-j}
Standard check (Jabi)	34.24 ^{c-i}	22.45 ^{d-i}	908.3 ^{d-j}	25.60 ^{d-h}	17.13 ^{f-j}	704.9 ^{f-j}
Local check	74.54 ^{a-d}	62.12 ^{abc}	2415.4 ^{a-d}	66.41 ^a	57.44 ^a	2136.7 ^{a-e}
Mean	61.26	44.97	1807.69	54.07	39.54	1589.60
CV (%)	29.59	33.26	34.44	27.69	32.21	34.26
Significance Levels (5%)	**	**	**	***	***	**

Genotypes	Finote Selam					
	2022			2023		
	HBI	HBS	HUDPC	HBI	HBS	HAUDPC
G1	68.15 ^{o-r}	42.69 ^{u-y}	920.0 ^{o-s}	77.54 ^{a-g}	72.69 ^{b-j}	1670 ^{b-l}
G4	67.45 ^{pqr}	42.66 ^{u-y}	710.0 ^{qrs}	45.09 ^o	34.60 ^w	585.00 ^t
G5	55.83 ^r	38.83 ^{wxy}	640.0 ^{rs}	57.42 ^{i-o}	50.43 ^{q-v}	980 ^{o-t}
G6	86.93 ^{e-o}	66.90 ^{f-q}	1640 ^{d-k}	48.66 ^{no}	37.47 ^{vw}	655 st
G11	100.00 ^{a-f}	80.82 ^{b-i}	2005.0 ^{b-f}	73.53 ^{c-i}	69.89 ^{c-l}	1595 ^{c-m}
G13	62.01 ^{qr}	36.23 ^y	670.0 ^{qrs}	60.86 ⁱ⁻ⁿ	55.29 ^{k-u}	1170 ^{j-s}
G14	80.54 ^{g-q}	56.03 ^{n-v}	1070.0 ^{l-r}	52.36 ^{mno}	45.13 ^{uvw}	800 ^{rst}
G27	100.00 ^{a-d}	91.88 ^{abc}	2385.0 ^{ab}	79.56 ^{a-f}	73.65 ^{a-i}	1770 ^{a-i}
G38	100.00 ^{ab}	93.69 ^{ab}	2370.0 ^{ab}	77.54 ^{a-g}	72.23 ^{b-j}	1750 ^{a-j}
G45	90.66 ^{b-m}	70.22 ^{e-o}	1555.0 ^{e-l}	66.33 ^{f-m}	61.44 ^{f-t}	1265 ^{h-r}
G51	100.00 ^a	99.03 ^a	2665.0 ^a	88.69 ^{ab}	85.83 ^{abc}	2220 ^{ab}
G60	69.45 ^{n-r}	37.48 ^{xy}	565.0 ^s	54.31 ^{l-o}	45.66 ^{t-w}	900 ^{p-t}
G61	72.45 ^{l-r}	51.82 ^{q-y}	1055.0 ^{m-r}	72.51 ^{c-i}	70.54 ^{b-l}	1630 ^{c-l}
Standard check(Jabi)	74.48 ^{k-q}	41.28 ^{v-y}	1060.0 ^{l-r}	78.54 ^{a-f}	51.11 ^{o-v}	1670 ^{b-l}
Local check	100.00 ^{a-e}	90.73 ^{a-d}	1995.0 ^{b-f}	91.69 ^a	86.46 ^{ab}	1725 ^{a-k}
Mean	87.10	64.63	1488.52	70.42	63.59	1406.64
CV (%)	27.63	31.29	26.61	20.24	24.27	23.55
Significance Levels (5%)	***	***	***	***	***	***

5.4.3 Genotype category: based on response to blast disease reaction

Finger millet genotypes show different reactions to blast disease, enabling their categorization into resistant, moderately resistant, moderately susceptible and highly susceptible groups. The classification of genotypes based on their reaction to blast disease is summarized as follows (Table 6.7, Appendix Table 6.7).

Table 5.7. Reactions of 64 finger millet genotypes to blast diseases at Adet, and Finote Selam in 2022 and 2023 cropping seasons

Location	Disease	Cropping Year											
		2022						2023					
		HR	R	MR	MS	S	HS	HR	R	MR	MS	S	HS
Adet	LBS	0	7	33	24	0	0	0	13	46	5	0	0
	NBS	2	13	14	26	9	0	5	16	19	23	1	0
	FBS	4	9	4	17	30	0	3	11	11	24	15	0
Finote Selam	LBS	0	0	7	54	3	0	0	13	46	5	0	0
	NBS	0	1	14	9	26	14	0	0	2	7	44	11
	FBS	0	0	3	7	32	22	0	0	2	6	38	18

Note: LBS, = leaf blast severity, NBS= neck blast severity, HBS= head blast severity, HR= highly resistant, R= resistant, MR= moderately resistant, S= susceptible, HS= highly susceptible

In 2022 at Adet, seven genotypes exhibited resistance (R), 33 genotypes including the standard check Jabi demonstrated moderate resistance (MR) and 24 genotypes including the local check were classified as moderately susceptible (MS). In 2023, 13 genotypes were categorized as resistant (R), 46 (including the standard check) as moderately resistant (MR) and five (including the local check) as moderately susceptible (MS). In 2022 at Finote Selam, seven genotypes were classified as MR, 54 including standard and local checks as MS and three as susceptible (S). In 2023, 13 genotypes were rated R, 46 including the standard check were rated MR and five were rated MS for leaf blast severity (LBS). Furthermore, G13, G52 and G21 were MR, while G1, G38 and G20 were MS throughout both years and locations for LBS (Table 5.7, Appendix Table 5.7).

In 2022 at Adet, G55 and G57 exhibited highly resistance (HR), 13 genotypes were R, 14 were MR, 26 genotypes including standard and local checks were MS and nine were S. In 2023, five genotypes were classified as highly resistant (HR), 16 genotypes including the standard check were R, 19 were MR, 23

genotypes including the local check were MS and G9 was S. In 2022 at Finote Selam, G60 exhibited R, 14 genotypes including standard check were MR, nine were MS, 26 were S and 14 genotypes including local check were HS. In 2023, G6, and G55 were MR, seven were MS, 44 genotypes including the standard and local checks were S and 11 genotypes were HS for Neck Blast Severity (NBS) (Table 5.7, Appendix Table 5.7).

In 2022 at Adet, G14, G60, G31 and G61 were classified as HR; nine, including standard check were R; G6, G21, G28 and G36 were MR, 17 were MS and 30 including local check were S. In 2023, G14, G32 and G60 were classified as HR; 11 genotypes including standard check as R, 11 as MR, 24 as MS and 15 genotypes including local check as S. At Finote Selam, in 2022, G13, G60 and G5 were MR, seven genotypes including standard check were MS, 32 S and 22 genotypes including local check were HS. In 2023, G4, and G6 were MR, six MS, 38 genotypes including standard check were S and 18 genotypes including local check and G46 were HS for Head Blast Severity (HBS) (Table 5.7, Appendix Table 5.7).

In addition, at Adet, genotypes G14, G31, G60, G16, G35 and G32 were R, while G33, standard check, G9, G8, G56, G39, G13, G49, G17, G47, G40, G42, G48, G23, G53, G21, G2, G15, G44, G28, G3, G29, G52, G58, G18, G45 and G5 were MR. Local check, G1, G51, G38 and G20 were MS for LBS in both years. At Finote Selam, genotypes G50, G13, G52, G44, G61 and G21 were MR; while G1, G38, local check and G20 were MS in both years for LBS (Appendix Table 5.7).

Overall, genotypes such as G14, G31, G60, G16, G35 and G32 displayed resistance to blast disease over two years (2022 and 2023) and across testing locations (Adet and Finote Selam). Moderately resistant genotypes including G33, the standard check (Jabi), G9, G8, G56, G39, G13, G49, G17 and G47 exhibited lower disease severity levels compared to susceptible genotypes. In contrast, the local check, G1, G38, G20 and G51 were consistently moderately

susceptible across both years and locations under natural diseased conditions. Blast disease incidence and severity were higher at Finote Selam than at Adet.

Such difference genotypic responses to blast disease to finger millet blast disease also observed in a screening study of 200 finger millet conducted by Ojha *et al.* (2024) as follows: For leaf blast, nine accessions showed strong resistance with low disease scores, 91 were moderately resistant, 96 were susceptible, and 4 were highly susceptible. For neck blast, 162 accessions were resistant, 14 moderately resistant, 22 susceptible, and 2 highly susceptible. For finger blast, 155 accessions were resistant, 20 moderately resistant, 23 susceptible, and 2 highly susceptible.

In addition, the disease was relatively higher in 2022 than in 2023. This could be attributed to environmental conditions especially high temperature and humidity at Finote Selam that favor the intensity of blast (Appendix Figure 1.2 and Table 2.1). It is indicated that the ecological conditions, especially relative humidity and temperature are the most important factors affecting sporulation, release and germination of blast conidia (Wekesa *et al.*, 2019). Elevated temperatures along with high humidity provide optimal conditions for leaf blast disease development. On the other hand, neck and panicle blast are more severe in cooler temperatures with moderate to high humidity. Moreover, persistent humidity following rainfall significantly progresses disease spread by supporting spore dispersal. To reduce the threat of blast disease, controlling humidity within the crop canopy, implementing crop rotation and adopting early planting can effectively lower infection rates and improve disease management (Ojha *et al.*, 2024).

The resistance difference of the screened genotypes among the locations might be also either from differences in the pathogen populations or from the environmental differences or a combination of both factors. It could be also because the existence of more virulent isolates at Finote Selam than at Adet locations as confirmed in the laboratory work of pathogen isolation (Table 3.1)

and characterization and high disease pressure (Figure 2.4, Appendix Table 2.2). Kumari et al. (2022) also reported varying disease severity among genotypes depending on the environmental factors that prevailed during the different seasons.

In addition, it was observed that genotypes that had dark-coloured seeds and compact heads were more resistant as compared to white-seeded and open-headed ones. It may be because air-borne pathogen inoculum readily entered open-headed varieties than compact ones (Wekesa *et al.*, 2019). The high levels of phenolic compounds and tannins found in dark seeds provide antifungal activities, while the compact head formation decreases humidity and restricts physical entry of spore and conidia of the pathogen, thus lowering rates of infection (Shivhare *et al.*, 2022).

Generally the results of this study demonstrated considerable variability in blast resistance among finger millet genotypes. The variations in the blast severity among genotypes might be due to the genetic differences of the genotypes. A potential explanation for the differential resistance observed among various plant genotypes to a specific disease lies in the existence of particular resistance (R) genes within the genetic makeup of the plant. These R genes are responsible for encoding proteins that identify pathogen-associated molecular patterns (PAMPs) or distinct pathogen effectors, which in turn activate defense strategies such as the hypersensitive reactions (HR) and systemic acquired resistance (SAR). The diversity of these genes among different plant genotypes plays a crucial role in determining a plant's susceptibility or resistance to disease (Sett *et al.*, 2022). On the other hand, the fungal pathogen is compatible with the host plant by forming resistance structures such as haustoria. In addition, less enzyme activity, and long-term resistance of the pathogen to the host through evolution and mutation that occur within the pathogen can lead to the susceptibility of the genotypes (Pawlowski and Hartman, 2016).

The mean AUDPC value showed an incremental trend throughout the growing period. The negative strong correlation between mean AUDPC and grain yield ($r = -0.05^*$) (Appendix Table 6.9) may be due to hindrance development and death of leave cells and tissues caused by blast lesions. This could be due to the pathogen infecting most aboveground parts of the plant, but neck and finger blasts are the most damaging phases of the disease. Crop growth rate and leaf area formation declined sharply during the establishment of the disease and continued till maturity. This resulted in a marked reduction of total dry matter and grain yield production (Bhatta *et al.*, 2017). Manyasi *et al.* (2022), also reported that the mean AUDPC value showed an incremental trend throughout the growing period. This rate is represented by a rapid rate of disease progress in S genotypes, a slower rate in MR, and a decreased trend in R genotypes.

5.4.4 Cluster analysis

Cluster II consists of genotypes with AUDPC more than 894.72, 1845.99 and 2081.41%–day for leaf, neck and head respectively and showing high susceptibility. Cluster I consists of genotypes showing final AUDPC less than 747.87, 1509.28 and 1685.68% per–day for leaf, neck and head, and thus S to blast. Cluster IV consists of genotypes having final AUDPC of 573.10, 1287.39 and 1530.24% per–day for the above plant parts and showing MS. Cluster III has a mean AUDPC of 479.62, 1192.14 and 1376.04% per–day for leaf, neck and head, and shows MR. Finally, cluster V which consists of genotypes with final AUDPC of 327.07, 877.83 and 757.38% per–day for leaf, neck and head blast, categorized as R. There was no genotype that was immune to the leaf, neck and head blast as shown in Table 5.8 and Figure 5.3. It could be generalized that genotypes in clusters III and IV might have a major and minor gene governing for the blast resistance, while others might have no gene for resistance. Manyasi *et al.* (2022) and Ojha *et al.* (2024), also reported that the mean AUDPC value showed an incremental trend throughout the growing period. This rate is represented by a rapid rate of disease progress in susceptible

genotypes, a slower rate in moderately resistance, and a decreased trend in resistance genotypes.

Table 5.8. Clustering of genotypes based on AUDPC rate (% per-day values)

Group	LAUDPC	NAUDPC	HAUDPC	Disease reaction	No. of genotypes
1	747.87	1509.28	1685.68	S	20
2	894.72	1845.99	2081.41	HS	14
3	479.62	1192.14	1376.04	MR	17
4	573.10	1287.39	1530.24	MS	6
5	327.07	877.83	757.38	R	7

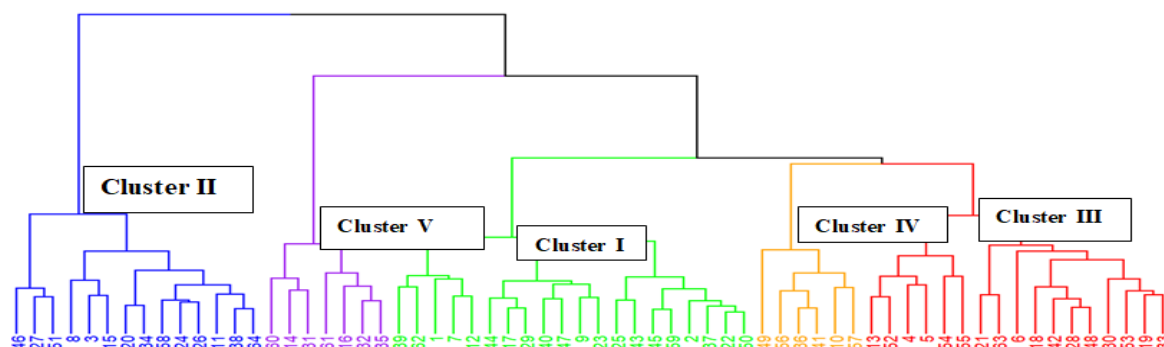


Figure 5.3. Unweighted Pair Group Method with Arithmetic Mean (UPGMA) dendrogram based on area under disease progress curve (AUDPC) of 64 finger millet genotypes, at Adet and Finote Selam

Similar genotypic clustering was reported by Andualem Wolie and Ketema Belete (2013) on 48 Ethiopian genotypes. Cluster I, containing many germplasm, exhibited low blast severity (7). Cluster VI containing two genotypes, demonstrated a moderate response to blast Cluster II displayed high blast severity (18), Cluster IV, consisting of three genotypes, showed very high blast severity. In contrast, Cluster V, which included six genotypes, exhibited the lowest blast severity (1).

The analysis revealed several notable relationships between agronomic and disease characteristics (Table 5.9, Appendix Table 5.8). Days to maturity (DM) demonstrates a negative correlation with leaf blast severity (LS) ($r = -0.32^{***}$), neck blast severity (NS) ($r = -0.14^*$), head blast severity (HS) ($r = -0.31^{***}$), leaf area under the disease progress curve (LAUDPC) ($r = -0.31^{***}$), and head area under the disease progress curve (HAUDPC) ($r = -0.31^{***}$). Conversely,

plant height (PH) exhibits a weak positive correlation with LS ($r = 0.19^{**}$), LAUDPC ($r = 0.19^{**}$) and HS ($r = 0.14^*$). The number of tillers per plant (NTP) is weakly positively correlated with LS ($r = 0.14^*$) and LAUDPC ($r = 0.14^*$). Grain yield (GY) showed a positive correlation with maturity duration (DM) ($r = 0.16^*$), PH ($r = 0.29^{***}$), NTP ($r = 0.34^{***}$) and the number of ears per plant (NEP) ($r = 0.34^{***}$) (Table 5.9, Appendix Table 5.8).

Table 5.9. Correlation analysis of some selected agronomic and blast disease parameters

Variables	DPM	PH	NTP	NEP	GY	LS	NS	HS	LAU DPC	NAU DPC	HAU DPC
MD	1										
PH	0.10*	1									
NTP	-0.16**	0.25***	1								
NEP	-0.19**	0.31***	0.85***	1							
GY	0.16*	0.29***	0.34***	0.34***	1						
LS	-0.32***	0.19**	0.14*	0.12 ^{ns}	0.06 ^{ns}	1					
NS	-0.14*	0.07 ^{ns}	-0.01 ^{ns}	0.01 ^{ns}	-0.02 ^{ns}	0.32***	1				
HS	-0.31***	0.14*	-0.01 ^{ns}	-0.05 ^{ns}	-0.01 ^{ns}	0.72***	0.36***	1			
LAUDPC	-0.31***	0.19**	0.14*	0.12 ^{ns}	0.07 ^{ns}	0.99***	0.33***	0.72***	1		
NAUDPC	-0.22***	0.10 ^{ns}	-0.01 ^{ns}	-0.01 ^{ns}	-0.03 ^{ns}	0.52***	0.94***	0.64***	0.52***	1	
HAUDPC	-0.31***	0.13*	-0.01 ^{ns}	-0.05 ^{ns}	-0.01 ^{ns}	0.72***	0.36***	0.99***	0.71***	0.64***	1

These results imply that specific agronomic traits, such as delayed maturity and plant growth may correlate with lower disease severity, whereas higher grain yield is associated with increased ear and tiller count. Nonetheless, the correlations between GY, and disease parameters: LS, NS, HS, LAUDPC, NAUDPC and HAUDPC are strongly negative, indicating that grain yield is more closely related to certain agronomic traits than to the measured disease parameters. The negative correlations of neck and head blast severity with DM indicate that late-maturing genotypes such as G60 and G13 might escape blast infection due to less favorable microclimatic conditions. Gani and Tunwari (2023), Kumari *et al.* (2022), and Kandel *et al.* (2019) also reported that most late-maturing genotypes showed reduced disease severity. This may be due to the susceptible stage of the crop (panicle emergence stage) may not coincide with favorable weather conditions for the virulent pathogen. Ojha *et al.* (2024) revealed that moderate ($r = 0.57^{**}$) and strong ($r = 0.70^{**}$) significant

correlations between leaf, neck, and head blasts suggest that a high level of leaf blast severity may result in increased neck or finger blast infections in the later growth stages. Other studies indicate a weak to moderate correlation between leaf blast, and neck or finger blast, implying that early leaf blast inoculation may not lead to severe neck or finger blast later on. This could be due to differential gene expression for resistance against leaf, neck, or finger blast infections (Thakur *et al.*, 2024).

The scatter plot regression analysis revealed a negative significant relationship between blast severity and yield and yield related parameters. As blast severity increases, GY and NTP tends to decrease. The fitted curve also suggests that as disease severity increases, grain yield and tiller number of genotypes decreases (Figure 5.4).

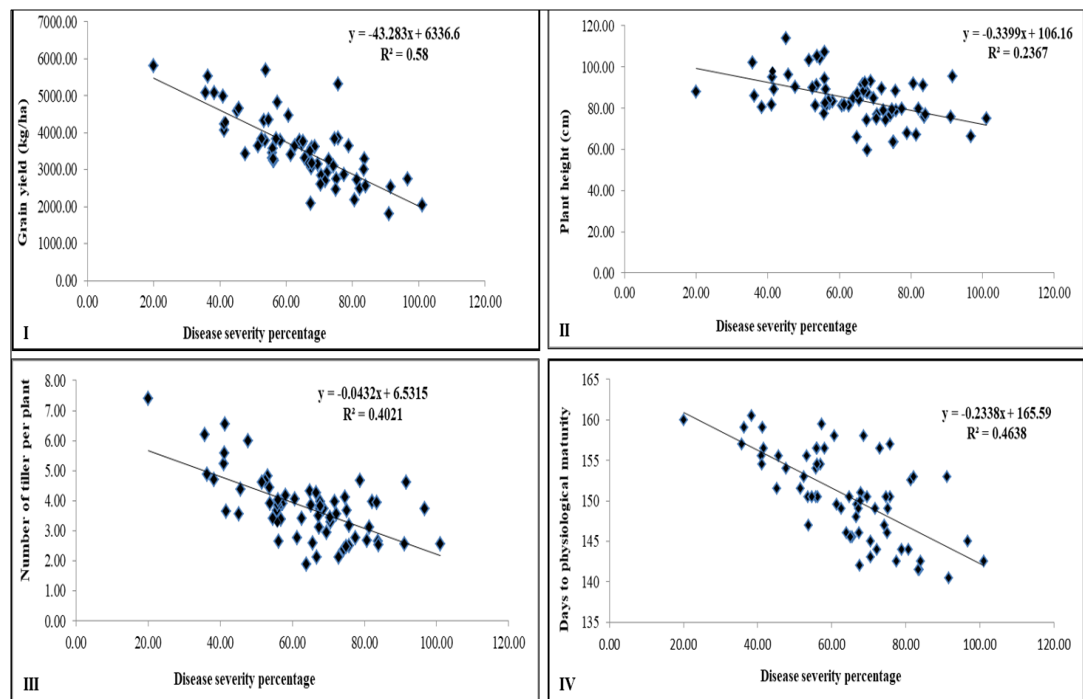


Figure 5.4. Estimated linear regression between mean blast disease severity and grain yield (I), Plant height (II), Number of tiller per plant (III) and Days to physiological maturity (IV)

The Pearson correlation coefficients revealed significant relationships between various agronomic and disease parameters. Notably, there is a weak positive correlation between grain yield (GY) and NEP ($r=0.34^{***ns}$) indicating that

plants having more NEP tend to produce higher yields. Additionally, a negative weak correlation ($r = -0.03^{ns}$) exists between grain yield and blast severity, and this result is in agreement with Das *et al.* (2021). There is a moderate ($r = 0.32^{***}$) and strong ($r = 0.72^{***}$) significant correlations between leaf blast with neck and finger blast may suggest that a high level of leaf blast severity may result in severe neck or finger blast infection during the later stages of plant development. The results are in agreement with Wekesa *et al.* (2019). While, Babu (2011) reported that a significant weak to moderate correlation was found between leaf blast with neck and finger blast probably suggesting that a high level of leaf blast achieved by early inoculation may not result in severe neck or finger blast during the later stages of plant development. This might be due to differential gene expression for resistance to leaf, neck and/or finger blast infection.

5.5 Conclusion and Recommendation

Based on the results of this study, potential finger millet genotypes with high productivity and low blast reaction were identified. The study showed that there is significant variation among the genotypes for disease resistance indicating high genetic variation among the genotypes. High-yielding genotypes including G7, G14 and the local check performed well across different years and locations. Genotypes G14, G31, G60, G16, G35 and G32 demonstrated resistance to blast disease in both locations indicating the existence of resistance genes capable of enduring pathogen pressures. Moderately resistant genotypes such as G33, the standard check (Jabi), G9, G56, G39, G13, G49, G17 and G47 exhibited reduced disease severity levels relative to susceptible genotypes. These genotypes are significant for breeding programs as they may possess partial resistance genes that increase quantitative resistance. In contrast, genotypes including the local check, G2, G4, G12, G18, G23, G25, G30, G37, G40, G43 and G59 exhibited moderate susceptibility across both years and locations. The resistance observed in certain genotypes across various environments and years highlights their potential as dependable sources for blast resistance in breeding programs. A

breeding program should be devised to cross the high yielder genotypes like G7 (5208.3 kg ha⁻¹) and G20 (4208.3 kg ha⁻¹) but susceptible with low yielder genotypes such as G13 (1375.0 kg ha⁻¹) and G61 (1479.2 kg ha⁻¹) having low terminal severity. Highly susceptible (HS) genotypes included G1, G3, G8, G11, G15, G24, G38, G46 and G51. Either of these the most susceptible to blast can be suggested to be used as a susceptible check.

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Chapter 6. INTEGRATED MANAGEMENT OF FINGER MILLET (*Elusine coracana* L. Gaertn) BLAST DISEASE BY *Magnaporthe grisea* (Hebert) USING VARIETIES AND FUNGICIDES

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Abstract

Finger millet is one of the very important cereal crops for food security and medicinal value. However, finger millet blast disease caused by *Magnaporthe grisea* (Hebert) Barr is the most important biotic constraints of its production. This study was conducted to evaluate the combined effect of varieties and fungicides in reducing finger millet blast disease and yield loss under field conditions at the Finote Selam and Semien Achefer districts during the 2022 and 2023 cropping seasons. Four finger millet varieties (Bako-09, Tessema, Necho and Local) and three fungicides (Contaf Max 350 SC, Nativo 300 SC and Tilt 250 EC) were evaluated in a factorial randomized complete block design with three replications. The yield, yield related, and other agronomic and disease data collected were analyzed using SAS (9.4). The lowest leaf disease severity (34%) and Area under Disease Progress Curve (817.54%-days) was recorded on Bako-09, whereas, the maximum head blast severity and Area under Disease Progress Curve were recorded on Necho (93% and 2836%-days) and Local (84% and 2576%-days) varieties. Similarly, the least leaf blast severity (40.37%) and Area

under Disease Progress Curve (984.63%-days) were recorded from plots treated with Hexaconazole + R Tricyclazole. In contrast, the maximum head blast severity (92.45%) and Area under Disease Progress Curve (2783.61%-days) were scored from the control plot. The maximum (3010.4 kg ha⁻¹) and minimum (2287.8 kg ha⁻¹) grain yields were recorded from local and Necho varieties, respectively. Hexaconazole + R Tricyclazole gave the maximum mean grain yield (3045.1 kg ha⁻¹); whereas the lowest grain yields (2016.1 kg ha⁻¹) was harvested from the untreated plots. The maximum marginal rates of return (13479% and 13128%) were obtained from local variety treated with Hexaconazole + R Tricyclazole and Trifloxystrobin 100 g/l+ Tebuconazole 200 g/l respectively. The combined application of Hexaconazole + R Tricyclazole and Bako-09 greatly decreased blast disease and increased yield. Moderate resistant variety Bako-09 and high yielder local variety in combination with Contaf Max 350 SC could be recommended for production at both locations.

Keywords: Finger millet blast, Fungicide, Integrated management, *Magnaporthe grisea*, resistance variety

6.1 Introduction

Finger millet (*E. coracana* L. Gaertn) is grown by subsistence farmers throughout Asia and Africa. It is mostly ignored crop and can be cultivated with less input (Negi *et al.*, 2017). It is particularly vital for weak and immune-compromised people (Rishitha and Soni, 2024) and plays a significant role in the diets and economies of subsistence farmers (Takan *et al.*, 2012). The crop is an excellent source of the amino acids such as tryptophan, cysteine and methionine as well as minerals: calcium, iron, zinc and manganese, all of which are deficient in most cereals but essential to human health and growth (Demeke Teklu *et al.*, 2024). Due to its high nutritional content, the crop is crucial for children's meals as well as pregnant women and breast feeding mothers (Sharat and Gokhale, 2022).

The growth of finger millet is impeded by a multitude of biotic and abiotic factors, ultimately limiting yield. Insects and diseases are the primary biotic

constricts affecting finger millet productivity globally (Preethi *et al.*, 2020). Among the diseases, fungal blast caused by *M. grisea* (Hebert) Barr, on leaves, fingers and necks has negatively impacted its productivity in all regions of the continent where finger millet is cultivated including East Africa (Lenne *et al.*, 2007; Odeph *et al.*, 2020). Due to its ability to affect the crop's reproductive and vegetative stages, the disease is extremely damaging (Jeevan *et al.*, 2021), and in endemic places, it can cause 80–90% yield loss (Navya *et al.*, 2023).

The sustainable method of controlling blast disease is genetic resistance, but its effectiveness is limited by the instability of the *M. grisea* genome, particularly the quickly evolving races, which cause break down of resistance genes (Mbinda *et al.*, 2021). Fungicides are one of the disease management alternatives for immediate action and have been the only available choice in continents like Africa (Kumar *et al.*, 2013) for managing finger millet blasts (Sekar *et al.*, 2018). Tricyclazole was found to be highly efficient among the many fungicides tested against blast disease in both finger millet and rice (Prajapati *et al.*, 2004; Mohiddin *et al.*, 2021). According to Anand *et al.* (2023), chemical fungicides like carbendazim and tricyclazole are quite successful at treating blast disease. The combination of Hexaconazole + R tricyclazole produced the highest grain yield (5617.06 kg/ha) and a superior disease reduction of over 80% (Horo and Gudisa, 2021). According to Kaurav *et al.* (2018), finger millet blast disease can be effectively managed with propiconazole and trifloxystrobin + tebuconazole. Three sprays of propiconazole or tebuconazole + trifloxystrobin can effectively manage finger millet blast (Sharma *et al.*, 2018). According to Ghazanfar *et al.* (2009), trifloxystrobin + tebuconazole can also effectively manage finger millet blast.

As fungicides typically only target one step in a biosynthetic pathway to kill the fungus, they are susceptible to fungi gaining resistance even while they can control and remove established infections (Massi *et al.*, 2021). The fungus population has less opportunity to develop resistance to a single chemical when the several classes of fungicides are alternated (Hahn, 2014). The yield of finger

millet has increased significantly as a result of the introduction of high yielding varieties (Sendhilvel and Veeramani, 2020). However, the best way to handle the disease when blast-resistant cultivars aren't available is combine fungicides and varieties (Anand *et al.*, 2023). Integration of varieties with fungicides can lead to synergistic effects, improving the overall management plan against blast disease and is currently seen as sustainable agriculture as well as environmentally friendly (Ahmed, 2019). However, there is a dearth of information on the integration of fungicides and varieties to manage finger millet blast disease in tropical Africa, particularly in Ethiopia (Anand *et al.*, 2023). In light of these facts, this study was carried out to evaluate the effectiveness of three released finger millet varieties (Bako-09, Tessema, Necho) together with one local cultivar in combination with three fungicides (Hexaconazole + R Tricyclazole, Trifloxystrobin 100 g/l + Tebuconazole 200 g/l, and Propiconazole) against finger millet blast under field conditions. The results of this study can be serving as supplementary information for further researcher work and better options for farmers and extension agents to use better combination of variety and fungicide to manage finger millet blast disease.

6.2 Materials and Methods

6.2.1 Description of the study areas

The experiment was carried out at North Achefer and Jabitenan districts (Figure 6.1) in western Amhara, Ethiopia for two consecutive years at Denbola Keble farmer training center (FTC) Semien Achefer, and Fenotselam research substations Jabi Tehnan districts during the 2022 and 2023 main cropping seasons. These experimental sites represent slightly different agroecologies of the Semien Gojam, and West Gojam zone's finger millet growing areas. Monthly weather data on temperature, relative humidity and rainfall for both experimental districts were collected from the Western Amhara Meteorological Services Center (WAMSC), Bahir Dar, Ethiopia, and used to correlate with the disease intensity (Wekesa *et al.*, 2019). The average maximum and minimum mean monthly temperatures at the Fenotselam in 2022 were 28.67°C and

14.17°C, respectively, while in 2023, these values were 28.15°C and 13.68°C. At the Semien Achefer, the average maximum and minimum mean monthly temperatures for 2022 were 25.71°C and 13.55°C respectively, compared 2023 of 24.60°C and 13.02°C. The average rainfall at Fenotselam was 194 mm in 2022 and 179.69 mm in 2023, whereas at Semien Achefer (Liben), it was 111.4 mm in 2022 and 177.28 mm in 2023. The relative humidity at Fenotselam was 67.30% in 2022 and 65.13% in 2023, while at Semien Achefer (Liben) ; it was 61.69% in 2022 and 62.01% in 2023 (Appendix Figure 1.2).

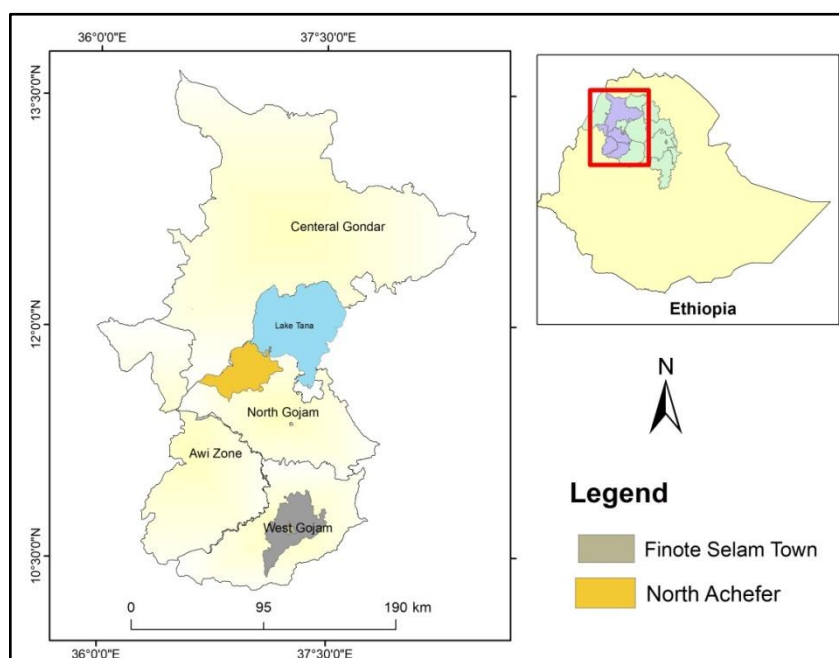


Figure 6.1. Location map of experimental sites (site_1: Denbola FTC and site_2: Fenotselam research sub-station)

6.2.2 Crop varieties and chemical fungicides

Three fungicides (Hexaconazole + R Tricyclazole, Trifloxystrobin 100 g/l + Tebuconazole 200 g/l, and Propiconazole) and three finger millet varieties (Necho, Bako-09 and Tessema) released between 2011 and 2017 and one local check were used along with an untreated check (Table 6.1). The fungicides were purchased from an agrochemical supply store in Addis Ababa, Ethiopia, while the seeds were obtained from the Ethiopian Institute of Agricultural Research (Adet Agricultural Research Center).

Table 6.1: Description of Finger millet varieties, and fungicides used in the experiment

S.no	Variety	Pedigree name	Year of release	Adaptation (m.a.s.l)	Disease reaction	Yield(kg/ha)	
						On farm	On-station
1	Bako-09	Acc.214995	2017	1400-2200	Moderately resistant to Blast	2400-2600	2900.8
2	Tessema	ACC#229469	2014	1600 -1900	Moderately susceptible to Blast	1750	2250
3	Necho	(PGRC/E20357	2011	1900-2500	Susceptible to blast	2000-3000	1500-2000
4	Local check	~					
Source: Zigale Semahegn <i>et al.</i> (2021)							
S.no	Fungicides (Technical name)	Trade name	Chemical group	Mode of action	Formulation Dosage/ha	g.a.i/ha	
1	Hexaconazole + R Tricyclazole	Contaf Max 350 SC	Triazole	Systemic	1L/Ha	800 g/ha	
2	Trifloxystrobin 100 gm./lit + Tebuconazole 200 gm./lit	Nativo SC 300	Triazole + strobilurin	Systematic, foliar broad spectrum, P and C	0.5- 0.75l/Ha	Trifloxystrobin 100g/l+ Tebuconazole 200g/l	
3	Propiconazole	Tilt 250 EC	Conazole	A systemic foliar broad spectrum	1L/ha	250g/l	

P=preventive, C= curative. Source: MoANR (2019) modified based on the manufacturer's manual

6.2.3 Experimental design and treatments

The field trials were conducted for two consecutive years during the rainy season of 2022 and 2023 at Fenotselam experimental substation and North Achefer district, Denbola Kebele FTC, Ethiopia. The treatments were arranged in factorial randomized complete block design (RCBD) with three replications of the sixteen treatments (Figure 6.2, Appendix Table 6.1) following the guidelines of Gomez and Gomez (1984).

6.2.4 Experimental procedure

A plot area of 3m x 2m and 10 rows that were 3m long and 2m wide, with spaces of 1.5, 1m and 0.3m between replications, plots and rows respectively was used for sowing. The recommended agronomic package for finger millet cultivation was performed as followed Abunu Marefia *et al.* (2022). The land was ploughing using tractors, with support from AdARC and local farmers for the Semein Achefer. The soil was leveled to ensure uniform fertility, and ditches were constructed to prevent flooding. Sowing was conducted at a seed rate of 15 kg ha⁻¹, with 15 g of seed allocated per plot. Drill planting was carried out manually, maintaining 15 cm spacing between rows, with the same seeding rate

applied at both locations. Urea and NPS were added at rates of 50 and 121 kg ha⁻¹ respectively. All NPS and half urea were applied during sowing and half urea was applied at the tillering stage. Fungicide solution was prepared as 4 ml L⁻¹ of water for Contaf Max 350 SC and 5 ml L⁻¹ of water for Nativo 300 SC and Tilt 250 EC based on the factory recommendations of the fungicides to manage finger millet blast. Totally 8 ml 2 L⁻¹ of water for Contaf Max 350 SC, and 10 ml 2 L⁻¹ of water for Nativo 300 SC and Tilt 250 EC solution prepared were enough for a one time spray. Fungicides were applied seven days after the first signs of the disease appeared, with a second spray applied at 15 days later. This schedule was maintained until the crop reached maturity. The experiment was conducted from June/July to December and spraying was done totally three times by checking periodically the progress of the disease (Agrios, 2005). The fungicides were applied using knapsack sprayer and because the plots were small, ultra-low pressure nozzles were used and its nozzle pressure was adjusted in order to uniformly apply the desired rate of chemical. Plots that were not sprayed served as negative control.



Figure 6.2. Images illustrating the field experiment: (A) Finger millet seedlings of various varieties at the tillering stage at the Denbola Kebele FTC experimental site, (B) Finger millet varieties at the physiological maturity, and (C) Finger millet varieties at the harvesting.

6.2.5 Data collection

Ten randomly selected plants were used from the eight central harvestable rows to collect information on agronomic traits and disease data (Patro *et al.*, 2020b) and disease scoring was done five times.

Disease Incidence (DI): assessment of leaf blast incidence was conducted from the seedling to the booting stage, whereas the evaluation of disease incidence for finger and neck blast was performed during physiological maturity until the harvest stage (Bal *et al.*, 2020). Following the completion of the disease data collection, the fully matured crops were harvested at their base, subjected to sun drying, and subsequently threshed in order to obtain yield and biomass data.

Leaf blast severity (LBS): the leaf blast severity was recorded at 10 days interval after the first symptom was observed using a progressive 1-9 scale (Appendix Figure 1) with the help of a field guide-book (IRRI, 2014).

Neck Blast Severity (NBS) and Finger Blast Severity (FBS): NBS and HBS were measured using a progressive rating system ranging from 0 to 5, where 0 represented no lesions, 1 represented pinhead size of lesions on the neck and head region, 2 represented a typical blast lesion size of 0.1 to 2.0 cm, 3 refers to 2.1 to 4.0 cm, 4 refers to 4.1 to 6.0 cm and 5 refers to > 6.0 cm lesions (Appendix Figure 2) (Bal *et al.*, 2020). Yield and yield - related parameters such as finger length and plant height among others were measured following (Hanson *et al.*, 1985).

The number of infected plants was used to compute disease incidence, which was then reported as a percentage of all the plants evaluated using the formula of Teng and James (2002).

$$Diseaseincidence(\%) = \frac{\text{Number of plants infected}}{\text{Total number of plants assesed}} \times 100.....(1)$$

The percent disease intensity (PDI) was computed based on the work of Miedaner *et al.* (1996).

$$PDI \text{ for Severity} = \frac{\text{Sum of individual disease ratings}}{\text{No.of observations assessed} \times \text{maximum disease rating}} \times 100 \dots\dots\dots(2)$$

The area under disease progress curve (AUPDC) was determined based on the blast severity scores that were obtained at various times following formula of Madden *et al.* (2007):

$$AUDPC = \sum_{i=1}^{n-1} 0.5(X_{i+1} + X_i)(t_{i+1} - t_i) \dots\dots\dots(3)$$

Where, x_i is the increasing disease severity expressed as a proportion at the i^{th} observation; t_i is the time (days after planting) at the i^{th} observation; and n is the total number of observations.

The relative yield gain and percent disease suppression were calculated based on the formula used by Jemal Tola and Tesfaye Gudisa (2021):

$$\text{Relative yield gain (\%)} = \frac{(\text{Yield of treated plot} - \text{Yield of untreated plot})}{\text{Yield of treated plot}} \times 100 \dots\dots\dots(4)$$

$$\text{Leaf blast suppression (LBS) (\%)} = \frac{(\text{LBS of untreated plot} - \text{LBS of treated plot})}{\text{LBS of untreated plot}} \times 100 \dots\dots(5)$$

$$\text{Neck blast suppression (NBS) (\%)} = \frac{(\text{NBS of untreated plot} - \text{NBS of treated plot})}{\text{NBS of untreated plot}} \times 100 \dots\dots(6)$$

$$\text{Head blast suppression (HBS) (\%)} = \frac{(\text{HBS of untreated plot} - \text{HBS of treated plot})}{\text{HBS of untreated plot}} \times 100 \dots\dots(7)$$

6.2.6 Data analysis

The data were arranged in Microsoft Excel and Arcsine transformed before analysis. Tests were made by F-test to confirm the homogeneity of error mean square between the two sites. As a result, combined analysis was done for both year and location. An analysis of variance (ANOVA) was done for yield and yield components and for disease parameters (Incidence, Severity and AUDPC)

using the General Linear Model (GLM) using SAS computer software version 9.4 (SAS, 2009).

6.3 Results and Discussion

The analysis of variance indicated that the variety significantly influenced plant height (PH), number of tillers per plant (NTP), number of ears per plant (NEP), leaf blot severity (LBS), neck blast severity (NBS), and head blast severity (HBS) ($P < 0.001$ for all traits except NBS at $P < 0.05$) (Table 6.2, Appendix Table 6.2 and 6.3). This indicates that genetic variability among cultivars is essential for these traits, resulting in variations in growth, yield and disease resistance. The utilization of fungicide markedly influences LBS, NBS and HBS ($P < 0.001$), demonstrating its efficacy in reducing disease severity. Nonetheless, it exerts minimal influence on PH, NTP, or NEP indicating that its effects are more pronounced in disease mitigation than in growth improvement. The interaction between variety and fungicide had no significant effects on NTP, NEP, LBS, or HBS, except it exhibited a little but significant effect on PH ($P < 0.05$) and NBS ($P < 0.01$), indicating that the fungicide's impact on these traits is largely consistent across the varieties (Table 6.2, Appendix Table 6.2 and 7.3).

Table 6.2. Summary of the analysis of variance mean squares for the effect of varieties, and fungicides on yield, yield components, and disease parameters

SOV.	Yield and yield components					
	DM	PH	NTP	NEP	FL	GY
Loc.	212.52 ^{***}	4394.93 ^{***}	8.67 ^{**}	49.21 ^{***}	82.29 ^{***}	100681.68 ^{ns}
Year	2552.08 ^{***}	753.67 ^{***}	1.14 ^{ns}	16.57 ^{***}	0.76 ^{ns}	501402.40 ^{ns}
Loc*Year	927.52 ^{***}	3013.09 ^{***}	53.34 ^{***}	27.60 ^{***}	20.22 ^{***}	4704186.70 ^{***}
Variety	361.76 ^{***}	1783.30 ^{***}	17.99 ^{***}	132.92 ^{***}	240.48 ^{***}	5862353.12 ^{***}
Fungicide	14.79 ^{ns}	57.83 ^{ns}	0.93 ^{ns}	0.34 ^{ns}	0.32 ^{ns}	8971348.79 ^{***}
Var.*Fungi.	31.29 ^{ns}	76.14 [*]	0.75 ^{ns}	2.09 ^{ns}	0.57 ^{ns}	130512.83 ^{ns}
Year*Variety	81.90 ^{**}	73.81 ^{ns}	1.99 ^{ns}	1.02 ^{ns}	0.63 ^{ns}	1135649.19 ^{***}
Loc*Variety	196.31 ^{***}	69.51 ^{ns}	0.48 ^{ns}	28.33 ^{***}	1.07 ^{ns}	2010080.31 ^{***}
Mean	148.75	78.05	4.49	7.38	9.49	2599.33
CV (%)	2.97	7.32	20.34	23.91	11.41	22.39
MSE ($\pm$)	3.51	4.18	2.22	1.79	0.72	31.91
SOV.	Disease parameters					
	LBI	NBI	HBI	LBS	NBS	HBS
Loc	3215.15 ^{**}	5210.52 ^{***}	7541.06 ^{***}	568.80 [*]	53.83 ^{ns}	4.06 ^{ns}
Year	5553.56 ^{***}	13005.87 ^{ns}	11672.23 ^{**}	2500.65 ^{***}	11560.23 ^{ns}	10886.6 ^{ns}
Loc*Year	475.99 ^{ns}	6740.39 ^{**}	631.98 ^{ns}	22.43 ^{ns}	1315.24 ^{ns}	61.68 ^{ns}
Variety	7375.63 ^{***}	6589.92 ^{***}	7399.24 ^{**}	3596.74 ^{***}	6652.63 ^{***}	9141.20 ^{***}
Fungicide	2553.59 ^{***}	8524.93 ^{***}	3762.47 ^{***}	1411.52 ^{***}	8556.37 ^{***}	5465.20 ^{***}
Var.*Fungi.	33.93 ^{ns}	967.43 ^{**}	108.06 ^{ns}	6.18 ^{ns}	555.26 [*]	260.89 ^{ns}

Year*Variety	53.01 ^{ns}	268.49 ^{ns}	1282.95**	39.73 ^{ns}	127.93 ^{ns}	970.50**
Loc*Variety	117.31 ^{ns}	706.93*	248.86 ^{ns}	33.56 ^{ns}	1053.52**	6.39 ^{ns}
Mean	79.60	82.98	100.79	43.41	62.76	79.49
CV (%)	55.05	42.41	31.09	59.26	37.35	30.48
MSE (±)	10.57	7.28	8.62	8.22	6.99	7.17

SOV. - Source of variation, Loc. Location, DM- days to maturity, PH- Plant Height, NTP- Number of tiller per plant, NEP- Number of ear per plant, FL- Finger length, GY- Grain yield(kg/ha), LBI- Leaf blast incidence, NBI- Neck blast incidence, HBI- head blast incidence, LBS- Leaf blast severity, NBS- Neck blast severity, HBS- Head blast severity, CV- coefficient of variation

6.3.1 Effect of finger millet varieties and fungicides on yield and yield components

Fungicides significantly increased grain yield and other agronomic parameters tested ($P < 0.01$, 0.001) except days to heading compared to the untreated plots (Table 6.2, Appendix Table 6.4). Hexaconazole + R Tricyclazole application resulted in the maximum mean grain yield (3045 kg ha⁻¹), followed by Trifloxystrobin 100 g /l + Tebuconazole 200 g/l (2747 kg ha⁻¹) and Propiconazole (2589 kg ha⁻¹). The lowest grain yield was obtained from the untreated plots (2016 kg ha⁻¹) (Table 7.3).

Table 6.3. The main effect of variety and fungicide on yield, yield components, and other agronomic traits of finger millet

Variety	Parameters									
	DH	DM	PH	FL	NFE	NTP	NEP	BY	GY	HI
Bako09	103.90 ^c	146.38 ^c	70.05 ^c	7.66 ^c	6.69 ^b	4.35 ^b	6.71 ^b	6120.8 ^b	2767.9 ^b	47.24 ^a
Tessema	106.10 ^b	146.92 ^c	82.85 ^a	7.47 ^c	6.35 ^b	3.94 ^c	5.95 ^c	5496.4 ^c	2331.1 ^c	44.80 ^{ab}
Necho	106.90 ^b	149.31 ^b	76.54 ^b	11.73 ^a	7.49 ^a	4.32 ^b	7.09 ^b	5388.7 ^c	2287.8 ^c	44.01 ^{ab}
Local	108.80 ^a	152.39 ^a	82.75 ^a	11.10 ^b	6.56 ^b	5.37 ^a	9.77 ^a	7459.0 ^a	3010.4 ^a	41.67 ^b
CV (%)	7.03	2.58	7.32	13.97	16.26	23.78	19.81	22.47	18.39	24.86
Sig.levels (0.5%)	ns	**	***	***	**	***	***	***	***	***
Fungicide										
Contaf	106.27 ^a	148.00 ^a	79.66 ^a	9.37 ^a	6.84 ^a	4.48 ^a	7.33 ^a	6306.9 ^a	3045.1 ^a	50.37 ^a
Max										
Nativo	106.56 ^a	149.11 ^a	77.76 ^{ab}	9.54 ^a	6.84 ^a	4.69 ^a	7.50 ^a	6031.6 ^b	2746.6 ^b	47.41 ^{ab}
Tilt	106.65 ^a	149.23 ^a	77.57 ^{ab}	9.54 ^a	6.73 ^a	4.43 ^a	7.33 ^a	5806.1 ^b	2589.6 ^c	46.75 ^b
Control	106.19 ^a	148.67 ^a	77.21 ^b	9.51 ^a	6.68 ^a	4.38 ^a	7.35 ^a	6320.3 ^a	2016.1 ^d	33.19 ^c
CV (%)	11.59	7.12	14.72	13.97	16.26	23.78	38.39	36.29	30.82	38.61
Sig. levels (0.05%)	ns	**	***	***	**	***	***	***	***	***

DH- heading date, DM- maturity date, PH- plant height, FL- finger length, NFE- number of finger per ear, NTP- number of tiller per plant, NEP- number of ear per plant, BY-biomass yield (kg/ha), GY- grain yield (kg/ha), HI- harvest index, CV- coefficient of variation, Sig. level- Significance level (at 1%-** and 0.1%=*** probability).

The current study revealed that FMBD incidence, severity, AUDPC, yield and yield components were significantly affected by both variety and fungicide

treatments. The local finger millet variety scored higher (10) number of ears per plant and Tessema demonstrated higher plant growth (83 cm) (Table 6.3) and this result is in line with Desu Assegid *et al.* (2024). The grain yield was greatly influenced by different varieties of finger millet. The maximum mean grain yields of 3010 kg ha⁻¹ and 2768 kg ha⁻¹ were achieved from the Local and Bako-09 varieties (Table 6.3), respectively and similar results also reported by Abunu Marefia *et al.* (2022). Variation among the cultivars regarding grain yield, plant height and number of ears per plant might be attributable to the influence of genotypic variation.

6.3.2 Effect of varieties and fungicides on blast incidence and severity

Fungicide application on the different varieties had a substantial influence on blast disease incidence, severity and AUDPC at $P < 0.001$ (Table 6.2). A comparison of fungicide treatment (Hexaconazole + R Tricyclazole, Trifloxystrobin 100 gm. /lit + Tebuconazole 200 gm. /lit and Propiconazole) on different variety showed that the fungicides significantly reduced disease incidence, severity and AUDPC ($P < 0.001$) compared to the untreated plots (Table 7.4, Appendix Table 6.3). Among the evaluated varieties, the lowest disease incidence was recorded on the Bako-09 (64%) for leaf blast (LB), (68%) for neck blast (NB), and (84%) for head blast (HB). The lowest disease severity (34%) of LB, (49%) NB and (61%) HB was obtained on Bako-09 (Table 7.4). On the other hand, the maximum disease incidence (91%) and severity (53%) for LB on Local, (94 and 76%) for NB and (100 and 93%) for HB were reported on the Necho variety (Table 6.4). The treatment of all fungicides has greatly reduced the LBS, NBS and HBS compared to the untreated control with strong significant variation on some of the varieties and fungicides. Among the three finger millet varieties, Bako-09 was found to be resistant to all the stages of the blast disease (leaf, neck and finger). But, Necho was observed to be susceptible to the three types of blast and this finding aligns with Wossen Tarekegne *et al.* (2019). Sendhilvel and Veeramani (2020) and Upamanya *et al.* (2019) observed that different finger millet varieties varied in yield and growth attributes and had

different disease reactions to blast. The overall mean of the pooled data showed that fungicides were significantly varied for LBS, NBS and HBS with the lowest severity recorded on the plot treated with Hexaconazole + R Tricyclazole followed by Trifloxystrobin 100 gm. /lit + Tebuconazole 200 gm./lit and Propiconazole (Table 6.4). The data collected by Rajesh *et al.* (2024) from two trials showed that Tricyclazole 75% WP (two sprays) and the combination of pre-released cultures (TNEc 1285 + TNEc 1294 + TNEc 1310) with GE4449 produced high grain yields in finger millet. The Tricyclazole 75% WP treatment recorded the highest mean yield of 2304 kg/ha, indicating both treatments effectively improved finger millet productivity. Patro *et al.* (2020a) reported that different fungicide treatments significantly reduced blast disease compared to the control. Disease intensity ranged from 1.7-3.3% (leaf blast), 7.7-80.0% (neck blast), and 7.0-80.0% (finger blast). Propiconazole was most effective, showing the lowest incidences of 1.7%, 7.7%, and 7.0%, respectively, followed by Tebuconazole + Trifloxystrobin (3.0%, 11.3%, and 9.7%). The control recorded the highest incidences (3.3%, 80.0%, and 80.0%).

Table 6.4. The effect of variety and fungicide on disease parameters of finger millet blast

Variety	Parameters								
	LBI	NBI	HBI	LBS	NBS	HBS	LBAU DPC	NBAU DPC	HBAU DPC
Bako09	64.16 ^c	68.32 ^c	84.15 ^c	34.10 ^d	49.75 ^c	61.16 ^c	817.54 ^d	1362.38 ^c	1666.81 ^d
Tessema	77.35 ^b	84.31 ^b	99.32 ^b	43.42 ^c	65.07 ^b	80.23 ^b	1031.23 ^c	1956.30 ^b	2301.53 ^c
Necho	87.05 ^a	94.13 ^a	100.00 ^a	49.20 ^b	75.90 ^a	92.62 ^a	1268.10 ^b	2370.01 ^a	2836.29 ^a
Local	90.73 ^a	86.14 ^b	100.00 ^a	52.73 ^a	65.48 ^b	84.09 ^b	1377.90 ^a	2017.47 ^b	2575.56 ^b
CV (%)	16.15	17.35	16.79	16.85	19.62	16.29	32.29	40.24	41.47
Sig. level	***	***	***	***	***	***	ns	***	***
Fungicide									
Contaf	73.35 ^c	70.86 ^c	89.91 ^b	40.37 ^c	52.70 ^c	61.19 ^c	984.63 ^b	1522.71 ^d	1943.58 ^c
Max									
Nativo	77.28 ^c	75.74 ^c	100.00 ^a	42.81 ^{bc}	57.10 ^c	78.51 ^b	1058.33 ^b	1702.31 ^c	2343.94 ^b
Tilt	78.92 ^b	87.44 ^b	100.00 ^a	44.05 ^b	66.39 ^b	79.74 ^b	1074.96 ^b	2001.04 ^b	2309.05 ^b
Control	89.75 ^a	98.85 ^a	100.00 ^a	52.24 ^a	79.99 ^a	92.45 ^a	1376.85 ^a	2480.09 ^a	2783.61 ^a
CV (%)	35.05	42.41	31.09	39.26	37.35	30.48	39.39	40.24	41.47
Sig. level	***	***	***	***	***	***	ns	***	***

LBI-leaf blast incidence, NBI- neck blast incidence, HBI- head blast incidence, LBS- leaf blast severity, NBS- neck blast severity, HBS- head blast severity, LBAUDPC-leaf blast area under disease progress curve, NBAUDPC- neck blast area under disease progress curve, HBAUDPC-head blast area under disease progress curve

The significant main effects of both the variety and fungicide in Muluken Getahun *et al.* (2024) indicated that the effectiveness of fungicides varied among

varieties, with moderately resistant varieties displaying greater efficacy to fungicide treatments. For instance, fungicides were more successful in reducing FHB incidence and severity in moderately resistant wheat varieties compared to those that were moderately susceptible or highly susceptible, and a similar trend was reported by the works of Wegulo *et al.* (2011) and McMullen *et al.* (2008). Additionally, Muluken Getahun *et al.* (2024) reported that both tebuconazole and propiconazole consistently decreased FHB severity index and incidence. Haidukowski *et al.* (2005) determined that tebuconazole in combination with azoxystrobin significantly lowered both incidence and severity when compared to untreated controls. Moreover, Getachew Gudero *et al.* (2021) demonstrated that combining fungicides with moderately resistant varieties considerably reduced AUDPC and slowed the rate of disease progression.

In the present study, all the tested fungicides have significantly decreased blast disease severity compared to the control. Hexaconazole + R Tricyclazole fungicide constitutes hexaconazole 50 and tricyclazole 300 g L⁻¹ SC active ingredients in the triazole family were superior among the studied fungicides in inhibiting finger millet blast disease growth. It had the highest percentage of leaf blast reduction (>33%) and produced a yield gain of up to 35% over the control. Nativo was the second most effective fungicide though the yield collected from the plot treated with it was lower by 298 kg ha⁻¹ than Hexaconazole + R Tricyclazole. However, a fungicide with a single active component, propiconazole was less effective for controlling finger millet blast disease. Similarly, Jemal Tola and Tesfaye Gudisa (2021) observed that Hexaconazole + R Tricyclazole showed superior disease reduction by more than 80% and increased grain yield (5617 kg ha⁻¹) among the fungicides on rice crop affected by blast disease. On the other hand, Kaurav *et al.* (2018) revealed that Trifloxystrobin 100 gm. /lit + Tebuconazole 200 g/l was considerably superior to other fungicides in the absence of Hexaconazole + R Tricyclazole. On the other hand, Patro *et al.* (2020b) reported that among all the treatments, Propiconazole proved to be the best and recorded better grain yield in the absences of Hexaconazole + R Tricyclazole and Trifloxystrobin 100 g /l + Tebuconazole 200

g/l Sharma *et al.* (2018) have tested nine fungicides; including Trifloxystrobin 100 g /l+ Tebuconazole 200 g/l and Propiconazole, for their efficacy in managing blast disease and reported that the disease can be effectively controlled with three sprays of Trifloxystrobin 100 g /l + Tebuconazole 200 g/l or Propiconazole.

In field trials concerning leaf blast disease, Tricyclazole 75% WP demonstrated the greatest efficacy as a fungicide, bringing down the incidence of leaf blast to 1.15%, followed by Carbendazim 50% WP at 3.79%, Hexaconazole 5% EC at 4.37% and Mancozeb 75% WP at 10.16%. In contrast, untreated control plots showed a significantly higher incidence of 20.26% (Upamanya *et al.*, 2019). The highest percentage of disease control was achieved with Tricyclazole (94.32%), while Carbendazim followed behind at 81.29%, confirming previous findings by Joshi and Gohel (2015) and Prajapati *et al.* (2004). In finger millet, none of the varieties tested by Patro *et al.* (2018), including PR 1639, KMR 652, WN 562, VR 1117, GSMC 1, and GPU 67, demonstrated immunity to leaf blast; however, VR1117 showed relatively better resistance.

The significant variety–fungicide interaction for some variables suggested that fungicide efficacy in regulating FMBD and yield can be greater in some varieties than others. This is proven by higher fungicide efficacy for incidence, severity and yield in the moderately resistant variety (Bako-09) than in the moderately susceptible (Tessema) and susceptible (Necho) varieties. Utilizing resistant and moderately resistance cultivars combined with fungicides establishes a combined defense strategy, decreasing disease severity more effectively. Moderate resistant and resistant varieties naturally hinder disease progression, enabling fungicides to be more efficiently target remaining pathogen populations. An integrated strategy mitigates the evolution of resistance in pathogen populations by lessening the selection pressure that arises from dependence on one control method. Furthermore, when fungicides are combined with resistant varieties, they can be applied in lower quantities or less often, which further lessens potential adverse effects (Oliver and Hewitt, 2014).

Although Muluken Getahun *et al.* (2024) noted generally non-significant variety–fungicide interactions for FHB (apart from grain yield), prior research has yielded mixed outcomes. Wegulo *et al.* (2011) similarly found non-significant interactions for disease incidence, severity and yield, while Mesterhazy *et al.* (2003) reported consistent interactions across all assessed variables, likely due to variations in genetic responses among varieties or environmental factors.

6.3.3 Disease progression and AUDPC

Disease progression (% day) varied amongst Hexaconazole + R Tricyclazole, Trifloxystrobin 100 g/l + Tebuconazole 200 g/l and Propiconazole sprayed plots. As can be seen in FMBD progression curves, the untreated plots of all varieties had the highest severity. Necho exhibited the most disease progress among the varieties, followed by Local and Tessema. Disease progress of a variety of Bako-09 combined with Hexaconazole + R Tricyclazole, Trifloxystrobin 100 g/l + Tebuconazole 200 g/l and Propiconazole, in contrast, progressed slowly. Furthermore, on different days after sowing (DAS), Bako-09 combined with Hexaconazole + R Tricyclazole exhibited the lowest levels of FMBD severity. Varieties without any management were laid above all progressive curves compared with those integrating ones (Figure 6.3).

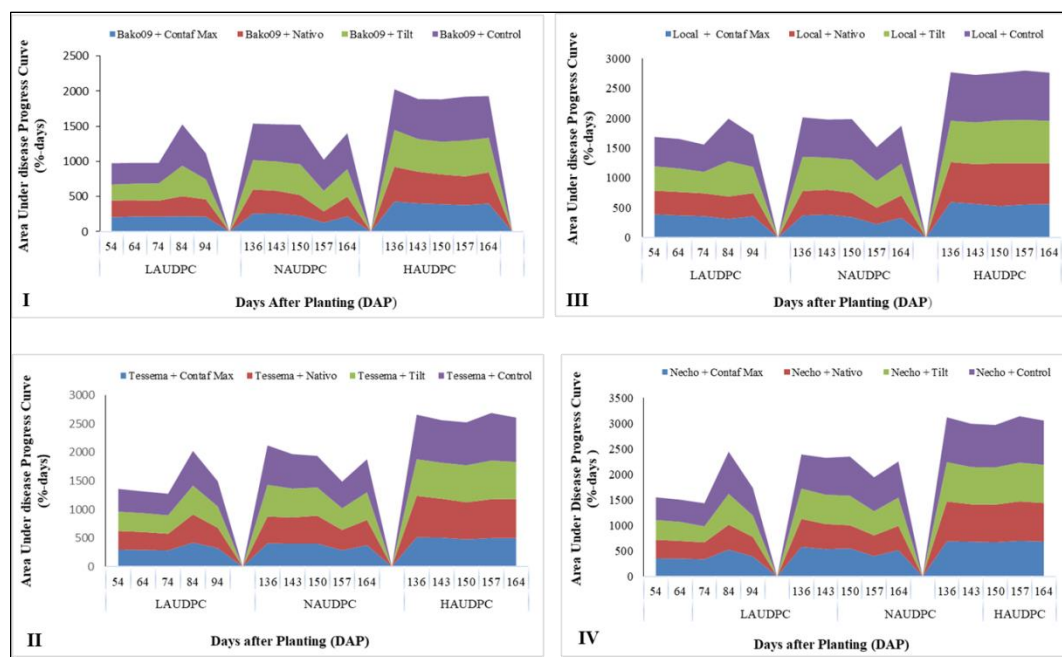


Figure 6.3. Finger millet blast disease progress curves as influenced by application of fungicides and finger millet varieties, Bako-09 (I), Tessema (II), Local (III), and Necho (IV).

As reported by Chaudhar *et al.* (2023), all the tested fungicides significantly reduced the AUDPC compared to control. The lowest AUDPC (824.58) was recorded with tricyclazole 45% + hexaconazole 10% WG, which was at par with tricyclazole 75% WP (828.34). Other effective treatments included propiconazole 10.7% + tricyclazole 34.2% SE (881.38), carbendazim 50% WP (982.37), edifenphos 50% EC (1104.82), tricyclazole 18% + mancozeb 62% WP (1191.68), and carbendazim 12% + mancozeb 63% WP (1339.88). The highest AUDPC (2150.39) occurred in the untreated control. It has been demonstrated that tricyclazole belongs to the melanin biosynthesis inhibitor (MBI) group of fungicides. It prevents melanin formation in the appressoria of *Pyricularia oryzae*, thereby inhibiting the penetration of pearl millet plants through the appressoria by blocking the enzyme polyhydroxynaphthalene reductase (Nath *et al.*, 2020).

According to Rajesh *et al.* (2024) report, Finger millet leaf blast severity, measured by AUDPC values, varied across treatments over two years. The chemical treatment (tricyclazole 75% WP) showed the lowest AUDPC (1577.33

and 1564.17) with a sharp decline in disease after spraying at 25 DAS. In contrast, the pre-released varieties (TNEc 1285 + TNEc 1294 + TNEc 1310) recorded higher AUDPC values (1794.79 and 1760.83 in 2020 and 2021) and exhibited slower disease progress without the abrupt decline observed in the chemical treatment. The observations of neck and finger blast incidences displayed variations compared to the leaf blast disease progress in both the seasons of 2020 and 2021. This study highlights the effectiveness of cultivar and fungicide mixtures in controlling finger millet blast and promoting sustainable disease management.

Admasie Kassaw *et al.* (2021) observed highly significant differences ($p < 0.001$) in the area under the disease progress curve (AUDPC) among various treatments. Belayneh Alamirew *et al.* (2020) observed that the disease progress curve for septoria leaf blotch exhibited a classic sigmoid pattern, characteristic of polycyclic diseases. The intensity of the disease increased linearly over time, with varietal resistance playing a significant role, as the moderately resistant variety Alidoro showed the slowest progression. Environmental factors, mainly rainfall and relative humidity were positively affect the disease's progression (Ghaffary, 2011).

Muluken Getahun *et al.* (2024) found that the severity of Fusarium head blight (FHB) advanced consistently from anthesis to the last observation. Disease progression was influenced by both treatment and wheat variety. Untreated plots experienced the faster rise in severity, while fungicide-treated plots, especially those with tebuconazole or propiconazole, demonstrated notably slower disease advancement. Danda'a showed the most rapid disease progression, followed by Hidase indicating greater susceptibility. Conversely, Kingbird treated with tebuconazole exhibited the slowest progression and the lowest severity overall.

These patterns were reinforced by area under the disease progress curve (AUDPC) values. The lowest AUDPC (316.17%-days) was noted in plots with tebuconazole, while the highest (743.75%-days) was found in untreated Danda'a plots. The application of fungicides significantly lowered AUDPC across all

varieties, with tebuconazole and propiconazole reducing AUDPC by 29.65% and 14.04% respectively (Muluken Getahun *et al.*, 2024). For septoria leaf blotch, the highest AUDPC (44.35%-days) was recorded in unsprayed Gambo, followed by Danda'a (30.14%-days), and the lowest in Alidoro (13.46%-days), confirming its moderate level of resistance (Belayneh Alamirew *et al.*, 2020).

6.3.4 Relative yield gain and disease suppression of fungicides

Pooled data analysis of disease characteristics, and yield components showed no significant effects were observed between experimental sites and cropping seasons for grain yield, neck and head blast severity (Table 6. 2). Yet, the relative yield gains due to the application of fungicides varied from 18.9 to 35%, and grain yield was improved by 35%, 32%, 32% and 31% when the varieties Local, Necho, Tessema and Bako-09 were sprayed with Hexaconazole + R Tricyclazole compared to the untreated plot (Figure 6.4, Appendix Table 6.5). The addition of fungicides reduced the mean FMBD severity by Hexaconazole + R Tricyclazole (33%) on Bako-09, (27%) on Tessema and (20%) on local but on Necho, Trifloxystrobin 100 g /l + Tebuconazole 200 g/l suppresses (20.1%) for LB severity. Similarly, on NB severity, Hexaconazole + R Tricyclazole suppresses (61%), and Trifloxystrobin 100 g /l + Tebuconazole 200 g/l suppresses (42%) on Bako-09, In addition, Hexaconazole + R Tricyclazole suppresses (41%) on local and (31%) on Tessema. But on the Necho variety, Trifloxystrobin 100 g /l + Tebuconazole 200 g/l suppresses (27%) (Figure 6.4, Appendix Table 6.4). Maximum head blast suppression was achieved with Hexaconazole + R Tricyclazole (34%) on Tessema, (30%) on Bako-09, (28%) on local and (19%) on Necho compared to the control (untreated plots). Furthermore, Hexaconazole + R Tricyclazole and Trifloxystrobin 100 g /l + Tebuconazole 200 g/l exhibited superior management efficiency (61% and 42%), in lowering PDI on the Bako-09 variety (Figure 6.4, Appendix Table 6.4).

Chaudhar *et al.* (2023) reported that all the tested fungicides significantly reduced blast disease under field conditions. The lowest disease intensity (19.63%) and highest reduction (71.98%) were recorded with tricyclazole 45% +

hexaconazole 10% WG (0.05%), followed by tricyclazole 75% WP (25.78% intensity, 63.20% reduction) and propiconazole 10.70% + tricyclazole 34.2% SE (28.81% intensity, 58.88% reduction). A study conducted by Patro *et al.* (2020a) revealed that Propiconazole gave the highest grain (15.7 q/ha) and fodder yields (41.3 q/ha) with the best cost–benefit ratio (3.01), while the control had the lowest yields (7.8 and 22.0 q/ha). In addition to improved grain yield, fungicide treatments suppressing the disease by disrupting fungal sterol biosynthesis through the inhibition of C14-demethylation, leading to membrane damage, and hindered fungal growth (Paul *et al.*, 2010). The increases in yield due to fungicide application reported as 34% (Jones, 2000), and Alemayehu Chala *et al.* (2003) documenting a 16.4% rise in TSW following fungicide treatment.

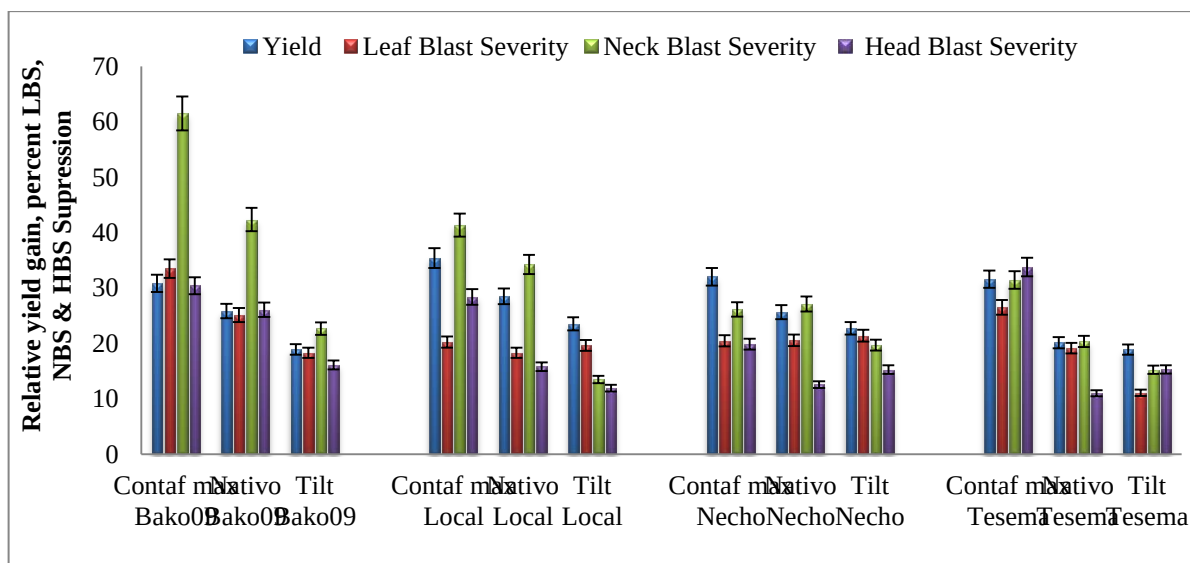


Figure 6.4 Percent blast suppression and relative yield gain by combining varieties and fungicides on finger millet during 2022 and 2023 cropping season at Semien Achefer and Finote Selam

The results of this investigation demonstrated that plots sprayed with Hexaconazole + R Tricyclazole, Trifloxystrobin 100 g/l + Tebuconazole 200 g/l and Propiconazole consistently reduced LAUDPC, NAUDPC and HAUDPC values and a decreased disease progress rate was computed from a moderately resistant variety (Bako-09) sprayed with Hexaconazole + R Tricyclazole (Figure 6.4, Appendix Table 6.5). According to Muluken Getahun *et al.* (2024), plots treated with fungicides reliably reduced disease severity. This may be related to

the fact that triazole fungicides proved to be the most successful in treating the disease by targeting cell membrane integrity through the prevention of C14-demethylation during ergosterol production. In the present study, the efficacy of fungicides in regulating finger millet blast disease varied among cultivars. This variation may be attributed to the active components of the fungicides, and the level of resistance of the cultivars against the disease. Finger millet varieties with moderate resistance to blast disease treated with Hexaconazole + R Tricyclazole demonstrated better fungicide efficacy than the susceptible type. This suggests that when there is high finger millet blast disease intensity, Hexaconazole + R Tricyclazole fungicide application in moderately resistant variety (Bako-09) helps to manage the disease more successfully than in susceptible varieties. Furthermore, inoculum buildup is anticipated to be reduced over time when moderately resistant varieties are planted since moderately resistant varieties tolerate finger millet blast disease. Our results suggested that applications of fungicides at or immediately after the beginning of disease manifestation, during the seedling, flowering and grain filling stage are beneficial in minimizing finger millet blast disease. This could be because finger millet cultivars are most sensitive to finger millet blast disease during these critical growth stages. A study conducted by Chaudhar *et al.* (2023) revealed that, All treatments showed significant finger millet grain yield improvement. The highest grain (1857.50 kg/ha) and fodder (2342.50 kg/ha) yields were obtained with tricyclazole 45% + hexaconazole 10% WG, followed by tricyclazole 75% WP (1445.81 kg/ha grain, 1901.67 kg/ha fodder). Subsequent effective treatments were propiconazole 10.7% + tricyclazole 34.2% SE, carbendazim 50% WP, edifenphos 50% EC, and tricyclazole 18% + mancozeb 62% WP, yielding 1290, 1211.67, 1090.17, and 985 kg/ha grain and 1731.67, 1645.83, 1434.29, and 1285 kg/ha fodder, respectively.

6.3.5 Cost and benefit analysis

The partial budget analysis was performed using net returns and marketable yield was considered to compute the marginal rate of return (MRR). A

significant variation was observed in net profit among the finger millet varieties as well as the fungicides evaluated. The maximum marginal rate of return was obtained on the finger millet varieties Bako-09 and local cultivars treated with fungicide Contaf max and Nativo alone. Especially, treatment of local cultivar with Hexaconazole + R Tricyclazole (13479.09 ETB/ha) and Trifloxystrobin 100 g /l + Tebuconazole 200 g/l (13127.91 ETB/ha), and Bako-09 treated with Nativo (12103.05 ETB/ha) indicated the higher marginal rate of return value than Propiconazole treated and unsprayed varieties on the different plots (Table 6.5).

Table 6.5. Partial budget analysis for the Finger millet blast management through host resistant and alternate applications of fungicides

Variety	Fungicide	Adjusted yield (t/ha)	Sale price (ETB/kg)	Sale revenue (ETB/ton)	Variable cost (ETB/ha)	Net Benefit (ETB/ha)	Marginal Rate of Return (%)
Bako09	Contaf max	2.87	60.00	60000	1420	170563.44	12011.51
	Nativo	2.68	60.00	60000	1320	159760.31	12103.05
	Tilt	2.44	60.00	60000	1620	144601.88	8926.04
	Unsprayed	1.98	60.00	60000	0.00	118593.75	0.00
Local	Contaf max	3.21	60.00	60000	1420	191403.13	13479.09
	Nativo	2.91	60.00	60000	1320	173288.44	13127.91
	Tilt	2.70	60.00	60000	1620	160354.69	9898.44
	Unsprayed	2.01	60.00	60000	0.00	120843.75	0.00
Tessema	Contaf max	2.41	60.00	60000	1420	143157.50	10081.51
	Nativo	2.15	60.00	60000	1320	127586.25	9665.63
	Tilt	2.09	60.00	60000	1620	123817.50	7643.06
	Unsprayed	1.59	60.00	60000	0.00	95250.00	0.00
Necho	Contaf max	2.47	60.00	60000	1420	146939.38	10347.84
	Nativo	2.14	60.00	60000	1320	127351.88	9647.87
	Tilt	2.10	60.00	60000	1620	124089.38	7659.84
	Unsprayed	1.68	60.00	60000	0.00	100781.25	0.00

Numerous studies indicate that the use of fungicides provides significant economic advantages in the control of crop diseases. A study conducted by Rajesh *et al.* (2024) combining different finger millet varieties and fungicides revealed that, two sprays of Tricyclazole 75% WP effectively controlled blast disease outbreaks, yielding a cost-benefit ratio of 1:1.47 and proving a better economic return relative to the input costs. As reported by Chaudhar *et al.* (2023) the highest net return (Rs. 34,072/ha) and cost-benefit ratio (1:1.9) were obtained from tricyclazole 45% + hexaconazole 10% WG, followed by tricyclazole 75% WP (Rs. 25,412/ha; 1:1.77). Other treatments in descending order were propiconazole 10.7% + tricyclazole 34.2% SE (**Rs.** 18,717/ha;

1:1.15), carbendazim 50% WP (Rs. 18,285/ha; 1:1.27), edifenphos 50% EC (Rs. 16,005/ha; 1:1.07), and tricyclazole 18% + mancozeb 62% WP (Rs. 12,294/ha; 1:0.88). The lowest net return (Rs. 9,678/ha; 1:0.71) was recorded with carbendazim 12% + mancozeb 63% WP.

Belayneh Alamirew *et al.* (2020) found that using Propiconazole or Trifloxystrobin 100 g /l + Tebuconazole 200 g/l was the most economically efficient approach for managing garlic rust, resulting in the greatest net returns and marginal rate of return (MRR).

6.4 Conclusion and Recommendation

According to the current research, integrating moderately resistant finger millet varieties, and applying fungicides lowered finger millet blast disease epidemics, and improved grain yield and yield components. Finger millet blast disease and yield loss were considerably minimized in Bako-09 and the local variety treated with Hexaconazole + R Tricyclazole and Trifloxystrobin 100 g /l + Tebuconazole 200 g/l fungicides. Hexaconazole + R Tricyclazole can therefore be a feasible fungicide over Trifloxystrobin 100 g /l + Tebuconazole 200 g/l or Propiconazole. However, there was a comparable pattern in the test efficacy of fungicides throughout both seasons. Consequently, the current data indicates that finger millet blast disease can be effectively managed in the study districts and other places with similar conditions by applying Hexaconazole + R Tricyclazole fungicide thrice at vegetative, flowering and grain filling stages. Application of Hexaconazole + R Tricyclazole to Bako-09, Local, Tessema and Necho varieties greatly decreased blast disease development at both locations. Moderately resistant variety Bako-09 and high yielder local variety could be recommended for cultivation in combination with Hexaconazole + R Tricyclazole at both locations.

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Chapter 7. GENERAL CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

Finger millet remains an important crop for food security and the livelihoods of rural communities in Ethiopia, particularly in Northwestern Amhara, where it provides food and income for many smallholder farmers. However, its productivity is consistently threatened by blast disease caused by *M. grisea*, which has been prevalent in the area since a decade. This study investigated the scope of finger millet blast in terms of its distribution, pathogen diversity, host resistance, and integrated management. The findings suggest that blast is widespread in all the districts surveyed, but the levels of intensity differ from place to place. Jabi Tehnan and Siemen Achefer were hot spots of the disease, while it has relatively less impact at West Dembiya, Takusa and Dangila. Disease incidence varied between 15.21% and 56.28%, while severity level ranged from 36.75% to 86.98%. This suggests a need for efficient and district based disease management interventions. One major problem identified is the limited awareness among farmers regarding the symptoms, mode of transmission and management of blast disease. Majority of farmers continue to plant susceptible varieties and some of them depend on fungicides that are not recommended for managing blast. Although agricultural extension services play a role in providing disease management information, the study revealed that their accessibility is limited. Improving these services through training, improved resources, and community involvement is vital to ensure timely and accurate assistance.

An important aspect of this study was to characterize the *M. grisea* isolates from finger millet samples in the study areas by exploring their morphology, physiology and cultural characteristics. An examination of 19 representative isolates indicated significant variation in conidial shape, septation, colony morphology, and pigmentation and growth responses to temperature, pH and nutrient sources. Optimal mycelial growth observed at temperatures ranging

from 25°C to 30°C and pH levels between 5 and 7. Dextrose was found to be the best carbon source while the best nitrogen source was NaNO₃. These results highlight the adaptability of the pathogen to different environmental and nutritional conditions.

Evaluation of finger millet genotypes demonstrated significant variation in resistance to blast disease, providing valuable information for breeding programs. Genotypes like G14, G31, G60, G16, G35 and G32, consistently showed adequate resistance across locations and seasons, suggesting the existence of strong potentially polygenic resistance traits. Additionally, genotypes such as G33, G9, G13 and G56 exhibited moderate resistance with reduced disease severity which could be useful for breeding. Conversely, highly susceptible genotypes like G8, G24, G46 and G51 could be utilized as susceptible checks in screening trials. The consistent performance of resistant genotypes across environments indicates their potential sources as parental lines for developing blast-resistant varieties through targeted breeding efforts.

The research also evaluated three fungicides that are typically accessible to farmers. Among these, Hexaconazole + R Tricyclazole identified to be the most effective in lowering blast severity when used during critical growth stages: vegetative, flowering and grain filling. The integration of this fungicide with moderately resistant cultivar such as Bako-09 or high-yielding local varieties, led to decreased disease progression, along with improvements in yield. These findings supported that integrated disease management strategies combining host resistance with selected fungicide application are essential for effectively controlling blast in the affected districts.

In addition to disease challenges, various insect pests and other diseases were observed during field evaluations, adding further risks to crop yield and quality. This emphasizes the importance of implementing integrated pest and disease management (IPDM) strategies that include routine pest monitoring, accurate identification and compatible biological, cultural and chemical control methods.

This study provides an integrated overview of finger millet blast and its management in Northwestern Amhara, Ethiopia. The results show that blast remains a major constraint to finger millet production, aggravated by farmers' limited knowledge, use of susceptible varieties, and inconsistent management practices. The observed morphological and physiological variability among *M. grisea* isolates points to a considerable level of pathogen adaptability, making control efforts more complex. However, identifying resistant genotypes and optimizing fungicide use offer a pathway to more sustainable and effective disease management. By integrating resistant varieties with fungicide treatments, stronger disease suppression was observed, resulting in healthier plants and ultimately improved yield. Improving extension services, promoting farmer education, advancing breeding programs, and improving collaboration among research institutions, government agencies, and farming communities are all vital for reducing the impact of blast disease and sustaining finger millet production, improving the livelihoods of smallholders, and contributing to national food security.

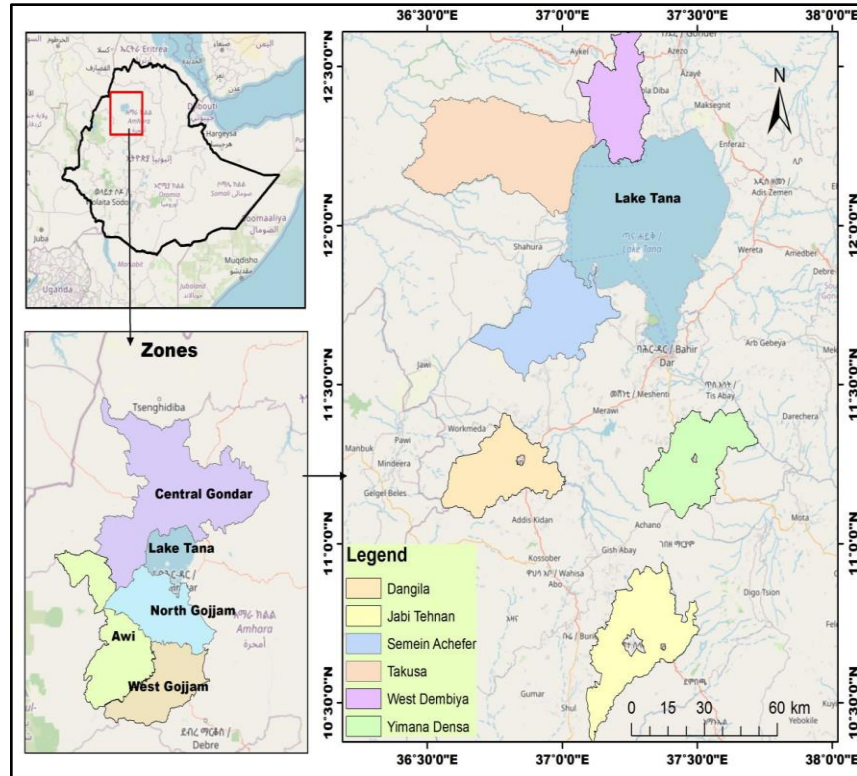
7.2 Recommendations

Based on the research findings, the following recommendations are forwarded for future directions:-

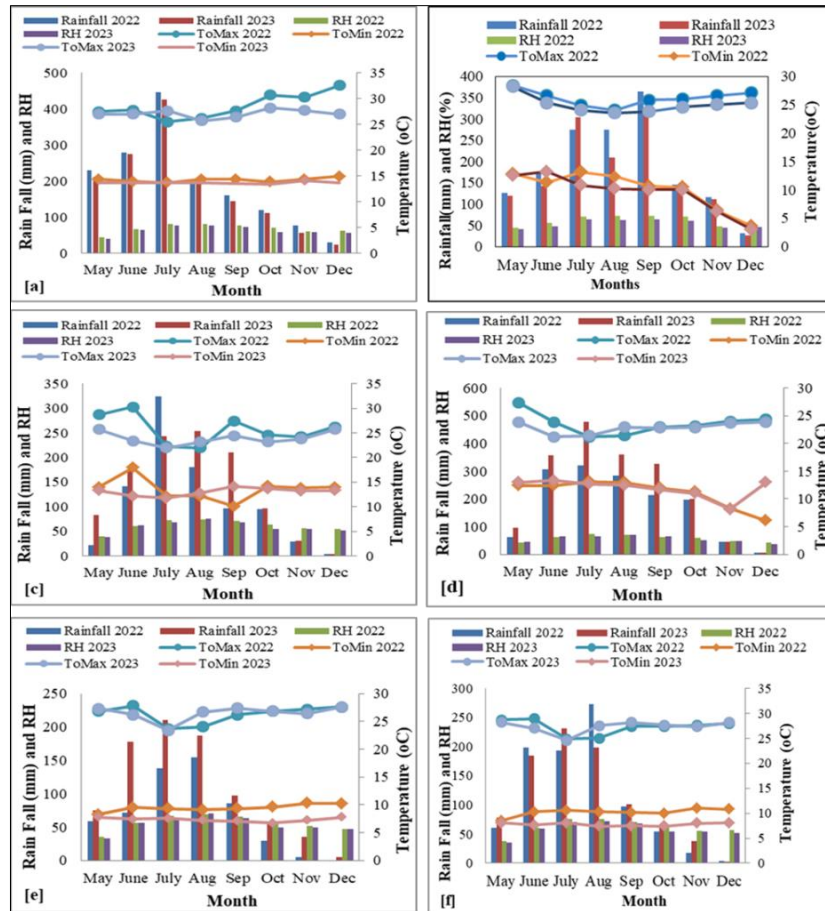
1. The regional or national breeding efforts should focus on the breeding and distribution of blast-resistant varieties using parent lines like G14, G31, G60, G16, G35 and G32.
2. Farmers could use resistant genotypes like G33, G9, G13, G56 as a short term strategy, and varieties like Bako-09 with moderate blast pressure for finger millet production in the study locations .
3. Multilocation and over two years evaluation is required to capture long-term climatic variability.
4. Molecular characterization of resistance genes in the identified genotypes is required
5. Develop farmer-friendly training materials (in local languages) that focus on:

- Blast symptoms across different growth stages
 - The cycles of the disease and its mode of transmission
 - Cultural and chemical control strategies through demonstration plots and field visit.
6. Strengthen the capacity of agricultural extension services on blast disease and integrated disease management (IDM)
7. Promote the rational use of fungicides by distributing clear, evidence-based guidelines:
- Focus the testing of other effective fungicides Inaddtion to the use of Hexaconazole + R Tricyclazole at vegetative, flowering and grain filling stages and other tested fungicides in the absence of Contaf Max 350.
 - Long-term impact of combining resistance varieties and fungicides should be verified

LIST OF APPENDIC



Appendix Figure 1.1. Map of general study area



Appendix Figure 1.2. Mean monthly rain fall, relative humidity, and temperature of the study districts ([a] Jabi Tehnan, [b] Adet, [c] Semein Achefer, [d] Dangila, [e] Takusa and [f] West Dembiya). Source: WAMSC (2023).

Appendix Table 2.1. Agronomic practices of farmers involved in finger millet farming

District	(a) Farm size (ha)			(b) Soil type			
	0.15–0.25	0.3–0.5	0.75–1	Nitosol	Vertisol	Leptosols	
J. Tehnan	32 (55.17%)	15 (25.86%)	10 (17.24%)	39 (67.24%)	0(0.00)	19 (32.76%)	
Dangila	18 (37.50%)	23 (47.92%)	7 (14.58%)	9 (18.75%)	21 (43.75%)	18 (37.50%)	
S. Achefer	17 (24.29%)	44 (62.86%)	10 (14.29%)	44 (62.86%)	0(0.00)	26 (37.14%)	
Takusa	45 (77.59%)	13 (22.41%)	0 (0%)	0(0.00)	17(29.31)	41(70.69%)	
W. Dembiya	27 (75.00%)	9 (25.00%)	0 (0%)	7 (19.44%)	22 (61.11)	7 (19.44%)	
District	(c) Previous crop			(d) Residue clearance		(h) Seep type	
	Cereal	Pulse	Other	Yes	No	Local	Improved
J. Tehnan	50 (86.21%)	0 (0%)	8 (13.79%)	14 (24.14%)	44 (75.86%)	50 (86.21%)	9 (15.52)
Dangila	34 (70.83%)	5 (10.42%)	9 (18.75%)	11 (22.92%)	25 (52.08%)	40 (83.33)	8 (16.67%)
S. Achefer	53 (75.71%)	6 (8.57%)	11 (15.71%)	17 (24.29%)	53 (75.71%)	59 (84.29%)	11 (15.71%)
Takusa	32 (55.17%)	4 (6.89%)	22 (37.93%)	22 (37.93%)	37 (63.79%)	54 (93.10%)	4 (6.89%)
W. Dembiya	20 (55.56%)	4 (11.11%)	12 (33.33%)	16 (44.44%)	20 (55.56%)	30 (83.33%)	6 (16.67%)
District	(g) Field management			(e) Cropping type		(f) Fertilizer application	
	Excellent	Good	Poor	Sole	Mixed	Yes	No
J. Tehnan	3 (5.17%)	34 (58.62%)	21 (36.21%)	51 (87.93%)	7 (12.07%)	46 (79.31%)	12(20.69)
Dangila	0 (0.00)	27 (56.25%)	21 (43.75%)	48 (100%)	0 (0%)	37(77.08%)	11(22.92%)
S. Achefer	0 (0.00)	47 (67.14%)	23 (32.86%)	70 (100%)	0 (0%)	59 (84.29%)	11(15.71%)
Takusa	4 (6.89%)	49 (84.48%)	4 (6.98%)	52 (89.67%)	6 (10.34%)	30 (51.72%)	28 (48.28%)
W. Dembiya	18 (50.00)	18 (50%)	0 (0%)	36 (100%)	0 (0%)	20 (55.56%)	16 (44.44%)
District	(i) Sowing date		(j) Plant density				
	Time period		Value	High		Medium	Low
J. Tehnan	End of June – Early July		58(100.00)	19 (32.76%)		34 (58.62%)	5 (8.62%)
Dangila	End of June – Early July		9(18.75%)	25 (52.08%)		23 (47.92%)	0(0%)
	Mid-June – Early July		39(81.25%)				
S. Achefer	End of June – Early July		70(100.00)	27 (38.57%)		41 (58.57%)	2(2.86)
Takusa	Mid-June – End of June		58 (100.00)	5 (8.62%)		15 (25.86%)	39 (67.24%)
W. Dembiya	Mid-June – End of June		36 (100.00)	7(19.44%)		29 (80.56%)	0 (0.00%)
District	(k) Crop management			(l) Weeding frequency			
	Good	Fair	Poor	Once	Twice	Thrice	
Jabi	41 (70.69%)	6 (10.34%)	11	51 (87.93%)	7 (12.07%)	0 (0%)	
Dangila	34 (70.83%)	0 (0%)	14	39 (81.25%)	9 (18.75%)	0 (0%)	
N. Achefer	59 (84.29%)	2 (2.86%)	9 (12.86%)	62 (88.57%)	8 (11.43%)	0 (0%)	
Takusa	49 (85.19%)	9 (15.52%)	0(0.00%)	26 (44.83%)	24 (41.38%)	8 (13.79%)	
W. Dembiya	29 (81.25%)	7 (19.44%)	0 (0.00%)	7 (18.75%)	20 (56.25%)	9 (25.00%)	
District	(m) Crop condition		(n) Fungicide application		(o) Crop condition		
	Good	Poor	Yes	No	Good	Poor	
J. Tehnan	46 (79.31%)	12 (20.69%)	0 (0%)	58 (100%)	46 (79.31%)	12 (20.69%)	
Dangila	34 (70.83%)	14 (29.17%)	7 (14.58%)	41 (85.42%)	34 (70.83%)	14 (29.17%)	
N. Achefer	60 (85.71%)	10 (14.29%)	6 (8.57%)	64 (91.43%)	61 (87.14%)	9 (12.86%)	
Takusa	49 (84.48%)	9 (15.52%)	11 (18.97%)	47 (81.03%)	49 (84.48%)	9 (15.52%)	
W. Dembiya	36 (100%)	0 (0%)	9(25.00%)	27 (75%)	36 (100%)	0 (0%)	

Appendix Table 2.2. Mean incidence and severity of finger millet blast disease (leaf, neck, and head types) across five districts in 2022 and 2023 cropping seasons

District	Incidence type (Mean±SE)						
	Leaf		Neck		Head		Mean±SE
	2022	2023	2022	2023	2022	2023	
Jabi	32.19 ^a ±0.99	28.73 ^b ±0.87	39.26 ^a ±1.09	34.97 ^a ±0.88	55.29 ^a ±1.42	46.39 ^a ±1.51	39.47±1.13
Tehnan	(30.23-34.17)	(27.01-30.46)	(37.09-41.42)	(33.22-36.72)	(52.49-58.11)	(43.38-49.41)	(37.24-41.72)
Semien	30.56 ^a ±0.92	35.25 ^a ±1.92	36.88 ^a ±1.20	34.65 ^a ±1.19	56.61 ^a ±1.66	45.69 ^a ±1.19	39.94±1.35
Achefer	(28.74-32.38)	(31.40-39.09)	(35.49-39.27)	(32.26-37.03)	(53.31-59.92)	(43.29-48.09)	(37.42-42.63)
Takusa	24.92 ^b ±0.63	19.38 ^b ±0.45	28.31 ^b ±0.97	22.08 ^b ±0.69	41.93 ^b ±1.27	31.75 ^c ±1.04	28.06±0.84
	(23.67-26.17)	(18.48-20.27)	(26.37-30.24)	(20.71-23.46)	(39.40-44.47)	(29.67-33.83)	(26.38-29.74)
West	22.84 ^b ±0.78	18.94 ^c ±0.57	31.34 ^b ±1.18	25.43 ^b ±1.01	47.68 ^b ±1.49	36.33 ^b ±0.92	30.43±0.99
Dembiya	(21.27-24.40)	(17.67-19.99)	(28.95-33.72)	(23.38-27.49)	(44.67-50.69)	(34.47-38.19)	(28.40-32.41)
Dangila	14.47 ^c ±0.53	14.68 ^c ±0.52	19.25 ^c ±0.65	16.85 ^c ±0.52	35.01 ^c ±1.67	27.36 ^c ±0.74	21.27±0.77
	(13.39-15.54)	(13.63-15.73)	(17.93-20.56)	(15.79-17.91)	(32.66-37.36)	(25.86-28.86)	(19.88-23.08)
Mean±SE	25.00±0.77	23.40±0.87	31.01±1.02	26.8±0.86	47.30±1.50	37.50±1.08	31.83±1.02
	(25.98-29.28)	(23.64-27.45)	(31.98-36.16)	(27.39-31.18)	(47.47-53.30)	(37.70-42.38)	(29.86-33.92)
District	Severity type (Mean±SE)						
	Leaf		Neck		Head		Mean±SE
	2022	2023	2022	2023	2022	2023	
Jabi Tehnan	50.56 ^a ±0.75	38.29 ^a ±0.85	81.84 ^a ±0.94	65.71 ^a ±1.16	85.48 ^a ±0.65	70.57 ^a ±0.95	65.41±0.88
	(49.07-52.04)	(36.59-39.98)	(79.98-83.70)	(63.40-68.03)	(84.19-86.77)	(68.67-72.47)	(63.65-67.17)
Semien	42.17 ^b ±0.79	34.26 ^b ±0.91	77.18 ^b ±1.11	60.95 ^a ±1.55	80.21 ^b ±1.04	70.47 ^a ±1.19	60.87±1.10
Achefer	(40.59-43.75)	(32.45-36.08)	(74.97-79.38)	(57.85-64.05)	(78.15-82.27)	(68.09-72.86)	(58.68-63.07)
Takusa	29.62 ^c ±0.79	20.52 ^c ±0.61	61.54 ^c ±1.76	45.71 ^b ±1.32	73.69 ^c ±1.13	48.34 ^b ±1.25	46.74±1.14
	(28.05-31.19)	(19.29-21.74)	(58.03-65.06)	(43.02-48.41)	(71.42-75.66)	(45.80-50.89)	(44.27-48.83)
West	29.83 ^c ±0.78	20.69 ^c ±0.64	72.53 ^b ±1.12	46.33 ^b ±1.68	66.29 ^d ±1.02	52.33 ^b ±1.35	48.33±1.10
Dembiya	(28.25-31.40)	(19.41-21.99)	(70.28-74.79)	(42.98-48.69)	(64.26-68.31)	(49.63-55.03)	(45.8-50.04)
Dangila	13.63 ^d ±0.86	20.49 ^c ±0.71	51.02 ^d ±1.52	35.82 ^c ±0.77	53.78 ^e ±1.30	42.31 ^c ±0.70	36.16±0.98
	(11.89-15.37)	(19.07-21.92)	(47.97-54.08)	(34.28-37.38)	(51.25-56.31)	(40.90-43.73)	(34.23-38.13)
Mean±SE	33.16±0.79	26.85±0.74	68.82±1.29	50.90±1.30	71.89±1.03	56.80±1.09	51.50±1.04
	(31.57-34.75)	(25.36-28.34)	(66.25-68.33)	(48.31-53.31)	(69.85-73.86)	(54.62-59.00)	(49.33-54.45)

Appendix Table 3.1. Geographical and environmental conditions of sampled areas

District	Kebele	Altitude range (m)	Latitude (°N)	Longitude (°E)	No of samples
Jabi Tehnan	A. zeguaye	1839- 1934	10°39'41.4"- 10°40'58.5"	037°12'29.3"- 037°14'19.1"	60
	Baker abater	1892-1967	10°42'01.9"- 10°42'36.9"	037°14'28.5"- 037°14'56.7"	42
	M. abedgoma	1918-2004	10°40'53.1"- 10°41'58.4"	037°11'47.0"- 037°14'49.0"	42
	Zabatsion	1961- 2034	10°41'18.1"- 10°42'18.9"	037°07'27.0"- 037°13'10.3"	60
S. Achefer	Amebeshen	1995-2071	11°36'38.0"-11°38'26.0"	036°54'51.6"-036°58'15.5"	42
	Liben	2016-2046	11°38'36.5"-11°40'54.0"	036°55'30.1"-036°55'57.2"	60
	Denbola	1911-2001	11°42'34.2"-11°44'13.7"	036°57'19.3"-036°58'59.2"	60
	Sankera	1811-1956	11°17'15.6"-11°52'31.9"	036°59'01.4"-037°28'49.0"	42
Dangila	Kunzla	1811-2207	11°17'15.6"-11°52'31.9"	037°00'06.7"-037°28'49.0"	42
	Bata Berayeta	2063-2096	11°14'61.4"-11°16'30.9"	036°47'8'07.3"-36°50'07.5"	42
	Z. k. meheret	2074-2133	11°16'19.35"-11°17'34.4"	36°52'38.5" - 036°54'21.0"	42
	Gunderi	2168- 2186	11°11'20.26"- 11°13'10.0"	036°41'27.1"- 036°51'37.9"	42
Takusa	G.T. hyemanote	2063-2164	11°17'10.1"-036°50'00.6"	036°50'00.6"-36°83'35.1"	42
	Chach	1789-1876	12° 13' 56.93"-12°20'30.5"	037°04'21.3"-37° 5' 16.12"	42
	Mekonta	1832-2054	12° 7' 15.46"-12°24'25.6"	37° 0' 25.1274"-37° 56' 31.4"	60
	Ayibga	2004-2058	12°09'05.2"-12°21'17.5"	036°49'12.3"-36° 58' 31.5"	42
W. Dembiya	Kurabas	2047-2065	12°07'22.8"-12°11'21.4"	036°56'42.5"-036°58'51.3"	60
	Guarhie	1818-1857	12°20'42.3"-12° 22' 57.2"	37° 8' 50.532"-037°12'21.7"	42
	Sankisa	1865-1872	12°18'57.5"-12°31'85.3"	037°08'51.0"-037°11'31.0"	42
	Narchecha	1887-1893	12°11'31.1"-12°27'11.8"	037°06'39.9"-037°26'37.9"	42
Zenzelema					9
Adet					9
Total					966

S. Achefer- Semien Achefer, Dembiya- West Dembiya, A. zeguaye- Abasem zeguaye, M. abedgoma- Mankussa
 abedgoma, Z.K. meheret- Zeguda kidanemeheret, G. T. hyemanote- Gerarege Teklehayemanote

Appendix Table 3.2 Total number of isolates, collected, and isolated from different sampling kebeles and plant parts

S. no	Isolate code	Colony ø (mm)	Colour on PDA	Margin	Colony texture	Colony form	Pigmentation	Elevation	Growth rate
1	A/ Zeguaye H	90	black	entire	velvety	regular	yellow	flat	poor
2	A/ Zeguaye H	90	black	undulate	velvety	irregular	dark	flat	poor
3	A/ Zeguaye H	80	white	undulate	cottony	irregular	light brown	flat	medium
4	A/ Zeguaye H	80	white	undulate	cottony	irregular	light brown	flat	medium
5	A/ Zeguaye H	70	olive grey	undulate	cottony	irregular	light brown	flat	medium
6	A/ Zeguaye H	80	Greyish white	undulate	cottony	irregular	light brown	flat	medium
7	A/ Zeguaye H	65	white	undulate	cottony	irregular	light brown	flat	medium
8	A/ Zeguaye H	75	white	undulate	cottony	irregular	light brown	flat	medium
9	A/ Zeguaye H	70	Greyish white	undulate	cottony	irregular	light brown	flat	medium
10	A/ Zeguaye L	90	Greyish brown	entire	thick cottony	regular	black, pale olive	flat	good
11	A/ Zeguaye L	90	Greyish brown	entire	velvety	regular	black, pale olive	flat	medium
12	A/ Zeguaye L	90	greyish brown	entire	velvety	regular	black, pale olive	flat	good
13	A/ Zeguaye L	90	greyish white	entire	thick cottony	regular	black, pale olive	flat	good
14	A/ Zeguaye L	85	greyish white	undulate	cottony	irregular	brown	raised	good
15	A/ Zeguaye L	60	Greyish brown	entire	cottony	regular	brown	flat	medium
16	A/ Zeguaye L	90	Grayish white with pink end	entire	thick cottony	regular	brown	flat	good
17	A/ Zeguaye L	90	greyish white	undulate	cottony	irregular	brown	raised	good
18	A/ Zeguaye L	90	white	entire	thick cottony	regular	black	flat	good
19	A/ zeguaye N	75	white	undulate	velvety	irregular	dark brown	flat	medium
20	A/ zeguaye N	70	white	entire	velvety	regular	light brown	flat	good
21	A/ zeguaye N	80	white	entire	velvety	regular	light brown	flat	good
22	A/ zeguaye N	60	greyish white	entire	cottony	regular	light brown	flat	good
23	A/ zeguaye N	80	white	entire	cottony	regular	light brown	flat	medium
24	A/ zeguaye N	70	greyish white	undulate	cottony	irregular	light brown	flat	medium
25	A/ zeguaye N	60	white	entire	cottony	regular	dark brown	raised	medium
26	A/ zeguaye N	80	white	entire	cottony	regular	dark brown	raised	good
27	A/ zeguaye N	80	greyish white	entire	fluffy	regular	dark brown	raised	good
28	Adet H	90	white	entire	cottony	regular	dark brown	raised	medium
29	Adet H	80	white	undulate	cottony	irregular	dark brown	raised	medium
30	Adet H	90	greyish white	undulate	cottony	irregular	light brown	raised	good
31	Adet H	75	greyish white	undulate	cottony	irregular	brown	flat	medium
32	Adet H	90	greyish white	undulate	cottony	irregular	dark brown	raised	good
33	Adet L	90	white	entire	cottony	irregular	yellow	raised	medium
34	Adet L	70	white	entire	cottony	irregular	light brown	flat	medium
35	Adet L	85	white	undulate	fluffy	regular	light brown	flat	medium
36	Adet L	70	white	entire	cottony	regular	brown	raised	medium

37	Adet L	65	white	entire	cottony	regular	brown	raised	medium
38	Adet N	65	greyish white	undulate	cottony	regular	light brown	flat	medium
39	Adet N	68	greyish white	undulate	cottony	irregular	light brown	raised	medium
40	Adet N	80	grey	undulate	fluffy	irregular	dark brown	flat	medium
41	Adet N	80	white	entire	spindle	regular	dark brown	flat	good
42	Adet N	70	white	entire	spindle	regular	dark brown	flat	good
43	Amebeshen H	84	grey	undulate	velvety	irregular	light brown	flat	medium
44	Amebeshen H	83	greyish white	undulate	cottony	regular	dark brown	raised	good
45	Amebeshen H	87	greyish white	undulate	velvety	regular	dark brown	flat	good
46	Amebeshen H	60	olive grey	undulate	cottony	irregular	light brown	raised	medium
47	Amebeshen H	70	white	undulate	cottony	irregular	light brown	raised	medium
48	Amebeshen H	60	white	undulate	cottony	irregular	light brown	raised	medium
49	Amebeshen H	50	white	undulate	cottony	irregular	light brown	raised	medium
50	Amebeshen H	60	white	undulate	cottony	irregular	light brown	raised	medium
51	Amebeshen H	80	pale grey	undulate	cottony	irregular	light brown	raised	medium
52	Amebeshen L	75	pale grey	undulate	cottony	irregular	light brown	raised	medium
53	Amebeshen L	70	pale grey	undulate	cottony	irregular	light brown	raised	medium
54	Amebeshen L	60	pale grey	undulate	cottony	irregular	light brown	raised	medium
55	Amebeshen L	65	pale grey	undulate	cottony	irregular	light brown	raised	medium
56	Amebeshen L	70	olive grey	undulate	cottony	irregular	light brown	raised	medium
57	Amebeshen L	65	olive grey	undulate	cottony	irregular	light brown	raised	medium
58	Amebeshen L	68	olive grey	entire	cottony	regular	light brown	raised	good
59	Amebeshen L	70	olive grey	entire	cottony	regular	light brown	raised	good
60	Amebeshen L	60	olive grey	entire	cottony	regular	light brown	raised	good
61	Amebeshen N	65	olive grey	entire	cottony	regular	light brown	raised	good
62	Amebeshen N	90	grayish white	entire	cottony	regular	light brown	raised	good
63	Amebeshen N	80	pale grey	entire	cottony	regular	light brown	raised	good
64	Amebeshen N	70	grey	entire	cottony	regular	light brown	raised	good
65	Amebeshen N	55	white	entire	cottony	regular	light brown	raised	good
66	Amebeshen N	60	olive grey	entire	cottony	regular	light brown	raised	good
67	Amebeshen N	80	pale grey	entire	cottony	regular	light brown	raised	good
68	Amebeshen N	60	greyish white	entire	cottony	regular	light brown	raised	good
69	Amebeshen N	70	pinkish white	entire	cottony	regular	light brown	raised	good
70	Ayibga H	70	white	undulate	cottony	irregular	dark brown	flat	good
71	Ayibga H	65	white	undulate	cottony	irregular	dark brown	flat	good
72	Ayibga H	50	white	undulate	cottony	irregular	light brown	flat	good
73	Ayibga H	60	white	undulate	cottony	irregular	light brown	flat	good
74	Ayibga H	70	white	undulate	cottony	irregular	light brown	flat	good
75	Ayibga H	60	white	undulate	cottony	irregular	light brown	flat	good
76	Ayibga N	60	white	entire	cottony	regular	dark brown	raised	medium
77	Ayibga N	65	greyish white	undulate	fluffy	regular	light brown	raised	medium

78	Ayibga N	55	greyish white	entire	fluffy	regular	light brown	flat	medium
79	Ayibga N	60	greyish white	entire	cottony	regular	dark brown	raised	medium
80	Ayibga N	70	white	entire	cottony	regular	light brown	raised	medium
81	Ayibga N	86	greyish white	undulate	cottony	regular	light brown	raised	medium
82	Baker abater H	63	grey	undulate	cottony	irregular	light brown	raised	medium
83	Baker abater H	76	pinkish white	undulate	cottony	regular	dark brown	raised	good
84	Baker abater H	81	greyish white	undulate	cottony	regular	black	raised	good
85	Baker abater H	73	grey	undulate	fluffy	irregular	dark brown	flat	medium
86	Baker abater H	55	white	undulate	cottony	regular	light brown	raised	medium
87	Baker abater H	60	olive grey	undulate	cottony	regular	light brown	raised	medium
88	Baker abater H	73	greyish white	undulate	velvety	irregular	black	flat	good
89	Baker abater H	79	white	undulate	velvety	regular	black	flat	good
90	Baker abater H	77	greyish white	entire	cottony	regular	dark brown	flat	good
91	Baker abater N	60	greyish white	undulate	cottony	irregular	light brown	raised	medium
92	Baker abater N	60	greyish white	undulate	cottony	regular	light brown	raised	medium
93	Baker abater N	60	white	undulate	cottony	regular	light brown	raised	medium
94	Baker abater N	70	white	undulate	cottony	regular	light brown	raised	medium
95	Baker abater N	65	white	undulate	cottony	regular	light brown	raised	medium
96	Baker abater N	70	white	undulate	spindle	irregular	light brown	flat	good
97	Baker abater N	70	grey	undulate	fluffy	regular	light brown	flat	good
98	Baker abater N	80	pinkish white	undulate	fluffy	regular	light brown	flat	good
99	Baker abater N	71	white	undulate	velvety	irregular	dark brown	raised	good
100	Baker abater L	90	grayish black	undulate	velvety	irregular	black	flat	good
101	Baker abater L	80	greyish white	undulate	velvety	irregular	black	flat	good
102	Baker abater L	70	grayish white	undulate	velvety	irregular	black	flat	good
103	Baker abater L	65	grayish black	undulate	cottony	irregular	black	flat	medium
104	Baker abater L	60	grayish black	undulate	velvety	irregular	black	flat	medium
105	Baker abater L	90	grey white	undulate	velvety	irregular	brown	flat	medium
106	Baker abater L	80	grey white	undulate	velvety	irregular	black	flat	good
107	Baker abater L	80	grey	entire	velvety	regular	black	flat	good
108	Baker abater L	70	grayish white	undulate	cottony	regular	dark brown	raised	good
109	Bata Berayeta H	77	white	undulate	cottony	regular	black	raised	medium
110	Bata Berayeta H	73	greyish white	undulate	cottony	regular	black	flat	poor
111	Bata Berayeta H	90	greyish white	undulate	fluffy	regular	dark brown	raised	poor
112	Bata Berayeta H	79	greyish white	undulate	cottony	regular	dark brown	raised	medium
113	Bata Berayeta H	82	greyish white	undulate	cottony	regular	dark brown	flat	medium
114	Bata Berayeta H	80	greyish white	undulate	cottony	regular	light brown	raised	good
115	Bata Berayeta N	78	greyish white	undulate	cottony	regular	light brown	raised	good
116	Bata Berayeta N	70	white	entire	cottony	regular	dark brown	raised	good
117	Bata Berayeta N	70	olive grey	entire	cottony	regular	dark brown	raised	good
118	Bata Berayeta N	80	greyish white	entire	cottony	regular	dark brown	flat	good

119	Bata Berayeta N	71	grey	entire	spindle	regular	dark brown	flat	good
120	Bata Berayeta N	60	grey	entire	spindle	regular	dark brown	flat	good
121	Chach H	70	grey	entire	cottony	regular	light brown	flat	medium
122	Chach H	69	pinkish white	undulate	cottony	irregular	light brown	flat	medium
123	Chach H	65	greyish white	undulate	cottony	irregular	light brown	flat	medium
124	Chach H	90	grey	undulate	cottony	irregular	dark brown	raised	good
125	Chach H	70	grey	entire	cottony	regular	light brown	raised	good
126	Chach H	80	greyish white	undulate	cottony	regular	dark brown	raised	good
127	Chach H	60	greyish white	undulate	cottony	regular	dark brown	flat	medium
128	Chach H	70	grey	undulate	fluffy	regular	light brown	flat	medium
129	Chach H	90	white	undulate	cottony	regular	light brown	raised	medium
130	Chach N	71	dark grey	undulate	fluffy	irregular	light brown	flat	medium
131	Chach N	78	grey	undulate	fluffy	irregular	dark brown	flat	medium
132	Chach N	82	white	entire	cottony	irregular	black	raised	good
133	Chach N	86	white	undulate	cottony	regular	light brown	raised	good
134	Chach N	86	white	undulate	velvety	irregular	light brown	raised	good
135	Chach N	78	greyish white	undulate	cottony	regular	light brown	raised	medium
136	Chach N	79	greyish white	undulate	cottony	regular	light brown	raised	good
137	Chach N	79	greyish white	undulate	cottony	regular	light brown	raised	good
138	Chach N	79	white	undulate	cottony	irregular	light brown	raised	good
139	Denbola H	73	olive grey	undulate	velvety	irregular	light brown	raised	good
140	Denbola H	81	greyish white	undulate	fluffy	irregular	light brown with pinkish center	raised	good
142	Denbola H	90	light grey	entire	cottony	regular	black	raised	good
143	Denbola H	70	light grey	entire	cottony	regular	black	raised	good
144	Denbola H	72	greyish white	entire	cottony	regular	light brown	raised	good
143	Denbola H	71	pale grey	undulate	cottony	regular	light brown	raised	good
146	Denbola H	90	greyish white	undulate	cottony	irregular	black	raised	good
147	Denbola H	72	white	entire	cottony	irregular	brown	flat	good
148	Denbola H	71	greyish white	undulate	cottony	irregular	dark brown	raised	good
149	Denbola N	90	greyish white	entire	velvety	irregular	black	flat	medium
150	Denbola N	71	grey white	undulate	cottony	irregular	black	raised	medium
151	Denbola N	70	grey	undulate	velvety	irregular	dark brown	flat	good
152	Denbola N	80	light grey	undulate	cottony	irregular	dark brown	raised	good
153	Denbola N	90	greyish white	undulate	cottony	irregular	dark brown	flat	medium
154	Denbola N	90	greyish white	undulate	cottony	irregular	light brown	raised	good
155	Denbola N	71	grey	undulate	fluffy	regular	dark brown	raised	good
156	Denbola N	64	greyish white	entire	cottony	regular	light brown	raised	good
157	Denbola N	70	olive grey with pinkish edge	undulate	fluffy	regular	black	flat	good
158	Denbola L	80	pinkish	undulate	velvety	regular	light brown	flat	good

159	Denbola L	60	greyish	entire	spindle	regular	light brown	flat	good
160	Denbola L	80	greyish	entire	fluffy	regular	black	flat	good
161	Denbola L	70	greyish	entire	fluffy	regular	light brown	flat	good
162	Denbola L	90	grayish white	entire	velvety	regular	light brown	flat	good
163	Denbola L	60	white	entire	cottony	regular	light brown	raised	medium
164	Denbola L	50	greyish white	undulate	fluffy	regular	pinkish	flat	medium
165	Denbola L	71	greyish white	entire	cottony	regular	black	raised	good
166	Denbola L	70	grey	undulate	fluffy	irregular	black	flat	medium
167	G/T/hyemanote H	90	greyish white	entire	velvety	regular	dark brown	flat	good
168	G/T/hyemanote H	65	pale grey	entire	cottony	regular	dark brown	flat	good
169	G/T/hyemanote H	60	white	entire	spindle	regular	dark brown	flat	good
170	G/T/hyemanote N	70	white	entire	spindle	regular	dark brown	flat	good
171	G/T/hyemanote N	70	pale grey	entire	spindle	regular	dark brown	flat	good
172	G/T/hyemanote N	68	grey	entire	spindle	regular	dark brown	flat	good
173	Guarhie H	77	greyish white	undulate	fluffy	regular	light brown	raised	good
174	Guarhie H	78	off white	undulate	fluffy	regular	light brown	raised	good
175	Guarhie H	77	white	undulate	fluffy	regular	black	raised	good
176	Guarhie N	72	white	undulate	cottony	regular	black	raised	good
177	Guarhie N	78	greyish white	undulate	fluffy	regular	light brown	raised	good
178	Guarhie N	70	white	undulate	cottony	irregular	light brown	raised	good
179	Gunderi H	72	white	undulate	fluffy	irregular	light brown	raised	medium
180	Gunderi H	74	dark grey	undulate	cottony	irregular	light brown	raised	medium
181	Gunderi H	73	grey	undulate	cottony	irregular	dark brown	raised	medium
182	Gunderi H	76	pale white	undulate	cottony	regular	dark brown	raised	medium
183	Gunderi H	75	grey	undulate	fluffy	regular	dark brown	flat	poor
184	Gunderi H	90	grey	undulate	cottony	regular	light brown	raised	poor
185	Gunderi N	71	grey	undulate	cottony	regular	dark brown	raised	medium
186	Gunderi N	70	greyish white	entire	cottony	regular	light brown	raised	good
187	Gunderi N	80	grey	undulate	spindle	regular	dark brown	flat	medium
188	Gunderi N	70	white	entire	cottony	regular	dark brown	raised	good
189	Gunderi N	57	white	entire	cottony	regular	dark brown	raised	medium
190	Gunderi N	65	white	entire	cottony	regular	light brown	raised	medium
191	Kunzla H	68	greyish white	undulate	cottony	irregular	dark brown	raised	good
192	Kunzla H	75	grey	undulate	cottony	irregular	light brown	raised	good
193	Kunzla H	70	pale grey	undulate	cottony	irregular	light brown	raised	good
194	Kunzla N	65	pinkish white	undulate	cottony	irregular	light brown	raised	good
195	Kunzla N	80	pinkish white	undulate	cottony	irregular	light brown	raised	good
196	Kunzla N	70	pale grey	undulate	cottony	irregular	dark brown	flat	medium
197	Kurabas H	90	pale white	undulate	cottony	regular	dark brown	raised	medium
198	Kurabas H	71	grey	undulate	cottony	regular	light brown	raised	medium
199	Kurabas H	70	grey	undulate	cottony	regular	dark brown	raised	medium

200	Kurabas N	73	pale grey	undulate	fluffy	irregular	light brown	flat	medium
201	Kurabas N	90	pinkish white	undulate	cottony	irregular	light brown	flat	good
202	Kurabas N	80	greyish white	entire	cottony	regular	light brown	flat	medium
203	Liben H	90	white	undulate	cottony	irregular	brown	flat	medium
204	Liben H	80	greyish	undulate	velvety	irregular	brown	flat	medium
205	Liben H	80	greyish white	undulate	cottony	irregular	light brown	flat	medium
206	Liben H	90	greyish white	undulate	cottony	irregular	black	flat	medium
207	Liben H	78	white	entire	cottony	regular	light brown	raised	good
208	Liben H	78	greyish white	undulate	fluffy	regular	dark brown	flat	good
209	Liben H	78	greyish white	undulate	fluffy	regular	dark brown	flat	good
210	Liben H	78	greyish white	undulate	fluffy	regular	dark brown	raised	medium
211	Liben H	78	greyish white	undulate	fluffy	regular	brown	flat	medium
212	Liben N	70	white	entire	velvety	regular	brown	flat	poor
213	Liben N	78	greyish white	undulate	fluffy	regular	brown	flat	good
214	Liben N	81	white	undulate	fluffy	irregular	dark brown	flat	good
215	Liben N	79	greyish white	undulate	fluffy	regular	dark brown	raised	good
216	Liben N	72	greyish white	undulate	fluffy	regular	dark brown	raised	medium
217	Liben N	75	white	undulate	fluffy	regular	dark brown	flat	medium
218	Liben N	60	greyish white	undulate	cottony	irregular	light brown	raised	medium
219	Liben N	70	white	undulate	cottony	irregular	light brown	raised	medium
220	Liben N	90	white	undulate	cottony	irregular	light brown	flat	medium
221	Liben L	70	white	undulate	cottony	irregular	light brown	flat	medium
222	Liben L	80	white	undulate	cottony	irregular	light brown	raised	poor
223	Liben L	70	white	undulate	cottony	irregular	light brown	flat	poor
224	Liben L	75	grayish white	undulate	cottony	irregular	light brown	flat	medium
225	Liben L	90	white	undulate	cottony	irregular	light brown	raised	medium
226	Liben L	60	grayish white	undulate	cottony	irregular	light brown	flat	poor
227	Liben L	71	pale grey	undulate	cottony	irregular	dark brown	flat	medium
228	Liben L	61	grayish white	undulate	velvety	irregular	black	flat	medium
229	Liben L	70	grayish white	undulate	velvety	irregular	dark brown	flat	medium
230	M/Abedgoma H	67	greyish white	undulate	cottony	regular	light brown	raised	poor
231	M/Abedgoma H	90	grayish white with pink end	entire	cottony	regular	black	flat	good
232	M/Abedgoma H	80	grayish white	undulate	cottony	regular	black, pale olive	flat	good
233	M/Abedgoma H	86	grayish white	entire	cottony	regular	black	flat	good
234	M/Abedgoma H	70	grayish white with pink end	entire	cottony	regular	brown	flat	good
235	M/Abedgoma H	85	grayish white	filamentous	velvety	irregular	black, pink brown	flat	medium
236	M/Abedgoma H	75	grayish white	entire	thick cottony	regular	black	flat	good
237	M/Abedgoma H	71	grayish white	entire	thick cottony	regular	black	raised	good

238	M/Abedgoma H	60	grayish white	entire	thick cottony	regular	brown black	raised	good
239	M/Abedgoma L	72	grayish white with pink end	entire	cottony velvety	regular	black	flat	good
240	M/Abedgoma L	71	grayish white with pink end	entire	velvety	regular	black, pale olive	flat	good
241	M/Abedgoma L	70	grayish white with pink end	entire	velvety	regular	black, pale olive	flat	good
242	M/Abedgoma L	70	grayish white	entire	cottony	regular	black, pale olive	raised	good
243	M/Abedgoma L	72	Gray	undulate	velvety	regular	dark brown	flat	good
244	M/Abedgoma L	71	white	undulate	velvety	regular	light brown	raised	good
245	M/Abedgoma L	71	white	undulate	cottony	regular	brown	raised	good
246	M/Abedgoma L	72	white	entire	cottony	regular	light brown	raised	medium
247	M/Abedgoma L	74	greyish white	undulate	cottony	regular	light brown	raised	medium
248	M/Abedgoma N	70	pinkish white	undulate	fluffy	regular	light brown	raised	good
249	M/Abedgoma N	82	grey	entire	fluffy	regular	light brown	raised	medium
250	M/Abedgoma N	70	greyish white	entire	cottony	regular	light brown	raised	poor
251	M/Abedgoma N	80	white	entire	cottony	regular	black	raised	medium
252	M/Abedgoma N	72	grey	undulate	velvety	irregular	black	flat	good
253	M/Abedgoma N	90	grey	entire	velvety	regular	light brown	flat	good
254	M/Abedgoma N	80	grey	undulate	cottony	regular	light brown	raised	good
255	M/Abedgoma N	88	greyish white	entire	velvety	irregular	pinkish	flat	good
256	M/Abedgoma N	80	grey	undulate	cottony	regular	light brown	raised	good
257	Mekonta H	77	greyish white	undulate	cottony	regular	light brown	raised	good
258	Mekonta H	78	white	undulate	cottony	regular	light brown	raised	good
259	Mekonta H	78	grey	undulate	fluffy	irregular	light brown	raised	medium
260	Mekonta H	74	dark grey	undulate	velvety	regular	dark brown	raised	medium
261	Mekonta H	79	greyish white	undulate	cottony	irregular	dark brown	raised	good
262	Mekonta H	81	greyish white	undulate	cottony	irregular	light brown	raised	good
263	Mekonta N	86	grayish white with pink end	entire	fluffy	regular	dark brown	raised	good
264	Mekonta N	90	grey	entire	fluffy	regular	dark brown	raised	medium
265	Mekonta N	77	greyish white	entire	fluffy	regular	black	raised	medium
266	Mekonta N	70	olive grey	entire	cottony	regular	dark brown	flat	good
267	Mekonta N	80	greyish white	undulate	spindle	irregular	light brown	flat	good
268	Mekonta N	75	pale grey	entire	velvety	regular	dark brown	flat	good
269	Narchecha H	90	white	undulate	velvety	irregular	light brown	flat	good
270	Narchecha H	74	greyish white	undulate	cottony	regular	dark brown	raised	good
271	Narchecha H	79	white	undulate	velvety	regular	light brown	raised	good
272	Narchecha N	82	white	undulate	cottony	regular	light brown	raised	good
273	Narchecha N	83	greyish white	undulate	velvety	irregular	light brown	flat	medium
274	Narchecha N	72	greyish white	undulate	cottony	irregular	dark brown	flat	medium

275	Sankisa H	80	White	undulate	cottony	regular	pink	raised	medium
276	Sankisa H	81	greyish white	undulate	fluffy	regular	pinkish	raised	good
277	Sankisa H	80	pale grey	undulate	cottony	irregular	dark brown	flat	medium
278	Sankisa N	73	olive grey	undulate	cottony	irregular	dark brown	flat	medium
279	Sankisa N	84	greyish white	undulate	fluffy	regular	pinkish	raised	good
280	Sankisa N	79	White	undulate	cottony	irregular	pink	raised	good
281	Sankera H	73	greyish white	undulate	fluffy	irregular	light brown	flat	medium
282	Sankera H	71	pinkish	entire	velvety	regular	pinkish	raised	good
283	Sankera H	70	black	entire	velvety	regular	yellow	convex	medium
284	Sankera H	70	pinkish	entire	cottony	regular	pinkish	raised	good
285	Sankera H	70	white	entire	cottony	regular	dark brown	flat	medium
286	Sankera H	80	greyish white	entire	spindle	regular	light brown	flat	medium
287	Sankera H	90	grey	entire	velvety	regular	light brown	flat	medium
288	Sankera H	90	greyish white	undulate	fluffy	irregular	dark brown	raised	good
289	Sankera H	85	grey	undulate	velvety	regular	black	flat	medium
290	Sankera L	70	greyish white	entire	fluffy	regular	yellow	flat	good
291	Sankera L	90	grey	undulate	velvety	irregular	dark brown	flat	poor
292	Sankera L	80	grey with pink	entire	velvety	regular	black	flat	good
293	Sankera L	80	greyish white	entire	velvety	regular	black	flat	good
294	Sankera L	75	greyish white	entire	fluffy	regular	light brown	raised	poor
295	Sankera L	56	greyish white	entire	fluffy	regular	light brown	raised	poor
296	Sankera L	70	pale grey	entire	cottony	irregular	dark brown	raised	medium
297	Sankera L	90	pale grey	entire	cottony	irregular	dark brown	raised	medium
298	Sankera L	67	dark grey	entire	cottony	regular	dark brown	raised	medium
299	Sankera N	70	pale grey	undulate	velvety	regular	dark brown	raised	medium
300	Sankera N	75	pale grey	entire	velvety	regular	brown	flat	good
301	Sankera N	70	pale grey	entire	cottony	regular	dark brown	raised	good
302	Sankera N	80	dark grey	entire	cottony	regular	dark brown	raised	good
303	Sankera N	90	greyish white	entire	velvety	regular	black	flat	good
304	Sankera N	90	white	undulate	cottony	irregular	brown	raised	good
305	Sankera N	80	greyish white	undulate	velvety	irregular	dark brown	flat	medium
306	Sankera N	80	white	undulate	velvety	regular	dark brown	flat	medium
307	Sankera N	70	white	undulate	velvety	regular	dark brown	flat	medium
308	Ysmala H	70	grey	entire	fluffy	regular	pinkish	raised	good
309	Ysmala H	71	greyish white	entire	cottony	irregular	brown	flat	medium
310	Ysmala H	70	white	entire	fluffy	regular	black	raised	good
311	Ysmala H	70	white	undulate	fluffy	irregular	black	flat	good
312	Ysmala H	90	white	undulate	fluffy	irregular	black	raised	medium
313	Ysmala H	65	white	undulate	fluffy	irregular	black	raised	good
314	Ysmala L	90	pale grey	undulate	cottony	irregular	black	flat	good
315	Ysmala L	90	pale grey	undulate	velvety	irregular	black	flat	good

316	Ysmala L	80	greyish white	undulate	cottony	irregular	brown	raised	good
317	Ysmala L	72	greyish white	entire	cottony	irregular	brown	raised	good
318	Ysmala L	90	pale grey	undulate	cottony	irregular	black	raised	good
319	Ysmala L	70	pale grey	undulate	cottony	irregular	dark brown	raised	medium
320	Ysmala N	70	greyish white	undulate	fluffy	irregular	black	raised	good
321	Ysmala N	65	grey	entire	cottony	regular	light brown	raised	medium
322	Ysmala N	70	grey	entire	cottony	regular	light brown	flat	medium
323	Ysmala N	80	grey	undulate	spindle	irregular	dark brown	flat	medium
324	Ysmala N	60	grey	entire	fluffy	regular	black	raised	good
325	Ysmala N	90	grey	entire	spindle	regular	black	flat	good
326	Zabatsion H	70	grey	undulate	fluffy	irregular	yellow	raised	medium
327	Zabatsion H	67	greyish white	undulate	velvety	regular	brown	raised	good
328	Zabatsion H	70	greyish white	entire	cottony	regular	light brown	raised	medium
329	Zabatsion H	75	grey white	undulate	cottony	regular	light brown	flat	good
330	Zabatsion H	90	greyish white with pink end	entire	velvety	regular	light brown	raised	good
331	Zabatsion H	90	white	undulate	cottony	regular	light brown	raised	good
332	Zabatsion H	80	white	entire	cottony	regular	light brown	flat	medium
333	Zabatsion H	72	greyish white	entire	velvety	regular	light brown	flat	good
334	Zabatsion H	70	black	entire	velvety	regular	light brown	flat	good
335	Zabatsion L	71	grey white	undulate	velvety	irregular	brown	flat	medium
336	Zabatsion L	71	grey white	entire	cottony	regular	black	raised	good
337	Zabatsion L	71	white	undulate	cottony	regular	brown	raised	good
338	Zabatsion L	90	greyish white	entire	cottony	regular	black	raised	good
339	Zabatsion L	80	greyish white	entire	cottony	regular	pinkish	raised	good
340	Zabatsion L	90	dark grey	entire	velvety	regular	light brown	raised	good
341	Zabatsion L	70	white grey	entire	velvety	regular	black	raised	good
342	Zabatsion L	75	black	undulate	velvety	irregular	yellow	raised	poor
343	Zabatsion L	70	greyish white	entire	cottony	regular	light brown	flat	medium
344	Zabatsion N	66	white	entire	fluffy	regular	light brown	flat	poor
345	Zabatsion N	90	grey white	entire	cottony	regular	pink	flat	medium
346	Zabatsion N	70	grey white	undulate	velvety	regular	white brown	raised	medium
347	Zabatsion N	90	off white	entire	thick cottony	irregular	black	raised	good
348	Zabatsion N	68	grayish white	entire	velvety	regular	brown	flat	medium
349	Zabatsion N	80	light grey	entire	velvety	regular	brown	flat	medium
350	Zabatsion N	70	grey white	entire	cottony	regular	brown	raised	excellent
351	Zabatsion N	69	grey white	entire	velvety	regular	black	raised	good
352	Zabatsion N	90	white	undulate	cottony	irregular	brown	raised	good
353	Z/K/meheret H	68	white	entire	cottony	regular	light brown	raised	medium
354	Z/K/meheret H	80	white	entire	cottony	regular	light brown	raised	good
355	Z/K/meheret H	67	white	entire	fluffy	regular	dark brown	raised	good

356	Z/K/meheret H	60	greyish white	entire	velvety	regular	dark brown	raised	medium
357	Z/K/meheret H	70	white	entire	cottony	regular	dark brown	flat	medium
358	Z/K/meheret H	60	white	entire	cottony	regular	dark brown	flat	medium
359	Z/K/meheret N	90	grey	entire	velvety	regular	dark brown	raised	good
360	Z/K/meheret N	90	greyish white	entire	cottony	regular	light brown	flat	good
361	Z/K/meheret N	69	white	entire	fluffy	regular	light brown	flat	medium
362	Z/K/meheret N	90	greyish white	entire	spindle	regular	light brown	flat	good
363	Z/K/meheret N	80	greyish white	entire	fluffy	regular	dark brown	flat	good
364	Z/K/meheret N	70	grey	entire	spindle	regular	dark brown	flat	good
365	Zenzelema H	71	greyish white	undulate	fluffy	regular	pinkish with	raised	good
366	Zenzelema H	71	white	undulate	fluffy	irregular	light brown	flat	poor
367	Zenzelema H	77	white	undulate	cottony	regular	dark brown	raised	good
368	Zenzelema H	80	creamy white	undulate	fluffy	irregular	dark brown	flat	poor
369	Zenzelema H	71	white	undulate	cottony	irregular	light brown	raised	good
370	Zenzelema H	72	pale white	undulate	cottony	irregular	light brown	raised	good
371	Zenzelema N	90	olive grey	entire	cottony	regular	light brown	raised	medium
372	Zenzelema N	80	greyish white	entire	cottony	regular	light brown	raised	medium
373	Zenzelema N	70	dark grey	entire	cottony	regular	light brown	raised	medium
374	Zenzelema N	70	pale grey	entire	cottony	regular	light brown	raised	medium
375	Zenzelema N	83	white	undulate	cottony	regular	dark brown	raised	medium
376	Zenzelema N	70	grey	undulate	fluffy	regular	light brown	flat	medium

Note: A/ zeguaye= Abasem zeguaye, G/T/ hyemanote= Gerarege Teklehayemanote, M/Abedgoma- Mankussa Abedgoma, Z/ K/Meheret- Zeguda Kidanemeheret, H- head, L- Leaf, N- Neck

Appendix Table 3.3 Evaluation of culture media for the mycelial growth of *M. grisea* isolates

S. no	Isolate	Colony Diameter (mm) at different growth media				Mean $\pm$ SD
		OMA	HSA	PDA	Richard's Agar	
1	Mg109	80.00 ^{a-d} $\pm$ 2.00	77.67 ^{a-e} $\pm$ 2.52	74.00 ^{ab} $\pm$ 7.55	78.33 ^{abc} $\pm$ 4.89	77.75 $\pm$ 3.14
2	Mg116	85.00 ^a $\pm$ 2.49	72.33 ^{def} $\pm$ 2.52	75.33 ^{ab} $\pm$ 2.52	68.33 ^{ef} $\pm$ 5.59	74.08 $\pm$ 1.34
3	Mg121	83.67 ^{ab} $\pm$ 5.00	85.00 ^{fg} $\pm$ 4.36	67.00 ^{ab} $\pm$ 3.51	79.33 ^{ab} $\pm$ 8.84	78.83 $\pm$ 8.26
4	Mg140	79.67 ^{bcd} $\pm$ 2.44	69.67 ^{efg} $\pm$ 1.53	70.00 ^{ab} $\pm$ 2.00	67.67 ^d $\pm$ 3.06	70.92 $\pm$ 1.27
5	Mg15	79.00 ^{a-d} $\pm$ 1.73	86.67 ^a $\pm$ 1.53	67.67 ^{ab} $\pm$ 9.29	74.33 ^{cd} $\pm$ 9.56	78.50 $\pm$ 8.09
6	Mg16	79.00 ^{a-d} $\pm$ 3.61	73.00 ^{c-f} $\pm$ 4.36	76.33 ^{ab} $\pm$ 3.21	75.67 ^{bc} $\pm$ 4.17	76.67 $\pm$ 2.79
7	Mg38	82.67 ^{abc} $\pm$ 2.52	74.33 ^{c-f} $\pm$ 6.03	69.00 ^{ab} $\pm$ 5.29	73.33 ^{cd} $\pm$ 7.29	75.75 $\pm$ 5.72
8	Mg39	78.67 ^{cd} $\pm$ 5.24	74.33 ^{c-f} $\pm$ 2.08	66.00 ^b $\pm$ 3.61	70.67 ^{bcd} $\pm$ 3.21	72.33 $\pm$ 4.13
9	Mg147	82.00 ^{a-d} $\pm$ 2.00	71.00 ^{d-g} $\pm$ 3.61	76.00 ^{ab} $\pm$ 5.29	73.33 ^{cd} $\pm$ 5.83	76.33 $\pm$ 4.79
10	Mg5	80.67 ^{a-d} $\pm$ 6.03	85.00 ^{ab} $\pm$ 2.00	66.33 ^b $\pm$ 5.13	72.00 ^d $\pm$ 9.39	78.08 $\pm$ 8.47
11	Mg68	86.33 ^a $\pm$ 2.08	71.33 ^{d-g} $\pm$ 4.16	66.67 ^{ab} $\pm$ 4.73	68.67 ^{ef} $\pm$ 9.49	77.00 $\pm$ 8.85
12	Mg70	79.67 ^{a-d} $\pm$ 2.31	75.67 ^{b-f} $\pm$ 4.04	68.67 ^{ab} $\pm$ 4.04	73.67 ^{bcd} $\pm$ 5.41	74.83 $\pm$ 4.43
13	Mg75	80.67 ^{a-d} $\pm$ 4.04	62.33 ^g $\pm$ 2.51	73.33 ^{ab} $\pm$ 4.73	71.33 ^{de} $\pm$ 8.67	72.33 $\pm$ 7.60
14	Mg8	84.67 ^{ab} $\pm$ 5.03	82.33 ^{abc} $\pm$ 1.53	80.33 ^a $\pm$ 4.51	75.67 ^{bc} $\pm$ 3.94	82.67 $\pm$ 2.01
15	Mg83	81.00 ^{a-d} $\pm$ 1.00	70.00 ^{efg} $\pm$ 2.00	68.33 ^{ab} $\pm$ 1.53	77.33 ^{abc} $\pm$ 6.11	74.75 $\pm$ 6.07
16	Mg96	80.67 ^{a-d} $\pm$ 2.08	72.33 ^{def} $\pm$ 2.52	73.00 ^{ab} $\pm$ 2.00	78.67 ^{abc} $\pm$ 4.44	76.67 $\pm$ 4.10
17	Mg99	82.00 ^{a-d} $\pm$ 2.00	77.67 ^{a-e} $\pm$ 2.52	70.00 ^{ab} $\pm$ 2.00	70.00 ^{cd} $\pm$ 2.00	77.58 $\pm$ 4.96
18	Mg27	87.67 ^a $\pm$ 2.08	80.00 ^{a-d} $\pm$ 2.00	70.67 ^{ab} $\pm$ 3.06	70.00 ^{de} $\pm$ 7.67	80.67 $\pm$ 7.10
19	Mg149	87.33 ^a $\pm$ 2.52	82.00 ^{abc} $\pm$ 2.00	69.67 ^{ab} $\pm$ 1.53	71.33 ^f $\pm$ 8.05	81.50 $\pm$ 7.76
Mean $\pm$ SD		81.02 $\pm$ 2.86	75.93 $\pm$ 2.83	70.96 $\pm$ 3.98	73.14 $\pm$ 6.29	78.91 $\pm$ 5.33

Each value is an average of three replicates $\pm$ standard deviation. Values in bold were compared within their respective column and row. Data followed by the same letters across the row are not significantly different ($p < 0.05$) according to Duncan multiple range test, Alpha=0.05, CV= 6.76%.

Appendix Table 3.4 Effect of temperature on mycelial growth of *M. grisea* isolates

		Colony mean diameter (mm)						
		Temperature (°C)						
No	Isolates	15	20	25	30	35	40	Mean ±SD
1	Mg109	47.67 ^{bc} ±4.51	56.00 ^{abc} ±4.00	75.25 ^a ±17.69	72.67 ^{ab} ±3.06	45.00 ^c ±9.89	7.00 ^d ±3.00	52.28±25.28
2	Mg116	41.33 ^c ±1.53	55.00 ^{bc} ±5.00	73.00 ^{ab} ±17.38	83.00 ^a ±3.00	52.50 ^{bc} ±3.54	8.00 ^d ±2.00	53.28±26.34
3	Mg121	48.33 ^a ±2.89	58.33 ^a ±1.53	68.00 ^a ±14.35	69.67 ^a ±6.43	52.50 ^a ±3.54	11.00 ^b ±2.00	52.17±21.58
4	Mg140	39.33 ^b ±5.51	57.00 ^{ab} ±3.00	58.75 ^{ab} ±18.59	71.67 ^a ±2.08	35.00 ^b ±1.42	4.33 ^c ±1.53	45.67±23.89
5	Mg15	38.00 ^b ±5.29	53.67 ^{ab} ±1.53	73.68 ^a ±22.50	80.83 ^a ±3.25	32.50 ^b ±3.54	0.00 ^c ±0.00	48.73±29.96
6	Mg16	38.00 ^c ±3.46	57.00 ^{ab} ±4.58	70.75 ^{ab} ±23.92	84.33 ^a ±4.04	50.00 ^{ab} ±0.00	6.00 ^b ±2.00	52.17±28.06
7	Mg38	29.33 ^{cd} ±6.11	54.00 ^{abc} ±2.00	63.00 ^{ab} ±20.02	73.00 ^a ±8.19	36.50 ^{bcd} ±6.36	6.33 ^d ±0.58	45.17±25.11
8	Mg39	32.33 ^c ±7.51	52.67 ^b ±2.52	57.25 ^b ±6.70	73.50 ^a ±1.50	42.50 ^{bc} ±16.61	0.00 ^d ±0.00	43.86±24.42
9	Mg147	25.67 ^d ±3.22	52.67 ^{bc} ±5.03	68.50 ^{ab} ±11.96	72.67 ^a ±2.52	48.50 ^c ±2.12	10.00 ^d ±2.00	47.44±24.16
10	Mg5	40.67 ^b ±1.54	50.00 ^{ab} ±4.00	67.50 ^a ±17.02	74.00 ^a ±7.94	33.00 ^b ±7.07	0.00 ^c ±0.00	46.11±26.68
11	Mg68	41.67 ^{ab} ±2.89	59.00 ^a ±3.61	67.25 ^a ±28.20	71.33 ^a ±2.31	37.50 ^{ab} ±3.54	6.50 ^b ±1.32	48.86±25.93
12	Mg70	40.00 ^c ±5.29	40.00 ^c ±5.00	59.25 ^{ab} ±9.54	72.33 ^a ±6.81	50.00 ^{bc} ±7.07	10.50 ^d ±2.29	45.86±20.78
13	Mg75	38.33 ^{bc} ±7.64	49.00 ^{abc} ±3.61	66.50 ^{ab} ±21.02	72.33 ^a ±6.81	32.50 ^c ±3.54	0.00 ^d ±0.00	45.00±28.82
14	Mg8	25.00 ^d ±5.00	57.67 ^{bc} ±2.52	71.75 ^{ab} ±12.15	85.00 ^a ±5.00	45.00 ^c ±0.00	10.33 ^d ±0.76	50.61±27.59
15	Mg83	30.00 ^{cd} ±5.00	60.00 ^{abc} ±5.00	67.00 ^{ab} ±19.13	77.83 ^a ±9.57	37.50 ^{bcd} ±3.54	10.73 ^d ±1.55	48.82±25.77
16	Mg96	41.33 ^c ±2.52	60.33 ^{ab} ±2.52	59.50 ^{ab} ±9.98	72.67 ^a ±3.06	49.50 ^{bc} ±3.54	9.00 ^d ±2.00	49.28±21.48
17	Mg99	25.00 ^{cd} ±5.00	49.00 ^{abc} ±1.00	68.00 ^{ab} ±23.08	75.33 ^a ±4.51	36.50 ^{bcd} ±9.19	13.17 ^d ±2.02	46.25±25.51
18	Mg27	38.33 ^c ±5.51	46.67 ^{bc} ±2.52	68.75 ^{ab} ±16.54	76.00 ^a ±5.20	51.00 ^{abc} ±4.24	11.67 ^d ±1.53	49.72±23.33
19	Mg149	44.33 ^c ±5.13	43.33 ^c ±3.51	76.75 ^a ±21.27	66.00 ^{ab} ±3.61	52.50 ^{ab} ±3.54	11.50 ^d ±1.50	50.42±24.00
Mean ±SD		37.09±4.50	53.23±3.29	67.39±17.42	74.96±4.68	43.16±4.86	7.16±1.37	47.16±22.89

Observation on mean colony diameter was recorded ten days after incubation

Means with the same letters across the row are not significantly different. NG- no growth, Alpha=0.05. CV%=48.54%

Appendix Table 3.5 Effect of different pH values on dry mycelial weight of *M. grisea* isolates

Dry mycelial growth(mg)										
pH	Mg109	Mg116	Mg121	Mg140	Mg15	Mg16	Mg38	Mg39	Mg147	Mg5
4	170.00 ^{de} ±3.5	230.33 ^b ±6.03	203.33 ^c ±3.06	168.67 ^d ±1.53	153.00 ^{ef} ±3.61	156.67 ^{fg} ±6.03	230.00 ^b ±6.00	171.67 ^{de} ±4.00	130.33 ^{fg} ±2.52	150.67 ^d ±5.13
4.5	179.67 ^d ±2.0	249.33 ^c ±6.03	210.00 ^c ±7.37	180.00 ^e ±3.06	150.67 ^{ef} ±6.4	260.00 ^a ±4.00	227.33 ^d ±3.51	183.33 ^d ±10.00	171.33 ^e ±5.03	214.00 ^c ±4.00
5	250.00 ^b ±4.04	205.00 ^c ±63.27	277.00 ^c ±3.06	182.67 ^d ±2.52	240.00 ^b ±6.11	279.33 ^d ±2.00	338.33 ^a ±3.61	342.67 ^b ±3.06	236.00 ^c ±2.52	260.00 ^a ±4.00
5.5	389.67 ^b ±3.51	270.00 ^a ±9.45	291.67 ^c ±3.61	242.67 ^b ±3.06	359.00 ^b ±3.06	289.33 ^d ±2.08	349.33 ^a ±12.58	249.33 ^b ±5.03	263.67 ^c ±2.52	260.00 ^a ±2.00
6	512.33 ^a ±8.74	224.00 ^{bc} ±9.71	320.67 ^b ±3.06	246.00 ^b ±3.06	290.00 ^b ±7.07	362.00 ^a ±2.00	392.00 ^a ±2.00	362.33 ^a ±2.52	231.67 ^{cd} ±4.51	264.00 ^a ±4.00
6.5	407.33 ^b ±2.52	253.00 ^c ±3.61	342.33 ^a ±2.52	306.67 ^a ±3.06	463.33 ^a ±3.51	354.00 ^b ±4.00	333.33 ^a ±2.00	324.00 ^c ±6.00	297.67 ^a ±6.81	325.00 ^b ±5.00
7	355.00 ^c ±1.53	251.00 ^c ±4.58	254.00 ^d ±2.08	242.33 ^b ±6.11	288.67 ^b ±1.16	288.67 ^b ±4.16	266.67 ^{bc} ±10.0	290.67 ^a ±5.03	206.33 ^d ±6.03	225.00 ^c ±5.00
7.5	150.67 ^{fg} ±4.16	193.00 ^d ±9.02	154.00 ^f ±3.06	202.00 ^c ±2.00	262.33 ^{bc} ±9.42	133.33 ^{fg} ±6.11	247.00 ^{cd} ±3.06	235.33 ^{bc} ±5.03	181.00 ^c ±3.06	220.00 ^c ±3.06
8	146.67 ^{fg} ±4.04	184.33 ^d ±5.69	151.67 ^f ±1.53	182.67 ^{cd} ±2.00	255.67 ^{bc} ±3.51	118.00 ^{gh} ±6.43	227.33 ^d ±6.00	220.00 ^c ±5.29	177.33 ^{ef} ±9.87	213.33 ^c ±10.00
8.5	126.66 ^{hi} ±3.51	157.00 ^e ±5.00	211.67 ^c ±7.37	159.67 ^c ±12.89	189.67 ^{de} ±9.45	117.33 ^{gh} ±3.51	193.33 ^a ±6.51	171.67 ^{de} ±11.02	149.33 ^b ±4.00	156.67 ^d ±15.28
9	158.67 ^{ef} ±3.51	141.67 ^c ±7.64	106.00 ^a ±6.56	149.33 ^{ef} ±2.51	167.00 ^{ef} ±3.61	110.67 ^h ±8.33	187.33 ^a ±11.37	151.33 ^c ±1.53	144.00 ^a ±6.00	156.67 ^d ±8.50
9.5	139.67 ^{gh} ±3.51	120.00 ^f ±10.00	107.33 ^a ±7.64	133.33 ^f ±3.06	124.00 ^a ±4.00	100.67 ^h ±8.33	110.00 ^f ±2.00	120.67 ^f ±3.61	142.67 ^a ±5.29	156.67 ^d ±30.55
10	116.00 ⁱ ±3.61	98.33 ^a ±7.64	106.67 ^a ±10.7	195.67 ^c ±6.11	120.33 ^b ±10.0	55.67 ⁱ ±5.13	97.33 ^f ±11.68	80.00 ^a ±10.00	103.33 ^b ±4.16	63.33 ^c ±15.28
Mean ±SD	238.64±3.71	226.31±5.68	210.49±4.75	199.36±3.92	222.28±5.39	178.51±5.18	238.25±6.80	200.05±6.41	227.15±4.50	205.03±7.29

Dry mycelial growth(mg)									
pH	Mg68	Mg70	Mg75	Mg8	Mg83	Mg96	Mg99	Mg27	Mg149
4	270.00 ^a ±20.00j	186.67 ^{de} ±8.33	220.00 ^d ±10.82	180.00 ^g ±3.51	175.00 ^f ±9.17	205.00 ^{ef} ±5.39	185.00 ^f ±11.24	160.00 ^h ±5.11	215.00 ^e ±3.15
4.5	280.00 ^{cd} ±4.00	200.67 ^{de} ±6.11	234.33 ^{de} ±6.67	189.33 ^{fg} ±2.52	184.00 ^{ef} ±6.03	211.33 ^{de} ±10.26	189.00 ^f ±4.58	161.67 ^h ±2.08	229.33 ^c ±1.15
5	306.67 ^{bc} ±20.00	241.33 ^c ±15.28	254.33 ^d ±8.54	200.00 ^d ±7.55	300.00 ^c ±6.11	220.33 ^d ±2.52	310.33 ^c ±9.61	201.67 ^a ±12.58	274.67 ^d ±1.53
5.5	311.33 ^{bc} ±5.77	275.00 ^a ±8.33	230.00 ^e ±6.66	241.33 ^d ±1.53	403.67 ^b ±13.5	271.00 ^b ±10.15	300.00 ^c ±1.53	261.67 ^d ±2.08	316.67 ^c ±4.16
6	346.67 ^b ±5.77	385.00 ^a ±4.58	284.00 ^c ±4.00	266.00 ^c ±6.56	469.67 ^a ±8.50	327.00 ^a ±6.65	356.00 ^b ±7.21	472.67 ^a ±2.52	470.00 ^b ±3.00
6.5	460.67 ^a ±9.02	329.33 ^b ±9.02	455.00 ^a ±6.25	402.00 ^a ±9.17	384.33 ^b ±10.0	320.67 ^a ±3.06	410.00 ^a ±3.00	461.67 ^a ±1.53	490.00 ^a ±3.00
7	261.33 ^d ±18.58	323.33 ^b ±11.02	364.00 ^b ±6.56	293.33 ^b ±3.51	246.67 ^d ±2.52	288.33 ^b ±2.89	221.33 ^e ±10.58	255.33 ^c ±5.03	366.33 ^b ±4.04
7.5	256.00 ^{de} ±10.58	213.67 ^{cd} ±8.74	218.00 ^e ±10.82	211.33 ^{ef} ±4.04	170.00 ^{fg} ±9.29	214.33 ^{de} ±4.04	187.67 ^f ±11.24	197.33 ^b ±3.06	254.67 ^f ±8.08
8	214.00 ^{ef} ±3.06	201.67 ^{de} ±7.64	193.00 ^f ±7.55	217.33 ^{de} ±2.00	157.00 ^g ±9.17	182.00 ^g ±7.21	175.00 ^g ±5.00	193.00 ^b ±6.56	251.33 ^{fg} ±4.16
8.5	214.67 ^{ef} ±3.06	204.67 ^d ±9.17	183.00 ^{fg} ±7.55	194.33 ^{ef} ±8.62	153.33 ^{gh} ±3.00	175.00 ^g ±4.58	166.00 ^h ±3.61	163.33 ⁱ ±6.11	201.67 ^g ±9.71
9	189.00 ^f ±20.07	172.67 ^e ±12.00	167.67 ^{gh} ±2.52	115.33 ^h ±5.03	132.00 ^{hi} ±6.11	139.33 ^h ±3.06	135.33 ⁱ ±4.16	153.33 ⁱ ±6.11	159.67 ^g ±6.03
9.5	173.33 ^{fg} ±6.11	172.00 ^e ±6.43	157.00 ^h ±3.00	101.33 ⁱ ±3.21	199.67 ^e ±4.36	134.67 ^h ±6.11	118.00 ⁱ ±2.00	115.67 ^j ±12.50	151.33 ^h ±7.78
10	140.00 ^g ±20.00	133.33 ^f ±6.11	173.33 ^{gh} ±6.11	193.00 ^{fg} ±7.55	113.67 ⁱ ±5.69	112.33 ⁱ ±16.62	118.00 ⁱ ±6.25	108.33 ^k ±4.16	122.67 ⁱ ±7.51
Mean ±SD	269.56±8.77	233.80±8.67	241.05±6.70	215.74±4.98	237.62±7.19	215.49±5.96	220.90±6.15	223.51±5.34	295.95±5.33

Means with the same letters are not significantly different. Alpha = 0.05, CV%= 36.77%

Appendix Table 3.6 Effect of carbon sources on mycelial growth of *M. grisea* isolates

S.no	Isolate	Diameter (mm)				
		Dextrose	Maltose	D-fructose	Sucrose	Mean $\pm$ SD
1	Mg109	80.67 ^a $\pm$ 4.04	45.00 ^c $\pm$ 10.00	36.00 ^d $\pm$ 5.29	55.33 ^b $\pm$ 0.58	54.25 $\pm$ 18.19
2	Mg116	65.00 ^a $\pm$ 2.00	45.00 ^{bc} $\pm$ 5.00	52.33 ^{ab} $\pm$ 7.51	34.33 ^d $\pm$ 5.13	49.17 $\pm$ 12.49
3	Mg121	71.67 ^a $\pm$ 1.53	45.00 ^{bc} $\pm$ 5.00	46.33 ^b $\pm$ 6.51	36.00 ^d $\pm$ 5.29	49.75 $\pm$ 14.48
4	Mg140	71.67 ^a $\pm$ 7.64	53.33 ^c $\pm$ 15.28	43.33 ^c $\pm$ 10.41	56.67 ^a $\pm$ 20.82	56.25 $\pm$ 16.26
5	Mg15	63.33 ^a $\pm$ 7.64	40.33 ^c $\pm$ 0.58	48.00 ^{ab} $\pm$ 2.00	47.67 ^b $\pm$ 12.50	49.83 $\pm$ 10.79
6	Mg16	66.00 ^a $\pm$ 5.29	53.67 ^b $\pm$ 4.16	45.33 ^c $\pm$ 5.03	35.33 ^d $\pm$ 5.03	50.08 $\pm$ 12.47
7	Mg38	71.67 ^a $\pm$ 10.41	51.67 ^b $\pm$ 16.07	50.00 ^{bc} $\pm$ 13.23	55.00 ^{ab} $\pm$ 22.91	57.08 $\pm$ 16.58
8	Mg39	74.33 ^a $\pm$ 1.15	51.67 ^b $\pm$ 7.64	46.33 ^c $\pm$ 1.16	37.67 ^d $\pm$ 7.51	52.50 $\pm$ 14.89
9	Mg147	75.00 ^a $\pm$ 8.66	55.00 ^b $\pm$ 15.00	43.33 ^c $\pm$ 10.41	54.67 ^b $\pm$ 23.35	57.00 $\pm$ 17.76
10	Mg5	73.33 ^a $\pm$ 15.28	50.00 ^b $\pm$ 13.23	41.67 ^b $\pm$ 12.58	53.33 ^b $\pm$ 25.17	54.58 $\pm$ 19.12
11	Mg68	71.66 ^a $\pm$ 7.64	35.00 ^c $\pm$ 5.00	27.33 ^d $\pm$ 2.52	43.67 ^b $\pm$ 6.51	44.42 $\pm$ 18.18
12	Mg70	74.33 ^a $\pm$ 8.14	50.00 ^b $\pm$ 10.00	35.67 ^c $\pm$ 5.13	45.33 ^{bc} $\pm$ 10.02	51.33 $\pm$ 16.58
13	Mg75	78.33 ^a $\pm$ 2.52	50.00 ^{bc} $\pm$ 5.00	55.00 ^{ab} $\pm$ 10.00	47.67 ^{bc} $\pm$ 2.52	57.75 $\pm$ 13.67
14	Mg8	65.00 ^b $\pm$ 5.00	52.33 ^b $\pm$ 2.50	35.33 ^d $\pm$ 5.03	50.67 ^{bc} $\pm$ 10.07	50.83 $\pm$ 12.23
15	Mg83	72.33 ^a $\pm$ 5.51	39.33 ^{bc} $\pm$ 4.04	35.00 ^c $\pm$ 5.00	35.33 ^d $\pm$ 5.03	45.50 $\pm$ 16.81
16	Mg96	67.33 ^b $\pm$ 2.52	50.00 ^b $\pm$ 10.00	55.00 ^a $\pm$ 15.00	40.67 ^c $\pm$ 10.07	53.25 $\pm$ 13.40
17	Mg99	81.67 ^a $\pm$ 4.51	60.00 ^b $\pm$ 10.00	56.00 ^{bc} $\pm$ 3.61	42.67 ^c $\pm$ 12.50	60.08 $\pm$ 16.34
18	Mg27	75.00 ^a $\pm$ 8.66	56.67 ^b $\pm$ 15.28	46.67 ^c $\pm$ 11.55	41.67 ^d $\pm$ 7.64	55.00 $\pm$ 16.38
19	Mg149	71.00 ^a $\pm$ 1.73	52.33 ^b $\pm$ 1.15	40.67 ^c $\pm$ 5.51	44.33 ^d $\pm$ 5.13	52.08 $\pm$ 12.67
Mean $\pm$ SD		71.12 $\pm$ 5.99	49.06 $\pm$ 7.79	44.35 $\pm$ 7.58	49.94 $\pm$ 8.25	53.87 $\pm$ 7.93

Values with the same letters across the row are not significantly different, Alpha=0.05. CV= 14.71% different

Appendix Table 3.7 Effect of nitrogen sources on mycelial growth of *M. grisea* isolates

S.no	Isolate	Diameter (mm)					
		KNO ₃	NaNO ₃	Peptone	L-arginine	L-glycine	Mean ± SD
1	Mg109	50.00 ^{ab} ±5.00	61.00 ^a ±5.29	50.00 ^{ab} ±4.50	55.00 ^{ab} ± 5.20	40.67 ^b ±5.13	50.56±9.88
2	Mg116	42.67 ^b ±2.52	60.33 ^a ±2.52	45.00 ^{ab} ±4.20	53.00 ^a ± 5.50	45.67 ^b ±5.13	49.56±8.76
3	Mg121	32.67 ^c ±2.52	55.33 ^a ±5.03	47.50 ^{ab} ±5.10	54.00 ^a ± 5.10	45.33 ^b ±5.03	44.44±10.54
4	Mg140	45.00 ^c ±8.67	60.00 ^a ±10.00	48.50 ^{bc} ±4.80	56.00 ^{ab} ± 4.90	56.67 ^{ab} ±15.28	53.89±12.19
5	Mg15	43.33 ^b ±7.64	63.00 ^a ±2.65	46.00 ^b ± 5.00	54.00 ^a ± 5.30	34.67 ^b ±5.03	47.00±13.44
6	Mg16	44.67 ^b ±5.03	69.00 ^a ±4.00	47.00 ^b ± 4.70	55.00 ^{ab} ± 5.10	47.67 ^b ±2.52	53.78±11.99
7	Mg38	38.00 ^b ±14.73	61.67 ^a ±12.58	49.50 ^{ab} ±5.20	57.00 ^a ± 5.40	38.33 ^b ±14.43	46.00±16.83
8	Mg39	39.33 ^c ±8.14	66.67 ^a ±12.58	48.00 ^{bc} ±4.90	56.00 ^{ab} ± 5.00	54.00 ^{ab} ±1.73	53.33±14.04
9	Mg147	41.67 ^b ±16.26	61.67 ^a ±7.64	49.00 ^{ab} ±4.80	56.00 ^{ab} ± 5.20	40.67 ^b ±14.01	48.00±15.33
10	Mg5	43.00 ^b ±12.12	60.00 ^a ±10.00	47.00 ^b ± 4.60	55.00 ^{ab} ± 5.00	55.00 ^{ab} ±5.00	52.67±11.19
11	Mg68	35.33 ^c ±5.03	68.00 ^a ±10.39	47.50 ^b ± 4.80	56.00 ^{ab} ± 4.90	52.67 ^b ±7.51	52.00±15.74
12	Mg70	49.33 ^b ±10.07	59.33 ^a ±3.06	48.00 ^b ± 4.90	55.50 ^{ab} ± 5.30	60.00 ^a ±10.00	56.22±8.91
13	Mg75	35.33 ^c ±5.03	60.00 ^a ±6.25	47.00 ^b ± 4.70	54.50 ^a ± 5.00	41.33 ^b ±10.26	45.56±12.90
14	Mg8	45.00 ^c ±5.00	61.67 ^a ±2.89	47.50 ^{bc} ±4.80	55.00 ^b ± 4.90	55.00 ^b ±5.00	53.89±8.21
15	Mg83	45.33 ^b ±5.03	70.67 ^a ±5.13	47.50 ^b ± 5.00	55.00 ^{ab} ± 5.10	34.67 ^c ±5.03	50.22±16.60
16	Mg96	40.67 ^c ±10.07	67.00 ^a ±11.53	47.50 ^{bc} ± 4.90	55.00 ^b ± 5.30	45.67 ^b ±15.04	51.11±16.18
17	Mg99	52.00 ^b ±2.00	75.67 ^a ±1.16	49.00 ^c ± 5.10	71.67 ^a ±7.64	56.00 ^b ± 5.40	66.64±11.67
18	Mg27	42.67 ^b ±11.24	60.00 ^a ±13.23	48.00 ^b ± 5.20	55.50 ^a ± 5.30	56.67 ^a ±20.82	53.11±15.72
19	Mg149	53.67 ^b ±5.51	56.00 ^a ±5.29	48.50 ^{bc} ±4.90	60.00 ^b ±5.00	56.00 ^{ab} ±5.10	56.56±5.34
Mean ± SD		43.14 ± 5.6	60.40 ± 9.17	47.79 ± 1.18	55.24 ± 0.93	51.88 ± 10.02	51.82 ± 12.79

Values with the same letters across the row are not significantly different. Alpha=0.05, CV=24.29%.

Appendix Table 3.8 Percentage of disease incidence and severity for pathogenicity test on Boneya susceptible finger millet variety inoculated with six *M. grisea* isolates

Isolates	Incidence	Severity
Mg83	80.33 ^a ±5.77	24.45 ^a ±4.21
Mg38	70.00 ^b ±5.77	15.92 ^{cd} ±2.06
Mg68	66.67 ^{bc} ±11.55	22.97 ^{ab} ±3.16
Mg15	63.33 ^c ±3.33	21.85 ^{ab} ±1.33
Mg39	53.33 ^{cd} ±8.82	18.52 ^{bc} ±3.23
Mg99	46.67 ^{de} ±12.02	12.22 ^{de} ±6.12
Mg96	10.00 ^f ±10.00	3.70 ^f ±3.70
Control	0.00 ^f ±0.00	0.00 ^g ±0.01
Mean ± SD	48.75±29.68	14.95±9.98

Appendix Table 4.1. Questionnaire used for interviewing famers during the surveys

Introductory and consent statement:

“Dear Sir/Madam, I am a Student at Bahir Dar University. I am conducting a research survey to study farmers’ knowledge and their management practices of finger millet blast disease in your district. Your response to these questions would remain **anonymous**. Taking part in this study is voluntary. If you choose not to take part, you have the right not to participate and there will be no consequences. Do you and your family consent to provide information? 1=yes, 0=No. Thank you for your kind co-operation”.

A: Geographical location

Region _____ District _____ Area _____ Village _____

B: Topography of the Area

Longitude _____ Latitude _____ Altitude _____

C: Farmers information

- i. Name of the respondent _____ Age _____ years
- ii. Sex _____ (1= Male 2= Female)
- iii. What is your Martial status? (1=Single or Never married, 2=Married, 3=Widow/widowed, 4=divorced)
- iv. Do you have a phone? (1= Yes, 2= No). If yes, Phone number _____
- v. Relationship with the head of the household _____ (1=head of the household, 2=Spouse, 3=Son/daughter 4=Grandson/daughter)
- vi. Level of education (1= none, 2= primary, 3= secondary, 4=tertiary 5=others)
- vii. The number of years in this area ... years. Years spent in finger millet farming _____ years

D: Finger millet production and source of inputs

- i. Size of all your farms in acres _____ Source 1= own, 2=inherited, 3=rented
- ii. Size of your finger millet fields in acres _____ Source 1= own, 2=inherited, 3=rented
- iii. Do you grow finger millet for (1= Food only, 2= Cash only 3= both)?

- iv. What finger millet seeds do you grow? (1= Local, 2= Improved)
- v. What are the sources of finger millet seeds you used? (1=own, 2= neighbours/friends 3=both 1and 2, 4= researchers 5= local market 6=others/specify)
- vi. During last year (2020), how many hectares of land did you use to grow finger millet? _____
- vii. What type of water source did you use (1=irrigation, 2=water stored in hole, 3=Rain fed)?
- viii. How far is your house from the nearest Agricultural input dealers/shops? (1=walking distance, 2=travelling distance (3-5km) 3=travelling distance (5-10km) 4=no input shops around)
- ix. How far is your house from the nearest Agricultural Extension office? (1=walking distance, 2 = travelling distance (3-5km) 3 = no extension office at all).

D: Knowledge on finger millet blast disease and management

- i. Have you ever heard or observed finger millet blast disease (*shown photos*)? (1= yes, 2= no)
- ii. What is its local name? _____
- iii. From where did you first hear or see this disease (1= friends/neighbours field, 2=own field, 3= market place, 4= others/specify)
- iv. Has the disease ever been observed in your _____?

		If YES ; when did the disease for the first time observed		
Farm	(1= yes; 2= no)	Week	Month	Year
Village	(1= yes; 2= no)	Week	Month	Year

- v. What type of blast do you find in your farm (*will be shown show the photo*)? 1) Leaf, 2) node, 3) neck, 4) head (finger)
- vi. What are the major means of dissemination of the above disease? _____
- vii. What percentage of your finger millet farm was infected by finger millet blast? _____
- viii. How severe were finger millet disease last year? 0=None, 1=Low, 2=Medium 3=High
- ix. Have you ever observed any other diseases in your farm? 1. Yes, 2. No
- x. If yes, which one 1= Rust 2= Cercospora brown spot 3= Bacterial leaf blight, 4= Downy mildew, 5= Cylinderosporium leaf spot, 6 if any other (*specify*) _____
- xi. How severe were above disease? 0=None, 1=Low, 2=Medium 3=High
- xii. Have you seen finger millet blast disease in other farms or neighbours farm? 1=Yes, 2= No
- If **YES**, indicate the month, year and distance of the farm in reference to your field

Year	Month	Distance from your farm

- xiii. Does the disease affect the finger millet crop in your farm throughout the growing season? (Please tick as appropriate) 1=yes 2=No

If **YES**, indicate which month(s) of the year the disease is prevalent (tick in the box)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec

- xiv. What factors do you think might have led to the presence of the disease in your farm?
- 1.
 - 2.
 - 3.
- xv. Does Finger millet blast disease occur in your village/farm over the past five years?

Year	Blast Disease occurrence
2022	1= Yes 2 = No
2021	1= Yes 2 = No
2020	1= Yes 2 = No
2019	1= Yes 2 = No
2018	1= Yes 2 = No

E: Control options by the farmers

- i. Is there any management practice used/know to control finger millet blast disease? 1=yes 2=No
- ii. What did you do to control finger millet blast disease when it occurs in your farm?
- iii. 1. Burning diseased plant parts 2. Use of resistance variety 3. Chemical use 4. Crop rotation 5. Reduce nitrogenous fertilizer applications 6. Other (specify)
- iv. From whom you learnt these practices? 1. Own, 2. Neighbours/friends 3. Both 1 and 2, 4. Researchers 5. Extension officer 6. Others (please specify)_____
- v. Is the method still used? 1. Yes 2. No
- vi. If method stopped, give a reason why stop using. 1. Effective, 2. Moderately effective, 3. Less effective 4. Not effective at all 4. I don't know the reason
- vii. If using chemicals what kind of chemicals do you use to control blast disease? Name of product_____ how much_____
- viii. From whom did you learn about the product? _____ 1) Extension staff, 2) Auricular Research Institute, 3) Agriculture office, 4) Fellow farmers, 5) TV, 6) Radio, 7) other (specify)
- ix. If not using any control method, give reasons why. 1. Blast is a new disease in the area 2. Lack of knowledge on blast control, 3. Both 1 and 2 4. The level of damage is low 5. No effective management method

F: Training on disease management options

- i. Have you ever received any training related to finger millet production? 1=Yes 2=No
- ii. If yes, how many times have you received on IPM and agronomic practices training?
- iii. From whom did you learn about finger millet production? _____ 1) Extension staff, 2) ARI, 3) MoA, 4) fellow farmers, 5) TV, 6) Radio, 7) other (specify)
- iv. Have you received any training related to IPM? 1=Yes 2=No
- v. If yes, how many times have you received IPM training?
- vi. From whom did you learn about finger millet production? _____ 1) Extension staff, 2) ARI, 3) MoA, 4) fellow farmers, 5) TV, 6) Radio, 7) other (specify).

Appendix Table 5.1 Treatment setup & randomization (Screening experiment)

TRT n ^o	Pedigree	Plot number		TRT n ^o	Pedigree	Plot number	
		Rep-I	Rep-II			Rep-I	Rep-II
1	P*N-P#17	63	65	33	D*N-P#18	36	101
2	N*W-P#1	5	94	34	W*N-P#P1-1	10	106
3	W*N-P#5	39	108	35	N*T-P#17	13	103
4	W*N-P#3	61	97	36	N*D-P#1	37	92
5	N*G-P#18	44	95	37	N*T-P#16	19	120
6	N*P-P#8	26	109	38	N*T-P#21	8	126
7	N*B-P#19	14	119	39	N*G-P#33	50	70
8	W*N-P#1-2	12	90	40	B*N-P#25	34	69
9	N*T-P#7	29	100	41	P*N-P#35	38	85
10	D*N-P#7	58	112	42	W*N-P#11-1	54	86
11	N*T-P#25	4	99	43	N*T-P#28	24	121
12	N*T-P#2	16	74	44	B*N-P#1	18	72
13	N*T-P#12	43	82	45	N*P-P#9	45	98
14	P*N-P#13	57	128	46	N*G-P#32	51	118
15	N*T-P#22	60	96	47	P*N-P#30-2	47	66
16	N*B-P#7	32	77	48	P*N-P#27	7	110
17	P*N-P#31	20	104	49	N*G-P#34	46	114
18	N*P-P#17	1	78	50	N*B-P#5	2	67
19	N*G-P#30	59	81	51	W*N-P#8	40	124
20	N*T-P#19	52	102	52	W*N-P#6-2	21	89
21	N*G-P#35	64	80	53	N*G-P#22	62	113
22	N*T-P#4	27	84	54	N*G-P#26	23	105
23	N*P-P#10	25	125	55	N*G-P#20-2	33	76
24	N*T-P#20	56	123	56	N*G-P#11	55	107
25	P*N-P#5	22	88	57	N*G-P#10	42	111
26	N*P-P#24	11	87	58	N*G-P#8	9	122
27	N*B-P#6	30	116	59	N*G-P#30-1	31	68
28	N*G-P#1	3	115	60	N*W-P#4	17	73
29	P*N-P#32	6	83	61	W*N-P#6-3	41	127
30	N*G-P#20-1	48	79	62	B*N-P#10	15	71
31	N*G-P#31	28	93	63	St. check (Jabi)	53	91
32	N*P-P#4	49	75	64	Local check	35	117

Appendix Table 5.2 Summary of analysis of variance mean squares for the effect of locations, year, treatments and their interactions on agronomic, yield, and disease parameters at Adet and Fenotselam, Western Amhara, Ethiopia

Trait	Range		Mean	SEM (+)	Mean square													
	Min.	Max.			Loc	Year	Year*	Group (df=1)	Block (df=7)	Block (group) (df=7)	Block (Loc) (df=7)	TRT (df=63)	Year* TRT	Loc* TRT	Loc*Year* TRT(df=63)	Error (df=234)	CV (%)	R ² (%)
DH	95	117	107.84	2.28	112.50**	2747.26***	33.01n	1.13 ^{ns}	9.88 ^{ns}	10.66 ^{ns}	9.75 ^{ns}	43.39***	18.56**	27.08***	14.18 ^{ns}	10.42	2.99	0.81
DM	135	168	147.41	3.12	285.01***	190.13**	1540.1	73.51 ^{ns}	28.27 ^{ns}	23.93 ^{ns}	31.02 ^{ns}	58.87***	28.66*	33.75**	17.99 ^{ns}	19.52	2.99	0.73
PH	44.2	126.4	77.63	5.13	3533.25***	12053.22***	278.19	692.38***	76.38 ^{ns}	85.82 ^{ns}	172.16**	528.15***	105.51 ^{ns}	45.77ns	53.65 ^{ns}	52.62	9.34	0.85
FL	4.8	15.4	9.75	0.64	62.02***	31.70***	90.28*	3.85*	0.91 ^{ns}	1.02 ^{ns}	2.16*	12.95***	2.02***	0.81ns	0.98 ^{ns}	0.83	9.35	0.89
NFE	3.4	10.2	6.85	0.59	236.26***	45.24***	30.52*	0.09 ^{ns}	0.50 ^{ns}	1.05 ^{ns}	1.92**	3.97***	0.58 ^{ns}	1.04*	0.74 ^{ns}	0.69	12.15	0.83
NTE	1.4	7.8	3.77	0.52	33.21***	64.13***	13.52*	6.75***	1.31*	1.95**	0.34 ^{ns}	2.08***	0.77*	0.63ns	0.52 ^{ns}	0.54	19.48	0.78
NEP	1.8	11	5.39	0.72	0.14 ^{ns}	0.01 ^{ns}	288.60	6.94*	3.21**	4.15***	0.68 ^{ns}	3.84***	1.15 ^{ns}	2.13***	1.11 ^{ns}	1.05	19.02	0.79
BY	3417	1575	8111.57	1022.74	248981704.5**	76087615.3*	84432	113557046	3938979.9 ^{ns}	4825171.	879365.1	7430343.6*	3365826.7**	1364300.9 ⁿ	1137794.0 ^{ns}	2091975	17.83	0.75
GY	916 7	6833	3084.03	473.42	3700051.7* *	10681585 6.5***	31210 99.7**	5155061. 8***	1344746.9 **	1061691 .2*	768932 .6 ^{ns}	2260674.2 ***	522327.0 ^{ns}	548356. 4*	158429.7 ^{ns}	448245	21.71	0.79
HI	12.61	71.57	38.52	5.35	2074.16***	8287.48***	818.76	697.56***	179.29**	155.34*	85.19 ^{ns}	187.12***	68.54 ^{ns}	57.25 ^{ns}	30.47 ^{ns}	57.2544	19.65	0.74
LI	0	105.8	49.81	11.35	105275.96***	15607.36***	35.84n	407.57 ^{ns}	435.19 ^{ns}	140.97 ^{ns}	587.08*	760.84***	219.11 ^{ns}	566.57***	160.54 ^{ns}	257.78	32.23	0.8
NI	0	115.9	61.4	10.23	74527.68***	7265.02***	1292.4	1260.80*	178.91 ^{ns}	226.71 ^{ns}	116.99 ^{ns}	973.95***	140.51 ^{ns}	366.94**	159.40 ^{ns}	209.33	23.56	0.8
HdI	0	121.7	68.21	9.76	56987.94***	18239.90***	2885.8	275.464 ^{ns}	265.59 ^{ns}	230.86 ^{ns}	236.37 ^{ns}	961.42***	123.12 ^{ns}	447.08***	98.58 ^{ns}	190.55	20.24	0.81
LS	0	64.3	27.47	7.18	48756.08***	365.73 ^{ns}	2345.1	3.79 ^{ns}	173.93 ^{ns}	58.79 ^{ns}	209.54 ^{ns}	271.44***	107.91 ^{ns}	209.47***	76.35 ^{ns}	103.09	36.96	0.81
NS	0	103.8	47.79	9.02	67803.57***	55.62ns	4230.2	2520.77**	135.40 ^{ns}	145.93 ^{ns}	169.22 ^{ns}	570.15***	202.28 ^{ns}	221.06 ^{ns}	302.87***	162.73	26.69	0.81
HS	0	105.0	53.19	9.13	61139.14***	1343.21**	619.3n	1358.41**	128.58 ^{ns}	195.04 ^{ns}	124.87 ^{ns}	927.99***	111.32 ^{ns}	357.36***	79.26 ^{ns}	166.64	24.27	0.81
LAU DPC	0	1808	661.24	248.44	1851395.49***	821778.03*	32780	225526.64	212628.44 ^{ns}	68746.52	321123.5	330689.14*	77695.22 ^{ns}	284148.43	52156.51 ^{ns}	123445	53.14	0.69
NAU DPC	0	2650	1413.04	300.47	6946664.52***	85096.43ns	41257	1294964.4	239962.98 ^{ns}	232796.2	199716.6	761028.37*	205315.31 ^{ns}	266691.37	278633.05*	180559	30.07	0.74
HAU DPC	0	3030	1573.11	355.77	8068613.99***	2879428.53*	59379	1142182.9	199629.01 ^{ns}	233110.6	168952.2	1223654.26	147301.22 ^{ns}	582559.10	99667.76 ^{ns}	253141	31.98	0.73

*Significance codes: ***** 0.001 **** 0.01 *** 0.05, ns=non-significant, Loc = location, df = Degree of freedom, TRT= treatment, SEM= standard error of the mean, DH= days to heading, DM= Days to physiological maturity, PH = Plant height (cm), NEP = Number of ears per plant, BY = Biomass yield (kg ha⁻¹), GY = Grain yield (kg ha⁻¹), LBI= leaf blast incidence, NBI = neck blast incidence, HBI= head blast incidence, LBS= leaf blast severity, NBS = Neck blast severity (%), HBS = Head blast severity (%), LBAUDPC, NBAUDPC and HBAUDPC= leaf, neck and head area under disease progress curve respectively and CV = Coefficient of variation.

Appendix Table 5.3 Yield and yield related parameters of the tested genotypes at both experimental sites and growth seasons

Geno.	Adet																			
	2022										2023									
	DH	DM	PH	FL	NFE	NTP	NEP	BY	GY	HI	DH	DM	PH	FL	NFE	NTP	NEP	BY	GY	HI
G1	DH	DM	PH	FL	NFE	NTP	NEP	BY	GY	HI	DH	DM	PH	FL	NFE	NTP	NEP	BY	GY	HI
G2	107 ^{a-e}	141.5 ^{f-j}	77.0 ^g	8.7 ^{k-u}	7.0 ^{e-k}	4.0 ^{j-n}	5.3 ^{ghi}	7917	3237.5 ^c	41.20 ^{a-f}	111 ^{a-f}	150 ^{a-f}	73.5 ^b	8.1 ^{h-t}	6.9 ^{h-r}	3.3 ^{d-k}	4.5 ^{d-j}	6938 ^{k-p}	2666.7 ^b	38.36 ^{a-f}
G3	104 ^{b-e}	148.5 ^{a-g}	78.4 ^f	8.7 ^{k-u}	6.9 ^{f-k}	4.5 ^{e-l}	5.9 ^{d-i}	8750	4625 ^{abc}	53.37 ^a	109 ^{b-i}	146.5 ^{b-f}	74.3 ^b	8.3 ^{f-s}	7.9 ^{c-l}	4.1 ^{a-j}	5.2 ^{b-i}	9250 ^{b-o}	3833.3 ^a	41.27 ^{a-d}
G4	110.5 ^{a-d}	146.5 ^{a-i}	73.0 ^h	7.0 ^u	8.3 ^{a-h}	4.4 ^{f-l}	6.3 ^{c-i}	9875	4291.7 ^a	43.055 ^a	112 ^{a-e}	139.5 ^f	65.7 ^h	7.2 ^{o-u}	8.2 ^{b-i}	2.9 ^{g-k}	3.8 ^{hij}	8792 ^{d-p}	2583.3 ^c	29.46 ^{c-g}
G5	105.5 ^{a-e}	150.5 ^{a-e}	65.0 ^a	10.8 ^c	7.6 ^{b-k}	4.8 ^{c-k}	6.1 ^{c-i}	9375	3929.2 ^a	41.95 ^{a-f}	112 ^{a-e}	141.0 ^f	52.4 ^t	10.6 ^a	6.4 ^{l-r}	4.1 ^{a-j}	5.1 ^{b-j}	8542 ^{d-p}	3416.7 ^a	40.08 ^{a-e}
G6	112.5 ^{ab}	151.5 ^{a-d}	77.0 ^g	10.0 ^d	6.8 ^{g-k}	4.3 ^{g-l}	5.3 ^{ghi}	1204	4970.8 ^a	41.84 ^{a-f}	113 ^{a-d}	151.5 ^{a-f}	79.3 ^a	9.6 ^{b-l}	7.5 ^{d-o}	2.9 ^{g-k}	3.5 ^j	12708 ^a	4041.7 ^a	31.86 ^{b-}
G7	104.5 ^{a-e}	141.0 ^{g-l}	56.4 ^o	7.5 ^{stu}	6.5 ^{b-k}	5.5 ^{b-e}	7.2 ^{a-d}	7000 ⁱ	2929.2 ^e	41.675 ^a	114 ^{ab}	147.5 ^{b-f}	58.6 ^q	7.9 ^{i-u}	6.7 ^{i-r}	5.5 ^a	5.9 ^{a-e}	7688 ^{g-p}	2750.0 ^b	34.36 ^{b-}
G8	105.5 ^{a-e}	144.5 ^{c-j}	77.0 ^g	9.8 ^{e-q}	7.2 ^{d-k}	4.6 ^{d-l}	5.8 ^{d-i}	1195	5208.3 ^a	43.48 ^{a-f}	110 ^{b-g}	144 ^{def}	73.6 ^b	11.7 ^a	7.7 ^{c-n}	3.1 ^{e-k}	3.9 ^{hij}	10083 ^{a-}	3291.7 ^a	32.71 ^{b-}
G9	103 ^{b-e}	144.5 ^{c-j}	77.9 ^f	7.3 ^{tu}	7.8 ^{a-k}	4.5 ^{e-l}	5.8 ^{d-i}	8625	3291.7 ^c	42.69 ^{a-f}	113 ^{a-d}	154 ^{a-e}	63.2 ⁱ	7.4 ^{m-}	7.7 ^{c-n}	3.1 ^{e-k}	4.0 ^{g-j}	6458 ^{m-p}	2666.7 ^b	41.19 ^{a-d}
G10	112.5 ^{ab}	149.0 ^{a-g}	71.0 ⁱ	10.4 ^d	7.0 ^{e-k}	4.2 ^{h-}	5.2 ^{hi}	9167	3750.0 ^a	41.675 ^a	110 ^{b-g}	148 ^{a-f}	62.1 ^l	9.9 ^{a-j}	6.9 ^{h-r}	2.5 ^k	3.6 ^{ij}	7208 ^{h-p}	2291.7 ^e	31.88 ^{b-}
G11	96.0 ^e	146.5 ^{a-i}	68.0 ⁱ	10.1 ^d	8.1 ^{a-j}	4.5 ^{e-l}	6.3 ^{c-i}	9833	4250.0 ^a	42.98 ^{a-f}	106 ^{f-k}	148.5 ^{a-f}	60.9 ^p	9.3 ^{b-n}	9 ^{a-d}	3.3 ^{d-k}	4.4 ^{d-j}	10000 ^{a-}	2833.3 ^b	28.68 ^{c-g}
G12	112.5 ^{ab}	145.0 ^{a-j}	71.0 ⁱ	9.4 ^{g-t}	8.9 ^{e-e}	4.5 ^{e-l}	6.0 ^{d-i}	8625	3837.5 ^a	48.62 ^{a-d}	112 ^{a-e}	150 ^{a-f}	63.0 ⁻	8.6 ^{d-q}	7.6 ^{d-o}	2.8 ^{h-k}	3.6 ^{ij}	7375 ^{h-p}	2666.7 ^b	36.22 ^{a-g}
G13	104.5 ^{a-e}	142.0 ^{e-j}	72.0 ^h	8.8 ^{j-u}	7.0 ^{e-k}	5.0 ^{c-j}	6.3 ^{c-i}	8167	3345.8 ^c	44.52 ^{a-f}	110 ^{b-g}	150.5 ^{a-f}	69.4 ^e	9.3 ^{b-n}	6.7 ^{i-r}	4.0 ^{a-k}	4.9 ^{c-j}	11833 ^a	3333.3 ^a	28.17 ^{c-g}
G14	104.5 ^{a-e}	145.5 ^{a-j}	78.3 ^f	8.4 ^{m-}	8a ^{-j}	6.6 ^a	8.00 ^a	8042	3658.3 ^b	45.41 ^{a-f}	116 ^a	150.5 ^{a-f}	62.4 ^k	7.9 ^{i-u}	6.3 ^{m-}	3.9 ^{b-k}	5.7 ^{b-f}	8146 ^{e-p}	2166.7 ^e	26.72 ^{c-g}
G15	111.5 ^{a-d}	152.0 ^{ab}	69.4 ^k	8.7 ^{k-u}	7.0 ^{e-k}	5.3 ^{c-g}	6.4 ^{c-h}	9458	4466.7 ^{a-}	47.49 ^{a-e}	114 ^{ab}	151 ^{a-f}	73.3 ^b	9.9 ^{a-j}	6.4 ^{l-r}	5.2 ^{ab}	7.4 ^a	8333 ^{c-p}	3125.0 ^b	38.18 ^{a-f}
G16	109.0 ^{a-d}	147.5 ^{a-i}	80.4 ^d	12.2 ^a	7.5 ^{b-k}	5.0 ^{c-j}	5.6 ^{e-i}	9125	3583.3 ^b	39.61 ^{a-f}	111 ^{a-f}	159.5 ^{ab}	81.7 ^a	10.1 ^a	8.6 ^{a-g}	2.7 ^{ijk}	3.5 ^j	11375 ^{a-}	3500.0 ^a	30.84 ^{b-}
G17	113.0 ^{ab}	145.0 ^{b-j}	74.5 ^g	12.2 ^a	6.8 ^{g-k}	5.5 ^{b-e}	6.5 ^{b-h}	8083	3583.3 ^b	44.18 ^{a-f}	111 ^{a-f}	143.5 ^{def}	68 ^{g-r}	11.2 ^a	6.8 ^{h-r}	3.2 ^{e-k}	4.1 ^{f-j}	7125 ^{h-p}	2750.0 ^b	38.83 ^{a-e}
G18	102.0 ^{b-e}	137.0 ^j	90.0 ^a	9.7 ^{f-r}	8.4 ^{a-h}	4.4 ^{f-l}	7.0 ^{b-f}	7667	2791.7 ^f	36.39 ^{a-f}	106 ^{f-k}	143 ^{def}	73.7 ^b	8.9 ^{c-p}	7.6 ^{d-o}	3.6 ^{c-k}	4.6 ^{d-j}	7792 ^{f-p}	2958.3 ^b	37.95 ^{a-g}
G19	100.0 ^{de}	139.0 ^{ij}	71.6 ⁱ	9.5 ^{g-s}	6.8 ^{g-k}	5.2 ^{c-h}	7.0 ^{b-f}	7875	3883.3 ^a	49.45 ^{ab}	107.5 ^{d-j}	145 ^{def}	68.4 ^{f-}	8 ^{i-u}	6.9 ^{h-r}	3.2 ^{e-k}	5.1 ^{b-j}	8083 ^{e-p}	3166.7 ^a	39.14 ^{a-e}
G20	101.5 nd	147.0 ^{a-i}	88.5 ^a	9.9 ^{e-p}	7.4 ^{c-k}	4.1 ⁱ⁻ⁿ	7.1 ^{b-e}	7667	3625.0 ^b	47.04 ^{a-e}	104 ^{h-k}	145 ^{def}	75 ^{b-j}	9.4 ^{b-}	7.8 ^{c-}	3.3 ^{d-k}	4.5 ^{d-j}	8833 ^{d-p}	3041.7 ^b	34.34 ^{b-}
G21	105.5 ^{a-e}	142.0 ^{e-j}	85.4 ^b	11.4 ^a	6.6 ^{g-k}	4.6 ^{d-l}	6.3 ^{ci}	1245	4208.3 ^a	33.79 ^{b-f}	110 ^{b-g}	147.5 ^{b-f}	75.9 ^b	8.7 ^{c-q}	6.9 ^{h-r}	2.9 ^{g-k}	4.0 ^{g-j}	10792 ^{a-}	3083.3 ^b	28.04 ^{c-g}
G22	106.5 ^{a-e}	145.5 ^{a-j}	66.9	9.9 ^{e-p}	6.6 ^{g-k}	5.2 ^{f-h}	8.6 ^a	9583	3416.7 ^c	38.035 ^a	114 ^{ab}	148 ^{a-f}	75.3 ^b	8.7 ^{c-q}	6.7 ^{i-r}	4.6 ^{a-e}	6.7 ^{ab}	9583 ^{b-l}	3833.3 ^a	40.88 ^{a-e}
G23	111 ^{a-d}	148.0 ^{a-h}	85.2 ^b	11.3 ^a	8.1 ^{a-j}	5.3 ^{c-g}	6.6 ^{b-h}	9625	3458.3 ^b	37.03 ^{a-f}	114 ^{ab}	142 ^{ef}	81.2 ^a	9.6 ^{b-l}	7.9 ^{c-l}	3.3 ^{d-k}	4.3 ^{e-j}	9083 ^{b-p}	3250.0 ^a	35.82 ^{b-}
G24	108.5 ^{a-d}	143.5 ^{c-j}	81.8 ^c	7.9 ^{p-u}	6.7 ^{g-k}	4.5 ^{e-l}	5.9 ^{d-i}	1070	3833.3 ^a	35.835 ^a	112 ^{a-e}	145.5 ^{c-f}	75.3 ^b	6.5 ^{r-u}	6.5 ^{k-r}	3.9 ^{b-k}	4.8 ^{c-j}	9417 ^{b-m}	2791.7 ^b	29.84 ^{c-g}
G25	104 ^{b-e}	142.5 ^{c-j}	87.4 ^b	12.0 ^a	7.9 ^{a-j}	4.3 ^{g-l}	6.5 ^{b-h}	1091	3666.7 ^b	33.89 ^{b-f}	107 ^{e-k}	145.5 ^{c-f}	73.8 ^b	9.5 ^{b-l}	7.9 ^{c-l}	3.5 ^{c-k}	4.8 ^{c-j}	7083 ^{i-p}	2750.0 ^b	38.87 ^{a-e}
G26	102.5 ^{b-e}	142.5 ^{c-j}	95.5 ^a	10.6 ^c	6.7 ^{g-k}	5.3 ^{c-g}	6.3 ^{c-i}	1016	3587.5 ^b	35.29 ^{a-f}	112 ^{a-e}	141 ^{ef}	88.6 ^b	10.0 ^a	7.0 ^{h-r}	3.3 ^{d-k}	4.7 ^{c-j}	8500 ^{d-p}	2708.3 ^b	32.29 ^{b-}
G27	108 ^{a-d}	144.0 ^{c-j}	75.5 ^g	7.1 ^u	8.2 ^{a-i}	4.6 ^{d-l}	6.3 ^{c-i}	8583	2666.7 ^l	32.27 ^{c-f}	105 ^{b-k}	143 ^{def}	69.7 ^d	6.1 ^{tu}	7.8 ^{c-}	3.9 ^{b-k}	4.8 ^{c-j}	7042 ^{i-p}	2583.3 ^c	36.22 ^{a-g}
G28	104.5 ^{a-e}	143.5 ^{c-j}	87.9 ^a	11.3	8.1 ^{a-j}	5.2 ^{c-h}	6.0 ^{d-i}	1087	3000.0 ^d	27.67 ^f	111.5 ^{a-f}	149.5 ^{a-f}	67.3 ^g	8.1 ^{h-t}	8.7 ^{a-f}	3.4 ^{d-k}	4.3 ^{e-j}	7125 ^{h-p}	2125.0 ^e	29.48 ^{c-g}
G29	105 ^{a-e}	149.5 ^{a-g}	80.8 ^d	11.9 ^a	6.3 ^{ijk}	5.7 ^{abc}	6.8 ^{b-g}	1016	3791.7 ^a	38.55 ^{a-f}	109 ^{b-i}	148.5 ^{a-f}	63.3 ⁱ	10.3 ^a	6.5 ^{k-r}	3.7 ^{b-k}	5.1 ^{b-j}	7458 ^{h-p}	2000.0 ^f	27.04 ^{c-g}

G30	102 ^{b-e}	142.5 ^{e-j}	75.8 ^g	110 ^{b-}	9 ^{a-d}	3.8 ^{k-n}	5.2 ^{hi}	8667	2541.7 ^l	30.12 ^{def}	107 ^{e-k}	145.5 ^{c-f}	70.6 ^c	8.8 ^{c-p}	9.7 ^{ab}	2.6 ^{jk}	3.8 ^{hij}	7083 ^{l-p}	1791.7 ^g	24.74 ^{efg}
G31	111 ^{a-d}	142.5 ^{e-j}	100.	13.1 ^a	9.3 ^{abc}	4.4 ^{f-l}	5.9 ^{d-i}	9500	2708.3 ^b	28.23 ^{ef}	111 ^{a-f}	147.5 ^{b-f}	88.6 ^a	10.6 ^a	10.1 ^a	2.9 ^{g-k}	4.1 ^{f-j}	9000 ^{c-p}	2583.3 ^c	28.48 ^{c-g}
G32	116.0 ^a	154.0 ^a	78.5 ^{f-}	11.5 ^a	7.4 ^{c-k}	5.4 ^{b-f}	6.6 ^{b-h}	9458	3875 ^{a-i}	42.21 ^{a-f}	110 ^{a-f}	151.5 ^{a-f}	61.3 ^o	8.5 ^{e-r}	6.7 ^{i-r}	4.8 ^{a-d}	5.9 ^{a-e}	6292 ^{op}	3291.7 ^a	52.33 ^a
G33	104.0 ^{b-e}	150.0 ^{a-f}	79.8 ^e	10.9 ^c	7.5 ^{b-k}	3.7 ^{lm}	5.7 ^{d-i}	9458	3583.3 ^b	39.09 ^{a-f}	116 ^a	152.5 ^{a-f}	72.2 ^b	7.8 ^{k-u}	7.4 ^{e-p}	3.6 ^{c-k}	5.6 ^{b-j}	7542 ^{b-p}	3041.7 ^b	41.65 ^{a-d}
G34	104.5 ^{a-e}	148.0 ^{a-h}	82.4 ^c	12.2	7.3 ^{d-k}	4.6 ^{f-h}	6.7 ^{b-h}	9875	4333.3 ^a	43.88 ^{a-f}	103 ^{jk}	140 ^f	61.4 ⁿ	8.9 ^{c-p}	7.9 ^{c-l}	3.1 ^{e-k}	4.4 ^{d-j}	7708 ^{f-p}	2250.0 ^e	29.21 ^{c-g}
G35	104.5 ^{a-e}	145.0 ^{b-j}	94.3 ^a	10.6 ^c	8.5 ^{a-g}	6.4 ^{ab}	7.2 ^{a-d}	8750	3500 ^{b-i}	40.65 ^{a-f}	107 ^{e-k}	147 ^{b-f}	83.8 ^a	10.3 ^a	8.9 ^{a-e}	4.4 ^{a-g}	5.1 ^{b-j}	10042 ^{a-}	2625.0 ^c	25.87 ^{d-}
G36	113.5 ^{ab}	146.5 ^{a-i}	96.5 ^a	11.8 ^a	7.8 ^{a-k}	3.7 ^{lm}	5.4 ^{ghi}	9333	3375 ^{c-i}	36.23 ^{a-f}	112 ^{a-e}	149 ^{a-f}	80.6 ^a	9.1 ^{c-o}	8.2 ^{b-i}	3.2 ^{e-k}	4.0 ^{g-j}	9188 ^{b-p}	2958.3 ^b	32.41 ^{b-}
G37	106.5 ^{a-e}	142 ^{e-j}	87.9 ^a	10.8 ^c	7.3 ^{d-k}	5.2 ^{c-h}	6.2 ^{c-i}	9833	3083.3 ^d	33.50 ^{c-f}	103.5 ^{ijk}	142 ^{ef}	66.1 ^h	9.6 ^{b-l}	8.0 ^{c-k}	4.2 ^{a-i}	4.9 ^{c-j}	9667 ^{b-l}	2500.0 ^c	25.82 ^{d-}
G38	105.0 ^{a-e}	139.5 ^{hij}	88.5 ^a	9.3 ^{g-t}	7.8 ^{a-k}	4.2 ^{h-}	6.2 ^{c-i}	9458	2750 ^{ghi}	30.45 ^{c-f}	108 ^{c-j}	143.5 ^{def}	62.9 ^{l-}	8.5 ^{e-r}	7.5 ^{d-o}	3.5 ^{c-k}	4.9 ^{c-j}	7250 ^{h-p}	2208.3 ^e	31.33 ^{b-}
G39	104.0 ^{b-e}	142.0 ^{e-j}	88.4 ^a	12.8 ^a	9.4 ^{ab}	3.8 ^{k-n}	5.6 ^{e-i}	9500	3125 ^{c-i}	32.95 ^{c-f}	109.5 ^{b-}	147 ^{b-f}	74.5 ^b	10.2 ^a	7.8 ^{c-}	2.9 ^{g-k}	4.1 ^{f-j}	8167 ^{e-p}	3416.7 ^a	41.55 ^{a-d}
G40	106.0 ^{a-e}	146.0 ^{a-i}	79.5 ^e	8.6 ^{l-u}	7.7 ^{b-k}	3.8 ^{k-n}	5.5 ^{f-i}	1054	3125 ^{c-i}	29.76 ^{def}	108 ^{c-j}	144.5 ^{def}	62.1 ^{l-}	6.4 ^{stu}	6.3 ^{m-r}	3.2 ^{e-k}	4.7 ^{c-j}	7792 ^{f-p}	2666.7 ^b	34.05 ^{b-}
G41	111.5 ^{a-d}	145.0 ^{b-j}	85.6 ^b	11.1 ^b	6.9 ^{f-k}	4.2 ^{h-}	5.4 ^{ghi}	7500	3345.8 ^c	44.94 ^{a-f}	113.5 ^{ab}	145 ^{def}	74.8 ^b	9.0 ^{c-o}	6.1 ^{o-r}	3.2 ^{e-k}	4.1 ^{f-j}	6375 ^{nop}	2208.3 ^e	34.72 ^{b-}
G42	104.0 ^{b-e}	146.0 ^{a-i}	84.3 ^c	10.6 ^c	9.6 ^a	3.9 ^{k-n}	5.5 ^{f-i}	9542	3833.3 ^a	41.11 ^{a-f}	110 ^{b-j}	144.5 ^{def}	60.9 ^p	7.8 ^{k-u}	9.2 ^{abc}	3.1 ^{e-k}	4.6 ^{d-j}	7208 ^{h-p}	2250.0 ^e	31.24 ^{b-}
G43	110.0 ^{a-d}	151.5 ^{a-d}	76.2 ^g	7.7 ^{q-u}	5.9 ^k	3.8 ^{k-n}	5.5 ^{f-i}	7125 ⁱ	3041.7 ^d	42.56 ^{a-f}	116 ^a	153 ^{a-f}	55.6 st	6.7 ^{q-u}	5.6 ^r	3.0 ^{f-k}	3.9 ^{hij}	6604 ^{m-p}	1416.7 ^h	21.65 ^g
G44	103.0 ^{b-e}	141.5 ^{f-j}	82.2 ^c	10.3 ^d	6.7 ^{g-k}	5.1 ^{c-i}	6.1 ^{c-i}	8625	2625 ⁱ	31.21 ^{c-f}	113 ^{a-d}	150.5 ^{a-f}	66.5 ^h	9.3 ^{b-n}	7.2 ^{f-q}	4.0 ^{a-k}	4.8 ^{c-j}	6250 ^p	2666.7 ^b	42.86 ^{ab}
G45	108.0 ^{a-d}	148.0 ^{a-h}	83.4 ^c	10.8 ^c	8.0 ^{a-j}	4.0 ^{lm}	5.8 ^{d-i}	9167	3750 ^{a-i}	40.96 ^{a-f}	111 ^{a-f}	150 ^{a-f}	68.2 ^g	8.8 ^{c-p}	7.1 ^{f-q}	3.0 ^{f-k}	4.4 ^{d-j}	6333 ^{op}	2208.3 ^e	34.87 ^{b-}
G46	100.0 ^{gr}	144.5 ^{c-j}	73.2 ^h	7.6 ^{r-u}	7.3 ^{d-k}	3.2 ^{mn}	4.8 ⁱ	7458	3383.3 ^c	45.19 ^{a-f}	109 ^{b-i}	148 ^{a-f}	64.8 ^h	7.1 ^{o-u}	7.3 ^{f-q}	2.7 ^{ijk}	3.7 ^{hij}	6792 ^{k-p}	2583.3 ^c	38.09 ^{a-f}
G47	106.0 ^{a-e}	144.5 ^{c-j}	86.0 ^b	10.4 ^d	7.7 ^{b-k}	4.1 ^{lm}	5.8 ^{d-i}	1083	3591.7 ^b	33.52 ^{c-f}	110 ^{b-g}	148 ^{a-f}	69.1 ^e	7.8 ^{k-u}	7.7 ^{f-q}	4.0 ^{a-k}	5.0 ^{c-j}	10083 ^{a-}	3000 ^{b-g}	29.71 ^{c-g}
G48	111.0 ^{a-d}	146.5 ^{a-i}	80.9 ^d	10.1 ^d	9.4 ^{ab}	3.1 ⁿ	5.3 ^{ghi}	8708	2958.3 ^e	34.19 ^{a-f}	114 ^{ab}	149 ^{a-f}	68 ^{g-r}	8.2 ^{g-s}	8.3 ^{b-h}	3.9 ^{b-k}	4.8 ^{c-j}	7000 ^{k-p}	2583.3 ^c	36.95 ^{a-g}
G49	108.5 ^{a-d}	148.5 ^{a-g}	76.0 ^g	10.3 ^d	8.8 ^{a-f}	4.3 ^{gl}	5.9 ^{d-i}	8500	4416.7 ^a	52.95 ^{ab}	109 ^{b-i}	148.5 ^{a-f}	70.5 ^c	9.8 ^{a-k}	9.0 ^{a-d}	3.3 ^{d-k}	5.1 ^{b-j}	8250 ^{e-p}	3875 ^{abc}	46.25 ^{ab}
G50	105.5 ^{a-e}	149.0 ^{a-g}	80.5 ^d	9.1 ^{h-u}	8.9 ^{a-e}	3.7 ^{lm}	5.7 ^{d-i}	1100	4000 ^{a-i}	37.11 ^{a-f}	111 ^{a-f}	151 ^{a-f}	70.7 ^c	8.5 ^{e-r}	9.0 ^{a-d}	3.4 ^{d-k}	4.5 ^{d-j}	8833 ^{d-p}	2833.3 ^b	31.69 ^{b-}
G51	102.0 ^{b-e}	141.5 ^{f-j}	72.4 ^h	10.7 ^c	7.5 ^{b-k}	5.1 ^{c-g}	6.4 ^{c-h}	7542	3150 ^{c-i}	41.71 ^{a-f}	108.5 ^{b-j}	149 ^{a-f}	60.5 ^p	10.7 ^a	8.3 ^{b-h}	4.3 ^{a-h}	5.3 ^{b-h}	7417 ^{h-p}	3083.3 ^b	41.47 ^{a-d}
G52	107.0 ^{a-e}	141.0 ^{g-j}	76.3 ^g	10.3 ^d	8.1 ^{a-j}	5.4 ^{b-f}	7.6 ^{abc}	1062	2725 ^{ghi}	26.36 ^f	101.5 ^k	140 ^f	59.9 ^q	8.8 ^{c-p}	9.0 ^{a-d}	3.9 ^{b-k}	4.1 ^{f-j}	10542 ^{a-}	2333.3 ^e	22.13 ^{fg}
G53	103.0 ^{b-e}	146.0 ^{a-i}	78.6 ^{f-}	9.4 ^{g-t}	7.6 ^{b-k}	4.0 ^{lm}	5.3 ^{ghi}	8750	3458.3 ^b	40.36 ^{a-f}	112 ^{a-e}	150.5 ^{a-f}	72.3 ^b	7.8 ^{k-u}	7.2 ^{f-q}	2.8 ^{h-k}	4.0 ^{g-j}	7708 ^{f-p}	2458.3 ^d	31.75 ^{b-}
G54	111.0 ^{a-d}	148.5 ^{a-g}	104.	12.2 ^a	7.0 ^{e-k}	4.1 ^{lm}	5.7 ^{d-i}	8542	3125 ^{c-i}	35.99 ^{a-f}	111 ^{a-f}	143 ^{def}	81.9 ^a	10.4 ^a	6.9 ^{b-r}	3.3 ^{d-k}	4.2 ^{f-j}	8229 ^{e-p}	2416.7 ^e	29.41 ^{c-g}
G55	105.0 ^{a-e}	146.5 ^{a-i}	91.0 ^a	13.4 ^a	8.3 ^{a-h}	5.1 ^{c-g}	5.9 ^{d-i}	8708	3625 ^{b-i}	41.12 ^{a-f}	113 ^{a-d}	146.5 ^{b-f}	72.7 ^b	9.3 ^{b-n}	8.1 ^{c-}	4.0 ^{a-k}	4.8 ^{c-j}	8271 ^{e-p}	2291.7 ^e	27.92 ^{c-g}
G56	104.0 ^{b-e}	143.5 ^{c-j}	97.6 ^a	12.8 ^a	7.3 ^{d-k}	4.1 ^{lm}	5.9 ^{d-i}	1045	3600 ^{b-i}	34.55 ^{a-f}	111 ^{a-f}	148 ^{a-f}	82.3 ^a	11.3 ^a	6.6 ^{i-r}	2.8 ^{h-k}	3.8 ^{hij}	10833 ^{a-}	2958. ^{3b}	26.96 ^{c-g}
G57	104.5 ^{a-e}	148.5 ^{a-g}	84.3 ^c	8.00 ^o	6.7 ^{g-k}	4.4	5.8 ^{d-i}	7042 ⁱ	2941.7 ^e	41.52 ^{a-f}	114 ^{ab}	161.5 ^a	57.2 ^r	6.1 ^{tu}	5.9 ^{pqr}	3.2 ^{e-k}	4.1 ^{f-j}	6792 ^{k-p}	2375 ^{a-h}	34.65 ^{b-}
G58	104.5 ^{a-e}	144.0 ^{c-j}	76.8 ^g	8.1 ^{n-u}	7.5 ^{b-k}	3.9 ^{lm}	5.4 ^{ghi}	8542	3429.2 ^c	39.85 ^{a-f}	112 ^{a-e}	159 ^{abc}	65.1 ^h	6.9 ^{p-u}	6.7i-	3.1 ^{e-k}	4.3 ^{e-j}	9333 ^{b-n}	2833.3 ^b	30.49 ^{b-}
G59	102.0 ^{b-e}	143.0 ^{d-j}	85.8 ^b	10.7 ^c	7.8 ^{a-k}	3.9 ^{lm}	6.2 ^{c-i}	9875	3062.5 ^d	30.98 ^{c-f}	105 ^{g-k}	146.5 ^{b-f}	66.5 ^h	7.3 ^{n-u}	8.7 ^{a-f}	3.3 ^{d-k}	4.3 ^{e-j}	8125 ^{e-p}	3125 ^{b-g}	39.98 ^{a-e}
G60	107.0 ^{a-e}	143.5 ^{c-j}	78.1 ^{f-}	10.9 ^c	7.5 ^{b-k}	3.9 ^{lm}	6.0 ^{d-i}	9125	3208.3 ^c	35.41 ^{a-f}	109 ^{b-i}	144 ^{def}	68.4 ^{f-}	9.1 ^{c-o}	7.6 ^{d-o}	3.4 ^{d-k}	4.2 ^{f-j}	7021 ^{k-p}	2166.7 ^e	30.82 ^{b-}
G61	110.5 ^{a-d}	149.0 ^{a-g}	94.0 ^a	10.6 ^c	7.1 ^{d-k}	5.3 ^{c-g}	7.0 ^{b-f}	8917	3875.0 ^a	44.38 ^{a-f}	111 ^{a-f}	152 ^{a-f}	83.4 ^a	9.8 ^{a-k}	5.8 ^{qr}	5.0 ^{abc}	6.3 ^{abc}	9750 ^{b-k}	3250 ^{a-f}	33.23 ^{b-}
G62	103.5 ^{b-e}	149.0 ^{a-g}	64.5 ⁿ	7.3 ^{tu}	6.5 ^{b-k}	3.8 ^{lm}	5.6 ^{e-i}	8208	2791.7 ^f	34.37 ^{a-f}	112 ^{a-e}	146.5 ^{b-f}	58.9 ^q	7.4 ^{m-}	6.2 ^{n-r}	3.4 ^{d-k}	4.8 ^{c-j}	6979 ^{k-p}	2208.3 ^e	31.41 ^{b-}

St. check	109.5 ^{a-d}	143.5 ^{c-j}	83.5 ^c	8.90 ^t	7.9 ^{a-j}	3.8 ^{lm}	5.7 ^{d-l}	9792	3779.2 ^a	37.64 ^{a-f}	113.5 ^{ab}	154.5 ^{a-e}	64.2 ^h	7.6 ^{l-u}	8 ^{c-k}	3.0 ^{l-k}	4.4 ^{d-j}	10667 ^{a-}	2833.3 ^b	26.74 ^{c-g}
Local	103.0 ^{b-e}	153.5 ^{ab}	69.5 ^k	7.6 ^{t-u}	6.2 ^{jk}	4.5 ^{e-l}	6.0 ^{d-i}	9333	4512.5 ^a	48.30 ^{a-d}	112.5 ^{a-e}	156 ^{a-d}	61.5	6.0 ^u	6.1 ^{o-r}	3.6 ^{c-k}	4.5 ^{d-j}	11958 ^a	4500 ^a	37.7 ^{a-g}
Mean	106.24	145.54	80.5	10.0	7.58	4.55	6.13	9235	3547.7	39.26	110.37	147.79	69.4	8.73	7.47	3.51	4.63	8382.8	2790.3	33.75
Sig. L.	ns	*	***	***	***	***	**	*	*	ns	***	ns	***	***	***	**	***	***	*	ns
CV (%)	4.43	2.46	8.29	8.88	10.0	9.7	10.2	13.0	17.45	19.82	4.09	2.22	9.35	8.29	17.0	20.6	22.7	21.64	22.45	20.19

Fenotselam																				
2022											2023									
Geno.	DH	DM	PH	FL	NFE	NTP	NEP	BY	GY	HI	DH	DM	PH	FL	NFE	NTP	NEP	BY	GY	HI
G1	112 ^a	156.5 ^{a-e}	86.9 ^e	9.2 ^{i-t}	7 ^{a-k}	3.6 ^{d-j}	4.7 ^{b-g}	7250	3166.7 ^e	44.885 ^a	111.5 ^{a-e}	147 ^g	77.9 ^d	9.8 ^{h-r}	4.3 ^{g-j}	2.7 ^{d-g}	4.3 ^{h-k}	6750 ^{b-h}	1625 ^{j-o}	24.18 ^{j-l}
G2	104 ^{def}	151.0 ^{a-k}	86.5 ^e	8.8 ^{k-u}	7.6 ^{a-e}	4.1 ^{a-j}	5.3 ^{a-g}	8333	4458.3 ^a	53.21 ^{a-j}	103 ^{ghi}	148 ^{a-g}	71.9 ^g	9.6 ^{i-r}	5.3 ^{b-j}	3.1 ^{b-g}	6.8 ^{a-k}	6458 ^{c-h}	2875 ^{c-k}	44.46 ^{a-f}
G3	105 ^{c-f}	155.5 ^{a-f}	81.1 ^h	8.9 ^{k-u}	5.4 ^{h-}	4.7 ^{a-g}	6.2 ^{a-d}	8250	3541.7 ^c	43.075 ^a	113 ^{a-d}	143.5 ^{c-g}	61.1 ^q	7.8 ^{t-u}	3.9 ^j	2.6 ^{d-g}	5.1 ^{d-k}	6000 ^{c-h}	2250 ^{f-o}	37.39 ^{b-l}
G4	106 ^{b-e}	155.5 ^{a-f}	69.8 ^p	11.7 ^a	5.5 ^{g-}	5.0 ^{a-e}	5.8 ^{a-e}	7333	3750 ^{a-k}	51.135 ^a	107 ^{e-i}	148 ^{a-g}	62.7 ^p	9.8 ^{h-r}	4.7 ^{e-j}	4.3 ^{a-d}	7.9 ^{a-g}	7333 ^{b-h}	2375 ^{e-o}	32.195 ^c
G5	108 ^{a-d}	160.5 ^a	84.3 ^e	9.6 ^{g-s}	7.1 ^{a-j}	4.2 ^{a-i}	5.3 ^{a-g}	9458	5208.3 ^a	54.08 ^{a-g}	113.5 ^{a-d}	153.5 ^a	90.2 ^c	12.0 ^b	7.3 ^{a-d}	3.7 ^{a-g}	6.8 ^{a-k}	8563 ^{b-h}	3750 ^{bcd}	44.24 ^{a-g}
G6	108 ^{a-d}	144.0 ^{b-l}	65.5 st	7.3 ^{tuw}	5.2 ^{j-m}	4.6 ^{a-h}	5.8 ^{a-e}	6250	2750 ^{b-l}	45.16 ^{a-i}	115 ^{ab}	142.5 ^{efg}	45.1 ^t	7.2 ^u	4.8 ^{e-j}	4.1 ^{a-f}	4.8 ^{f-k}	6042 ^{c-h}	2166.7 ^e	36.31 ^{b-l}
G7	108 ^{a-d}	159.5 ^{ab}	87.9 ^e	12 ^{a-e}	7.6 ^{a-e}	2.8 ^{e-j}	4.8 ^{a-g}	1033	5333.3 ^a	51.88 ^{a-g}	110 ^{b-e}	147.5 ^{a-g}	81.6 ^d	12.9 ^a	5.7 ^{b-j}	3.9 ^{a-g}	8.3 ^{a-e}	10500 ^a	3520.8 ^b	33.32 ^{c-l}
G8	102 ^{ef}	144.0 ^{b-l}	81.9 ^g	8.6 ^{l-v}	7.1 ^{a-j}	3.3 ^{d-j}	4.3 ^{c-g}	7375	3166.7 ^e	50.585 ^a	103 ^{ghi}	143 ^{d-g}	66.9 ^k	8.9 ^{m-}	7.3 ^{a-d}	2.8 ^{c-g}	4.7 ^{f-k}	4833 ^h	1916.7 ^h	39.385 ^a
G9	102 ^{ef}	152.5 ^{a-j}	93.4 ^b	10.4 ^e	5.1 ^{kl}	3.0 ^{e-j}	4.0 ^{c-g}	7792	3791.7 ^a	48.565 ^a	110 ^{b-e}	143 ^{d-g}	57.4 st	10 ^{g-q}	4.0 ^{ij}	3.3 ^{a-g}	6.3 ^{a-k}	5125 ^{fgh}	1666.7 ^j	31.1 ^{d-l}
G10	110.5 ^{ab}	158.0 ^{a-d}	68.5 ^q	10.5 ^d	7.3 ^{a-h}	3.9 ^{b-j}	4.4 ^{c-g}	7458	3708.3 ^a	49.39 ^{a-h}	117.0 ^a	148 ^{a-g}	73.1 ^{f-}	10.3 ^{f-}	7.6 ^{ab}	2.5 ^{efg}	5.7 ^{b-k}	8313 ^{b-h}	2833.3 ^c	34.33 ^{c-l}
G11	105 ^{c-f}	153.0 ^{a-i}	80.0 ^h	10.2 ^e	6.7 ^{a-l}	4.3 ^{a-i}	5.3 ^{a-g}	8375	4333.3 ^a	51.64 ^{a-g}	113 ^{a-d}	143.5 ^{c-g}	58.8 ^r	8.4 ^{p-u}	4.5 ^{f-j}	3.4 ^{a-g}	6.5 ^{a-k}	5750 ^{d-h}	2333.3 ^f	40.81 ^{a-i}
G12	104 ^{def}	149.0 ^{c-l}	77.7 ^k	8.7 ^{k-u}	5.7 ^{e-}	3.4 ^{d-j}	3.6 ^{d-g}	6625	2375 ^{ijkl}	36.08 ^{e-j}	110 ^{b-e}	143 ^{d-g}	77.6 ^d	9.5 ^{j-s}	6.3 ^{a-i}	2.4 ^{fg}	4.1 ^{ijk}	6854 ^{b-h}	1229.2 ^o	20.79 ^l
G13	110.5 ^{ab}	150.5 ^{a-l}	61.5 ^u	7.7 ^{t-v}	5.5 ^{g-}	4.5 ^{a-i}	5.2 ^{a-g}	5708	2333.3 ^j	40.74 ^{b-j}	117 ^a	143 ^{d-g}	61.4 ^q	9.1 ^{l-u}	5.1 ^{c-j}	3.0 ^{b-g}	6.4 ^{a-k}	6313 ^{c-h}	1375 ^{no}	21.82 ^{kl}
G14	105 ^{c-f}	156.5 ^{a-e}	66.5 ^{r-}	8.7 ^{k-u}	7.2 ^{a-i}	3.9 ^{b-j}	4.7 ^{b-g}	8375	5208.3 ^a	62.05 ^a	115 ^{ab}	153 ^{ab}	80.3 ^d	11.1 ^d	8.2 ^a	3.3 ^{a-g}	6.6 ^{a-k}	9146 ^{a-e}	3791.7 ^b	41.49 ^{a-i}
G15	101 ^f	149.0 ^{c-l}	86.2 ^e	13.2 ^a	7.4 ^{a-g}	3.3 ^{d-j}	4.7 ^{b-g}	7417	3375 ^{e-l}	45.81 ^{a-i}	111.5 ^{a-e}	146 ^{a-g}	78.4 ^d	12.8 ^a	5.8 ^{b-j}	2.5 ^{fg}	6.2 ^{a-k}	7458 ^{b-h}	2479.2 ^c	33.05 ^{c-l}
G16	106 ^{b-e}	151.5 ^{a-k}	78.4 ⁱ⁻	12.6 ^a	6.6 ^{a-l}	4.8 ^{a-f}	5.6 ^{a-e}	6042 ^j	3416.7 ^d	56.14 ^{a-e}	111.5 ^{a-e}	143 ^{d-g}	67.7 ^{j-}	12.4 ^a	5.1 ^{c-j}	3.2 ^{a-g}	7.5 ^{a-i}	5646 ^{d-h}	1854.2 ⁱ	36.12 ^{b-l}
G17	102 ^{ef}	146.0 ^{f-l}	89.3 ^d	8.65 ^{l-}	6.7 ^{a-l}	3.0 ^{e-j}	3.9 ^{d-g}	5417 ^l	2291.7 ^j	42.81 ^{a-j}	108.5 ^{c-g}	148 ^{a-g}	78.2 ^d	10.7 ^{f-}	4.8 ^{e-j}	3.2 ^{a-g}	5.6 ^{b-k}	7021 ^{b-h}	2416.7 ^d	35.24 ^{b-l}
G18	101 ^f	150.5 ^{a-l}	74.7 ⁿ	9.4 ^{i-s}	7.5 ^{a-f}	4.1 ^{a-j}	5.0 ^{a-g}	7292	3541.7 ^c	48.12 ^{a-h}	107 ^{e-i}	142.5 ^{efg}	66 ^{m-s}	9.7 ^{i-r}	5.0 ^{d-j}	2.6 ^{d-g}	5.0 ^{e-k}	5813 ^{d-h}	2083.3 ^g	35.69 ^{b-l}
G19	101 ^f	146.0 ^{f-l}	87.0 ^e	11 ^{b-j}	7.1 ^{a-j}	2.3 ^{hij}	3.1 ^{efg}	6625	3666.7 ^a	55.93 ^{a-f}	104 ^{f-i}	145.5 ^{a-g}	92.7 ^b	11.5 ^c	5.9 ^{a-j}	2.9 ^{b-g}	4.5 ^{g-k}	8063 ^{b-h}	2791.7 ^c	34.74 ^{c-l}
G20	103 ^{ef}	144.0 ^{b-l}	90.2 ^d	10.7 ^c	7.5 ^{a-f}	3.8 ^{c-j}	4.6 ^{b-g}	1083	3708.3 ^a	35.24 ^{f-j}	102 ⁱ	147.5 ^{a-g}	72.4 ^g	10.7 ^{f-}	5.5 ^{b-j}	3.1 ^{b-g}	6.4 ^{a-k}	9792 ^{abc}	2708.3 ^c	27.54 ^{e-l}
G21	102 ^{ef}	150.5 ^{a-l}	74.6 ⁿ	10.4 ^e	5.1 ^{kl}	4.3 ^{a-i}	5.6 ^{a-e}	9042	4833.3 ^a	53.42 ^{a-g}	104 ^{f-i}	143.5 ^{c-g}	90.2 ^c	11.7 ^c	5.0 ^{d-j}	3.1 ^{b-g}	8.0 ^{a-f}	12688 ^a	3729.2 ^b	31.84 ^{d-l}
G22	103 ^{ef}	150.5 ^{a-l}	91.2 ^c	10.4 ^e	6.8 ^{a-k}	2.5 ^{f-j}	3.4 ^{d-g}	6708	3208.3 ^e	49.295 ^a	104 ^{f-i}	148 ^{a-g}	84.1 ^d	11 ^{d-m}	6.3 ^{a-i}	3.3 ^{a-g}	6.2 ^{a-k}	7458 ^{b-h}	3166.7 ^c	44.09 ^{a-g}
G23	109 ^{abc}	147.0 ^{e-l}	78.0 ^{j-}	7.6 ^{s-v}	6.7 ^{a-l}	2.6 ^{f-j}	3.6 ^{d-g}	8208	3958.3 ^a	48.305 ^a	107 ^{e-i}	143.5 ^{c-g}	78.5 ^d	9.7 ^{i-r}	5.8 ^{b-j}	3.1 ^{b-g}	4.2 ^{ijk}	7667 ^{b-h}	2916.7 ^c	38.56 ^{a-k}
G24	101 ^f	141.5 ^{kl}	88.0 ^d	13.2 ^a	6.4 ^{b-}	3.6 ^{d-j}	4.9 ^{a-g}	7875	3291.7 ^e	41.225 ^b	102 ⁱ	140 ^g	84.5 ^d	13.9 ^a	6.4 ^{a-h}	3.5 ^{a-g}	7.1 ^{a-k}	8375 ^{b-h}	2500 ^{c-o}	29.45 ^{d-l}
G25	102 ^{ef}	150.5 ^{a-l}	104.	9.7 ^{g-r}	5.5 ^{g-}	2.5 ^{f-j}	2.9 ^{efg}	8833	4416.7 ^a	49.91 ^{a-g}	102.5 ^{hi}	143 ^{d-g}	102.	10.9 ^d	5 ^{d-j}	3.2 ^{a-g}	4.4 ^{h-k}	8000 ^{b-h}	2500 ^{c-o}	31.47 ^{d-l}

G26	101 ^f	142.0 ^{kl}	75.6 ^{l-}	7.75 ^{l-}	7.5 ^{a-f}	3.6 ^{d-j}	4.6 ^{b-g}	6667	2708.3 ^h	40.365 ^b	106.5 ^{e-i}	141 ^{fg}	66.7 ^{l-}	8.2 ^{q-u}	4.7 ^{d-j}	3.2 ^{a-g}	3.7 ^k	5792 ^{d-h}	1750 ^{j-o}	30.35 ^{d-l}
G27	102 ^{ef}	140.5 ^{l^{ef}}	98.1 ^a	11.1 ^b	7.7 ^{a-d}	4.7 ^{a-g}	5.5 ^{a-f}	1012	2333.3 ^j	23.725 ^j	113.5 ^{a-d}	142.5 ^{fg}	78.7 ^d	9.9 ^{g-r}	6.7 ^{a-f}	3.5 ^{a-g}	6.4 ^{a-k}	6083 ^{c-h}	1458.3 ^l	25.69 ^{h-l}
G28	106 ^{b-e}	158.0 ^{a-d}	83.9 ^e	11.6 ^a	6 ^{c-m}	4.6 ^{a-h}	5.6 ^{a-e}	8833	4166.7 ^a	47.59 ^{a-h}	115 ^{ab}	148.5 ^{a-f}	73.9 ^{f-}	11.3 ^c	5.1 ^{c-j}	4.2 ^{a-e}	7.7 ^{a-h}	5771 ^{d-h}	2291.7 ^f	39.99 ^{a-j}
G29	102 ^{ef}	143.0 ^{i-l}	79.1 ^{l-}	9.6 ^{g-s}	8.5 ^a	3.6 ^{d-j}	3.9 ^{d-g}	7667	2708.3 ^h	35.405 ^f	107 ^{e-i}	142.5 ^{efg}	72.7 ^{f-}	9.0 ^{l-u}	5.9 ^{a-j}	3.0 ^{b-g}	5.0 ^{e-k}	5396 ^{e-h}	1583.3 ^k	29.98 ^{d-l}
G30	108 ^{a-d}	151.5 ^{a-k}	111.	11.5 ^a	7.0 ^{a-k}	3.3 ^{d-j}	3.7 ^{d-g}	7917	3375 ^{e-l}	42.155 ^a	111.5 ^{a-e}	150.5 ^{a-e}	94.9 ^b	11.1 ^d	5.0 ^{d-j}	3.0 ^{b-g}	5.5 ^{b-k}	9208 ^{a-d}	3500 ^{b-f}	37.35 ^{b-l}
G31	106 ^{b-e}	156.5 ^{a-e}	80.6	10.6 ^d	6.5 ^{b-}	4.4 ^{a-i}	6.1 ^{a-d}	8042	4041.7 ^a	49.175 ^a	110 ^{b-e}	142.5 ^{efg}	65.8	11.1 ^d	5.7 ^{b-j}	4.9 ^a	8.0 ^{a-f}	4875 ^h	2145.8 ^f	45 ^{a-e}
G32	108 ^{a-d}	154.0 ^{a-h}	85.5	9.6 ^{g-s}	6.4 ^{b-}	1.8 ^j	3.1 ^{efg}	7458	3458.3 ^c	44.485 ^a	117 ^a	151 ^{a-d}	85.6 ^d	11.3 ^c	5.9 ^{a-j}	3.6 ^{a-g}	5.5 ^{b-k}	9167 ^{a-e}	2895.8 ^c	31.59 ^{d-l}
G33	102 ^{ef}	148.0 ^{d-l}	91.5 ^c	12.4 ^a	6.0 ^{c-}	3.9 ^{b-j}	4.6 ^{b-g}	7833	4791.7 ^a	60.95 ^{ab}	104 ^{f-i}	147.5 ^{a-g}	70.4 ^h	9.9 ^{g-r}	5.1 ^{c-j}	2.7 ^{d-g}	5.4 ^{c-k}	6354 ^{c-h}	2729.2 ^c	42.57 ^{a-h}
G34	105 ^{c-f}	142.5 ^{kl}	83.9 ^e	8.6 ^{l-v}	7.4 ^{a-g}	2.8 ^{e-j}	3.5 ^{d-g}	6917	3125 ^{e-l}	45.82 ^{a-i}	117 ^a	151 ^{a-d}	85.3 ^d	11.9 ^c	6.2 ^{a-j}	3.5 ^{a-g}	6.6 ^{a-k}	8583 ^{b-h}	2833.3 ^c	32.99 ^{c-l}
G35	108.5 ^{a-d}	156.5 ^{a-e}	107.	11.6 ^a	8.1 ^{ab}	2.4 ^{g-j}	3.0 ^{efg}	8667	3666.7 ^a	42.27 ^{a-j}	114 ^{abc}	147.5 ^{a-g}	87.0 ^c	11.9 ^c	6.2 ^{a-j}	3.1 ^{b-g}	7.7 ^{a-h}	9229 ^{a-d}	3458.3 ^b	39.11 ^{a-k}
G36	102 ^{ef}	150.5 ^{a-l}	82.5 ^g	9.7 ^{g-r}	6.7 ^{a-l}	5.5 ^{a-d}	6.9 ^{abc}	9875	4000 ^{a-j}	42.865 ^a	111.5 ^{a-e}	148 ^{a-g}	76.7 ^e	10.5 ^{f-}	6.8 ^{a-f}	4 ^{a-f}	9.2 ^a	6500 ^{c-h}	3250 ^{b-g}	49.85 ^{ab}
G37	110.5 ^{ab}	154.0 ^{a-h}	94.4 ^b	9.9 ^{f-q}	8.5 ^a	3.4 ^{d-j}	4.5 ^{b-g}	9250	2458.3 ⁱ	29.065 ^h	117 ^a	150.5 ^{a-e}	82.1 ^d	10.5 ^{f-}	6.2 ^{a-j}	4.2 ^{a-e}	6.1 ^{a-k}	6958 ^{b-h}	2208.3 ^f	31.77 ^{d-l}
G38	103 ^{ef}	145.0 ^{g-l}	98.0 ^a	13.1 ^a	8.5 ^a	4.4 ^{a-i}	5.5 ^{a-f}	8583	3833.3 ^a	43.885 ^a	110 ^{b-e}	148 ^{a-g}	89.1 ^c	12.3 ^a	6.8 ^{a-f}	3.1 ^{b-g}	5.7 ^{b-k}	7250 ^{b-h}	2458.3 ^c	34.06 ^{c-l}
G39	108 ^{a-d}	153.0 ^{a-i}	84.0 ^e	9.6 ^{g-s}	5.8 ^{d-}	3.2 ^{d-j}	3.8 ^{d-g}	8875	3500 ^{c-l}	39.395 ^c	103.5 ^{f-i}	143.5 ^{c-g}	74.2 ^{f-}	8.7 ^{o-u}	5.8 ^{b-j}	3.0 ^{b-g}	6.0 ^{a-k}	6729 ^{b-h}	2666.7 ^c	38.91 ^{a-k}
G40	101 ^f	142.5 ^{kl}	85.2 ^e	9.95 ^{f-}	4.6 ^m	3.8 ^{c-j}	4.2 ^{c-g}	5333	2416.7 ⁱ⁻	45.235 ^a	104 ^{f-i}	143 ^{d-g}	76.8 ^e	10.3 ^{f-}	4.5 ^{f-j}	3.8 ^{a-g}	5.5 ^{b-k}	5000 ^{gh}	1729.2 ^j	35.63 ^{b-l}
G41	101 ^f	157.0 ^{a-e}	90.1 ^d	10 ^{f-b}	7.7 ^{a-d}	3.5 ^{d-j}	4.2 ^{c-g}	8917	5166.7 ^{a-}	58.845 ^a	110 ^{b-e}	145.5 ^{a-g}	72.4 ^g	10.5 ^{f-}	7.4 ^{abc}	2.7 ^{d-g}	4.8 ^{f-k}	5792 ^{d-h}	2291.7 ^f	39.07 ^{a-k}
G42	109 ^{abc}	155.5 ^{a-f}	75.0	8.5 ^{m-}	5.3 ^{a-m}	2.4 ^{g-j}	2.4 ^g	6875	3208.3 ^e	46.47 ^{a-i}	117 ^a	142 ^{fg}	69.1 ⁱ⁻	9.4 ^{i-t}	5.8 ^{b-j}	3.4 ^{a-g}	4.5 ^{g-k}	6417 ^{c-h}	1729.2 ^j	27.06 ^{f-l}
G43	101f	145.5 ^{f-l}	83.5 ^{f-}	8.4 ^{n-v}	5.6 ^{f-}	4.6 ^{a-h}	5.8 ^{a-e}	6667	3583.3 ^b	53.96 ^{a-g}	108.5 ^{c-g}	143 ^{d-g}	69.9 ^h	10.8 ^e	5.1 ^{c-j}	4.6 ^{ab}	8.8 ^{abc}	4875 ^h	2208.3 ^f	45.505 ^a
G44	108 ^{a-d}	150.5 ^{a-l}	78.9 ⁱ⁻	9.9 ^{f-q}	6 ^{c-m}	3.0 ^{e-j}	3.5 ^{d-g}	8208	3083.3 ^e	37.36 ^{d-j}	111.5 ^{a-e}	142.5 ^{efg}	67.5 ^k	9.8 ^{h-r}	5.8 ^{b-j}	2.2 ^g	4.7 ^{f-k}	5792 ^{d-h}	1291.7 ⁿ	22.39 ^{kl}
G45	101 ^f	145 ^{g-l}	66.8 ^{r-}	6.7 ^v	6.1 ^{c-}	3.1 ^{e-j}	5.0 ^{a-g}	7000	3250 ^{e-l}	45.95 ^{a-i}	104 ^{f-i}	145 ^{b-g}	64.1 ⁿ	7.5 ^{tu}	5.0 ^{b-j}	4.0 ^{a-f}	8.5 ^{a-d}	6167 ^{c-h}	2333.3 ^f	37.92 ^{b-l}
G46	105.5 ^{c-f}	141.5 ^{kl}	91.5 ^c	9.4 ^{i-s}	7.7 ^{a-d}	4.0 ^{b-j}	4.4 ^{c-g}	9250	3708.3 ^a	42.765 ^a	110 ^{b-e}	141 ^{fg}	76.1 ^e	10 ^{g-q}	5.6 ^{b-j}	3.2 ^{a-g}	4.7 ^{f-k}	7333 ^{b-h}	2541.7	37.5 ^{b-l}
G47	103 ^{ef}	145.5 ^{f-l}	83.2 ^{f-}	9.2 ^{i-t}	7.9 ^{abc}	3.7 ^{d-j}	4.4 ^{c-g}	5250	2458.3 ⁱ	46.99 ^{a-h}	115 ^{ab}	141 ^{fg}	79.9 ^d	9.6 ^{i-r}	6.3 ^{a-i}	3.4 ^{a-g}	4.6 ^{f-k}	6208 ^{c-h}	1729.2 ^j	30.06 ^{d-l}
G48	106 ^{b-e}	154.5 ^{a-g}	83.0	9.8 ^{f-q}	7.4 ^{a-g}	4.1 ^{a-j}	5.2 ^{a-g}	7500	3750 ^{a-k}	51.595 ^a	109 ^{c-f}	150.5 ^{a-e}	83.9 ^d	9.5 ^{i-s}	6.9 ^{a-e}	3.3 ^{a-g}	6.1 ^{a-k}	7000 ^{b-h}	3000 ^{c-j}	42.74 ^{a-h}
G49	109 ^{abc}	150.5 ^{a-l}	85.1 ^e	9.0 ^{i-t}	7.8 ^{abc}	4.0 ^{b-j}	5.1 ^{a-g}	8458	3500 ^{c-l}	43.245 ^a	111.5 ^{a-e}	142.5 ^{efg}	76.1 ^e	10 ^{g-q}	6.5 ^{a-}	2.7 ^{d-g}	4.1 ^{ijk}	6167 ^{c-h}	2208.3 ^f	36.51 ^{b-l}
G50	105 ^{c-f}	156.5 ^{a-e}	70.4 ^o	11.6 ^a	7.2 ^{a-i}	6.1 ^{abc}	6.9 ^{abc}	6917	3000 ^{g-l}	43.175 ^a	113 ^{a-d}	148 ^{a-g}	63.4 ^o	11.1 ^d	4.7 ^{e-j}	4.5 ^{abc}	5.7 ^{b-k}	6208 ^{c-h}	2250 ^{f-o}	36.54 ^{b-l}
G51	103 ^{ef}	142.5 ^{kl}	76.2 ^{l-}	8.5 ^{m-}	7.9 ^{abc}	6.2 ^{ab}	7.4 ^{ab}	7750	2083.3 ^k	26.025 ^j	102 ^j	143 ^{d-g}	71.2 ^h	10.9 ^d	6.1 ^{a-j}	3.2 ^{a-g}	7.2 ^{a-j}	6771 ^{b-h}	1812.5 ^j	26.67 ^{g-l}
G52	105 ^{c-f}	154.5 ^{a-g}	81.0 ^h	7.9 ^{q-v}	8.5 ^a	2.3 ^{hij}	3.7 ^{d-g}	6833	2958.3 ^g	42.89 ^{a-j}	113 ^{a-d}	143.5 ^{c-g}	70.4 ^h	8.2 ^{q-u}	5.9 ^{a-j}	3.0 ^{b-g}	6.6 ^{a-k}	5333 ^{gh}	1541.7 ^k	30.05 ^{d-l}
G53	110.5 ^{ab}	159 ^{abc}	107.	13.1 ^a	5.2 ^{a-m}	3.5 ^{d-j}	3.8 ^{d-g}	8083	3500 ^{c-l}	43.08 ^{a-j}	111.5 ^{a-e}	148.5 ^{a-f}	114.	14.2 ^a	4.1 ^{hij}	3.7 ^{a-g}	5.4 ^{c-k}	8229 ^{c-h}	2416.7 ^d	29.2 ^{d-l}
G54	103 ^{ef}	149.5 ^{b-l}	99.5 ^a	13.2 ^a	5.7 ^{e-}	2.4 ^{g-j}	3.0 ^{efg}	7083	3291.7 ^e	46.545 ^a	113.5 ^{a-d}	145.5 ^{a-g}	67.4 ^k	10 ^{g-q}	5.1 ^{c-j}	2.6 ^{d-g}	4.0 ^{ik}	5917 ^{d-h}	2062.5 ^h	35.67 ^{b-l}
G55	106 ^{b-e}	159 ^{abc}	94.8 ^b	12.8 ^a	6.3 ^{b-}	3.9 ^{b-j}	4.3 ^{c-g}	8375	4291.7 ^a	51.015 ^a	111.5 ^{a-e}	151.5 ^{ab}	107.	13.2 ^a	4.7 ^{e-j}	3.2 ^{a-g}	6.6 ^{a-k}	8521 ^{b-h}	2479.2 ^c	29.29 ^{d-l}
G56	102 ^{ef}	146 ^{f-l}	85.1 ^e	8.2 ^{o-v}	6 ^{c-m}	2.7 ^{e-j}	5.8 ^{a-e}	6042 ^j	2333.3 ^j	37.825 ^d	115 ^{ab}	145 ^{b-g}	70.3 ^h	7.4 ^{tu}	4.7 ^{e-j}	3.0 ^{b-g}	6.4 ^{a-k}	6667 ^{c-h}	2312.5 ^f	35.285 ^b
G57	102 ^{ef}	149 ^{c-l}	75.3 ^{l-}	7.4 ^{uvw}	6.4 ^{b-}	2.8 ^{e-j}	3.4 ^{d-g}	8208	4541.7 ^a	54.835 ^a	107 ^{e-i}	147.5 ^{a-g}	78.5 ^d	8.7 ^{o-u}	6.0 ^{a-j}	3.7 ^{a-g}	6.0 ^{a-k}	7667 ^{b-h}	3166.7 ^c	41.415 ^a
G58	105 ^{f-c}	149.5 ^{b-l}	95.9 ^a	12 ^{a-e}	7.3 ^{a-h}	3.0 ^{e-j}	4.0 ^{c-g}	8708	3041.7 ^f	34.92 ^{g-j}	115 ^{ab}	145.5 ^{a-g}	65.6	8.7 ^{o-u}	6.0 ^{a-j}	2.9 ^{b-g}	8.7 ^{abc}	5958 ^{d-h}	2479.2 ^c	42.82 ^{a-h}

G59	104 ^{def}	150 ^{b-l}	84.5 ^e	8.9 ^{k-u}	6.8 ^{a-k}	3.9 ^{b-j}	4.2 ^{c-g}	6167 ⁱ	2833.3 ^g	46.43 ^{a-i}	114 ^{abc}	145.5 ^{a-g}	74.8 ^f	9.8 ^{b-r}	5.6 ^{b-j}	3.7 ^{a-g}	6.4 ^{a-k}	5854 ^{d-h}	1708.3 ^j	31.75 ^{d-l}
G60	109 ^{abc}	157 ^{a-e}	100.	10.4	6.3 ^b	4.0 ^{b-j}	6.2 ^{a-d}	7708	3458.3 ^c	44.5 ^{a-i}	111.5 ^{a-e}	153.5 ^a	80.5 ^d	10.1 ^g	5.5 ^{b-j}	4.6 ^{ab}	8.9 ^{ab}	8771 ^{b-g}	2520.8 ^c	28.765 ^d
G61	106 ^{b-e}	147 ^{e-l}	64.8 ^t	9.9 ^{f-q}	6.6 ^{a-l}	3.9 ^{b-j}	4.8 ^{a-g}	5125	1833.3 ^l	36.015 ^e	107 ^{a-i}	141 ^{fg}	67.1 ^k	9.2 ^{k-u}	4.8 ^{e-j}	2.9 ^{b-g}	5.4 ^{c-k}	5771 ^{d-h}	1479.2 ^l	25.78 ^{h-l}
G62	105 ^{c-f}	149 ^{c-l}	87.8 ^e	8.0 ^{p-v}	7.6 ^{a-d}	2.2 ^{ij}	2.6 ^{fg}	7625	3333.3 ^e	43.885 ^a	104 ^{g-h}	148.5 ^{a-f}	83.1 ^d	9.5 ^{j-s}	5.9 ^{a-j}	3.1 ^{b-g}	7.7 ^{a-h}	8125 ^{b-h}	2520.8 ^c	30.91 ^{d-l}
St. check	101 ^f	154.5 ^{a-g}	81.5 ^h	7.0 ^{uv}	4.8 ^{lm}	4.3 ^{a-i}	5.0 ^{a-g}	8917	5166.7 ^a	57.27 ^{a-d}	108 ^{d-h}	152 ^{ab}	80.3 ^d	8.8 ^{n-u}	5.1 ^{c-j}	3.7 ^{a-g}	6.5 ^{a-k}	9229 ^{a-d}	5208.3 ^a	55.5 ^a
Local	103 ^{ef}	153 ^{a-i}	83.9 ^e	9.5 ^{h-s}	6.8 ^{a-k}	6.4 ^a	7.7 ^a	9667	5375 ^a	55.68 ^{a-f}	110 ^{b-e}	153 ^{ab}	77.8 ^d	10.8 ^e	5.3 ^{b-j}	4.1 ^{a-f}	8.8 ^{abc}	8813 ^{b-f}	4604.2 ^a	52.68 ^{ab}
Mean	104.79	150.5	84.3	9.92	7.58	3.71	4.66	7759	3533.8	45.82	109.94	145.81	76.1	10.2	5.63	3.33	6.16	7069.3	2464.1	35.24
LSD	4.08	8.41	14.2	1.62	1.55	2.02	2.54	2358	1513.5	17.61	4.85	6.48	15.2	1.76	1.92	1.45	2.81	3056.4	1172.1	15.07
Sig. L.	****	****	****	****	****	*	ns	**	****	*	****	****	****	****	*	ns	*	ns	****	*
CV (%)	1.79	2.79	7.83	8.17	11.5	25.4	25.6	14.1	20.16	18.21	2.09	2.22	9.35	8.29	17.0	20.6	22.7	21.64	22.45	20.19

Sig. L. – Significant level, CV- Coefficient of Variation

Means along the column with the same letter are not significantly different

Appendix Table 5.4 Percent Mean leaf incidence and severity in 2022 and 2023 cropping season

Genotypes	Adet						Fenotselam					
	2022			2023			2022			2023		
	LBI	LBS	LAUD PC	LBI	LBS	LAUD PC	LBI	LBS	LAUD PC	LBI	LBS	LAUD PC
G1	60.11 ^a	33.78 ^a	1365.6 ^{a-}	48.78 ^a	25.60 ^a	1066 ^{a-d}	67.34 ^b	32.21 ^e	466.7 ^{f-o}	48.78 ^a	25.60 ^a	852.8 ^{a-i}
G2	43.28 ^a	20.11 ^a	796.0 ^{a-f}	24.41 ^a	13.09 ^a	569.4 ^{a-d}	72.51 ^a	37.68 ^a	552.8 ^{e-o}	24.41 ^a	13.09 ^a	683.3 ^{a-m}
G3	45.47 ^a	21.68 ^a	851.5 ^{a-g}	24.41 ^a	11.84 ^a	511.7 ^{a-d}	82.54 ^a	45.75 ^a	727.8 ^{b-k}	24.41 ^a	11.84 ^a	569.4 ^{d-n}
G4	48.66 ^a	29.08 ^a	1174.7 ^{a-f}	44.78 ^a	24.63 ^a	1008.1 ^{a-}	63.22 ^c	30.29 ^{f-}	377.8 ^{j-o}	44.78 ^a	24.63 ^a	627.8 ^{c-m}
G5	52.16 ^a	25.09 ^a	1043.8 ^{a-f}	47.33 ^a	21.3 ^{abc}	891.9 ^{a-d}	64.15 ^c	30.06 ^{f-}	488.9 ^{f-o}	47.33 ^a	21.30 ^a	211.1 ^{nm}
G6	16.09 ^b	6.01 ^{bcd}	215.5 ^{c-f}	0.00 ^{bc}	0.00 ^c	0.0 ^d	77.52 ^a	43.19 ^a	794.4 ^{a-h}	0.00 ^{bc}	0.00 ^c	338.9 ^{j-n}
G7	55.74 ^a	29.04 ^a	1223.5 ^{a-f}	27.88 ^a	13.6 ^{abc}	586.2 ^{a-d}	62.19 ^c	32.85 ^d	488.9 ^{f-o}	27.88 ^a	13.60 ^a	1150 ^{ab}
G8	35.67 ^a	14.68 ^a	582.6 ^{a-f}	19.18 ^a	8.77 ^{abc}	353.6 ^{a-d}	84.64 ^a	45.99 ^a	802.8 ^{a-h}	19.18 ^a	8.77 ^{abc}	772.2 ^{a-l}
G9	35.37 ^a	13.48 ^a	483.3 ^{a-f}	40.14 ^a	19.01 ^a	715.9 ^{a-d}	66.25 ^b	30.12 ^{f-}	436.1 ^{g-o}	40.14 ^a	19.01 ^a	561.1 ^{e-n}
G10	25.60 ^a	14.15 ^a	580.7 ^{a-f}	0.00 ^{bc}	0.00 ^c	0.0 ^d	82.55 ^a	43.87 ^a	813.9 ^{a-f}	0.00 ^{bc}	0.00 ^c	883.3 ^{a-g}
G11	63.28 ^a	33.92 ^a	1410.4 ^{a-}	46.32 ^a	23.56 ^a	949.4 ^{a-d}	75.51 ^a	37.39 ^a	558.3 ^{d-o}	46.32 ^a	23.56 ^a	358.3 ^{j-n}
G12	57.62 ^a	31.70 ^a	1332.5 ^{a-}	42.48 ^a	20.64 ^a	862.1 ^{a-d}	63.02 ^c	32.23 ^e	455.6 ^{f-o}	42.48 ^a	20.64 ^a	713.9 ^{a-l}
G13	26.76 ^a	15.43 ^a	632.1 ^{a-f}	35.56 ^a	16.22 ^a	658.1 ^{a-d}	43.32 ^{ij}	18.92 ⁿ	225 ^o	35.56 ^a	16.22 ^a	305.6 ^{j-n}
G14	0.00 ^e	0.00 ^d	0.00 ^f	0.00 ^c	0.00 ^c	0.0 ^d	58.44 ^d	31.10 ^e	405.6 ^{j-o}	0.00 ^c	0.00 ^c	397.2 ^{g-n}
G15	46.52 ^a	21.05 ^a	867.5 ^{a-f}	37.98 ^a	17.29 ^a	711.5 ^{a-d}	88.62 ^a	45.26 ^a	805.6 ^{a-g}	37.98 ^a	17.29 ^a	483.3 ^{f-n}
G16	12.38 ^c	3.03 ^{cd}	151.4 ^{def}	10.07 ^a	3.03 ^{bc}	75.7 ^{bcd}	81.62 ^a	40.32 ^a	633.3 ^{b-n}	10.07 ^a	3.03 ^{bc}	791.7 ^{a-k}
G17	34.48 ^a	15.57 ^a	618.4 ^{a-f}	45.93 ^a	23.19 ^a	961.3 ^{a-d}	65.15 ^b	36.90 ^b	547.2 ^{e-o}	45.93 ^a	23.19 ^a	794.4 ^{a-k}
G18	44.99 ^a	22.89 ^a	961.4 ^{a-f}	20.58 ^a	9.15 ^{abc}	363.8 ^{a-d}	32.18 ^k	31.53 ^e	225 ^o	20.58 ^a	9.15 ^{abc}	472.2 ^{f-n}
G19	26.76 ^a	15.97 ^a	652.4 ^{a-f}	10.07 ^a	2.38 ^{bc}	59.5 ^{cd}	76.54 ^a	40.24 ^a	625 ^{b-n}	10.07 ^a	2.38 ^{bc}	377.8 ^{h-n}
G20	70.48 ^a	38.69 ^a	1570.1 ^a	51.17 ^a	25.71 ^a	1088.1 ^{ab}	94.97 ^a	50.42 ^a	927.8 ^{a-d}	51.17 ^a	25.71 ^a	583.3 ^{c-m}
G21	45.09 ^a	19.39 ^a	774.3 ^{a-f}	38.26 ^a	15.58 ^a	605.1 ^{a-d}	50.01 ^g	25.48 ^{j-}	300 ^{no}	38.26 ^a	15.58 ^a	283.3 ^{mn}
G22	51.20 ^a	28.48 ^a	1167.7 ^{a-f}	39.75 ^a	19.13 ^a	871.2 ^{a-d}	57.96 ^e	27.87 ^h	386.1 ^{j-o}	39.75 ^a	19.13 ^a	611.1 ^{c-m}
G23	31.13 ^a	17.65 ^a	729.7 ^{a-f}	47.33 ^a	25.19 ^a	1044.2 ^{a-}	69.15 ^b	31.13 ^e	427.8 ^{h-o}	47.33 ^a	25.19 ^a	708.3 ^{a-m}
G24	56.73 ^a	28.15 ^a	1145.1 ^{a-f}	48.66 ^a	24.01 ^a	976.9 ^{a-d}	76.53 ^a	38.45 ^a	569.4 ^{d-o}	48.66 ^a	24.01 ^a	675 ^{b-m}
G25	53.25 ^a	28.33 ^a	1206.4 ^{a-f}	43.81 ^a	22.94 ^a	951.8 ^{a-d}	76.53 ^a	40.37 ^a	497.2 ^{e-o}	43.81 ^a	22.94 ^a	358.3 ^{j-n}
G26	55.74 ^a	31.66 ^a	1288.4 ^{a-}	39.27 ^a	19.78 ^a	819.7 ^{a-d}	68.34 ^b	33.15 ^c	500 ^{e-o}	39.27 ^a	19.78 ^a	677.8 ^{b-m}
G27	64.35 ^a	38.22 ^a	1546.5 ^{ab}	46.32 ^a	24.64 ^a	1029.6 ^{a-}	90.70 ^a	51.05 ^a	961.1 ^{abc}	46.32 ^a	24.64 ^a	1077.8 ^{ab}
G28	48.82 ^a	21.47 ^a	870.4 ^{a-f}	43.81 ^a	14.57 ^a	575.5 ^{a-d}	67.34 ^b	30.49 ^e	525 ^{e-o}	43.81 ^a	14.57 ^a	608.3 ^{c-m}
G29	47.63 ^a	22.06 ^a	846.8 ^{a-f}	39.13 ^a	18.93 ^a	723.7 ^{a-d}	79.54 ^a	41.19 ^a	669.4 ^{b-m}	39.13 ^a	18.93 ^a	863.9 ^{a-h}

G30	51.17 ^a	27.77 ^a	1152.6 ^{a-f}	10.07 ^a	3.33 ^{bc}	120.7 ^{bc}	65.32 ^b	36.62 ^b	530.6 ^{e-o}	10.07 ^a	3.33 ^{bc}	300.00 ^{k-}
G31	0.00 ^e	0.00 ^d	0.00 ^f	0.00 ^c	0.00 ^c	0.0 ^d	64.35 ^c	33.36 ^c	508.3 ^{e-o}	0.00 ^c	0.00 ^c	311.1 ^{j-n}
G32	16.09 ^b	5.41 ^{bcd}	270.3 ^{b-f}	0.00 ^c	0.00 ^c	0.0 ^d	60.13 ^d	29.29 ^{f-}	388.9 ^{l-o}	0.00 ^c	0.00 ^c	861.1 ^{a-h}
G33	21.91 ^a	9.65 ^{a-d}	397.2 ^{a-f}	19.18 ^a	8.66 ^{abc}	362.1 ^{a-d}	82.63 ^a	43.48 ^a	730.6 ^{b-k}	19.18 ^a	8.66 ^{abc}	288.91 ^{mn}
G34	58.81 ^a	30.62 ^a	1303.4 ^{a-}	45.09 ^a	23.08 ^a	992.7 ^{a-d}	84.56 ^a	46.66 ^a	788.9 ^{a-i}	45.09 ^a	23.08 ^a	588.9 ^{c-m}
G35	12.38 ^c	3.03 ^{cd}	75.7 ^{ef}	10.07 ^a	2.83 ^{bc}	70.7 ^{cd}	75.54 ^a	36.56 ^b	550 ^{e-o}	10.07 ^a	2.83 ^{bc}	863.9 ^{a-h}
G36	25.60 ^a	14.13 ^a	559.8 ^{a-f}	10.07 ^a	2.38 ^{bc}	59.5 ^{cd}	74.54 ^a	37.23 ^b	630.6 ^{b-n}	10.07 ^a	2.38 ^{bc}	344.4 ^{j-n}
G37	52.16 ^a	26.67 ^a	1099.5 ^{a-f}	47.51 ^a	23.20 ^a	961.8 ^{a-d}	62.19 ^c	30.25 ^{f-}	413.9 ^{j-o}	47.51 ^a	23.2 ^{abc}	858.3 ^{a-i}
G38	69.15 ^a	36.94 ^a	1530.2 ^{ab}	54.48 ^a	30.84 ^a	1269.4 ^a	69.48 ^b	33.67 ^b	500 ^{e-o}	54.48 ^a	30.84 ^a	719.4 ^{a-l}
G39	26.76 ^a	15.01 ^a	603.8 ^{a-f}	14.34 ^a	6.79 ^{abc}	268.7 ^{a-d}	80.59 ^a	41.23 ^a	669.4 ^{b-m}	14.34 ^a	6.79 ^{abc}	991.7 ^{a-e}
G40	36.25 ^a	15.92 ^a	631.6 ^{a-f}	20.58 ^a	9.97 ^{abc}	404.7 ^{a-d}	81.54 ^a	40.60 ^a	683.3 ^{b-l}	20.58 ^a	9.97 ^{abc}	705.6 ^{a-m}
G41	24.75 ^a	6.43 ^{bcd}	160.6 ^{def}	0.00 ^{bc}	0.00 ^c	0.0 ^d	70.50 ^a	35.69 ^b	630.6 ^{b-n}	0.00 ^{bc}	0.00 ^c	419.4 ^{g-n}
G42	39.59 ^a	16.92 ^a	681.9 ^{a-f}	30.65 ^a	11.64 ^a	430.9 ^{a-d}	63.30 ^c	31.26 ^e	438.9 ^{f-o}	30.65 ^a	11.64 ^a	805.6 ^{a-j}
G43	55.67 ^a	31.47 ^a	1291.5 ^{a-}	38.00 ^a	18.08 ^a	762.5 ^{a-d}	65.32 ^b	35.49 ^b	547.2 ^{e-o}	38.00 ^a	18.08 ^a	422.2 ^{g-n}
G44	35.26 ^a	21.09 ^a	872 ^{a-f}	27.88 ^a	14.89 ^a	635.6 ^{a-d}	51.70 ^{f-}	23.14 ^{l-}	361.1 ^{k-o}	27.88 ^a	14.89 ^a	966.7 ^{a-f}
G45	50.01 ^a	24.92 ^a	1043 ^{a-f}	41.08 ^a	18.83 ^a	800.1 ^{a-d}	70.51 ^a	34.38 ^b	483.3 ^{f-o}	41.08 ^a	18.83 ^a	555.6 ^{e-n}
G46	61.19 ^a	33.59 ^a	1430.9 ^{a-}	49.94 ^a	25.38 ^a	1035.2 ^{a-}	90.70 ^a	51.64 ^a	983.3 ^{ab}	49.94 ^a	25.38 ^a	805.6 ^{a-j}
G47	36.83 ^a	15.86 ^a	632.1 ^{a-f}	24.41 ^a	11.81 ^a	501 ^{a-d}	64.87 ^b	32.41 ^d	444.4 ^{f-o}	24.41 ^a	11.81 ^a	769.4 ^{a-l}
G48	28.98 ^a	17.30 ^a	720.7 ^{a-f}	23.18 ^a	13.75 ^a	560.7 ^{a-d}	61.16 ^c	29.87 ^{f-}	475 ^{f-o}	23.18 ^a	13.75 ^a	677.8 ^{b-m}
G49	36.79 ^a	15.54 ^a	612.7 ^{a-f}	19.18 ^a	9.44 ^{abc}	387.2 ^{a-d}	90.75 ^a	48.43 ^a	866.7 ^{a-e}	19.18 ^a	9.44 ^{abc}	886.1 ^{a-g}
G50	49.79 ^a	26.44 ^a	1070.1 ^{a-f}	32.95 ^a	18.68 ^a	794.2 ^{a-d}	56.39 ^e	16.02 ^p	277.8 ^{no}	32.95 ^a	18.68 ^a	769.4 ^{a-l}
G51	65.25 ^a	35.57 ^a	1487.3 ^{ab}	49.79 ^a	27.17 ^a	1149.2 ^{ab}	100.3	55.41 ^a	1136.1 ^a	49.79 ^a	27.17 ^a	1180.6 ^a
G52	48.64 ^a	22.45 ^a	860.1 ^{a-f}	39.05 ^a	17.99 ^a	683.1 ^{a-d}	48.78 ^h	22.83	261.1 ^{no}	39.05 ^a	17.99 ^a	633.3 ^{c-m}
G53	41.36 ^a	19.3 ^{a-d}	724.8 ^{a-f}	31.98 ^a	12.57 ^a	455.1 ^{a-d}	78.54 ^a	42.78 ^a	738.9 ^{b-j}	31.98 ^a	12.57 ^a	394.4 ^{g-n}
G54	55.67 ^a	30.37 ^a	1271.6 ^{a-f}	46.32 ^a	24.35 ^a	1019.1 ^{a-}	72.45 ^a	37.76 ^a	597.2 ^{c-o}	46.32 ^a	24.35 ^a	400 ^{g-n}
G55	51.97 ^a	26.76 ^a	1073 ^{a-f}	40.50 ^a	19.34 ^a	748.9 ^{a-d}	77.54 ^a	41.16 ^a	602.8 ^{c-n}	40.50 ^a	19.34 ^a	794.4 ^{a-k}
G56	27.88 ^a	14.88 ^a	600.6 ^{a-f}	21.91 ^a	9.17 ^{abc}	369.1 ^{a-d}	71.52 ^a	38.31 ^a	686.1 ^{b-l}	21.91 ^a	9.17 ^{abc}	566.7 ^{e-n}
G57	27.76 ^a	9.94 ^{a-d}	366.9 ^{a-f}	0.00 ^c	0.00 ^c	0.00 ^d	71.51 ^a	37.11 ^b	513.9 ^{e-o}	0.00 ^c	0.00 ^c	572.2 ^{d-n}
G58	44.41 ^a	22.45 ^a	873.9 ^{a-f}	34.98 ^a	17.09 ^a	668.3 ^{a-d}	72.48 ^a	35.91 ^b	513.9 ^{e-o}	34.98 ^a	17.09 ^a	711.1 ^{a-m}
G59	57.88 ^a	32.14 ^a	1310.7 ^{a-e}	47.59 ^a	25.37 ^a	1019.2 ^{a-}	59.05 ^d	27.46 ⁱ⁻	433.3 ^{g-o}	47.59 ^a	25.37 ^a	619.4 ^{c-m}
G60	0.00 ^e	0.00 ^d	0.00 ^f	0.00 ^c	0.00 ^c	0.0 ^d	35.26 ^j	18.47 ^o	258.3 ^{no}	0.00 ^c	0.00 ^c	725 ^{a-l}
G61	10.07 ^d	2.83 ^{cd}	70.7 ^{ef}	34.48 ^a	14.51 ^a	557.4 ^{a-d}	51.97 ^{f-}	25.18 ^{l-}	330.6 ^{l-o}	34.48 ^a	14.51 ^a	861.1 ^{a-h}
G62	52.36 ^a	28.02 ^a	1154.5 ^{a-f}	43.76 ^a	21.38 ^a	870.9 ^{a-d}	82.54 ^a	43.09 ^a	713.9 ^{b-k}	43.76 ^a	21.38 ^a	1069.4 ^{a-}

Std. check	25.6 ^{a-e}	13.18 ^a	543.2 ^{a-f}	19.18 ^a	10.26 ^a	432.5 ^{a-d}	61.19 ^c	28.38 ^g	411.1 ^{j-o}	19.18 ^a	10.26 ^a	83.3 ⁿ
Local check	53.48 ^a	31.61 ^a	1287.5 ^{a-}	42.36 ^a	26.23 ^a	1062.7 ^{a-}	68.47 ^b	43.44 ^a	619.4 ^{b-n}	42.36 ^a	26.23 ^a	713.9 ^{a-l}
Mean	40.73	20.69	841.45	30.22	14.73	601.29	69.94	35.94	561.15	58.38	38.53	641.06
Sig.L (5%)	ns	ns	ns	ns	ns	ns	**	**	***	**	**	***
CV (%)	41.05	42.02	38.13	39.57	27.69	43.78	19.89	24.76	26.94	32.23	36.96	31.38

Std. standard, Sig. L. - Significant level

Appendix Table 5.5 Percent mean neck incidence and severity in western Amhara, Ethiopia

Genotypes	Adet						Fenotselam					
	2022			2023			2022			2023		
	NBI	NBS	NAUD PC	NBI	NBS	NAUD PC	NBI	NBS	NAUD PC	NBI	NBS	NAUD PC
G1	66.41 ^a	33.06 ^a	1644.4 ^{a-}	56.82 ^a	43.94 ^a	1943.3 ^{ab}	50.64 ^v	33.76 ^{c-}	605 ^{v-y}	75.54 ^a	69.83 ^b	1570 ^{e-p}
G2	62.87 ^a	46.70 ^a	1990.3 ^{a-}	51.06 ^a	38.95 ^a	1651.5 ^{a-}	66.69 ⁿ	44.31 ^o	920 ^{o-x}	67.45 ^{f-}	62.73 ^e	1345 ^{g-s}
G3	66.38 ^a	15.51 ^c	1005.3 ^{c-}	61.16 ^a	46.67 ^a	1946 ^{abc}	92.40 ^a	64.42 ^c	1465 ^{d-n}	81.54 ^a	76.88 ^a	1915 ^{a-f}
G4	32.18 ^a	40.83 ^a	1700.9 ^{a-f}	52.16 ^a	37.43 ^a	1395.7 ^{a-}	57.95 ^{s-}	33.92 ^{t-}	520 ^{xy}	50.01 ^{s-}	45.82 ^q	825 ^{u-y}
G5	38.27 ^a	44.36 ^a	1934.3 ^{a-}	61.19 ^a	45.56 ^a	1890.8 ^{ab}	51.92 ^u	33.02 ^u	645 ^{u-y}	52.29 ^{r-}	41.79 ^t	670 ^{xy}
G6	24.41 ^b	52.65 ^a	2016.5 ^{a-}	39.75 ^a	27.31 ^a	971.3 ^{a-h}	78.54 ^d	57.38 ^g	1290 ^{f-r}	43.76 ^w	37.89 ^v	590 ^y
G7	61.16 ^a	25.01 ^a	1262.8 ^{a-}	54.64 ^a	38.95 ^a	1621.9 ^{a-}	89.06 ^a	59.26 ^e	1420 ^{d-p}	79.54 ^a	73.02 ^a	1680 ^{b-k}
G8	66.15 ^a	58.71 ^a	2261.2 ^a	57.95 ^a	43.23 ^a	1815.3 ^{a-}	91.93 ^a	73.73 ^e	1645 ^{c-g}	82.55 ^a	79.15 ^a	1965 ^{a-e}
G9	61.18 ^a	31.97 ^a	1355.6 ^{a-}	66.42 ^a	51.05 ^a	2018.2 ^{ab}	95.22 ^a	77.07 ^a	1855 ^{a-e}	68.25 ^e	64.92 ^d	1420 ^{g-r}
G10	54.58 ^a	22.29 ^a	1210.3 ^{a-}	50.01 ^a	37.43 ^a	1540.4 ^{a-}	88.61 ^a	62.38 ^c	1380 ^{e-p}	69.48 ^e	62.40 ^e	1315 ^{i-u}
G11	68.47 ^a	39.11 ^a	1818.5 ^{a-}	61.19 ^a	47.89 ^a	2013.9 ^{ab}	100.2	78.68 ^a	2050 ^{abc}	70.50 ^e	65.22 ^d	1410 ^{g-r}
G12	55.83 ^a	22.57 ^a	1015.0 ^{c-}	57.96 ^a	41.34 ^a	1637.8 ^{a-}	74.45 ^g	54.58 ⁱ⁻	1255 ^{g-s}	74.53 ^b	69.76 ^b	1655 ^{c-}
G13	49.30 ^a	35.42 ^a	1592.8 ^{a-}	45.07 ^a	31.79 ^a	1428.5 ^{a-}	50.89 ^v	32.42 ^u	595 ^{v-y}	55.67 ^p	50.92 ⁿ	1060 ^{q-y}
G14	0.00 ^f	22.18 ^a	634.9 ^{fg}	0.00 ⁱ	0.00 ⁱ	0 ^h	70.34 ^{l-}	47.69 ⁿ	855 ^{q-x}	48.82 ^u	42.87 ^{s-}	705 ^{wwx}
G15	55.67 ^a	38.29 ^a	1665.3 ^{a-}	51.06 ^a	37.03 ^a	1675.7 ^{a-}	95.93 ^a	72.71 ^a	1790 ^{a-f}	74.54 ^b	68.79 ^c	1595 ^{d-o}
G16	24.41 ^b	50.05 ^a	1741.3 ^{a-f}	27.88 ^c	19.99 ^d	819.4 ^{c-h}	74.41 ^g	52.17 ^k	1125 ^{i-u}	58.81	50.09 ^o	955 ^{r-y}
G17	43.50 ^a	28.24 ^a	1393.7 ^{a-}	60.11 ^a	44.17 ^a	1816.7 ^{a-}	93.21 ^a	68.73 ^b	1600 ^{c-j}	65.39 ^g	55.84 ^{j-}	1120 ^{o-x}
G18	62.19 ^a	43.73 ^a	1841.5 ^{a-}	56.86 ^a	20.07 ^c	1044.3 ^{a-}	86.58 ^a	44.88 ^o	1300 ^{f-r}	57.95 ⁿ	49.98 ^o	855 ^{s-y}
G19	48.16 ^a	34.69 ^a	1435.1 ^{a-}	43.29 ^a	29.51 ^a	1244.4 ^{a-f}	63.30 ^p	42.93 ^p	755 ^{l-x}	66.41 ^g	60.42 ^g	1165 ^{m-}
G20	70.48 ^a	47.12 ^a	2060.5 ^{ab}	60.11 ^a	44.66 ^a	1973.7 ^{ac}	90.83 ^a	68.76 ^b	1555 ^{c-k}	71.52 ^d	66.63 ^d	1440 ^{f-r}
G21	48.78 ^a	42.03 ^a	1723.3 ^{a-f}	43.59 ^a	24.11 ^a	1085.2 ^{a-}	71.51 ^{j-}	53.11 ^k	1005 ^{l-x}	71.52 ^d	64.04 ^d	1350 ^{g-r}
G22	52.16 ^a	34.71 ^a	1599.3 ^{a-}	55.74 ^a	43.74 ^a	1785.6 ^{a-}	80.54 ^c	53.00 ^k	1095 ^{j-v}	66.42 ^g	60.04 ^g	1295 ^{i-u}
G23	34.24 ^a	48.21 ^a	1732 ^{a-f}	56.82 ^a	44.81 ^a	1851.7 ^{a-}	92.78 ^a	67.38 ^c	1500 ^{d-l}	74.48 ^b	69.66 ^b	1645 ^{c-}

G24	62.24 ^a	54.81 ^a	2285.4 ^a	57.95 ^a	42.13 ^a	1815.2 ^{a-}	90.75 ^a	74.65 ^a	1710 ^{b-g}	85.58 ^a	83.49 ^a	2060 ^{a-d}
G25	42.44 ^a	44.08 ^a	2001.7 ^{a-}	39.13 ^a	22.56 ^b	1220.5 ^{a-}	72.48 ⁱ⁻	41.69 ^p	715 ^{u-x}	72.53 ^c	67.69 ^d	1480 ^{e-q}
G26	69.40 ^a	44.32 ^a	1914 ^{a-d}	54.31 ^a	39.50 ^a	1613.7 ^{a-}	86.75 ^a	63.63 ^c	1385 ^{e-p}	78.54 ^a	73.23 ^a	1665 ^{c-l}
G27	70.50 ^a	46.40 ^a	2047.5 ^{ab}	61.16 ^a	45.73 ^a	1883.7 ^{ab}	95.38 ^a	86.65 ^a	2175 ^{ab}	72.27 ^d	69.92 ^b	1625 ^{c-n}
G28	50.01 ^a	26.02 ^a	1319.7 ^{a-}	46.36 ^a	31.45 ^a	1463.7 ^{a-}	70.78 ^k	49.51	950 ^{o-x}	60.06 ⁻	52.80	1175 ^{-w}
G29	65.25 ^a	39.30 ^a	1709.8 ^{a-f}	55.54 ^a	44.92 ^a	1911 ^{abc}	84.82 ^a	62.75 ^c	1410 ^{e-p}	66.33 ^g	59.28 ^g	1290 ^{-u}
G30	53.48 ^a	42.74 ^a	1757.2 ^{a-}	38.75 ^a	25.32 ^a	961.3 ^{a-h}	62.12 ^q	39.61 ^q	690 ^{u-y}	55.67 ^p	53.45 ⁻	1040 ^{q-y}
G31	44.44 ^a	48.58 ^a	1426.8 ^{a-}	12.38 ^g	5.12 ^{ghi}	128 ^{fgh}	69.91 ⁻	47.51 ⁿ	975 ^{m-x}	60.05 ⁻	53.78 ⁻	1040 ^{q-y}
G32	17.69 ^c	34.38 ^a	1246 ^{a-g}	0.00 ⁱ	0.00 ⁱ	0.00 ^h	59.85 ^{r-}	37.58 ^{r-}	680 ^{u-y}	63.28 ⁻	57.63 ^h	1175 ^{-w}
G33	56.86 ^a	37.59 ^a	1699.3 ^{a-f}	51.20 ^a	35.73 ^a	1571.5 ^{a-}	79.60 ^c	57.17 ^h	1395 ^{e-p}	68.34 ^e	64.04 ^d	1415 ^{g-r}
G34	61.16 ^a	52.70 ^a	2217.7 ^{ab}	59.01 ^a	45.19 ^a	1895.6 ^{ab}	98.64 ^a	73.42 ^a	1765 ^{a-f}	67.45 ⁻	61.68 ⁻	1305 ^{-u}
G35	12.38 ^d	56.38 ^a	1729.0 ^{a-f}	10.07 ^h	3.84 ^{hi}	217.9 ^{fgh}	65.87 ⁿ	39.63 ^q	845 ^{q-x}	64.15 ^h	59.51 ^g	1235 ^{-u}
G36	41.20 ^a	17.92 ^b	926.5 ^{d-g}	31.98 ^b	19.51 ^d	901.5 ^{b-h}	89.75 ^a	63.56 ^c	1500 ^{d-l}	67.15 ⁻	63.34 ^e	1365 ^{g-r}
G37	57.88 ^a	49.65 ^a	2059.4 ^{ab}	52.29 ^a	39.67 ^a	1678.8 ^{a-}	73.12 ^h	48.07 ⁿ	915 ^{p-x}	65.38 ^g	60.59 ^g	1330 ^{h-t}
G38	68.03 ^a	48.53 ^a	2164.6 ^{ab}	60.11 ^a	46.66 ^a	1992.8 ^{ab}	99.14 ^a	76.91 ^a	1855 ^{a-e}	76.54 ^a	70.29 ^b	1715 ^{b-j}
G39	56.73 ^a	33.69 ^a	1467.1 ^{a-}	51.17 ^a	36.74 ^a	1576 ^{a-e}	51.92 ^u	32.44 ^u	605 ^{v-y}	77.54 ^a	74.29 ^a	1800 ⁻ⁱ
G40	64.34 ^a	44.69 ^a	1830.5 ^{a-}	56.82 ^a	44.35 ^a	1805 ^{a-d}	93.87 ^a	70.76 ^b	1635 ^{c-h}	67.43 ⁻	63.14 ^e	1360 ^{g-r}
G41	36.67 ^a	26.40 ^a	1012.7 ^{c-}	28.47 ^c	12.46 ^{f-}	542.9 ^{e-h}	90.83 ^a	67.78 ^c	1550 ^{d-k}	72.39 ^c	67.26 ^d	1495 ^{e-q}
G42	43.29 ^a	26.55 ^a	1135.3 ^{b-}	41.36 ^a	25.79 ^a	1210.9 ^{a-}	63.87 ^o	37.77 ^{r-}	600 ^{v-y}	56.73 ^o	54.20 ^k	1085 ^{p-x}
G43	60.13 ^a	45.96 ^a	1944.1 ^{a-}	26.76 ^d	19.68 ^d	1047.7 ^{a-}	85.64 ^a	59.87 ^e	1250 ^{g-s}	66.33 ^g	62.24 ^e	1310 ^{-l-u}
G44	61.18 ^a	23.08 ^a	1331.5 ^{a-}	53.03 ^a	38.27 ^a	1697.9 ^{a-}	80.56 ^c	58.34 ^{f-}	1230 ^{g-t}	68.39 ^e	61.54 ^{f-}	1335 ^{h-t}
G45	55.67 ^a	39.61 ^a	1835.6 ^{a-}	59.01 ^a	44.01 ^a	1952.5 ^{ab}	83.58 ^b	65.51 ^c	1425 ^{d-o}	66.41 ^g	63.11 ^e	1350 ^{g-r}
G46	68.47 ^a	44.26 ^a	1939.4 ^{a-}	53.48 ^a	39.15 ^a	1695.7 ^{a-}	94.05 ^a	80.36 ^a	1920 ^{a-d}	89.63	85.82 ^a	2230 ^a
G47	56.86 ^a	44.29 ^a	1746.3 ^{a-f}	51.17 ^a	38.54 ^a	1476.8 ^{a-}	83.55 ^b	60.21 ^d	1370 ^{e-p}	75.54 ^a	71.77 ^a	1835 ^{a-g}
G48	42.35 ^a	44.30 ^a	1579.5 ^{a-}	45.47 ^a	28.44 ^a	1122.9 ^{a-}	79.58 ^c	51.83 ⁻	1135 ^{h-u}	61.19 ^k	56.16 ⁻	1085 ^{p-x}
G49	42.22 ^a	53.94 ^a	1868.7 ^{a-}	20.58 ^{f-}	12.98 ^{f-}	578.8 ^{e-h}	88.75 ^a	65.45 ^c	1335 ^{f-q}	87.59 ^a	85.35 ^a	2150 ^{ab}
G50	59.05 ^a	41.56 ^a	1766.5 ^{a-}	48.46 ^a	34.37 ^a	1551.1 ^{a-}	68.03	62.76 ^c	935 ^{o-x}	65.25 ^g	56.59 ⁻	1140 ^{x-n}
G51	72.53 ^a	50.80 ^a	2166.4 ^{ab}	62.19 ^a	47.26 ^a	1937.1 ^{ab}	96.19 ^a	89.75 ^a	2220 ^a	86.64 ^a	84.53 ^a	2100 ^{abc}
G52	64.3 ^{ab}	26.28 ^a	1260.6 ^{a-}	55.54 ^a	43.14 ^a	1784.9 ^{a-}	59.85 ^{r-}	38.43 ^{r-}	740 ^{-x}	62.25 ⁻	58.90 ^g	1205 ^{k-v}
G53	59.84 ^a	44.51 ^a	1926.1 ^{a-d}	52.29 ^a	37.32 ^a	1609.2 ^{a-}	53.79 ^{r-}	32.22 ^u	605 ^{v-y}	63.30 ⁻	53.44 ⁻	1090 ^{p-x}
G54	66.38 ^a	22.95 ^a	1199.6 ^{a-}	62.24 ^a	45.91 ^a	1915.1 ^{ab}	88.75 ^a	65.24 ^c	1480 ^{d-m}	49.79 ^{r-}	44.89 ^{r-}	730 ^{v-y}
G55	64.3 ^{ab}	0.00 ^e	583.1 ^g	52.16 ^a	37.86 ^a	1660.7 ^{a-e}	53.61 ^{t-}	31.09 ^v	570 ^{wxy}	47.59 ^v	39.81 ^u	730 ^{v-y}
G56	41.20 ^a	31.06 ^a	1406.1 ^{a-}	46.32 ^a	29.69 ^a	1070.5 ^{a-}	94.06 ^a	73.13 ^a	1780 ^{a-f}	71.52 ^d	67.48 ^d	1485 ^{e-q}

G57	50.64 ^a	6.99 ^{de}	702.2 ^{efg}	45.93 ^a	32.93 ^a	1377 ^{a-e}	77.51 ^e	49.90	970 ^{u-x}	67.39 ^f	64.55 ^d	1435 ^{f-r}
G58	77.54 ^a	54.52 ^a	2296.5 ^a	64.34 ^a	49.45 ^a	2037.2 ^{ab}	93.78 ^a	72.61 ^a	1680 ^{c-g}	75.53	69.14 ^c	1655 ^{c-}
G59	65.39 ^a	49.21 ^a	2053.8 ^{ab}	55.74 ^a	43.19 ^a	1766 ^{8a-d}	82.58 ^c	62.04 ^c	1480 ^{d-m}	68.25 ^e	62.28 ^e	1365 ^{g-r}
G60	10.07 ^e	39.94 ^a	1114.3 ^{bg}	10.07 ^h	3.22 ^{hi}	80.4 ^{gh}	40.87 ^w	18.50 ^w	21 ^{5y}	54.08 ^q	47.88 ^p	850 ^{t-y}
G61	12.38 ^d	54.50 ^a	1661.8 ^{a-}	35.67 ^a	21.29 ^c	964.3 ^{a-h}	62.01 ^q	35.92 ^{s-}	665 ^{u-y}	70.45 ^e	67.84 ^d	1495 ^{e-q}
G62	59.01 ^a	45.00 ^a	1928.8 ^{a-}	57.78 ^a	38.93 ^a	1643.7 ^{a-}	76.48 ^{f-}	54.41 ^{j-}	1050 ^{k-w}	82.56 ^a	77.84 ^a	1825 ^{a-h}
Std. check	28.98 ^a	43.42 ^a	1499.2 ^{a-}	23.18 ^e	17.53 ^e	695 ^{d-h}	67.88	39.65 ^q	810 ^{f-x}	79.54 ^a	51.49 ⁿ	1730 ^{b-j}
Local check	57.78 ^a	47.08 ^a	2064.7 ^{ab}	57.95 ^a	50.25 ^a	2092.8 ^a	96.23 ^a	75.91 ^a	1615 ^{c-i}	75.54 ^a	69.67 ^b	1570 ^{e-p}
Mean	51.52	38.83	897.82	47.16	33.74	1426.86	78.28	56.09	1219.6	68.11	62.51	1373.4
Sig. (5%)	ns	ns	ns	***	***	***	***	***	***	***	***	***
CV (%)	38.19	38.87	27.53	26.84	33.22	32.87	32.02	36.23	34.46	23.56	26.69	34.26

Std. standard, Sig. – significant

Appendix Table 5.6 Percent mean head incidence and severity in western Amhara, Ethiopia

Genotypes	Adet						Fenotselam					
	2022			2023			2022			2023		
	HBI	HBS	HAUD PC	HBI	HBS	HAUD PC	HBI	HBS	HADU PC	HBI	HBS	HAUD PC
G1	80.55 ^a	62.27 ^a	2521.5 ^{ab}	73.53 ^a	57.50 ^a	2316 ^a	68.15 ^{o-r}	42.69 ^{u-y}	920 ^{o-s}	77.54 ^{a-g}	72.69 ^{b-j}	1670 ^{b-l}
G2	67.34 ^a	52.28 ^a	2152.3 ^{a-}	57.62 ^a	44.35 ^a	1817.8 ^{a-}	80.69 ^{g-q}	56.68 ^{m-v}	1245 ^{j-p}	71.52 ^{c-j}	63.69 ^{e-r}	1385 ^{f-q}
G3	77.54 ^a	58.40 ^a	2327.4 ^{a-}	67.34 ^a	52.32 ^a	2111.5 ^{a-}	99.92 ^{a-g}	80.27 ^{b-i}	2050 ^{b-e}	79.54 ^{a-f}	75.09 ^{a-h}	1855 ^{a-g}
G4	61.09 ^a	45.48 ^a	1822.8 ^{a-f}	45.33 ^a	30.03 ^a	1162.2 ^{a-j}	67.45 ^{pqr}	42.66 ^{u-y}	710 ^{qrs}	45.09 ^o	34.60 ^w	585.00 ^t
G5	68.44 ^a	54.31 ^a	2194.3 ^{a-}	67.45 ^a	50.43 ^a	2047 ^{a-f}	55.83 ^r	38.83 ^{wxy}	640 ^{rs}	57.42 ^{j-o}	50.43 ^{q-v}	980 ^{o-t}
G6	51.06 ^a	34.61 ^a	1451.8 ^{a-j}	20.58 ^f	13.95 ^g	575.4 ^{g-j}	86.93 ^{e-o}	66.90 ^{f-q}	1640 ^{d-k}	48.66 ^{no}	37.47 ^{vw}	655 st
G7	74.54 ^a	55.56 ^a	2281.8 ^{a-}	54.58 ^a	40.22 ^a	1660.6 ^{a-}	89.65 ^{b-m}	66.43 ^{f-q}	1455 ^{g-n}	78.54 ^{a-f}	73.21 ^{a-j}	1660 ^{b-l}
G8	74.48 ^a	58.53 ^a	2314.7 ^{a-}	66.41 ^a	51.10 ^a	2044.2 ^{a-f}	91.06 ^{b-l}	71.74 ^{e-n}	1830 ^{c-h}	82.56 ^{a-d}	79.75 ^{a-e}	2005 ^{a-d}
G9	61.18 ^a	40.58 ^a	1590.8 ^{a-i}	65.36 ^a	50.08 ^a	2034.1 ^{a-f}	100.26 ^{a-f}	81.82 ^{b-g}	2125 ^{bcd}	72.45 ^{c-j}	65.31 ^{d-q}	1480 ^{c-p}
G10	65.39 ^a	50.41 ^a	2048.9 ^{a-}	51.17 ^a	39.20 ^a	1599.9 ^{a-}	94.97 ^{a-j}	72.03 ^{e-n}	1725 ^{d-j}	72.53 ^{c-i}	66.95 ^{d-p}	1505 ^{c-o}
G11	83.60 ^a	65.85 ^a	2619.4 ^a	70.40 ^a	54.59 ^a	2200.7 ^{ab}	100.26 ^{a-f}	80.82 ^{b-i}	2005 ^{b-f}	73.53 ^{c-i}	69.89 ^{c-l}	1595 ^{c-m}
G12	68.25 ^a	49.25 ^a	1929.5 ^{a-f}	65.36 ^a	45.80 ^a	1788.1 ^{a-}	85.56 ^{e-p}	62.47 ^{i-s}	1380 ^{h-o}	72.51 ^{c-i}	67.17 ^{d-p}	1465 ^{c-p}
G13	60.18 ^a	43.59 ^a	1789.9 ^{a-}	55.36 ^a	41.08 ^a	1711.1 ^{a-}	62.01 ^{qr}	36.23 ^y	670 ^{qrs}	60.86 ⁱ⁻ⁿ	55.29 ^{k-u}	1170 ^{j-s}
G14	0.00 ⁱ	0.00 ⁱ	0.00 ^j	0.00 ^h	0.00 ^j	0.00 ^j	80.54 ^{g-q}	56.03 ^{n-v}	1070 ^{l-r}	52.36 ^{mno}	45.13 ^{uvw}	800 ^{rst}
G15	33.21 ^c	25.45 ^c	1048.5 ^{c-j}	27.88 ^c	20.94 ^d	856.8 ^{c-h}	75.43 ^{a-k}	54.79 ^{c-i}	1060 ^{l-i}	61.68 ^{h-o}	50.95 ^{b-v}	1040 ^{m-t}
G16	66.41 ^a	51.85 ^a	2104.9 ^{a-}	61.16 ^a	46.48 ^a	1868.6 ^{a-}	97.03 ^{a-i}	67.97 ^{e-q}	1630 ^{d-k}	69.45 ^{c-k}	61.51 ^{f-t}	1280 ^{g-r}
G17	66.41 ^a	51.85 ^a	2104.9 ^{a-}	61.16 ^a	46.48 ^a	1868.6 ^{a-}	97.03 ^{a-i}	67.97 ^{e-q}	1630 ^{d-k}	69.45 ^{c-k}	61.51 ^{f-t}	1280 ^{g-r}
G18	67.45 ^a	53.06 ^a	2143.5 ^{a-}	59.05 ^a	44.54 ^a	1785.5 ^{a-}	88.62 ^{c-n}	55.60 ^{n-v}	1635 ^{i-p}	54.64 ^{k-o}	47.60 ^{f-w}	880 ^{q-t}

G19	62.01 ^a	44.68 ^a	1778.8 ^{a-}	52.36 ^a	36.57 ^a	1508.7 ^{a-}	85.58 ^{e-p}	59.94 ^{k-t}	1280 ^{t-p}	73.51 ^{c-i}	67.12 ^{d-p}	1410 ^{e-q}
G20	77.54 ^a	60.89 ^a	2465.3 ^{ab}	71.52 ^a	56.01 ^a	2282.4 ^{ab}	107.53 ^{ab}	80.02 ^{b-i}	1890 ^{c-g}	72.53 ^{c-i}	66.03 ^{d-q}	1470 ^{c-p}
G21	55.74 ^a	36.46 ^a	1409.5 ^{a-j}	55.74 ^a	35.22 ^a	1363 ^{a-i}	82.54 ^{f-p}	56.42 ^{m-v}	1210 ^{k-p}	73.53 ^{c-i}	67.3 ^{d-o}	1575 ^{c-n}
G22	72.51 ^a	54.52 ^a	2197.0 ^{a-}	59.97 ^a	46.71 ^a	1892.8 ^{a-}	75.54 ^{j-q}	56.75 ^{m-v}	1235 ^{t-p}	70.5 ^{c-j}	63.79 ^{e-q}	1315 ^{f-r}
G23	37.27 ^b	28.17 ^b	1141.3 ^{a-j}	60.06 ^a	44.93 ^a	1854.8 ^{a-}	100.36 ^{a-f}	72.93 ^{e-m}	1725 ^{d-j}	70.39 ^{c-j}	64.10 ^{e-q}	1350 ^{f-r}
G24	79.55 ^a	62.32 ^a	2504.0 ^{ab}	69.34 ^a	53.52 ^a	2148.1 ^{a-}	97.03 ^{a-i}	81.26 ^{b-h}	1880 ^{c-g}	82.58 ^{a-d}	81.19 ^{a-d}	1975 ^{a-e}
G25	63.28 ^a	42.81 ^a	1757.6 ^{a-}	61.19 ^a	41.17 ^a	1685.8 ^{a-g}	78.54 ^{i-q}	55.39 ^{n-v}	1210 ^{k-p}	77.54 ^{a-g}	70.22 ^{c-l}	1715 ^{a-k}
G26	72.45 ^a	55.35 ^a	2229.1 ^{a-}	61.68 ^a	48.39 ^a	1934.7 ^{a-f}	84.64 ^{e-p}	66.46 ^{f-q}	1635 ^{d-k}	80.54 ^{a-f}	77.13 ^{a-f}	1870 ^{a-f}
G27	79.54 ^a	64.12 ^a	2599.6 ^{ab}	66.03 ^a	50.96 ^a	2038.8 ^{a-f}	107.29 ^{a-}	91.88 ^{abc}	2385 ^{ab}	79.56 ^{a-f}	73.65 ^{a-i}	1770 ^{a-i}
G28	56.73 ^a	38.89 ^a	1607.4 ^{a-i}	59.05 ^a	40.18 ^a	1682.1 ^{a-}	83.6 ^{f-p}	59.28 ^{t-u}	1300 ^{t-p}	61.09 ^{ln}	52.27 ^{n-v}	980 ^{o-t}
G29	72.27 ^a	54.59 ^a	2186.9 ^{a-}	67.15 ^a	51.44 ^a	2073.6 ^{a-}	92.40 ^{a-k}	69.37 ^{e-p}	1755 ^{d-i}	67.43 ^{e-l}	60.24 ^{g-u}	1225 ^{i-s}
G30	59.97 ^a	40.66 ^a	1643.8 ^{a-i}	39.27 ^a	24.91 ^b	951.1 ^{b-j}	75.23 ^{k-q}	46.08 ^{s-y}	945 ^{o-s}	60.86 ⁿ⁻ⁱ	53.18 ^{m-u}	990 ^{o-t}
G31	17.69 ^f	7.26 ^{ghi}	181.3 ^{hij}	27.76 ^c	11.37 ^h	284.2 ^{hij}	87.61 ^{e-n}	65.08 ^{g-q}	1495 ^{g-m}	63.28 ^{g-n}	54.75 ^{t-u}	1110 ^{t-l}
G32	21.91 ^e	11.35 ^f	567.3 ^{e-j}	0.00 ^h	0.00 ^j	0.00 ^j	76.46 ^{j-q}	48.14 ^{t-y}	990 ^{n-s}	66.41 ^{f-m}	57.49 ^{i-u}	1265 ^{h-r}
G33	65.36 ^a	46.62 ^a	1925 ^{a-f}	59.01 ^a	41.43 ^a	1713.9 ^{a-g}	88.05 ^{d-n}	66.27 ^{f-q}	1610 ^{e-k}	69.45 ^{c-k}	62.03 ^{f-s}	1275 ^{g-r}
G34	72.48 ^a	55.58 ^a	2293.7 ^{a-}	60.86 ^a	46.84 ^a	1926.7 ^{a-}	107.22 ^{a-}	84.42 ^{a-e}	2280 ^{abc}	69.49 ^{c-k}	62.01 ^{f-s}	1285 ^{g-r}
G35	32.03 ^d	13.08 ^e	398.7 ^{f-j}	24.41 ^e	13.65 ^g	572.7 ^{g-j}	75.49 ^{j-q}	54.59 ^{q-w}	1225 ^{k-p}	69.45 ^{c-k}	61.44 ^{f-t}	1340 ^{f-r}
G36	56.84 ^a	39.19 ^a	1574.0 ^{a-i}	46.67 ^a	31.15 ^a	1207.9 ^{a-j}	93.87 ^{a-k}	76.23 ^{c-k}	1900 ^{c-g}	74.51 ^{b-i}	68.57 ^{d-m}	1615 ^{c-m}
G37	71.51 ^a	52.94 ^a	2152.4 ^{a-}	56.82 ^a	41.59 ^a	1708.1 ^{a-}	81.59 ^{f-p}	56.3 ^{m-v}	1285 ^{t-p}	70.51 ^{c-j}	64.33 ^{e-q}	1425 ^{e-q}
G38	81.62 ^a	63.13 ^a	2547.2 ^{ab}	70.45 ^a	54.74 ^a	2188.6 ^{a-}	108.29 ^{ab}	93.69 ^{ab}	2370 ^{ab}	77.54 ^{a-g}	72.23 ^{b-j}	1750 ^{a-j}
G39	66.41 ^a	50.72 ^a	2031.0 ^{a-}	57.88 ^a	43.29 ^a	1784.8 ^{a-}	78.54 ^{i-q}	51.21 ^{q-y}	1050 ^{m-r}	81.54 ^{a-e}	75.73 ^{a-g}	1825 ^{a-h}
G40	59.97 ^a	42.21 ^a	1754.4 ^{a-}	56.82 ^a	40.41 ^a	1686 ^{a-g}	93.95 ^{a-k}	70.86 ^{e-o}	1600 ^{e-k}	71.51 ^{c-j}	66.14 ^{d-q}	1500 ^{c-o}
G41	46.67 ^a	28.96 ^a	1063.1 ^{b-j}	41.69 ^a	26.99 ^a	1009.1 ^{a-j}	97.03 ^{a-i}	75.61 ^{c-l}	1820 ^{c-h}	77.53 ^{a-g}	71.99 ^{b-j}	1715 ^{a-k}
G42	42.44 ^a	25.56 ^c	1086.3 ^{a-j}	53.25 ^a	33.93 ^a	1334.1 ^{a-i}	71.26 ^{m-r}	45.18 ^{t-y}	910 ^{o-s}	63.14 ^{g-n}	57.15 ^{t-u}	1165 ^{k-s}
G43	67.45 ^a	50.21 ^a	2031.2 ^{a-}	56.39 ^a	41.94 ^a	1697.9 ^{a-}	92.78 ^{a-k}	64.44 ^{h-r}	1510 ^{f-m}	68.39 ^{d-l}	61.84 ^{f-s}	1290 ^{f-r}
G44	68.72 ^a	48.34 ^a	1983.0 ^{a-}	63.68 ^a	46.03 ^a	1877.4 ^{a-}	93.87 ^{a-k}	69.53 ^{e-p}	1615 ^{e-k}	68.39 ^{d-l}	58.23 ^{t-u}	1245 ^{h-r}
G45	77.54 ^a	59.62 ^a	2418.9 ^{a-}	73.51 ^a	56.94 ^a	2323.4 ^a	90.66 ^{b-m}	70.22 ^{e-o}	1555 ^{e-l}	66.33 ^{f-m}	61.44 ^{f-t}	1265 ^{h-r}
G46	66.03 ^a	48.58 ^a	1970.6 ^{a-}	67.25 ^a	48.97 ^a	1970.3 ^{a-f}	98.15 ^{a-h}	82.64 ^{b-f}	2120 ^{bcd}	91.72 ^a	88.51 ^a	2260 ^a
G47	68.25 ^a	47.54 ^a	1874.5 ^{a-f}	50.89 ^a	35.41 ^a	1406 ^{a-i}	82.54 ^{f-p}	64.28 ^{i-r}	1485 ^{g-n}	69.39 ^{c-k}	63.39 ^{f-r}	1445 ^{d-q}
G48	40.27 ^a	30.15 ^a	1183.9 ^{a-j}	49.30 ^a	32.85 ^a	1240.1 ^{a-j}	82.71 ^{f-p}	57.28 ^{m-v}	1275 ^{t-p}	67.45 ^{e-l}	58.00 ^{t-u}	1160 ^{k-s}
G49	46.52 ^a	27.95 ^b	1084.0 ^{a-j}	28.98 ^b	20.50 ^e	838.6 ^{d-j}	92.85 ^{a-k}	74.31 ^{e-l}	1730 ^{d-j}	83.55 ^{abc}	81.47 ^{a-d}	2035 ^{abc}
G50	69.49 ^a	51.20 ^a	2043.4 ^{a-}	58.81 ^a	44.99 ^a	1816.5 ^{a-}	82.67 ^{f-p}	70.94 ^{e-o}	1245 ^{t-p}	66.15 ^{f-m}	59.26 ^{h-u}	1205 ^{t-s}
G51	77.52 ^a	59.70 ^a	2412.1 ^{a-}	66.03 ^a	51.29 ^a	2062.8 ^{a-}	111.52 ^a	99.03 ^a	2665 ^a	88.69 ^{ab}	85.83 ^{abc}	2220 ^{ab}

G52	70.25 ^a	52.36 ^a	2088.6 ^{a-}	64.03 ^a	48.44 ^a	1942. ^{4a-f}	83.56 ^{f-p}	57.39 ^{m-v}	1155 ^{k-q}	68.39 ^{d-l}	57.69 ^{l-u}	1190 ^{is}
G53	76.54 ^a	57.11 ^a	2306.6 ^{a-}	62.19 ^a	45.7 ^{a-f}	1841 ^{a-g}	80.55 ^{g-q}	53.08 ^{p-x}	1145 ^{k-q}	62.25 ^{h-n}	54.32 ^{l-u}	1000 ^{n-t}
G54	74.54 ^a	56.79 ^a	2295.5 ^{a-}	67.43 ^a	50.74 ^a	2055.2 ^{a-f}	97.12 ^{a-i}	69.08 ^{e-p}	1520 ^{f-m}	55.36 ^{k-o}	46.38 ^{s-w}	910 ^{p-t}
G55	71.48 ^a	56.04 ^a	2203 ^{a-d}	64.35 ^a	48.85 ^a	1953. ^{9a-f}	70.04 ^{n-r}	42.19 ^{v-y}	870 ^{p-s}	54.58 ^{k-o}	46.42 ^{s-w}	790 ^{rst}
G56	67.45 ^a	48.08 ^a	1963.7 ^{a-}	36.79 ^a	21.51 ^c	794.4 ^{e-j}	92.78 ^{a-k}	76.04 ^{c-l}	1870 ^{c-h}	77.53 ^{a-g}	71.53 ^{b-k}	1650 ^{b-l}
G57	59.84 ^a	42.19 ^a	1691.7 ^{a-}	51.17 ^a	35.97 ^a	1430.5 ^{a-i}	79.58 ^{h-q}	62.87 ^{i-r}	1455 ^{g-n}	72.53 ^{c-i}	64.60 ^{e-q}	1400 ^{e-q}
G58	79.55 ^a	61.16 ^a	2463.3 ^{ab}	70.45 ^a	52.76 ^a	2151.6 ^{a-}	98.08 ^{a-h}	74.45 ^{d-l}	1805 ^{c-h}	73.48 ^{c-i}	68.15 ^{d-n}	1555 ^{c-o}
G59	73.45 ^a	56.17 ^a	2253 ^{a-d}	57.42 ^a	44.70 ^a	1828.8 ^{a-}	90.70 ^{b-m}	67.53 ^{f-q}	1525 ^{f-m}	66.25 ^{f-m}	58.36 ^{i-u}	1200 ^{i-s}
G60	14.34 ^h	5.80 ^{hi}	144.9 ^{ij}	12.38 ^g	4.12 ^{ij}	102.9 ^{ij}	69.45 ^{n-r}	37.48 ^{xy}	565.00 ^s	54.31 ^{l-o}	45.66 ^{l-w}	900 ^{p-t}
G61	16.09 ^g	7.34 ^{ghi}	263.8 ^{g-j}	49.30 ^a	29.99 ^a	1240. ^{7a-j}	72.45 ^{l-r}	51.82 ^{q-y}	1055 ^{m-r}	72.51 ^{c-i}	70.54 ^{b-l}	1630 ^{c-l}
G62	66.38 ^a	47.56 ^a	1902.4 ^{a-f}	59.01 ^a	41.62 ^a	1710.9 ^{a-}	86.83 ^{e-p}	65.33 ^{g-q}	1525 ^{f-m}	76.53 ^{b-h}	71.84 ^{b-j}	1695 ^{b-k}
Std. check	34.24 ^c	22.45 ^d	908.3 ^{d-j}	25.60 ^d	17.13 ^f	704.9 ^{f-j}	74.48 ^{k-q}	41.28 ^{v-y}	1060 ^{l-r}	78.54 ^{a-f}	51.11 ^{o-v}	1670 ^{b-l}
Local check	74.54 ^a	62.12 ^a	2415.4 ^{a-}	66.41 ^a	57.44 ^a	2136.7 ^{a-}	103.60 ^{a-}	90.73 ^{a-d}	1995 ^{b-f}	91.69 ^a	86.46 ^{ab}	1725 ^{a-k}
Mean	61.26	44.97	1807.69	54.07	39.54	1589.6	87.1	64.63	1488.52	70.42	63.59	1406.64
Sig. L (5%)	***	***	***	***	***	***	***	***	***	***	***	***
CV (%)	29.59	33.26	34.44	27.69	32.21	34.26	27.63	31.29	23.55	20.24	24.27	26.63

Sig. L. – significant level

Appendix Table 5.7 Reaction of genotypes for blast diseases at Adet and Fenotselam experimental sites during 2022 and 2023 growing seasons

Location	2022									2023								
	Leaf			Neck			Head			Leaf			Neck			Head		
	Geno.	MS	Rxn	Geno.	MS	Rxn	Geno.	MS	Rxn	Geno.	MS	Rxn	Geno.	MS	Rxn	Geno.	MS	Rxn
Adet	G32	5.41	R	G57	0.00	R	G12	22.57	R	G49	12.98	R	Jabi	22.45	R	Jabi	17.13	R
Adet	G6	6.01	MR	G60	0.00	R	G54	22.95	R	Jabi	17.53	R	G16	25.45	R	G49	20.50	R
Adet	G41	6.43	MR	G19	2.38	R	G44	23.08	R	G36	19.51	R	G42	25.56	R	G16	20.94	R
Adet	G33	9.65	MR	G36	2.38	R	G7	25.01	R	G43	19.68	R	G49	27.95	R	G56	21.51	R
Adet	G57	9.94	MR	G35	2.83	R	G28	26.02	R	G16	19.99	R	G23	28.17	R	G30	24.91	R
Adet	Jabi	13.18	MR	G16	3.03	R	G52	26.28	R	G18	20.07	R	G41	28.96	R	G41	26.99	R
Adet	G9	13.48	MR	G30	3.33	R	G41	26.40	R	G61	21.29	R	G48	30.15	R	G61	29.99	R
Adet	G36	14.13	MR	G39	6.79	MR	G42	26.55	R	G25	22.56	R	G6	34.61	MR	G4	30.03	R
Adet	G10	14.15	MR	G33	8.66	MR	G17	28.24	R	G21	24.11	R	G21	36.46	MR	G36	31.15	MR
Adet	G8	14.68	MR	G8	8.77	MR	G56	31.06	MR	G30	25.32	R	G28	38.89	MR	G48	32.85	MR
Adet	G56	14.88	MR	G18	9.15	MR	G9	31.97	MR	G42	25.79	R	G36	39.19	MR	G42	33.93	MR
Adet	G39	15.01	MR	G56	9.17	MR	G1	33.06	MR	G6	27.31	R	G9	40.58	MS	G21	35.22	MR
Adet	G13	15.43	MR	G49	9.44	MR	G39	33.69	MR	G48	28.44	R	G30	40.66	MS	G47	35.41	MR
Adet	G49	15.54	MR	G40	9.97	MR	G32	34.38	MR	G19	29.51	R	G57	42.19	MS	G57	35.97	MR
Adet	G17	15.57	MR	Jabi	10.26	MR	G19	34.69	MR	G56	29.69	R	G40	42.21	MS	G19	36.57	MR
Adet	G47	15.86	MR	G42	11.64	MR	G22	34.71	MR	G28	31.45	MR	G25	42.81	MS	G10	39.20	MR
Adet	G40	15.92	MR	G47	11.81	MR	G13	35.42	MR	G13	31.79	MR	G13	43.59	MS	G28	40.18	MR
Adet	G19	15.97	MR	G3	11.84	MR	G33	37.59	MR	G57	32.93	MR	G19	44.68	MS	G7	40.22	MR
Adet	G42	16.92	MR	G53	12.57	MR	G15	38.29	MR	G50	34.37	MR	G4	45.48	MS	G40	40.41	MR
Adet	G48	17.30	MR	G2	13.09	MR	G11	39.11	MR	G33	35.73	MR	G33	46.62	MS	G13	41.08	MS
Adet	G23	17.65	MR	G7	13.60	MR	G29	39.30	MR	G39	36.74	MR	G47	47.54	MS	G25	41.17	MS
Adet	G53	19.30	MR	G48	13.75	MR	G45	39.61	MR	G15	37.03	MR	G62	47.56	MS	G33	41.43	MS
Adet	G21	19.39	MR	G61	14.51	MR	G60	39.94	MR	G53	37.32	MR	G56	48.08	MS	G37	41.59	MS
Adet	G2	20.11	MR	G28	14.57	MR	G4	40.83	MS	G4	37.43	MR	G44	48.34	MS	G62	41.62	MS
Adet	G15	21.05	MR	G44	14.89	MR	G50	41.56	MS	G10	37.43	MR	G46	48.58	MS	G43	41.94	MS
Adet	G44	21.09	MR	G21	15.58	MR	G21	42.03	MS	G55	37.86	MR	G12	49.25	MS	G39	43.29	MS
Adet	G28	21.47	MR	G13	16.22	MR	G30	42.74	MS	G44	38.27	MR	G43	50.21	MS	G2	44.35	MS
Adet	G3	21.68	MR	G58	17.09	MR	Jabi	43.42	MS	G47	38.54	MR	G10	50.41	MS	G18	44.54	MS
Adet	G29	22.06	MR	G15	17.29	MR	G18	43.73	MS	G62	38.93	MR	G39	50.72	S	G59	44.70	MS
Adet	G52	22.45	MR	G52	17.99	MR	G25	44.08	MS	G2	38.95	MR	G50	51.20	S	G23	44.93	MS
Adet	G58	22.45	MR	G43	18.08	MR	G46	44.26	MS	G7	38.95	MR	G17	51.85	S	G50	44.99	MS
Adet	G18	22.89	MR	G50	18.68	MR	G47	44.29	MS	G46	39.15	MR	G2	52.28	S	G53	45.70	MS
Adet	G45	24.92	MR	G45	18.83	MR	G48	44.3	MS	G26	39.50	MR	G52	52.36	S	G12	45.80	MS
Adet	G5	25.09	MR	G29	18.93	MR	G26	44.32	MS	G37	39.67	MR	G37	52.94	S	G44	46.03	MS
Adet	G50	26.44	MS	G9	19.01	MR	G5	44.36	MS	G12	41.34	MS	G18	53.06	S	G17	46.48	MS
Adet	G37	26.67	MS	G22	19.13	MR	G53	44.51	MS	G24	42.13	MS	G5	54.31	S	G22	46.71	MS
Adet	G55	26.76	MS	G55	19.34	MR	G40	44.69	MS	G52	43.14	MS	G22	54.52	S	G34	46.84	MS
Adet	G30	27.77	MS	G26	19.78	MR	G62	45.00	MS	G59	43.19	MS	G29	54.59	S	G26	48.39	MS
Adet	G62	28.02	MS	G12	20.64	MR	G43	45.96	MS	G8	43.23	MS	G26	55.35	S	G52	48.44	MS
Adet	G24	28.15	MS	G5	21.30	MR	G27	46.40	MS	G22	43.74	MS	G7	55.56	S	G55	48.85	MS
Adet	G25	28.33	MS	G62	21.38	MR	G2	46.70	MS	G1	43.94	MS	G34	55.58	S	G46	48.97	MS
Adet	G22	28.48	MS	G25	22.94	MR	Local	47.08	MS	G45	44.01	MS	G55	56.04	S	G9	50.08	MS

Adet	G7	29.04	MS	G34	23.08	MR	G20	47.12	MS	G17	44.17	MS	G59	56.17	S	G5	50.43	MS
Adet	G4	29.08	MS	G17	23.19	MR	G23	48.21	MS	G40	44.35	MS	G54	56.79	S	G54	50.74	S
Adet	G54	30.37	MS	G37	23.20	MR	G38	48.53	MS	G20	44.66	MS	G53	57.11	S	G27	50.96	S
Adet	G34	30.62	MS	G11	23.56	MR	G31	48.58	MS	G23	44.81	MS	G3	58.40	S	G8	51.10	S
Adet	G43	31.47	MS	G24	24.01	MR	G59	49.21	MS	G29	44.92	MS	G8	58.53	S	G51	51.29	S
Adet	Local	31.61	MS	G54	24.35	MR	G37	49.65	MS	G34	45.19	MS	G15	58.82	S	G29	51.44	S
Adet	G26	31.66	MS	G4	24.63	MR	G16	50.05	MS	G5	45.56	MS	G45	59.62	S	G3	52.32	S
Adet	G12	31.70	MS	G27	24.64	MR	G51	50.80	S	G27	45.73	MS	G51	59.70	S	G58	52.76	S
Adet	G59	32.14	MS	G23	25.19	MR	G6	52.65	S	G54	45.91	MS	G20	60.89	S	G24	53.52	S
Adet	G46	33.59	MS	G59	25.37	MR	G34	52.70	S	G38	46.66	MS	G58	61.16	S	G11	54.59	S
Adet	G1	33.78	MS	G46	25.38	MR	G49	53.94	S	G3	46.67	MS	Local	62.12	S	G38	54.74	S
Adet	G11	33.92	MS	G1	25.60	MS	G61	54.50	S	G51	47.26	MS	G1	62.27	S	G15	54.79	S
Adet	G51	35.57	MS	G20	25.71	MS	G58	54.52	S	G11	47.89	MS	G24	62.32	S	G20	56.01	S
Adet	G38	36.94	MS	Local	26.23	MS	G24	54.81	S	G58	49.45	MS	G38	63.13	S	G45	56.94	S
Adet	G27	38.22	MS	G51	27.17	MS	G35	56.38	S	Local	50.25	MS	G27	64.12	S	Local	57.44	S
Adet	G20	38.69	MS	G38	30.84	MS	G8	58.71	S	G9	51.05	S	G11	65.85	S	G1	57.50	S
F/selam	G50	16.02	MR	G6	0.00	R	G60	18.50	R	G6	37.89	MR	G13	36.23	MR	G4	34.60	MR
F/selam	G60	18.47	MR	G10	0.00	R	G55	31.09	MR	G55	39.81	MR	G60	37.48	MR	G6	37.47	MR
F/selam	G13	18.92	MR	G14	0.00	R	G53	32.22	MR	G5	41.79	MS	G5	38.83	MR	G14	45.13	MS
F/selam	G52	22.83	MR	G31	0.00	R	G13	32.42	MR	G14	42.87	MS	Jabi	41.28	MS	G60	45.66	MS
F/selam	G44	23.14	MR	G32	0.00	R	G39	32.44	MR	G54	44.89	MS	G55	42.19	MS	G54	46.38	MS
F/selam	G61	25.18	MR	G41	0.00	R	G5	33.02	MR	G4	45.82	MS	G4	42.66	MS	G55	46.42	MS
F/selam	G21	25.48	MR	G57	0.00	R	G1	33.76	MR	G60	47.88	MS	G1	42.69	MS	G18	47.60	MS
F/selam	G59	27.46	MS	G60	0.00	R	G4	33.92	MR	G18	49.98	MS	G42	45.18	MS	G5	50.43	MS
F/selam	G22	27.87	MS	G19	2.38	R	G61	35.92	MR	G16	50.09	MS	G30	46.08	MS	G16	50.95	S
F/selam	Jabi	28.38	MS	G36	2.38	R	G32	37.58	MR	G13	50.92	S	G32	48.14	MS	Jabi	51.11	S
F/selam	G32	29.29	MS	G35	2.83	R	G42	37.77	MR	Jabi	51.49	S	G39	51.21	S	G28	52.27	S
F/selam	G48	29.87	MS	G16	3.03	R	G52	38.43	MR	G28	52.80	S	G61	51.82	S	G30	53.18	S
F/selam	G5	30.06	MS	G30	3.33	R	G30	39.61	MR	G53	53.44	S	G53	53.08	S	G53	54.32	S
F/selam	G9	30.12	MS	G39	6.79	MR	G35	39.63	MR	G30	53.45	S	G35	54.59	S	G31	54.75	S
F/selam	G37	30.25	MS	G33	8.66	MR	Jabi	39.65	MR	G31	53.78	S	G16	54.79	S	G13	55.29	S
F/selam	G4	30.29	MS	G8	8.77	MR	G25	41.69	MS	G42	54.20	S	G25	55.39	S	G42	57.15	S
F/selam	G28	30.49	MS	G18	9.15	MR	G19	42.93	MS	G17	55.84	S	G18	55.60	S	G32	57.49	S
F/selam	G14	31.10	MS	G56	9.17	MR	G2	44.31	MS	G48	56.16	S	G14	56.03	S	G52	57.69	S
F/selam	G23	31.13	MS	G49	9.44	MR	G18	44.88	MS	G50	56.59	S	G37	56.30	S	G48	58.00	S
F/selam	G42	31.26	MS	G40	9.97	MR	G31	47.51	MS	G32	57.63	S	G21	56.42	S	G44	58.23	S
F/selam	G18	31.53	MS	Jabi	10.26	MR	G14	47.69	MS	G52	58.90	S	G2	56.68	S	G59	58.36	S
F/selam	G1	32.21	MS	G42	11.64	MR	G37	48.07	MS	G29	59.28	S	G22	56.75	S	G50	59.26	S
F/selam	G12	32.23	MS	G47	11.81	MR	G28	49.51	MS	G35	59.51	S	G48	57.28	S	G29	60.24	S
F/selam	G47	32.41	MS	G3	11.84	MR	G57	49.90	MS	G22	60.04	S	G52	57.39	S	G35	61.44	S
F/selam	G7	32.85	MS	G53	12.57	MR	G48	51.83	S	G19	60.42	S	G28	59.28	S	G45	61.44	S
F/selam	G26	33.15	MS	G2	13.09	MR	G16	52.17	S	G37	60.59	S	G19	59.94	S	G17	61.51	S
F/selam	G31	33.36	MS	G7	13.60	MR	G22	53.00	S	G44	61.50	S	G12	62.47	S	G43	61.84	S
F/selam	G38	33.67	MS	G48	13.75	MR	G21	53.11	S	G34	61.68	S	G57	62.87	S	G34	62.01	S
F/selam	G45	34.38	MS	G61	14.51	MR	G62	54.41	S	G43	62.24	S	G47	64.28	S	G33	62.03	S
F/selam	G43	35.49	MS	G28	14.57	MR	G12	54.58	S	G59	62.28	S	G43	64.44	S	G47	63.39	S
F/selam	G41	35.69	MS	G44	14.89	MR	G33	57.17	S	G10	62.40	S	G31	65.08	S	G2	63.69	S
F/selam	G58	35.91	MS	G21	15.58	MR	G6	57.38	S	G2	62.73	S	G62	65.33	S	G22	63.79	S
F/selam	G35	36.56	MS	G13	16.22	MR	G44	58.34	S	G45	63.11	S	G33	66.27	S	G23	64.10	S
F/selam	G30	36.62	MS	G58	17.09	MR	G7	59.26	S	G40	63.14	S	G7	66.43	S	G37	64.33	S

F/selam	G17	36.90	MS	G15	17.29	MR	G43	59.87	S	G36	63.34	S	G26	66.46	S	G57	64.60	S
F/selam	G57	37.11	MS	G52	17.99	MR	G47	60.21	S	G21	64.04	S	G6	66.90	S	G9	65.31	S
F/selam	G36	37.23	MS	G43	18.08	MR	G59	62.04	S	G33	64.04	S	G59	67.53	S	G20	66.03	S
F/selam	G11	37.39	MS	G50	18.68	MR	G10	62.38	S	G57	64.55	S	G17	67.97	S	G40	66.14	S
F/selam	G2	37.68	MS	G45	18.83	MR	G29	62.75	S	G9	64.92	S	G54	69.08	S	G10	66.95	S
F/selam	G54	37.76	MS	G29	18.93	MR	G50	62.76	S	G11	65.22	S	G29	69.37	S	G19	67.12	S
F/selam	G56	38.31	MS	G9	19.01	MR	G36	63.56	S	G20	66.63	S	G44	69.53	S	G12	67.17	S
F/selam	G24	38.45	MS	G22	19.13	MR	G26	63.63	S	G41	67.26	S	G45	70.22	S	G21	67.30	S
F/selam	G19	40.24	MS	G55	19.34	MR	G3	64.42	S	G56	67.48	S	G40	70.86	HS	G58	68.15	S
F/selam	G16	40.32	MS	G26	19.78	MR	G54	65.24	S	G25	67.69	S	G50	70.94	HS	G36	68.57	S
F/selam	G25	40.37	MS	G12	20.64	MR	G49	65.45	S	G61	67.84	S	G8	71.74	HS	G11	69.89	S
F/selam	G40	40.60	MS	G5	21.30	MR	G45	65.51	S	G15	68.79	S	G10	72.03	HS	G25	70.22	S
F/selam	G55	41.16	MS	G62	21.38	MR	G23	67.38	S	G58	69.14	S	G23	72.93	HS	G61	70.54	HS
F/selam	G29	41.19	MS	G25	22.94	MR	G41	67.78	S	G23	69.66	S	G49	74.31	HS	G56	71.53	HS
F/selam	G39	41.23	MS	G34	23.08	MR	G17	68.73	S	Local	69.67	S	G58	74.45	HS	G62	71.84	HS
F/selam	G53	42.78	MS	G17	23.19	MR	G20	68.76	S	G12	69.76	S	G41	75.61	HS	G41	71.99	HS
F/selam	G62	43.09	MS	G37	23.20	MR	G40	70.76	HS	G1	69.83	S	G56	76.04	HS	G38	72.23	HS
F/selam	G6	43.19	MS	G11	23.56	MR	G58	72.61	HS	G27	69.92	S	G36	76.23	HS	G15	72.31	HS
F/selam	Local	43.44	MS	G24	24.01	MR	G15	72.71	HS	G38	70.29	S	G15	77.49	HS	G1	72.69	HS
F/selam	G33	43.48	MS	G54	24.35	MR	G56	73.13	HS	G47	71.77	HS	G20	80.02	HS	G7	73.21	HS
F/selam	G10	43.87	MS	G4	24.63	MR	G34	73.42	HS	G7	73.02	HS	G3	80.27	HS	G27	73.65	HS
F/selam	G15	45.26	MS	G27	24.64	MR	G8	73.73	HS	G26	73.23	HS	G11	80.82	HS	G3	75.09	HS
F/selam	G3	45.75	MS	G23	25.19	MR	G24	74.65	HS	G39	74.29	HS	G24	81.26	HS	G39	75.73	HS
F/selam	G8	45.99	MS	G59	25.37	MR	Local	75.91	HS	G3	76.88	HS	G9	81.82	HS	G26	77.13	HS
F/selam	G34	46.66	MS	G46	25.38	MR	G38	76.91	HS	G62	77.84	HS	G46	82.64	HS	G8	79.75	HS
F/selam	G49	48.43	MS	G1	25.60	MS	G9	77.07	HS	G8	79.15	HS	G34	84.42	HS	G24	81.19	HS
F/selam	G20	50.42	MS	G20	25.71	MS	G11	78.68	HS	G24	83.49	HS	Local	90.73	HS	G49	81.47	HS
F/selam	G27	51.05	S	Local	26.23	MS	G46	80.36	HS	G51	84.53	HS	G27	91.88	HS	G51	85.83	HS
F/selam	G46	51.64	S	G51	27.17	MS	G27	86.65	HS	G49	85.35	HS	G38	93.69	HS	Local	86.46	HS
F/selam	G51	55.41	S	G38	30.84	MS	G51	89.75	HS	G46	85.82	HS	G51	99.03	HS	G46	88.51	HS

F/selam-Finote Selam, Geno.-Genotype, MS-Mean Severity, Rx_n- Reaction

Appendix Table 5.8 Pearson correlation coefficients for agronomic and disease parameters at Adet and Fenotselam experimental sites

	HD	MD	PH	FL	NFE	NTP	NEP	BY	GY	HI	LI	NI	HdI	LS	NS	HS	LAU DPC	NAU DPC	HAU DPC
HD	1																		
MD	0.18***	1																	
PH	-0.18***	0.10*	1																
FL	-0.05 ^{ns}	0.01 ^{ns}	0.54**	1															
NFE	-0.09*	-0.03 ^{ns}	0.12**	0.03 ^{ns}	1														
NTP	-0.11*	-0.02 ^{ns}	-0.02 ^{ns}	0.11*	0.10*	1													
NEP	0.02 ^{ns}	-0.09*	-0.03 ^{ns}	0.17**	-0.118	0.60***	1												
BY	-0.07 ^{ns}	0.16***	0.34**	0.18**	0.31***	0.15**	0.05 ^{ns}	1											
GY	-0.21***	0.40***	0.32**	0.16**	0.15***	0.21***	0.03 ^{ns}	0.57***	1										
HI	-0.21***	0.32***	0.08 ^{ns}	0.04 ^{ns}	-0.07 ^{ns}	0.15***	0.01 ^{ns}	-0.20***	0.67***	1									
LI	-0.21***	-0.08 ^{ns}	0.28**	0.22**	-0.19	-0.09	-0.05 ⁿ	-0.11	-0.04 ⁿ	0.09*	1								
NI	-0.29***	-0.16***	0.23**	0.14**	-0.16	-0.15***	-0.09*	-0.07 ^{ns}	0.03 ^{ns}	0.10*	0.71**	1							
HdI	-0.35***	-0.12**	0.27**	0.14**	-0.08 ^{ns}	-0.11*	-0.11*	-0.07 ^{ns}	0.08 ^{ns}	0.16**	0.73**	0.89*	1						
LS	-0.13**	-0.13**	0.23**	0.22**	-0.26***	-0.14**	0.04 ^{ns}	-0.15***	-0.10*	0.02 ^{ns}	0.94**	0.66*	0.65**	1					
NS	-0.18***	-0.19***	0.16**	0.15**	-0.26***	0.17***	0.05 ^{ns}	0.15**	-0.11*	-0.01 ^{ns}	0.53**	0.72*	0.61**	0.57**	1				
HS	-0.28***	-0.21***	0.22**	0.17**	-0.17***	-0.15***	-0.02 ^{ns}	-0.09*	-0.03 ^{ns}	0.04 ^{ns}	0.71**	0.89*	0.93**	0.70**	0.73**	1			
LAU DPC	-0.087*	-0.29***	0.09*	0.11*	0.13**	0.10*	0.07 ^{ns}	0.14**	-0.02 ^{ns}	-0.13 ***	0.64**	0.36*	0.42**	0.64**	0.18**	0.42**	1		
NAU DPC	-0.17***	-0.36***	0.03 ^{ns}	0.02 ^{ns}	0.16***	0.01 ^{ns}	0.02 ^{ns}	0.15***	-0.03 ^{ns}	***	0.21**	0.47*	0.44**	0.20**	0.64**	0.49**	0.48 ***	1	
HAU DPC	-0.25***	-0.35***	0.09*	0.02 ^{ns}	0.21***	0.02 ^{ns}	-0.05 ^{ns}	0.18***	0.05 ^{ns}	-0.11*	0.36**	0.59*	0.69**	0.31**	0.34**	0.70**	0.63 ***	0.74 ***	1

Appendix Table 6.1 Treatment setup & randomization (Integrated management of finger millet blast disease combining finger millet varieties and fungicides experiment)

Treatment n ^o	Treatment combination	Plot number		
		Rep-I	Rep-II	Rep-III
1	Bako-09 * Contaf max	2	25	35
2	Bako-09 * Nativo	4	18	36
3	Bako-09 * Tilt	8	20	48
4	Bako-09 * Control	13	27	33
5	Tessema * Contaf max	1	19	34
6	Tessema * Nativo	9	29	42
7	Tessema * Tilt	10	23	37
8	Tessema * Control	16	28	47
9	Necho * Contaf max	15	22	41
10	Necho * Nativo	14	32	43
11	Necho * Tilt	6	17	46
12	Necho * Control	7	31	39
13	Local * Contaf max	11	24	44
14	Local * Nativo	12	21	45
15	Local * Tilt	5	30	40
16	Local * Control	3	26	38

Appendix Table 6.2 Summary of mean squares for the effect of varieties and fungicides on yield, and yield related components at Fenotselam and Achefer, West Amhara, Ethiopia

SOV.	Df	DH	DM	PH	FL	NFE	NTP	NEP	BY	GY	HI
Loc	1	5376.33 ^{***}	212.52 ^{***}	4394.93 ^{***}	82.29 ^{***}	8.00 ^{**}	8.67 ^{**}	49.21 ^{***}	38531835.00 ^{***}	100681.68 ^{ns}	2313.94 ^{***}
Year	1	1240.33 ^{***}	2552.08 ^{***}	753.67 ^{***}	0.76 ^{ns}	23.80 ^{***}	1.14 ^{ns}	16.57 ^{***}	32735471.80 ^{***}	501402.40 ^{ns}	2831.62 ^{***}
Loc*Year	1	10.08 ^{ns}	927.52 ^{***}	3013.09 ^{***}	20.22 ^{***}	2.08 ^{ns}	53.34 ^{***}	27.60 ^{***}	7153421.60 [*]	4704186.70 ^{***}	478.80 [*]
Variety	3	198.15 ^{***}	361.76 ^{***}	1783.30 ^{***}	240.48 ^{***}	11.89 ^{***}	17.99 ^{***}	132.92 ^{***}	43464366.50 ^{***}	5862353.12 ^{***}	253.44 [*]
Fungicide	3	2.36 ^{ns}	14.79 ^{ns}	57.83 ^{ns}	0.32 ^{ns}	0.32 ^{ns}	0.93 ^{ns}	0.34 ^{ns}	2902247.70 ^{ns}	8971348.79 ^{***}	2815.16 ^{***}
Variety*Fungicide	9	15.99 ^{ns}	31.29 ^{ns}	76.14 [*]	0.57 ^{ns}	0.77 ^{ns}	0.75 ^{ns}	2.09 ^{ns}	2255380.40 ^{ns}	130512.83 ^{ns}	72.31 ^{ns}
Year*Variety	3	102.76 ^{***}	81.90 ^{**}	73.81 ^{ns}	0.63 ^{ns}	6.18 ^{***}	1.99 ^{ns}	1.02 ^{ns}	5033188.10 ^{**}	1135649.19 ^{***}	142.33 ^{ns}
Year*Fungicide	3	15.81 ^{ns}	6.93 ^{ns}	7.67 ^{ns}	1.22 ^{ns}	0.21 ^{ns}	0.47 ^{ns}	0.11 ^{ns}	1955076.40 ^{ns}	271786.91 ^{ns}	240.59 [*]
Year*Variety*Fungicide	9	16.87 ^{ns}	7.49 ^{ns}	77.10 [*]	0.35 ^{ns}	0.80 ^{ns}	0.55 ^{ns}	0.91 ^{ns}	1858619.30 ^{ns}	253406.24 ^{ns}	89.71 ^{ns}
Loc*Variety	3	263.15 ^{***}	196.31 ^{***}	69.51 ^{ns}	1.07 ^{ns}	1.47 ^{ns}	0.48 ^{ns}	28.33 ^{***}	4236554.00 [*]	2010080.31 ^{***}	50.76 ^{ns}
Loc*Fungicide	3	1.42 ^{ns}	6.42 ^{ns}	61.42 ^{ns}	2.35 ^{ns}	0.97 ^{ns}	0.42 ^{ns}	0.74 ^{ns}	184154.50 ^{ns}	79946.96 ^{ns}	64.66 ^{ns}
Loc*Variety*Fungi	9	6.31 ^{ns}	7.81 ^{ns}	9.83 [*]	1.95 ^{ns}	1.34 ^{ns}	0.32 ^{ns}	1.39 ^{ns}	884193.2 ^{ns}	137918.90 ^{ns}	65.46 ^{ns}
Loc*Year*Variety	3	206.35 ^{***}	50.65 [*]	79.89 ^{ns}	2.76 ^{ns}	3.86 ^{**}	0.63 ^{ns}	0.52 ^{ns}	2395377.00 ^{ns}	658842.10 ^{**}	197.68 [*]
Loc*Year*Fungicide	3	2.22 ^{ns}	17.59 ^{ns}	35.92 ^{ns}	0.29 ^{ns}	0.33 ^{ns}	0.48 ^{ns}	1.19 ^{ns}	2396233.20 ^{ns}	122655.83 ^{ns}	192.11 [*]
Loc*Year*Variety*Fungicide	9	15.04 ^{ns}	50.83 ^{***}	23.04 ^{ns}	1.14 ^{ns}	0.69 ^{ns}	0.49 ^{ns}	0.75 ^{ns}	522067.10 ^{ns}	95572.60 ^{ns}	33.30 ^{ns}
Mean		106.42	148.75	78.05	9.49	6.77	4.49	7.38	6116.22	2599.33	44.43
CV (%)		2.78	2.97	7.32	11.41	13.69	20.34	23.91	26.19	22.39	21.34

**** Significant at 0.001 *** Significant at 0.01 ** Significant at 0.05 ns=non-significant, SOV= source of variation, df= degree of freedom, Loc=location, Fungi-fungicide, DH= days to heading, DM= days to maturity, PH= plant height, FL= Finger length, NFE= number of finger per ear, NTP= number of reproductive tiller per plant, NEP= number of ear per plant, BY= Biomass yield, GY= grain yield, HI= harvest index, MSE= mean square error, and CV= coefficient of variation.

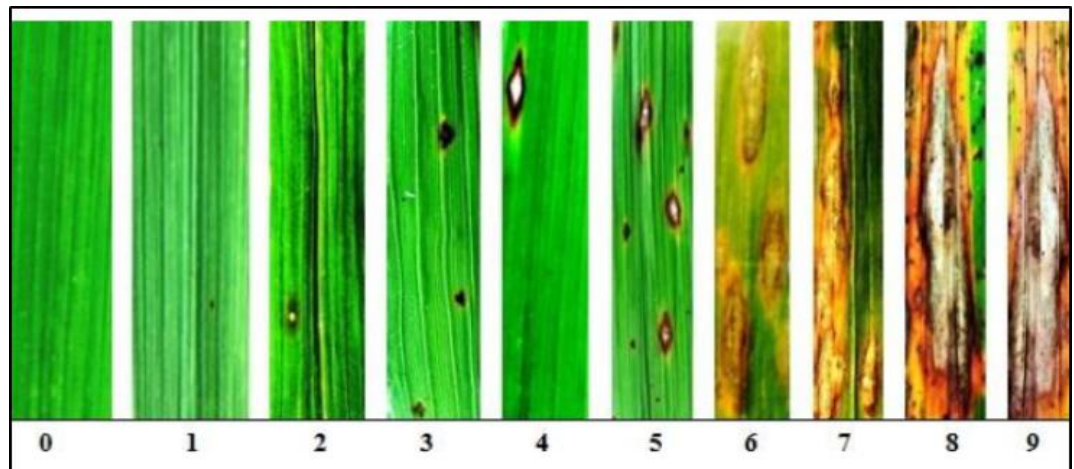
Appendix Table 6.3 Summary of mean squares for the effect of varieties and fungicides on disease parameters at Fenotselam and Achefer sites

SOV.	LBI	NBI	HBI	LBS	NBS	HBS	LBAUDPC	NBAUDPC	HBAUDPC
Loc.	3215.15 ^{**}	5210.52 ^{***}	7541.06 ^{***}	568.80 [*]	53.83 ^{ns}	4.06 ^{ns}	97554178.67 ^{***}	63892667.5 ^{***}	126843162.1 ^{***}
Year	5553.56 ^{***}	13005.87 ^{ns}	11672.23 ^{**}	2500.65 ^{***}	11560.23 ^{ns}	10886.6 ^{ns}	1385024.85 ^{***}	6073584.6 ^{ns}	10490064.2 ^{**}
Loc*Year	475.99 ^{ns}	6740.39 ^{**}	631.98 ^{ns}	22.43 ^{ns}	1315.24 ^{ns}	61.68 ^{ns}	738449.81 [*]	10848352.3 ^{***}	1949843.1 ^{ns}
Variety	7375.63 ^{***}	6589.92 ^{***}	7399.24 ^{**}	3596.74 ^{***}	6652.63 ^{***}	9141.2 ^{***}	3280482.18 ^{***}	8438662.1 ^{***}	12515927.6 ^{***}
Fungicide	2553.59 ^{***}	8524.93 ^{***}	3762.47 ^{***}	1411.52 ^{***}	8556.37 ^{***}	5465.2 ^{***}	1550766.00 ^{***}	9276982.2 ^{***}	5947844.0 ^{***}
Variety*Fungi.	60.13 ^{ns}	476.58 ^{ns}	152.59 ^{ns}	21.05 ^{ns}	244.67 ^{ns}	146.3 ^{ns}	24091.53 ^{ns}	228157.4 ^{ns}	222217.8 ^{ns}
Year*Variety	53.01 ^{ns}	268.49 ^{ns}	1282.95 ^{**}	39.73 ^{ns}	127.93 ^{ns}	970.5 ^{**}	131096.59 ^{ns}	747251.4 ^{**}	1938005.3 ^{***}
Year*Fungicide	33.93 ^{ns}	967.43 ^{**}	108.06 ^{ns}	6.18 ^{ns}	555.26 [*]	260.9 ^{ns}	6534.00 ^{ns}	540731.9 [*]	260571.9 ^{ns}
Year*Variety*Fungi.	53.28 ^{ns}	252.59 ^{ns}	136.34 ^{ns}	29.12 ^{ns}	126.07 ^{ns}	100.8 ^{ns}	23480.92 ^{ns}	129999.9 ^{ns}	144893.0 ^{ns}
Loc*Variety	117.31 ^{ns}	706.93 [*]	248.86 ^{ns}	33.56 ^{ns}	1053.52 ^{**}	6.39 ^{ns}	292077.79 ^{ns}	1432977.7 ^{***}	80133.3 ^{ns}
Loc*Fungicide	6.93 ^{ns}	269.64 ^{ns}	29.49 ^{ns}	14.94 ^{ns}	76.03 ^{ns}	4.28 ^{ns}	28796.81 ^{ns}	819492.6 ^{**}	178167.5 ^{ns}
Loc*Variety*Fungi.	53.91 ^{ns}	181.78 ^{ns}	27.09 ^{ns}	15.52 ^{ns}	82.92 ^{ns}	7.23 ^{ns}	16271.69 ^{ns}	195094.4 ^{ns}	31831.8 ^{ns}
Loc*Year*Variety	32.94 ^{ns}	847.95 [*]	14.58 ^{ns}	11.60 ^{ns}	478.38 ^{ns}	3.94 ^{ns}	94782.32 ^{ns}	1402362.7 ^{***}	63335.3 ^{ns}
Loc*Year*Fungi.	25.78 ^{ns}	75.34 ^{ns}	16.35 ^{ns}	0.60 ^{ns}	9.35 ^{ns}	2.30 ^{ns}	31156.10 ^{ns}	157811.6 ^{ns}	46042.5 ^{ns}
Loc*Year*Variety*Fungi.	16.24 ^{ns}	173.28 ^{ns}	37.37 ^{ns}	1.09 ^{ns}	41.68 ^{ns}	2.08 ^{ns}	12305.55 ^{ns}	120102.0 ^{ns}	63525.4 ^{ns}
Mean	79.60	82.98	100.79	43.41	62.76	79.49	1098.11	1902.96	2344.73
SEM (±)	10.57	7.28	8.62	8.22	6.99	7.17	29.09	32.77	33.53
CV (%)	55.05	42.41	31.09	59.26	37.35	30.48	59.39	37.92	32.08

**** Significant at 0.001 *** Significant at 0.01 ** Significant at 0.5, ns=non-significant, SOV= source of variation, df= degree of freedom, Loc- location, Fungi- fungicide, LBI= live blast incidence, NBI= neck blast incidence, HBI= head i blast incidence, LBS= leaf blast severity(%), NBS= neck blast severity(%), HBS= head blast severity(%), LBAUDPC= leaf blast area under disease progress curve, NBAUDPC= neck blast area under disease progress curve, HBAUDPC= head blast area under disease progress curve, MSE= mean square error, and CV= coefficient of variation.

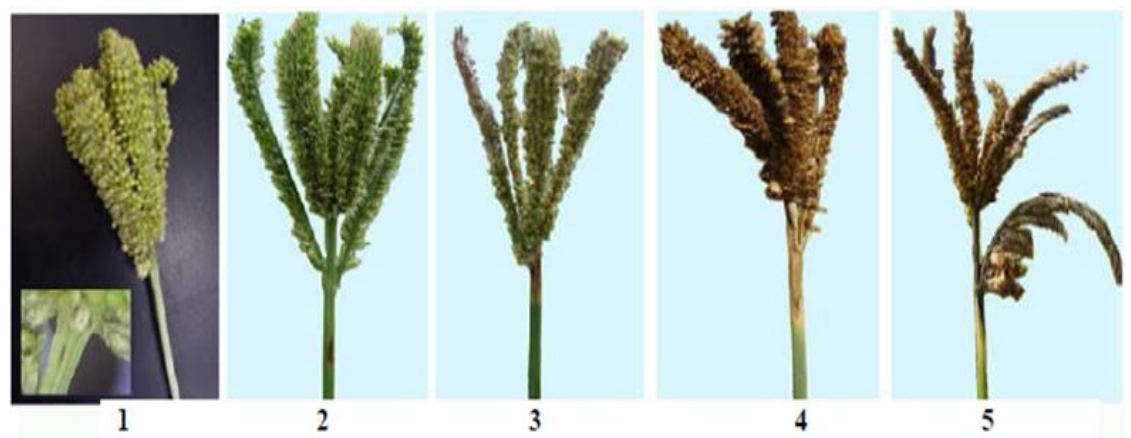
Appendix Table 6.4 Relative yield gain and disease suppression by fungicides and varieties during the 2022 and 2023 cropping seasons

Variety	Fungicide	Relative Yield Gain (%)	Percent LBS Suppression (%)	Percent NBS Suppression (%)	Percent HBS Suppression (%)
Bako09	Contaf max	30.835	33.4625	61.4925	30.400
Bako09	Nativo	25.835	25.1025	42.3325	26.035
Bako09	Tilt	18.883	18.275	22.6725	16.105
Local	Contaf max	35.393	20.225	41.355	28.385
Local	Nativo	28.495	18.300	34.235	15.775
Local	Tilt	23.535	19.630	13.468	11.905
Necho	Contaf max	32.025	20.445	26.105	19.8575
Necho	Nativo	25.623	20.545	27.108	12.540
Necho	Tilt	22.700	21.370	19.680	15.248
Tessema	Contaf max	31.575	26.518	31.435	33.760
Tessema	Nativo	20.110	19.130	20.325	10.955
Tessema	Tilt	18.865	11.065	15.245	15.275



Appendix Figure 2.1 Scoring scale of Leaf blast disease of 0-9

Source: IRRI (2014)

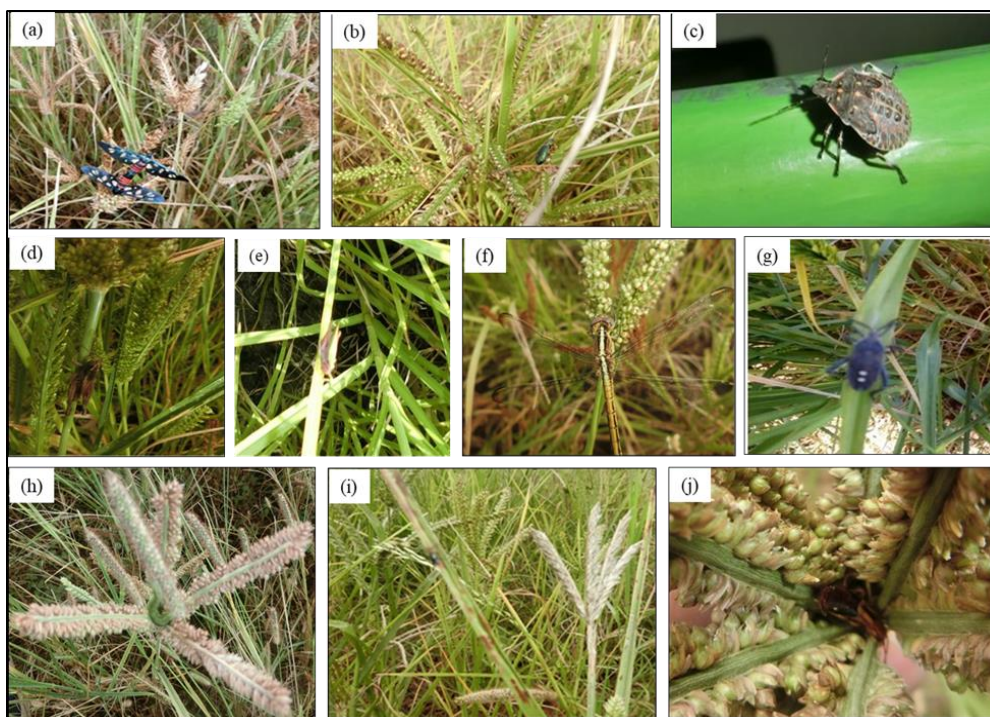


Appendix Figure 2.2 Panicle showing neck and finger damage rating

Source: Babu *et al.* (2013)



Appendix Figure 3.1 Last disease symptom development during pathogenicity test



Appendix Figure 2.4. Insect pests of finger millet observed during field survey a) Lepidoptera - butterflies: *Amata cerbera*, b) Blister beetle - *Oulema* spp., c) Stink bug - *Nezara viridula*, d-e) Grasshopper: *Hieroglyphus* spp., f) Order Odonata - dragonflies: Anisoptera, g) unidentified, h) Stem borer: *Coniesta ignefusalis*, i) Diptera (shoot fly): *Atherigona soccata*, and j) unidentified

Appendix Figure 3.1 Photos demonstrating laboratory work during pathogen isolation and characterization



Appendix Figure 4.1 Some photos demonstrating Farmers Interview



Appendix Figure 5.1 Land preparation for the field experiment



Appendix Figure 5.2 Screening of finger millet genotypes field experiment at Adet, and Finote Selam Experimental sites



Appendix Figure 6.1 Integrated field experiment at Finote Selam and Semein Achefer



BIOGRAPHY OF THE AUTHOR

The author was born to his father Mr. Andargie Dagneu and his mother Mrs. Huluagresh Worku on 30 November 1986, in Amhara Regional State, Central Gondar zone (West Belessa *woreda*). He attended his elementary school at Guhalla primary school from 1992-2000 and continued his secondary education at Addis Zemen Comprehensive Secondary and Preparatory School from 2001-2004. He then joined University of Gondar after having passed the Ethiopian higher education entrance examination to study BSc in 2005 and graduated in August, 16, 2008 with Degree in Applied Biology. After graduation, he was employed by the Amhara Educational Bureau as a biology teacher of high school in September, 2009, and served for one and half year and then joined Bahir Dar University in March, 26, 2010 as Technical Assistant in the Department of Biology. He joined the post graduate program at Bahir Dar University to pursue his master's degree in Botanical Sciences and graduated in June 29, 2016. He had been working as a lecture at Debre Tabor University until September 11, 2016 was employed by Bahir Dar University in July 17, 2019 and served as a lecturer until he joined post graduate program in October 03, 2020 to pursue his PhD in plant Pathology at Bahir Dar University, collage of Agriculture, and Environmental Sciences.

ARTICLE PUBLICATIONS

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

1. Melkamu Andargie, Merkuz Abera, Tesfaye Alemu, and Berhanu Bekele. (2025). Disease Occurrence, Distribution and Intensity of Finger Millet Blast in Northwest Amhara, Ethiopia. Published by Willey, *Journal of Phytopathology*, 173:e70159. DOI: <https://doi.org/10.1111/jph.70159> (Scopus and web of Science indexed).
2. Melkamu Andargie, Merkuz Abera, Alemu Tesfaye and Berhanu Feyissa. (2025). Phenotypic Characterization of *Magnaporthe grisea* Isolates Causing Finger Millet Blast in Northwestern Amhara, Ethiopia. Summited, and Under Review Process.
3. Melkamu Andargie, Merkuz Abera, Tesfaye Alemu, and Berhanu Bekele. (2025). Assessing the knowledge of farmers in managing finger millet blast disease for sustainable agriculture and food security. Published by Springer nature: *Discover Applied Sciences*, 7:883. DOI: <https://doi.org/10.1007/s42452-025-07533-w> (Scopus and web of Science indexed).
4. Melkamu Andargie, Merkuz Abera, Tesfaye Alemu, and Berhanu Bekele. (2024). Screening of Finger Millet Genotypes for Resistance to *Magnaporthe grisea* in Northwestern Ethiopia. Published by EScience Press: *International Journal of phytopathology*, 13 (3): 251-266. DOI: [10.33687/phytopath.013.03.5423](https://doi.org/10.33687/phytopath.013.03.5423) (Scopus and web of Science indexed).
5. Melkamu Andargie, Merkuz Abera, Tesfaye Alemu, and Berhanu Bekele. (2024). Finger millet (*Elusine coracana* L. Gaertn) blast disease integrated management techniques: combining fungicide sprays and resistant cultivars for long-term crop protection. Published by *Chock Journal of Science and Technology*, 5(1):798-816. (Accredited By MoE).

CONFERENCE PRESENTATIONS





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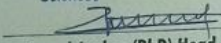
Bahir Dar University

CERTIFICATE OF RECOGNITION

To: Mr. Melkamu Andargie

This is to recognize Mr. Melkamu Andargie for presenting a seminar on May, 20/2021 "Occurrence, distribution, and management experiences of rice (*Oryza sativa* L.) Major diseases and pests in Ethiopia: a review" by recognizing your contribution, the department has issued this certificate.

Abaynew Jemal Jenber (PhD)
Head, Department of Plant
Sciences


Abaynew Jemal Jenber (PhD) Head department
of Plant Sciences

Date of issue
19 Aug. 2025


Alemu Abate Aslaw (PhD)
Postgraduate, Research &
Community Service V/Dean
Postgraduate, Research and community service vice
dean, College of Agriculture and Environmental Sciences
Bahir Dar University