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Epidemiology, Characterization, and Management of Faba Bean Gall (Physoderma Viciae) Disease in Faba Bean (Vicia Faba) in South Wollo, North-Eastern Ethiopia

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BAHIR DAR UNIVERSITY

COLLEGE OF AGRICULTURE AND ENVIRONMENTAL SCIENCES

DEPARTMENT OF PLANT SCIENCES

Ph.D. IN PLANT PATHOLOGY

**EPIDEMIOLOGY, CHARACTERIZATION, AND MANAGEMENT OF
FABA BEAN GALL (*Physoderma viciae*) DISEASE IN FABA BEAN (*Vicia
faba*) IN SOUTH WOLLO, NORTH-EASTERN ETHIOPIA**

Ph.D. Dissertation

By

Seid Hussen Ahmed

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Bahir Dar, Ethiopia

BAHIR DAR UNIVERSITY

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GALL (*Physoderma viciae*) DISEASE IN FABA BEAN (*Vicia faba*) IN SOUTH WOLLO,
NORTH-EASTERN ETHIOPIA**

A Dissertation

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

By

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DISSERTATION APPROVAL SHEET

As members of the Board of Examiners for the Doctor of Philosophy (Ph.D.) degree, we have read and evaluated this dissertation prepared by Mr. Seid Hussen Ahmed and examined the candidate during the open defense examination. We hereby certify that the dissertation fulfils the requirements for the award of the degree of Doctor of Philosophy (PhD) in Plant Pathology.

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DECLARATION

This is to certify that this **Epidemiology, Characterization and Management of Faba Bean Gall (*Physoderma viciae*) Disease in South Wollo, North-Eastern Ethiopia** submitted in 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. Seid Hussen Ahmed** (ID. No. BDU1301225) 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

This PhD dissertation is dedicated to my father, Hussen Ahmed, and my mother, Zerie Muhye, for their love, guidance, and unwavering support throughout my life. It is also dedicated to my elder brother, Awol Hussen, for his inspiration, encouragement, and brotherly support. Furthermore, I dedicate this dissertation to my beloved wife, Kemila Hussen, and my children, Eleham Seid and Nebilah Seid, for their patience, endurance, and continuous support throughout my academic journey.

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ABBREVIATIONS AND ACRONYMS

AGY	Adjusted Grain Yield
ANOVA	Analysis of Variance
APPRC	Ambo Plant Protection Research Center
ARC	Agricultural Research Center
AUDPC	Area Under Disease Progress Curve
BLAST	Basic Local Alignment Search Tool
CABI	Commonwealth Agricultural and Bioscience International
CN	Coon's Medium
CSA	Central Statistical Agency
CRD	Completely Randomized Design
DAS	Days After Sowing
DI	Disease Incidence
DMRT	Duncan Multiple Range Test
DNA	Deoxyribonucleic Acid
DR	Deviance Reduction
EIAR	Ethiopian Institute of Agricultural Research
EB	Ethidium Bromide
FAOSTAT	Food and Agriculture Organization of the United Nations Statistical Database
FAS	Farmers' Associations
FBG	Faba Bean Gall
GFB	Gross Field Benefit
GLM	General Linear Model
GPS	Global Positioning System
HARC	Holetta Agricultural Research Center
ICARDA	International Center for Agricultural Research in the Dry Areas
KOAc	Potassium Acetate
LDANRDO	Legambo District Agricultural and Natural Resource Development Office

LRTs	Likelihood Ratio Tests
LSD	Least Significant Difference
MEA	Malt Extract Agar
MoARD	Ministry of Agriculture and Rural Development
MRR	Marginal Rate of Return
NB	Net Benefit
Ors	Odds Ratios
PCR	Polymerase Chain Reaction
PDA	Potato Dextrose Agar
RCBD	Randomized Complete Block Design
RYLP	Relative Yield Loss Percentage
SAS	Statistical Analysis System
SPSS	Statistical Package for the Social Sciences
TVC	Total Variable Cost
VEF	Variables Entered First
VEL	Variables Entered Last
WG	Wettable Granular
WP	Wettable Powder
YBT	Yield of Basic Treatment
YLT	Yield from the Lower Treatment

TABLE OF CONTENTS

Contents	page
DISSERTATION APPROVAL SHEET.....	i
DEDICATION.....	iii
ACKNOWLEDGEMENTS	iv
ABBREVIATIONS AND ACRONYMS.....	v
TABLE OF CONTENTS	vii
LIST OF TABLES	x
LIST OF FIGURES	xii
LIST OF TABLES IN THE APPENDIX	xiv
LIST OF FIGURES IN THE APPENDIX	xvi
GENERAL ABSTRACT	xvii
Chapter .1 GENERAL INTRODUCTION.....	1
1.1 Background and Justification	1
1.2 Statement of the Problem	6
1.3 . Objective of the Study	8
1.3.1 General objective.....	8
1.3.2 Specific objectives	8
1.4 Research Questions	9
1.5 . Significance of the Study	9
1.6 Organization of the Dissertation	10
Chapter 2. GENERAL MATERIALS AND METHODS	11
2.1 . Description of the Study Areas	11
2.2 Sampling Procedure and Experimental Design.....	13
2.3 Data Collection.....	15
2.4 Data Analysis	17
Chapter 3. Survey on the Distribution and Epidemiology of Faba Bean Gall (<i>Physoderma viciae</i>) in South Wollo, Northeastern Ethiopia.....	18
3.1 Introduction	19
3.2 Materials and Methods	21
3.2.1 Surveyed Areas.....	21
3.2.2 Sampling Procedures and Disease Assessment	24
3.2.3 Data Collection	24
3.2.4 Data Analysis	25
3.3 Results and Discussion.....	27
3.3.1 Faba Bean Gall Prevalence, Incidence, and Severity	27
3.3.2 Association of Faba Bean Gall with Agro-Ecological Factors.....	33
3.4 Conclusion.....	40
3.5 Recommendations	41

Chapter 4. Histopathological and Molecular Characterization of <i>Physoderma viciae</i> Associated with Faba Bean Gall Disease in Ethiopia	42
4.1 Introduction	43
4.2 Materials and Methods	44
4.2.1 Sample Collection.....	44
4.2.2 Histopathological Examination	44
4.2.3 Isolation of Microorganisms from Faba Bean Gall Tissues	45
4.2.4 Cultural and Morphological Characterization of Recovered Isolates	46
4.2.5 Molecular Identification of Faba Bean Gall	47
4.2.6 Collection of Faba Bean Gall (FBG) Samples for DNA Analysis	47
4.2.7 DNA Extraction and PCR Conditions	47
4.2.8 Statistical data analysis	49
4.3 Results and Discussion.....	49
4.3.1 Symptoms of Faba Bean Gall Disease	49
4.3.2 Histopathological Detection of <i>Physoderma viciae</i> in Gall Tissues	50
4.3.3 Isolation and Characterization of Gall-Associated Saprophytic Fungi	51
4.3.4 Growth Characteristics of Gall-Associated Saprophytic Isolates on Different Media.....	52
4.3.5 Morphological Characteristics of Gall-Associated Saprophytic Isolates	54
4.3.6 Molecular Detection of <i>Physoderma viciae</i> in Symptomatic Faba Bean Tissues	56
4.4 Conclusion.....	58
4.5 Recommendation.....	59
Chapter 5. Evaluation of Faba Beans (<i>Vicia faba</i> L.) Genotypes against Faba Bean Gall (<i>Physoderma viciae</i>) in the Highlands of South Wollo, North-Eastern Ethiopia.....	60
5.1 Introduction	61
5.2 Materials and Methods	62
5.2.1 Description of the Study Area	62
5.2.2 Treatments and Experimental Design.....	64
5.2.3 Data Collection	65
5.2.4 Disease assessment	65
5.2.5 Yield and Yield Component Data	66
5.2.6 Data Analysis.....	66
5.3 Results and Discussions	67
5.3.1 Faba Bean Gall Incidence	67
5.3.2 Disease Severity	69
5.3.3 Area Under Disease Progress Curve	71
5.3.4 Yield and Yield Components	73
5.3.5 Plant Height, Pods per Plant, and Seeds per Pod.....	73
5.3.6 Hundred Seed Weight and Yield.....	76
5.3.7 Association of Disease Parameters with Yield.....	77
5.3.8 Regression Analysis of Yield with Percentage Gall Severity Index	78

5.4 Conclusion.....	79
5.5 Recommendations	81
Chapter 6. Faba Bean Gall (<i>Physoderma viciae</i>) Disease Management through Faba Bean Varieties and Fungicides in the Highlands of South Wollo, Northeastern Ethiopia	82
6.1 Introduction	83
6.2 Materials and Methods	85
6.2.1 Description of the Study Area	85
6.2.2 Agronomic procedures and plant material.....	87
6.2.3 Experimental Design and Layout	87
6.2.4 Data Collation.....	88
6.2.5 Disease-related parameters	88
6.2.6 Agronomic parameters	90
6.2.7 Relative Yield Loss	90
6.2.8 Cost-benefit analysis.....	90
6.3 Statistical Analysis	91
6.4 Results and Discussion.....	92
6.4.1 Disease Parameters	92
6.4.2 Disease incidence	93
6.4.3 Disease Severity	95
6.4.4 Area under Disease Progress Curve (AUDPC)	96
6.4.5 Progression Rate of Faba Bean Gall Disease	100
6.4.6 Crop Yield Parameter	102
6.4.7 Plant height of faba bean	103
6.4.8 Seeds per pod and number of pods per plant.....	104
6.4.9 Faba bean grain yield.....	106
6.4.10 Relative yield loss due to faba bean gall epidemic.....	107
6.5 Cost–Benefit Analysis.....	110
6.6 Correlation of Disease Parameters with Yield and Yield Components	114
6.7 Conclusion.....	115
6.8 Recommendations	116
Chapter 7. General Conclusion and Recommendations	117
7.1 Conclusion.....	117
7.2 Recommendations	118
REFERENCE	122
APPENDIX	133

LIST OF TABLES

Table 2. 1. Altitude and Weather Conditions of Faba Bean Gall Surveyed Districts in South Wollo Zone, Eastern Amhara, Ethiopia.....	13
Table 3. 1. Altitude, rainfall, and temperature conditions of the four surveyed districts in South Wollo, northeastern Ethiopia, during the 2022 and 2023 cropping seasons. 22	
Table 3. 2. Prevalence, incidence, and severity (Mean $\pm$ SE) of faba bean gall across different independent variables in north-eastern Ethiopia during the 2022 and 2023 cropping seasons. ...	32
Table 3. 3. Logistic regression model for mean faba bean gall disease incidence and severity, and likelihood ratio test on independent variables during the 2022 and 2023 main rainy seasons.	34
Table 3. 4. Analysis of Deviance, Natural Logarithms of Odds Ratios, and Standard Errors for Faba Bean Gall Disease Incidence Based on a Reduced Logistic Regression Model.....	36
Table 3. 5. Analysis of Deviance, Natural Logarithms of Odds Ratios, and Standard Errors for Faba Bean Gall Disease Severity Based on a Reduced Logistic Regression Model	38
Table 4. 1. <i>Physotheria viciae</i> -specific primers.....	48
Table 4. 2. Evaluation of different culture media on colony diameter (mm) and growth rate (mm/day) of saprophytic fungi isolated from faba bean gall tissues incubated at 23 ± 2 °C.....	53
Table 4. 3. Colony morphology and growth characteristics of saprophytic fungi isolated from faba bean gall tissues	55
Table 5. 1. Faba bean genotypes evaluated for their reaction against the faba bean gall in the 2022 and 2023 main cropping seasons.....	65
Table 5. 2. Faba bean gall disease incidence, Severity, and AUDPC on different faba bean genotypes at Legambo district in the 2022 and 2023 cropping seasons.	68
Table 5. 3. Faba bean gall disease incidence, Severity, and AUDPC on different faba bean genotypes in 2022 and 2023 cropping seasons at Tenta district.	70
Table 5. 4. Mean yield components of faba bean genotypes evaluated for faba bean disease under field conditions in the 2022 and 2023 cropping seasons at Legambo.	74
Table 5. 5. Mean of yield components of faba bean genotype evaluated for faba bean disease under field conditions in the 2022 and 2023 cropping seasons at Tenta.	75
Table 5. 6. Yields and hundred seed weights of faba bean genotypes at Legambo and Tenta in the 2022 and 2023 main cropping seasons.	77
Table 5. 7. Correlation coefficients (r) of disease parameters with yield at Legambo district.....	78
Table 5. 8. Correlation coefficients (r) of disease parameters with yield at Tenta in districts ...	78
Table 6. 1 Description of Faba bean varieties.....	87
Table 6. 2. Fungicides dose and mode of application used	88
Table 6. 3. Mean squares analysis of location, year, varieties, fungicide and the combined effect on faba bean gall disease incidence, severity and AUDPC at Legambo and Tenta in 2022 and 2023 main growing seasons.	92

Table 6. 4. Interaction effect of fungicide treatments and faba bean varieties on faba bean gall disease incidence (%) at Legambo and Tenta districts during the 2022 and 2023 main cropping seasons.	94
Table 6. 5. Interaction effect of fungicide treatments and faba bean varieties on percentage severity index (PSI) of faba bean gall disease at Legambo and Tenta districts during the 2022 and 2023 main cropping seasons.	96
Table 6. 6. Interaction effect of fungicide treatments and faba bean varieties on area under the disease progress curve (AUDPC) of faba bean gall disease at Legambo and Tenta districts during the 2022 and 2023 main cropping seasons.	100
Table 6. 7. Adjusted coefficient of determination (R ²) and faba bean gall progression rate (r) in logit per day for faba bean varieties combined with fungicide in Legambo and Tenta districts during the 2022 and 2023 growing seasons.	102
Table 6. 8. Analysis of the combined effects of year, location, fungicide, and variety on faba bean yield and yield components in Tenta and Legambo during the 2022 and 2023 growing seasons.	103
Table 6. 9. Interaction effect of fungicide and varieties on plant height of faba bean over years and locations.	104
Table 6. 10. Interaction effect of fungicide and varieties on number of pods per plant of faba bean over years and locations.	105
Table 6. 11. Interaction effect of fungicide and varieties on a seed per pod of faba bean over years and locations.	105
Table 6. 12. Interaction effect of fungicide and varieties on a yield of faba bean over years and locations.	107
Table 6. 13. The combined impact of a fungicide-treated faba bean variety on yield loss due to faba bean gall disease in Legambo district, North-Eastern Ethiopia, during the main growing seasons of 2022 and 2023.	110
Table 6. 14. Cost benefits analysis for managing faba bean gall disease in Legambo and Tenta for the cropping seasons of 2022 using various varieties and fungicides.	112
Table 6. 15. Cost benefits analysis for managing faba bean gall disease in Legambo and Tenta for the cropping seasons of 2023 using various varieties and fungicides.	113
Table 6. 16. Correlation coefficient (r) between yield and yield components and disease parameters at Legambo district in the crop seasons of 2022(Lower Diagonal) and 2023(Upper Diagonal).....	114
Table 6. 17. Correlation coefficient (r) between yield and yield components and disease parameters at Tenta district in the crop seasons of 2022(Lower diagonal) and 2023(Upper diagonal).	114

LIST OF FIGURES

Figure 1. 1. Field and plant host symptoms for faba bean gall (FBG) disease in Ethiopia showing poor faba bean growth and major foliage death in a severely infested farm field (Bitew Beyene <i>et al.</i> , 2021)	4
Figure 2. 1 . Map showing surveyed districts for faba bean gall in South Wollo, North-Eastern Ethiopia during the 2022 and 2023 cropping seasons.....	12
Figure 3. 1. Map showing surveyed districts for faba bean gall in South Wollo, North-Eastern Ethiopia during the 2022 and 2023 cropping seasons.....	22
Figure 3. 2. Rainfall, maximum and minimum temperatures, and relative humidity of surveyed districts in north-eastern Ethiopia during the 2022 and 2023 faba bean-growing seasons.....	23
Figure 3. 3. Collection of plant disease parameters and physical factors from farmers' fields during the 2022 and 2023 main cropping season.....	28
Figure 3. 4. Mean of faba bean gall disease (Prevalence, Incidence, and Percentage Severity index) across four districts in 2022 and 2023	29
Figure 3. 5. Mean of faba bean gall disease prevalence, incidence and percentage severity index on different altitudes in 2022 and 2023 cropping seasons.....	30
Figure 3. 6. Summarizing odds ratios from the reduced logistic regression model showing the effects of district, year, altitude, variety, fungicide application, and field drainage on faba bean gall disease incidence.....	37
Figure 3. 7. Summarizing odds ratios and estimate from the reduced logistic regression model showing the effects of district, year, altitude, variety, fungicide application, and field drainage on faba bean gall disease severity.....	39
Figure 4. 1. Faba bean gall symptoms on the lower side of faba bean leaves (a-c), poor plant growth and major foliage death in a severely infested field (d-e).....	50
Figure 4. 2. Histopathological features associated with faba bean gall disease caused by <i>Physoderma viciae</i> . (a) Gall-associated tissue discoloration and necrosis; (b) thick-walled resting spores within infected tissue; (c) resting spores in senescent infected plant residue; (d) turbinate cells within infected tissue; (e) epibiotic zoosporangia on the infected tissue surface; and (f) zoosporangium containing zoospores with a discharge opening. Arrows indicate diagnostic pathogen structures. Scale bars are shown in each panel.....	51
Figure 4. 3. Colony morphology of saprophytic fungi isolated from faba bean gall tissues on different media after 14 days of incubation at $23 \pm 2^{\circ}\text{C}$	54
Figure 4. 4. Microscopic morphology of <i>Alternaria</i> -like isolates different medium (a–g) the view under the microscope (40 $\times$)	55
Figure 4. 5. PCR amplification of <i>Physoderma viciae</i> using the Physo1 primer pair. Amplification products of approximately 300–400 bp were detected in DNA extracted directly from symptomatic faba bean gall tissues	57

Figure 4. 6. PCR amplification of <i>Physoderma viciae</i> using the Physo D' primer pair. Amplification products of approximately 400–500 bp were detected in DNA extracted directly from symptomatic faba bean gall tissues.	58
Figure 5. 1. Monthly weather conditions at Legambo (a, b) and Tenta (c, d) during the 2022 and 2023 faba bean growing seasons.	63
Figure 5. 2. Photo demonstrating field experiment data collection	64
Figure 5. 3. Area under the disease progress curve (AUDPC) of faba bean genotypes evaluated against faba bean gall disease at Legambo during the 2022 (a) and 2023 (b) main cropping seasons.	72
Figure 5. 4. Area under the disease progress curve (AUDPC) of faba bean genotypes evaluated against faba bean gall disease at Tenta during the 2022 (a) and 2023 (b) main cropping seasons.	72
Figure 6. 1. The average annual maximum temperature, minimum temperature, and Relative humidity and mean monthly rainfall of 2 years at Legambo 2022(a) and 2023 (b) and Tenta 2022(c) and 2023(d) respectively.	86
Figure 6. 2. Area under the disease progress curve (AUDPC) as affected by variety × fungicide combinations for faba bean gall disease at Legambo and Tenta during the 2022 and 2023 cropping seasons.	98
Figure 6. 3. Area under the disease progress curve (AUDPC) of faba bean varieties for faba bean gall disease at Legambo and Tenta during the 2022 and 2023 cropping seasons.	99

LIST OF TABLES IN THE APPENDIX

Appendix Table 2. 1. Altitude and Weather Conditions of Faba Bean Gall Surveyed Districts in South Wollo zone, Eastern Amhara, Ethiopia.	135
Appendix Table 3. 1. Prevalence, incidence, and severity (Mean $\pm$ SE) of faba bean gall across different independent variables in north-eastern Ethiopia during the 2022 and 2023 cropping seasons.	137
Appendix Table 3. 2. Logistic regression model for mean faba bean gall disease incidence and severity, and likelihood ratio test on independent variables during the 2022 and the 2023 main rainy seasons.	138
Appendix Table 3. 3. Analysis of deviance, natural logarithms of odds ratios, and standard errors for faba bean gall disease incidence based on a reduced logistic regression model. Independent variables were evaluated using likelihood ratio tests during the 2022 and 2023 main cropping season.	138
Appendix Table 3. 4. Analysis of deviance, natural logarithms of odds ratios, and standard errors for faba bean gall disease severity based on a reduced logistic regression model. Independent variables were evaluated using likelihood ratio tests during the 2022 and 2023 main cropping season.	140
Appendix Table 5. 1. Treatment setup and randomization for evaluating different faba bean genotypes against faba bean gall disease at Legambo and Tenta Districts.	143
Appendix Table 5. 2. Faba bean genotypes evaluated for their reaction against the faba bean gall in the 2022 and 2023 main cropping seasons.	144
Appendix Table 5. 3. Summary of analysis of variance mean squares for the effect of locations, year, treatments and their interactions on agronomic, yield, and disease parameters at Legambo and Tenta, north-eastern Ethiopia.	145
Appendix Table 5. 4. Faba bean gall disease incidence, Severity and AUDPC on different faba bean genotypes at Legambo district in the 2022 and 2023 cropping seasons.	146
Appendix Table 5. 5. Faba bean gall disease incidence, Severity and AUDPC on different faba bean genotypes in 2022 and 2023 cropping seasons at Tenta district.	147
Appendix Table 5. 6. Mean yield components of faba bean genotypes evaluated for faba bean disease under field conditions in the 2022 and 2023 cropping seasons at Legambo.	151
Appendix Table 5. 7. Mean of yield and yield components of faba bean genotype evaluated for faba bean disease under field conditions in the 2022 and 2023 cropping seasons at Tenta.	152
Appendix Table 5. 8. Yields and hundred seed weights of faba bean genotypes at Legambo and Tenta in the 2022 and 2023 main cropping seasons.	153
Appendix Table 5. 9. Correlation coefficients (r) of disease parameters with yield at Legambo district in 2022 and 2023 main cropping season.	154
Appendix Table 5. 10. Correlation coefficients (r) of disease parameters with yield at Tenta districts in 2022 and 2023 main cropping seasons.	154

Appendix Table 6. 1. Treatment setup and randomization for the integrated management of faba bean gall disease combining faba bean varieties and fungicides.....	154
Appendix Table 6. 2. Description of Faba bean varieties.....	155
Appendix Table 6. 3. Fungicides dose and mode of application were used.....	155
Appendix Table 6. 4. Mean squares analysis of location, year, varieties, fungicide and the combined effect on faba bean gall disease at Legambo and Tenta in 2022 and 2023 main growing seasons of disease Incidence, Severity and AUDPC.	155
Appendix Table 6. 5. Adjusted coefficient of determination (R ²) and faba bean gall progression rate (r) in logit per day for faba bean varieties combined with fungicide in Legambo and Tenta districts during the 2022 and 2023 growing seasons.	156
Appendix Table 6. 6. Analysis of the combined effects of year, location, fungicide, and variety on faba bean yield and components in Tenta and Legambo during the 2022 and 2023 growing seasons.	156
Appendix Table 6. 7. The combined impact of a fungicide-treated faba bean variety on yield loss due to faba bean gall disease in Legambo district, north-eastern Ethiopia, during the main growing seasons of 2022 and 2023.....	157
Appendix Table 6. 8. Combined cost benefit analysis for managing faba bean gall disease at Legambo and Tenta for the cropping seasons of 2022 using various varieties and fungicides..	159
Appendix Table 6. 9. Cost benefit analysis for managing faba bean gall disease in Legambo and Tenta for the cropping seasons of 2023 using various varieties and fungicides.....	160
Appendix Table 6. 10. Correlation coefficient (r) between yield and yield components and disease characteristics at Legambo district in the crops seasons of 2022(Lower Diagonal) and 2023(upper diagonal).....	161
Appendix Table 6. 11. Correlation coefficient (r) between yield and yield components and disease characteristics at Tenta district in the crops seasons of 2022(Lower diagonal) and 2023(Upper diagonal).	161

LIST OF FIGURES IN THE APPENDIX

Appendix Figure 2. 1. Map showing surveyed districts for faba bean gall in South Wollo, North-Eastern Ethiopia, during the 2022 and 2023 cropping seasons.	135
Appendix Figure 3. 1. Rainfall, maximum and minimum temperatures, and relative humidity of surveyed districts in north-eastern Ethiopia during the 2022 and 2023 faba bean-growing seasons.....	136
Appendix Figure 3. 2. Photographs showing data collection on disease parameters and physical factors during field surveys conducted in the 2022 and 2023 cropping seasons.....	141
Appendix Figure 4. 1. Symptoms of faba bean gall disease at different growth stages, showing (a) gall symptoms at the seedling stage, (b) symptoms at the flowering stage, (c) gall development on the stem during the vegetative stage, and (d) severe gall infection on the leaf	141
Appendix Figure 4. 2. Photos demonstrating laboratory work on pathogen isolation and characterization.....	142
Appendix Figure 4. 3. Typical cross section of a bean leaf with symptoms of faba bean gall disease showing dark brown regions (arrows) on underside of leaf gall (a), in which large masses of resting spores are produced (arrow) (b), and typical masses of resting spores in end.	142
Appendix Figure 4. 4. Photo showing the demonstration and observation of molecular materials during a laboratory experiment.....	143
Appendix Figure 5. 1. Photographs showing land preparation, sowing, seedling, vegetative, flowering, podding, and harvesting stages during the field experiments conducted in the 2022 and 2023 cropping seasons.....	147
Appendix Figure 5. 2. Area under disease progress curve of the different faba bean genotype for the faba bean gall at Legambo in the 2022(a) and 2023(b) main cropping seasons.....	148
Appendix Figure 5. 3. Area under disease progress curve of the different faba bean genotype for the faba bean gall at Tenta in the 2022(c) and 2023(d) main cropping seasons.....	149
Appendix Figure 5. 4. Yield Vs PSI on faba bean gall disease at Legambo 2022	149
Appendix Figure 5. 5. Yield Vs PSI on faba bean gall disease at Tenta 2022	150
Appendix Figure 5. 6. Yield VS PSI on faba bean gall disease at Legambo 2023.....	150
Appendix Figure 5. 7. Yield VS PSI on faba bean gall disease at Tenta 2023.....	150
Appendix Figure 6. 1. Field demonstration of faba bean gall disease management at Legambo and Tenta Districts.....	158

EPIDEMIOLOGY, CHARACTERIZATION, AND MANAGEMENT OF FABA BEAN GALL (*Physoderma viciae*) DISEASE IN Faba Bean (*Vicia faba*) IN SOUTH WOLLO, NORTH-EASTERN ETHIOPIA

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GENERAL ABSTRACT

*Faba bean (*Vicia faba* L.) is an important food and cash crop in the highlands of South Wollo, northeastern Ethiopia. Its production is increasingly threatened by faba bean gall disease caused by *Physoderma viciae*. This study investigated the epidemiology of the disease, characterized the causal pathogen, evaluated host resistance, and assessed integrated management options during the 2022 and 2023 main cropping seasons. A total of 200 farmers' fields were surveyed to determine disease prevalence, incidence, and percentage severity index (PSI) in relation to agro-ecological and crop management factors. Pathogen characterization combined symptom assessment, histopathological examination, cultural isolation, and molecular detection using *Physoderma*-specific primers. Field experiments evaluated 28 faba bean genotypes and four varieties × five fungicide treatments using randomized complete block designs, with analysis of variance in R. Faba bean gall was widely distributed across all surveyed districts. Prevalence, incidence, and PSI were higher in 2022 (97.41%, 74.81%, and 64.01%, respectively) than in 2023 (90.19%, 64.17%, and 47.21%, respectively), corresponding with greater rainfall and relative humidity in 2022. Disease intensity increased with altitude, particularly above 2,844 m a.s.l., and was highest at the flowering stage. Logistic regression identified district, year, altitude, variety, previous crop, fungicide application, and field drainage as significant determinants of disease development, with odds ratios and 95% confidence*

intervals reported in the main text. Histopathological examination and molecular detection confirmed *P. viciae* directly from symptomatic field tissues, whereas culture-based methods yielded only saprophytic fungi. Among genotypes, Dosha, Obse, Wolkie, and FB-26869 showed the lowest disease incidence, severity, and AUDPC values, while local varieties and genotypes EH96048-1, EH00102-8-1, EH97091-2, and Gora were the most susceptible. Grain yield was negatively correlated with disease parameters ($r = -0.75$ to -0.86) and decreased by 0.031 – 0.040 t ha⁻¹ for every 1% increase in disease severity. Integrated management combining moderately resistant varieties with fungicide application significantly reduced disease incidence, severity, and AUDPC and increased grain yield. The combination of Dosha with Noble 25 WP produced the highest grain yield (3.79 t ha⁻¹) and the highest net benefit (US\$ 2,293.63–4,168.20 ha⁻¹). In conclusion, faba bean gall is a major environmentally driven constraint to faba bean production in South Wollo, with disease development strongly influenced by altitude, moisture conditions, and host susceptibility. Integrated management involving moderately resistant varieties, improved field drainage, cereal-based crop rotation, and timely fungicide application is recommended for sustainable disease management. Future research should prioritize DNA sequencing and phylogenetic characterization of *P. viciae* populations, development of reliable inoculation techniques, breeding for durable resistance, and improvement of disease forecasting systems to support sustainable faba bean production in the highlands of northeastern Ethiopia.

Keywords: AUDPC, disease intensity, epidemiology, faba bean, fungicide, genotype, histopathology, integrated disease management, molecular detection, *Physoderma viciae*

Chapter .1 GENERAL INTRODUCTION

1.1 Background and Justification

Faba bean (*Vicia faba* L.) is an important cool-season food legume cultivated in temperate, Mediterranean, subtropical, and highland environments worldwide. It ranks as the fourth most important cool-season pulse crop after pea (*Pisum sativum* L.), chickpea (*Cicer arietinum* L.), and lentil (*Lens culinaris* Medik.) (Sainte, 2011; Maalouf *et al.*, 2019). The crop occupies approximately 3.2 million hectares globally (Torres *et al.*, 2006) and The crop is valued for its nutritional, economic, and agronomic benefits. Faba bean seeds contain approximately 20–41% protein, in addition to carbohydrates, dietary fiber, minerals, and vitamins (Crépon *et al.*, 2010). The crop is consumed as green or dry grain and is also used for livestock feed, forage, and silage (Crépon *et al.*, 2010; Oplinger *et al.*, 2000).

In addition to its direct food and feed value, faba bean plays an important role in sustainable agricultural production systems. As a legume, it establishes symbiotic associations with rhizobia and fixes atmospheric nitrogen through biological nitrogen fixation. The amount of nitrogen fixed varies with genotype, soil characteristics, environmental conditions, and crop-management practices (Jensen *et al.*, 2010). Its inclusion in cereal–legume rotations can improve soil fertility, increase nitrogen availability, diversify farm production, and provide beneficial rotational effects for subsequent cereal crops (Jensen *et al.*, 2010; Köpke and Nemecek, 2010). These benefits are particularly important in smallholder farming systems where declining soil fertility, high fertilizer costs, and limited access to agricultural inputs constrains crop productivity.

Faba bean production is concentrated in Asia, Africa, and Europe, with China being the leading producer globally and Ethiopia among the major producers (FAOSTAT, 2024). Africa is also an important faba bean-producing continent, with major production occurring in Ethiopia, Egypt, Sudan, Morocco, Algeria, and Tunisia (FAOSTAT, 2024). Although Ethiopia is one of the leading producers globally and the second-largest producer according to some sources, its share of global production remains relatively modest (IUCN NL, 2023). In Ethiopia, faba bean is the leading pulse crop in terms of cultivated area and production.

During the 2021/22 main cropping season, faba bean covered approximately 520,551.70 hectares, equivalent to about 4.27% of the total grain-crop area, and contributed approximately 3.33% of total grain production(CSA, 2022). The crop is predominantly cultivated in the highland and mid-highland agroecologies of Ethiopia, particularly in the Amhara, Oromia, and Tigray regions. In the Amhara Region, faba bean is widely cultivated because of its economic, nutritional, and agronomic importance, with major production areas including North Shewa, South Wollo, East Gojjam, and other highland zones(Bereda Biruk, 2009; Beyene Bitew and Abiro Tigabie, 2016).

South Wollo is one of the important faba bean-producing zones of the Amhara Region. During the 2021/22 main cropping season, faba bean was cultivated on approximately 28,582.97 hectares by about 314,914 smallholder farmers, with total production of approximately 46,565.57 tones and average productivity of 1.63 t ha⁻¹(CSA, 2022). However, its productivity remains below the attainable potential despite the availability of improved varieties and production technologies. The yield gap is associated with several interacting biotic and abiotic constraints, including soil fertility problems, climatic stresses, weeds, insect pests, inadequate agronomic practices, and plant diseases(Sahile Samuel *et al.*, 2008; Mussa Jarso *et al.*, 2008). Among these constraints, diseases are particularly important because they can directly reduce photosynthetic capacity, interfere with reproductive development, and ultimately cause substantial yield losses(Wondwosen Wulita, 2015).

Several diseases affect faba bean production in Ethiopia, including faba bean gall disease caused by *Physoderma viciae*, chocolate spot caused mainly by *Botrytis fabae*, rust caused by *Uromyces viciae-fabae*, black root rot caused by *Fusarium* spp., ascochyta blight caused by *Ascochyta fabae* and faba bean necrotic yellow virus (Dereje Gorfu *et al.*, 2012, Gezahegne Getaneh *et al.*, 2014; Yitayih Getnet *et al.*, 2023). Among these diseases, FBG has emerged as an increasingly important threat to faba bean production in the central, northern, and northwestern highlands of Ethiopia (Gezahegne Getaneh *et al.*, 2014; Teferi Teklay *et al.*, 2018). The increasing distribution and severity of the disease are of particular concern because severe epidemics can cause extensive foliage damage and substantial yield losses.

Faba bean gall disease is considered a relatively recent disease problem in Ethiopia. Although its exact origin and time of introduction into the country remain unclear, the disease was first officially reported in 2011 from parts of the Amhara and Oromia regions (Dereje Gorfu *et al.*, 2012; Gezahegne Getaneh *et al.*, 2014; Wondwosen Wulita, 2015). Early investigations identified *Olpidium viciae* as the causal agent based primarily on symptom similarity and the observation of resting spores in leaf galls. However, subsequent molecular investigations did not consistently support this identification. More comprehensive morphological and molecular studies later identified *Physoderma viciae* as the pathogen associated with faba bean gall disease in Ethiopia (You *et al.*, 2021). This clarification was important because accurate pathogen identification is fundamental to understanding disease biology, epidemiology, diagnosis, host–pathogen interactions, and management.

Physoderma viciae belongs to the family Physodermataceae and has a distinctive infection biology involving specialized reproductive structures and motile zoospores. The pathogen develops within infected host tissues and produces the characteristic gall symptoms associated with the disease. Its development and infection are closely associated with moisture conditions, while resistant resting structures may facilitate survival between favorable periods (You *et al.*, 2021). The characteristic symptoms of FBG disease facilitate preliminary field diagnosis. Initial symptoms generally appear as small greenish or sunken lesions on the upper leaf surface, accompanied by corresponding swellings on the lower surface (Figure 1. 1). As disease development progresses, lesions may become light brown or chlorotic and develop into enlarged, irregular, circular, or elliptical galls(Gezahegne Getaneh *et al.*, 2014). Under favorable conditions, individual lesions may increase in number and size and eventually coalesce. Severe infection can cause extensive necrosis and premature foliage death, thereby substantially reducing the functional photosynthetic leaf area. Symptoms may also develop on stems and pods. Because some of these symptoms can resemble those caused by other foliar diseases, microscopic and molecular methods are important for accurate pathogen identification(You *et al.*, 2021).

In South Wollo, FBG disease has become an important production constraint. The disease was initially observed in limited areas, including Meket, Wadila, Jamma, and Woreilu, before 2009. During the 2012 and 2013 cropping seasons, however, the disease increased in distribution and severity (Hailemariam Bogale *et al.*, 2016). Surveys conducted in the Wollo highlands subsequently reported disease incidence ranging from 50% to 100% and severity from 10% to 59% (Hailemariam Bogale *et al.*, 2017). These observations indicate that the disease can become severe under favorable environmental and crop-management conditions.

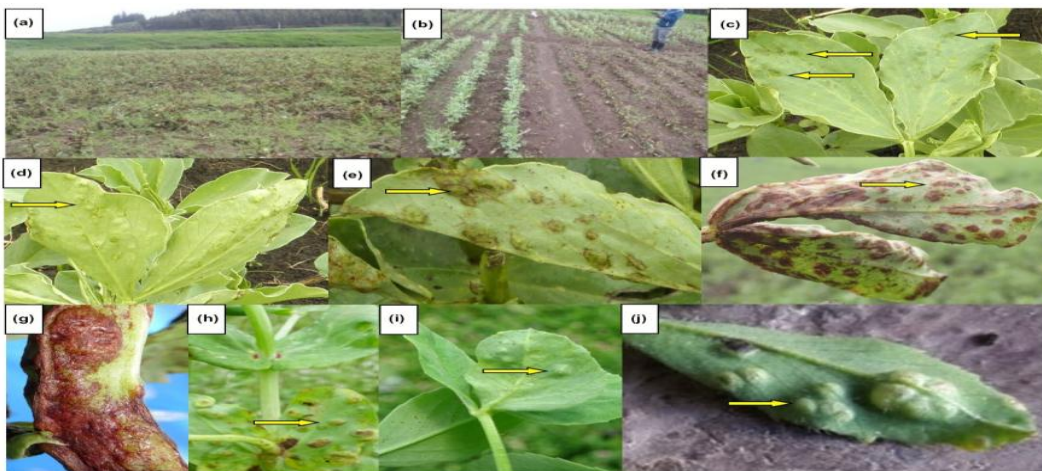


Figure 1. 1. Field and plant host symptoms for faba bean gall (FBG) disease in Ethiopia showing poor faba bean growth and major foliage death in a severely infested farm field (Bitew Beyene *et al.*, 2021)

Disease development results from interactions among the pathogen, host, and environment. Moisture availability is particularly important because the infection process of *P. viciae* is associated with wet conditions. Consequently, differences in rainfall, relative humidity, leaf wetness, cloud cover, and temperature may result in considerable variation in disease intensity among locations and seasons. Host genotype is another important determinant, as faba bean varieties differ in their reactions to FBG disease. Cropping history, previous crop, field drainage, planting practices, crop growth stage, and fungicide application may also influence disease development. Understanding how these factors interact under the diverse agroecological conditions of South Wollo is therefore essential for predicting disease impact and developing effective management strategies.

FBG disease can cause substantial yield losses under favorable environmental conditions and susceptible host genotypes. Previous studies have reported yield losses ranging from approximately 30% to 100% under severe disease conditions(Abebe Teklay *et al.*, 2014). However, the magnitude of loss depends on disease incidence, severity, and timing of infection, host genotype, environmental conditions, and crop-management practices. The disease affects leaves, stems, and pods and can consequently reduce both grain yield and quality (Gezahegne Getaneh *et al.*, 2014). Severe disease may also increase production costs because farmers may need to invest in fungicides and other control measures. Persistent disease pressure could further discourage faba bean production, potentially affecting household income, food security, livestock-feed availability, crop diversification, and soil fertility management.

Several approaches have been investigated for managing FBG disease, including cultural practices, chemical control, host resistance, and integrated disease management. Cultural practices such as crop rotation, field sanitation, management of infected crop residues, use of healthy planting material, and improved field drainage may help reduce disease pressure. In particular, rotation with non-host crops may reduce pathogen carry-over between seasons, while improved drainage may reduce prolonged moisture conditions favorable for disease development. Chemical control has also shown potential for reducing FBG disease. Seed treatment with Bayleton WP 25 containing triadimefon at a rate of 300 g kg⁻¹ seed has been reported to reduce disease development and associated yield losses under some production conditions (Hailemariam Bogale *et al.*, 2016). Similarly, foliar application of fungicides such as Ridomil Gold MZ 68 WG has been reported to reduce disease severity and improve grain yield(Dereje Gorfu *et al.*,2012; Teferi Teklay *et al.*, 2018; Kebede Wulita *et al.*, 2019). Nevertheless, the effectiveness of fungicides depends on the active ingredient, application rate, timing, frequency, disease pressure, and prevailing environmental conditions. Repeated fungicide use can also increase production costs and raise environmental concerns. Chemical control alone is therefore unlikely to provide a sustainable solution for resource-constrained smallholder farmers. Host resistance provides another important component of sustainable FBG disease management. Improved varieties such as Gora and Gachena have been recommended as immediate management options for affected areas of northern Ethiopia(Wondwosen Wulita, 2015).

Other studies have also demonstrated variation among faba bean genotypes in their responses to FBG disease(Alehegn Mastewal *et al.*, 2018; Bimrew Solomon *et al.*, 2025). Resistant or tolerant varieties can reduce disease development without requiring additional chemical inputs and may therefore provide a cost-effective and environmentally sound management option. However, disease resistance may be influenced by environmental conditions, pathogen populations, crop growth stage, and genotype $\times$ environment interactions. Therefore, genotypes need to be evaluated under the specific environmental conditions where they are intended for production.

Integrated disease management provides an opportunity to combine complementary disease-control approaches and improve the reliability of disease suppression. Studies have shown that combining relatively resistant varieties, such as Adet-Hana, Bulga-70, CS20DK, NC58, and Kasa, with fungicide application can improve disease management and grain yield(Yitayih Getnet and Azmeraw Yehizbalem, 2017). The effectiveness of particular variety–fungicide combinations, however, may vary according to disease pressure, environmental conditions, host genotype, and application practices. Therefore, field-based evaluation is necessary to identify combinations that provide effective disease suppression, acceptable grain yield, and favorable economic returns under local production conditions.

1.2 Statement of the Problem

Faba bean (*Vicia faba* L.) is one of the most important food legume crops in Ethiopia, particularly in the highland agro-ecologies, where it plays a significant role in ensuring food security, improving soil fertility, and generating income for smallholder farmers. Despite its importance, the national average yield of faba bean remains low (about 1.2 t ha⁻¹) compared to its potential yield (4.4 t ha⁻¹) (Dereje Gorfu *et al.*, 2012). This substantial yield gap is mainly attributed to several production constraints, including limited access to improved varieties, poor agronomic practices, and the increasing pressure of biotic stresses, particularly plant diseases(Mussa Jarso *et al.*, 2008). Among the major diseases affecting faba bean production in Ethiopia, faba bean gall disease, caused by *Physoderma viciae*, has recently emerged as one of the most destructive and rapidly spreading diseases. Recent findings, including those by Bimrew Solomon *et al.* (2025), highlight the increasing economic importance and rapid expansion of this disease in the country.

The disease is widely distributed in major faba bean-producing regions, particularly Amhara, Tigray, and Oromia, where its prevalence has reached up to 100% in some areas (Abebe Teklay *et al.*, 2014). Moreover, disease severity has been reported to be highest in the Amhara region, making it a critical hotspot for the disease (Gezahegne Getaneh *et al.*, 2014).

Within the Amhara region, the problem is particularly severe in the eastern highlands, especially in the South Wollo Zone, where faba bean is a dominant crop in the farming system. Surveys conducted in the highlands of Wollo reported FBG disease incidence ranging from 50% to 100% and severity levels between 10% and 59% (Hailemariam Bogale *et al.*, 2016). The disease spreads rapidly and causes significant yield losses, discouraging farmers from continuing faba bean production in the area (Abebe Teklay *et al.*, 2014). However, despite the severity of the problem, most previous studies have been conducted at broader regional levels and do not provide adequate location-specific information at zonal, district, and farm levels in Eastern Amhara, particularly in the South Wollo zone. Although studies such as Bimrew Solomon *et al.* (2025) have contributed valuable insights into the distribution and importance of faba bean gall disease at national and regional scales, there is still limited detailed, field-based information on disease distribution, prevalence, incidence, and severity under the specific local conditions of the study districts. This lack of localized data limits the development of effective and targeted disease management strategies.

Furthermore, the causal agent of faba bean gall disease has generally been identified as *Olpidium viciae* based on field symptoms and microscopic observations (Gezahegne Getaneh *et al.*, 2018). Although studies by You *et al.* (2021) have provided important insights into the morphological and molecular characterization of the pathogen, these studies are limited in scope and are not sufficiently representative of pathogen variability across different agro-ecologies. In particular, there is no detailed morphological and molecular characterization conducted under field conditions in Eastern Amhara, specifically in South Wollo Zone, where the disease is highly prevalent. This gap limits a clear understanding of pathogen diversity in the study area and may hinder the development of effective and location-specific control strategies. In terms of disease management, the available options in Ethiopia are very limited.

Farmers mainly rely on fungicide applications, which are expensive and require repeated use, making them inaccessible to most smallholder farmers. Although the use of resistant varieties is widely recognized as the most economical and environmentally sound approach (Alehegn Mastewal *et al.*, 2018; Bimrew Solomon *et al.*, 2025), there has been little effort to identify and evaluate faba bean varieties resistant to gall disease under the specific conditions of Eastern Amhara. In addition, biological control methods, which are important components of sustainable disease management, have not been adequately studied for this disease in Ethiopia. Despite the increasing importance and rapid spread of faba bean gall disease in the Amhara region, particularly in South Wollo Zone, there is a clear lack of comprehensive, location-specific research on disease distribution, pathogen characterization, and management options. Therefore, this study was initiated to assess the distribution, epidemiology, characterize the pathogen, evaluate genotype resistance, and develop integrated management strategies for faba bean gall disease in South Wollo, north-eastern Ethiopia.

1.3 . Objective of the Study

1.3.1 General objective

To investigate the distribution, epidemiology, characterize the pathogen, evaluate genotype resistance, and integrated management strategies for faba bean gall disease (*Physoderma viciae*) in South Wollo, north-eastern Ethiopia.

1.3.2 Specific objectives

- I. To assess the prevalence, incidence, and severity of faba bean gall disease in major faba bean-growing districts of South Wollo, north-eastern Ethiopia.
- II. To characterize and identify the pathogen associated with faba bean gall disease using histopathological and molecular approaches.
- III. To evaluate the responses of various faba bean genotypes against faba bean gall for the management of the disease.
- IV. To determine the combination of fungicides and faba bean varieties for the management of faba bean gall (*Physoderma viciae*) disease.

1.4 Research Questions

The study was guided by the following research questions:

1. What are the prevalence, incidence, severity, and distribution of faba bean gall disease in the major faba bean-growing districts of South Wollo?
2. What environmental, agronomic, and crop-management factors are associated with the development and intensity of faba bean gall disease in the study area?
3. What are the morphological, histopathological, cultural, and molecular characteristics of the pathogen associated with faba bean gall disease in South Wollo?
4. Do faba bean genotypes differ in their resistance or tolerance to faba bean gall disease under the environmental conditions of South Wollo?
5. Which faba bean genotypes combine reduced disease intensity with desirable agronomic performance and grain yield?
6. Which variety–fungicide combinations provide effective, economically feasible, and practically applicable management of faba bean gall disease under field conditions?

1.5 . Significance of the Study

Faba bean gall disease caused by *Physoderma viciae* has emerged as one of the most serious threats to faba bean production in the Ethiopian highlands, particularly in the Amhara Region. Despite the economic and nutritional importance of the faba bean, limited scientific information has been available on the distribution, etiology, epidemiology, and effective management of this faba bean gall disease under local field conditions. This study provides comprehensive and up-to-date information that is crucial for addressing knowledge gaps about FBG in the study area.

The study generates baseline data on the prevalence, incidence, and severity of faba bean gall disease across major faba bean-growing districts of the South Wollo Zone. Such information is essential for understanding the spatial distribution and relative importance of the disease, prioritizing research and extension efforts, and guiding policymakers and development organizations in allocating resources for disease management and food security interventions.

By isolating, characterizing, and molecularly identifying the causal pathogen, this research provides definitive evidence that *Physoderma viciae* is the primary agent responsible for faba

bean gall disease in Ethiopia. This contributes significantly to the scientific understanding of the disease, resolves long-standing taxonomic confusion, and strengthens the foundation for future diagnostic, epidemiological, and breeding studies. The evaluation of faba bean genotypes for resistance to faba bean gall disease identifies relatively tolerant and high-yielding varieties that can be promoted to farmers as part of an integrated disease management strategy. This is particularly important for resource-poor smallholder farmers, as the use of resistant varieties is cost-effective, environmentally friendly, and sustainable.

Furthermore, the study assesses the effectiveness of integrating fungicides with faba bean varieties for FBG disease management. The identification of effective variety–fungicide combinations provides practical, field-tested recommendations that can reduce disease severity, increase yield, and improve farmers' income while minimizing unnecessary chemical use. In general, the findings of this study contribute to the development of integrated and sustainable management strategies for faba bean gall disease. The results are valuable to researchers, plant breeders, extension agents, policymakers, and farmers and they support national efforts to enhance faba bean productivity, strengthen food security, and improve livelihoods in Ethiopia's highland farming systems.

1.6 Organization of the Dissertation

This dissertation is organized into seven chapters. Chapter one presents the background and justification of the study, statement of the problem, the objectives, the significance of the study, and the overall organization of the dissertation. Chapter Two describes the materials and methods used in the study, including the research design, study area, data collection techniques, and experimental procedures. Chapters Three through Six consist of individual manuscripts developed from independent research activities. Each manuscript contains an abstract, introduction or background, results, discussion, and conclusion. The discussion sections interpret the findings in relation to existing literature. These chapters represent the major scientific contributions of the dissertation and are formatted in accordance with the requirements of peer-reviewed journals.

Finally, Chapter Seven provides a comprehensive summary of the entire dissertation by synthesizing the major findings and presenting integrated insights. It also offers practical recommendations for future research, policy development, and professional practice in the field.

Chapter 2. GENERAL MATERIALS AND METHODS

2.1 . Description of the Study Areas

This study was conducted in selected districts of the South Wollo Zone, Amhara Region, Ethiopia, and comprised two major components: a field survey to assess the distribution, prevalence, incidence, and severity of faba bean gall disease, and field, laboratory, and greenhouse experiments to evaluate disease management options, including varietal screening and integrated disease management practices. The study areas were selected based on their potential in faba bean production, hotspot status for FBG, accessibility, and representativeness of the major agro-ecological conditions.

The field survey was conducted in four purposively selected districts: Legambo, Tenta, Kelala, and Woreilu (Figure 2. 1). Agriculture in these districts is predominantly rain-fed and practiced under smallholder mixed crop–livestock farming systems. Major crops grown in the area include teff, wheat, barley, maize, chickpea, and faba bean, while livestock production mainly involves cattle, sheep, and goats. Crop production is concentrated during the *meher* (main rainy) season, and farming practices are largely traditional and subsistence-oriented, with limited use of improved agricultural technologies and inputs (Tesfaye Bichaye *et al.*, 2023).

The agro-ecology of the study area ranges from mid-altitude to highland zones, with elevations generally between 1,500 and 3,500 meters above sea level. According to Assefa Bekele *et al.* (2021), the South Wollo Zone consists of approximately 25% highland, 44% mid-altitude, and 31% lowland areas. Climatic conditions vary with altitude, with mean annual temperatures in the highlands ranging from 15°C to 20°C. Rainfall follows a bimodal distribution pattern, with the main rainy season (*kiremt*) extending from June to September and contributing most of the annual rainfall, which ranges between 500 mm and 900 mm. These environmental conditions are favourable for faba bean production; however, they also create conducive conditions for the development and spread of faba bean gall disease. Field experiments involving the screening of faba bean varieties and the evaluation of integrated disease management practices were conducted in Legambo and Tenta districts.

These sites, selected from the surveyed districts, have high disease incidence and severity, are accessible, and represent dominant agro-ecological conditions, making them suitable for evaluating management options under natural field conditions.

The selected districts are characterized by diverse agro-climatic conditions that influence both faba bean production and the occurrence of faba bean gall disease. Variations in altitude, rainfall, and temperature create favourable environments for disease development and spread. The districts generally fall within the midland to highland agro-ecological zones, with altitudes ranging from 2,426 to 3,230 meters above sea level. Detailed geographic information, including latitude, longitude, and altitude of each district, is presented in Table 2. 1.

Agriculture is the primary source of livelihood in the study area, and farmers commonly practice traditional soil fertility and disease management strategies such as crop rotation and intercropping, particularly cereal–legume rotations (Melese Daniel *et al.*, 2025). However, agricultural productivity remains low due to constraints such as erratic rainfall, land degradation, limited access to improved agricultural inputs, and increasing crop disease pressure.

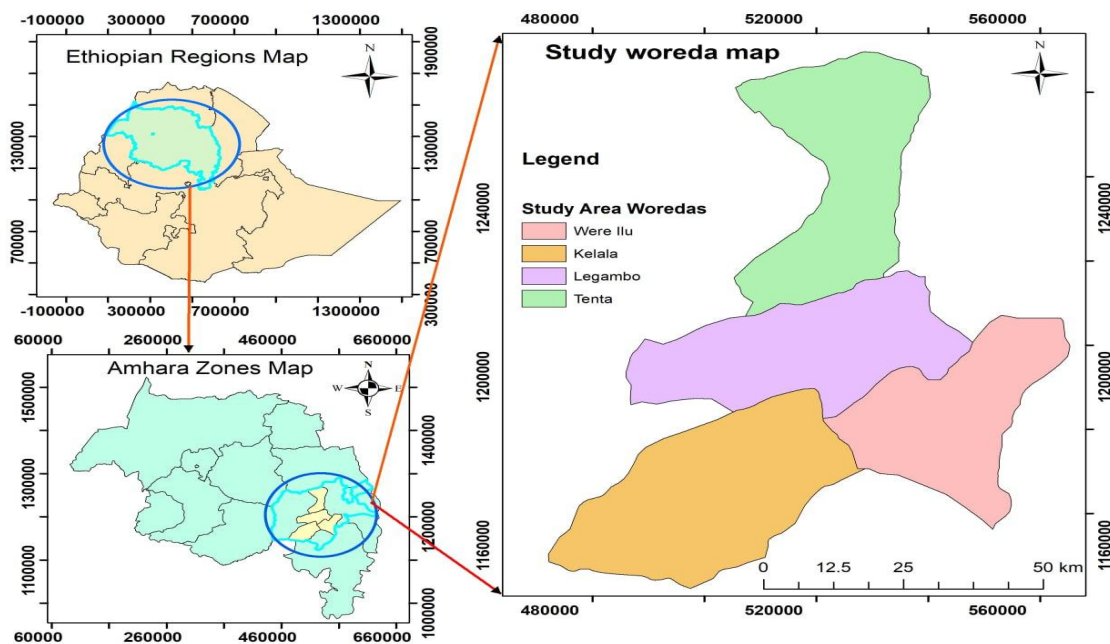


Figure 2. 1 . Map showing surveyed districts for faba bean gall in South Wollo, North-Eastern Ethiopia during the 2022 and 2023 cropping seasons.

Table 2. 1. Altitude and Weather Conditions of Faba Bean Gall Surveyed Districts in South Wollo Zone, Eastern Amhara, Ethiopia

District	Number of fields	Altitude (m a.s.l.)	Rainfall (mm)		Mean of Temperature ($^{\circ}\text{C}$)			
			2022	2023	2022		2023	
					Maximum	Minimum	Maximum	Minimum
Legambo	50	2900-3230	1216.98	912.72	20.00	6.36	20.93	7.04
Woreilu	40	2647-2861	1051.23	809.23	21.67	8.12	22.88	9.94
Tenta	50	2436- 3007	1203.06	896.16	20.47	6.92	21.64	7.45
Kelala	60	2426–2663	1007.96	761.03	23.33	10.38	24.60	11.58

*Average rainfall, and maximum and minimum temperatures of surveyed locations were obtained from respective districts' meteorological stations (<https://power.larc.nasa.gov/data-access-viewer/>) and Altitude ranges of surveyed fields were measured by a global positioning system (GPS) (NASA, 2025).

2.2 Sampling Procedure and Experimental Design

The study was conducted during the main growing seasons of 2022 and 2023 across three agro-ecological zones, namely *Dega*, *Woina Dega*, and *Kolla*, in South Wollo Zone, Ethiopia. Four districts, namely Legambo, Tenta, Woreilu, and Kelala, were purposively selected based on their faba bean production potential, disease occurrence, accessibility, and representation of the major agro-ecological zones.

A multistage sampling procedure was used to select the study sites and farmer fields. In the first stage, four districts were purposively selected based on faba bean production potential, reported FBG occurrence, and accessibility. In the second stage, five kebeles (local administrative units) were randomly selected from each district using a lottery method. In the third stage, a farmer field was selected using systematic sampling along accessible roads and transects at approximately 5–10 km intervals, depending on field availability. Within each selected kebele, up to five faba bean fields were assessed. Field selection was conducted with the assistance of agricultural development agents, considering cropping history and the availability of faba bean fields. In total, 200 farmer fields were surveyed across the four districts. It should be noted that although simple random sampling was initially considered, the practical realities of field surveys

including accessibility, field distribution, and the need to cover representative agro-ecological conditions necessitated the use of a multistage systematic sampling approach.

This approach ensured that data were collected from a representative range of localities while maintaining logistical feasibility and reducing potential selection bias.

Disease assessment followed standard plant disease survey procedures using systematic and transect sampling methods (Campbell and Madden, 1990; Agrios, 2005). In each field, five sampling points were established following a diagonal (X-shaped) pattern. A 1 m² quadrat was placed at each sampling point, and the total number of plants, infected plants, and healthy plants within each quadrat was recorded. The collected data were used to assess the occurrence and distribution of faba bean diseases across the three agro-ecological zones. In addition, farmers were interviewed using a structured questionnaire to collect information on field history, altitude, previous crops, weed infestation, drainage conditions, slope, fungicide usage, soil type, faba bean variety, cropping system, planting date, weeding practices, disease management practices, and fertilizer use.

Pathogen isolation followed the procedures described by Dugassa *et al.* (2021) and Caiazzo *et al.* (2006). Infected tissues were surface-sterilized, cultured on potato dextrose agar (PDA), incubated at 23 ± 2°C, and purified through repeated sub-culturing as described by Ahmed and El-Fiki (2017). Morphological and cultural characterization of the faba bean gall-causing pathogen was conducted using Coon's medium following the procedures of Dugassa *et al.* (2021). For genotype evaluation, 28 faba bean genotypes (Table 5. 1, Appendix Table 5. 2) were tested using a randomized complete block design (RCBD) with three replications at experimental sites in Legambo and Tenta districts, applying all recommended agronomic practices. Each experimental plot consisted of five rows, with plot size of 2 m × 1.6 m (3.2 m²). Spacing between plants and rows was 0.1 m and 0.4 m, respectively. Spacing between plots and blocks was 0.5 m and 1.0 m, respectively. Disease, yield, and yield component data were taken from the three central rows of plants.

For integrated disease management, a factorial RCBD was used to evaluate four faba bean varieties (Dosha, Wolkie, Gora, and Local) and five fungicide treatments (Noble 25 WP,

Ridomil Gold MZ 68 WG, Matco, Mancozebe 80% WP, and untreated control), with three replications. Each experimental plot measured 2 m × 2 m (4 m²), with spacing between plots and blocks of 0.5 m and 1.0 m, respectively.

Plants were spaced 10 cm apart within rows, with 40 cm between rows. Fungicides were applied as foliar sprays at manufacturer-recommended rates using knapsack sprayers, starting at the first disease appearance and repeated every 10 days throughout the growing season. Details of fungicide treatments and application rates are presented in Table 6. 1 and Table 6. 2.

2.3 Data Collection

Disease Prevalence: Disease prevalence was determined as the percentage of surveyed fields in which typical symptoms of faba bean gall disease were observed. Prevalence was calculated at the field, district, and agro-ecological zone levels based on the number of fields showing typical disease symptoms relative to the total number of fields assessed at each respective level.

Disease Incidence: Disease incidence was determined as the percentage of infected plants among the total number of plants assessed within the sampled quadrats. Disease incidence was calculated using the following formula:

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

Disease severity was assessed on five randomly selected plants from each quadrat using the 0–9 disease severity scale described by Ding *et al.* (1993).

$$\text{PSI} = \frac{\text{Sum of numerical rating} \times 100}{\text{Number of plants scored} \times \text{Maximum score on scale}}$$

The area under the disease progress curve (AUDPC): AUDPC was calculated for each plot using the formula of Shaner and Finney (1977) and expressed in %-days.

$$\text{AUDPC} = \sum_{i=1}^{n-1} 0.5(x_{i+1} + x_i)(t_{i+1} - t_i)$$

Where x_i is the cumulative disease severity at the i^{th} observation, t_i is the time (days after sowing) at the i^{th} observation and n is the total number of observations.

Symptomatic leaf and stem tissues were collected from infected plants and transported to the laboratory for pathogen isolation. The tissues were surface-sterilized, cultured on Coon's medium supplemented with chloramphenicol, and incubated at $23 \pm 2^{\circ}\text{C}$ for 14 days.

Pure cultures were obtained through repeated single hyphal tip sub-culturing and preserved on PDA slants at 4°C . Morphological and cultural characterization was conducted on Coon's medium for up to 14 days, during which colony characteristics such as color, texture, shape, growth pattern, and radial growth were recorded. Microscopic observations of structures, including pycnidia, conidia, and chlamydospores, were made using a compound microscope.

For histopathological examination, small tissue sections (approximately $5 \times 5 \text{ mm}$) were excised from infected regions using a sterile razor blade and hand-sectioned into thin transverse sections. For general microscopic observation, tissue sections were mounted on clean glass slides containing a drop of lactophenol cotton blue. Additional sections were stained with safranin to enhance visualization of host tissue damage and pathogen structures. The prepared slides were covered with cover slips and examined under a microscope at magnifications of $100\times$, $200\times$, and $400\times$.

One hundred and sixty (160) symptomatic samples were collected from Legambo, Kelala, Woreilu, and Tenta districts using simple random sampling. Gall tissues were excised, labeled, and transported on ice to the laboratory. DNA was extracted using a modified Dellaporta method (Dellaporta *et al.*, 1983). Of the 100 samples from which DNA was extracted, 40 yielded DNA of sufficient quality and quantity for PCR analysis. Amplification was carried out using *Physoderma*-specific primers Physo1 and Physo D' (Table 4.1), and PCR products were visualized using agarose gel electrophoresis under UV light.

For faba bean genotype evaluation and integrated disease management, disease incidence and severity were determined on pre-tagged plants in the central rows of each plot at 10-day intervals starting from disease onset. Disease progression over time was also monitored. Agronomic data collected at maturity included plant height, number of pods per plant, seeds per pod, 100-seed weight, and grain yield. Yield performance and relative differences among treatments were used to evaluate genotype response and the effectiveness of integrated disease management practices.

2.4 Data Analysis

Descriptive statistics, including means, percentages, standard errors, and graphs, were used to summarize disease prevalence, incidence, and severity. These analyses were performed using SPSS to describe the spatial distribution of faba bean gall disease across the study areas.

To examine the association between disease parameters (incidence and severity) and biophysical factors, logistic regression analysis was conducted using the GENMOD procedure in SAS 9.4 (SAS Institute Inc., Cary, NC, USA). The proportional odds assumption was assessed prior to model fitting. For the regression analysis, disease incidence was categorised into two classes: $\leq 75\%$ as moderate incidence and $> 75\%$ as high incidence. Similarly, the percent severity index (PSI) was classified into two categories: $\leq 50\%$ as low severity and $> 50\%$ as high severity. Model development followed a stepwise approach, with variables first evaluated in single-variable models, then included in a full multivariable model, and finally a reduced model derived by retaining only significant variables based on likelihood ratio tests (LRTs) and overall model fit statistics. Model fit was assessed using residual deviance, Akaike Information Criterion (AIC), and the Hosmer-Lemeshow test. Odds ratios (ORs) were calculated by exponentiating regression coefficients

For genotype evaluation and integrated disease management experiments, analysis of variance (ANOVA) was used to determine treatment effects on disease parameters (incidence, PSI, and AUDPC), yield, and yield components (pods per plant, seeds per pod, 100-seed weight, and grain yield). Data normality and homogeneity of variance were assessed prior to analysis using Bartlett's test. All analyses were conducted using R software version 4.4.1 (R Core Team, 2024). When significant differences were detected, treatment means were separated using Duncan's Multiple Range Test (DMRT) at a 5% probability level (Gomez and Gomez, 1984). Pearson correlation coefficients were also computed to assess the strength and direction of relationships among measured variables. Regression analysis was performed to evaluate the relationship between percentage severity index (PSI) and grain yield.

Chapter 3. Survey on the Distribution and Epidemiology of Faba Bean Gall (*Physoderma viciae*) in South Wollo, Northeastern Ethiopia

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Abstract

*Faba bean gall disease caused by *Physoderma viciae* has recently emerged as a major constraint to faba bean production in the highlands of northeastern Ethiopia, where information on its distribution and epidemiology remains limited. This study assessed the prevalence, incidence, and severity (Percent Severity Index, PSI) of the disease and identified key agro-ecological and management factors influencing its epidemics in South Wollo during the 2022 and 2023 main cropping seasons. A total of 200 farmers' fields were surveyed using systematic sampling, and disease parameters together with environmental and agronomic variables were analyzed using descriptive statistics and logistic regression models. The results revealed that faba bean gall disease was widely distributed across all surveyed districts, with significantly higher prevalence (97.41%), incidence (74.81%), and PSI (64.01%) recorded in 2022 than in 2023 (90.19%, 64.17%, and 47.21%, respectively), indicating strong seasonal effects linked to more favourable moisture and humidity conditions in 2022. Disease intensity increased with altitude, particularly above 2,844 m a.s.l., and was highest at the flowering stage. Fields planted with the improved variety Wolkie, rotated with cereals, and managed under well-drained conditions consistently showed lower disease levels, although no variety showed complete*

resistance. These findings reveal that both environmental conditions and management practices significantly affect disease development and highlight the need for integrated, location-specific management strategies focusing on improved drainage, cereal-based crop rotation, and the use of relatively tolerant varieties.

Keywords: agro ecological factors, incidence, logistic regression, percent severity index, *Physoderma viciae*, prevalence

3.1 Introduction

Faba bean (*Vicia faba* L.) is one of the most important food legumes cultivated worldwide and plays a major role in the highland farming systems of Ethiopia (You et al., 2021). Ethiopia is the second-largest producer of faba bean after China and is considered a secondary center of diversity for the crop (Keneni Gemechu *et al.*, 2005; FAOSTAT, 2018). In Ethiopia, faba bean is widely cultivated by smallholder farmers and contributes substantially to food security, household income, and livestock feed (CSA, 2022; Abera Merkuz and Semagn Meseret, 2022). In addition, its ability to fix atmospheric nitrogen through symbiotic association with soil microorganisms contributes to soil fertility improvement and can reduce farmers' dependence on inorganic nitrogen fertilizers (Agegnehu Getachew and Fessehaie Rezene, 2006).

In the Amhara Region, faba bean is an important pulse crop, particularly in the suitable agro-ecological areas of South Wollo, where it is predominantly grown under rain-fed conditions. However, its productivity remains below its attainable potential because of several biotic and abiotic constraints, including the use of low-yielding varieties, declining soil fertility, and inadequate crop management practices (Mussa Jarso *et al.*, 2008). A national yield-gap assessment indicated that farmers in major faba bean-growing areas of Ethiopia achieved less than 40% of the water-limited yield potential, demonstrating considerable scope for increasing productivity through improved agronomic practices and effective crop protection measures (Kabthiymer et al., 2019). Among the biotic constraints, faba bean gall (*Physoderma viciae*), chocolate spot (*Botrytis fabae*), rust (*Uromyces viciae-fabae*), and wilt and root-rot complexes are important diseases affecting faba bean production (Abera Merkuz and Semagn Meseret, 2022).

Faba bean gall disease has recently emerged as a serious constraint to faba bean production in Ethiopia and other faba bean-growing countries. The disease was first reported in East Africa in 2012 and has subsequently been reported from major faba bean-growing areas of Ethiopia, including North Shewa, the Selale highlands, and the Wollo highlands (Gezahegne Getaneh *et al.*, 2014; Hailemariam Bogale *et al.*, 2016). In the Amhara Region, particularly in high altitude areas, the disease has become a major production constraint, with yield losses reaching up to 100% under favourable conditions, sometimes forcing farmers to abandon faba bean cultivation (Abebe Teklay *et al.*, 2014; Bitew Beyene *et al.*, 2021; Bimrew Solomon *et al.*, 2025). The increasing occurrence of faba bean gall disease therefore poses a significant threat to sustainable faba bean production in affected areas.

The causal organism of faba bean gall disease in Ethiopia was initially identified as *Olpidium viciae*, based mainly on symptom characteristics and the presence of resting spores (Dereje Gorfu *et al.*, 2012; Kebede Earecho, 2019). However, subsequent molecular investigations produced inconsistent taxonomic results. More recent integrative morphological and molecular analyses have confirmed *Physoderma viciae* as the causal pathogen, resolving previous taxonomic uncertainty (Bitew Beyene *et al.*, 2021). This clarification is essential for accurate disease diagnosis, epidemiological studies, and the development of effective management strategies. The occurrence and severity of faba bean gall disease are strongly influenced by agro-ecological factors such as altitude, temperature, rainfall, and relative humidity, as well as by agronomic practices including variety selection, crop rotation, drainage conditions, and field management (Yitayih Getnet *et al.*, 2021; Bitew Beyene *et al.*, 2021). Highland areas like South Wollo, characterized by cool temperatures and high moisture, provide highly favourable conditions for disease development.

Despite the increasing importance of the disease, detailed information on its distribution, prevalence, and associated disease factors in this area remains limited. Understanding the spatial distribution and epidemiology of faba bean gall disease is critical for developing effective and location-specific management strategies. Disease survey studies provide essential baseline information on disease prevalence, incidence, and severity, as well as their relationships with environmental and management factors (Bimrew Solomon *et al.*, 2025).

Such information is particularly important in South Wollo, where faba bean is a key crop for food security and farmer livelihoods but is increasingly threatened by emerging diseases.

Therefore, this study was conducted to assess the distribution, prevalence, incidence, and severity of faba bean gall disease and to identify the major agro-ecological and management factors influencing its occurrence in the major faba bean growing areas of South Wollo Zone, Eastern Amhara Region, and Ethiopia

3.2 Materials and Methods

3.2.1 Surveyed Areas

Field surveys were conducted in the major faba bean growing areas of four districts in the South Wollo Administrative Zone of the Amhara Region, namely Legambo, Tenta, Woreilu, and Kelala (Figure 3. 1 and Appendix Figure 2. 1). The survey was conducted during the main cropping seasons of 2022 and 2023. The districts were selected using purposive sampling based on reports of faba bean gall disease from district agricultural offices, production potential, accessibility, and area coverage. Areas known to have high FBG incidence based on previous reports and farmer interviews were prioritized. Within each district, five *Kebele* Administrations (localities) were selected randomly for data collection. The assessment of faba bean gall (FBG) was conducted in these randomly selected *Kebeles*. This approach ensured that data were collected from a representative range of localities while maintaining logistical feasibility. Random selection at the *Kebele* level enhances the objectivity of the survey and reduces potential selection bias, which is important for the reliability of plant disease surveillance.

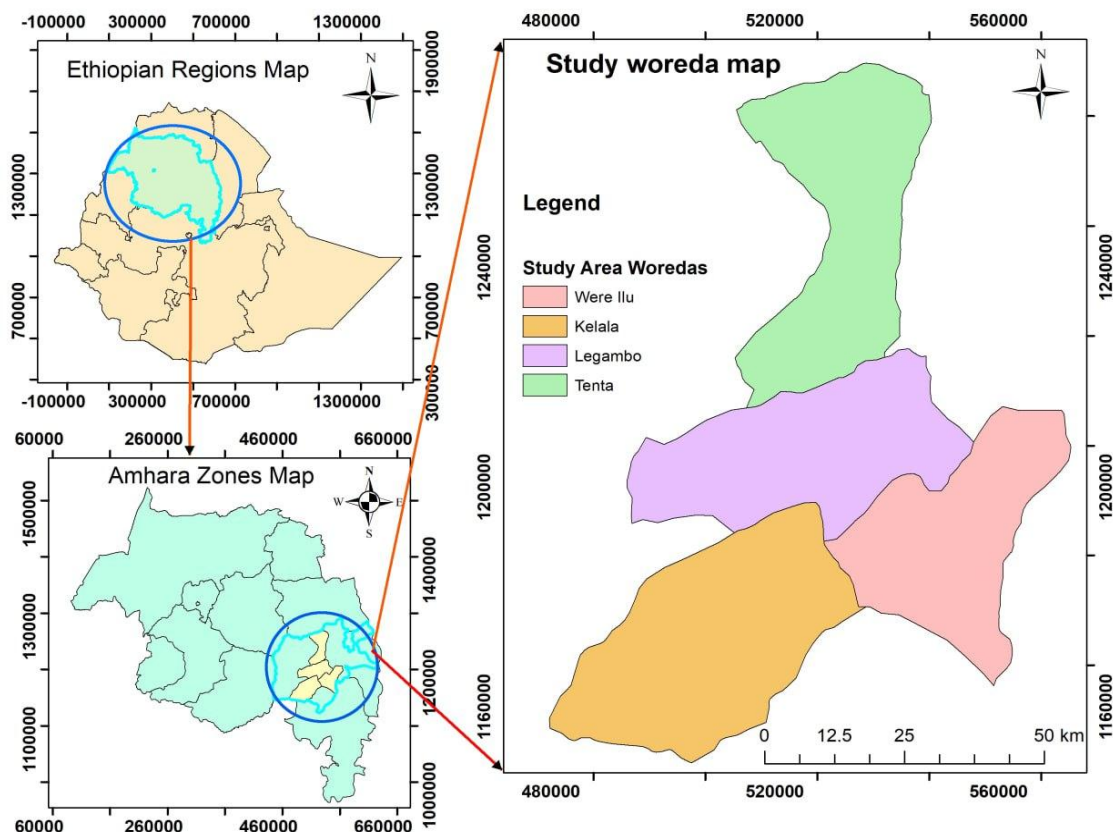


Figure 3. 1. Map showing surveyed districts for faba bean gall in South Wollo, North-Eastern Ethiopia during the 2022 and 2023 cropping seasons.

Table 3. 1. Altitude, rainfall, and temperature conditions of the four surveyed districts in South Wollo, northeastern Ethiopia, during the 2022 and 2023 cropping seasons.

District	Number of fields	Altitude (m a.s.l.)	Rainfall (mm)		Mean of Temperature ($^{\circ}$ C)			
			2022	2023	2022		2023	
					Maximum	Minimum	Maximum	Minimum
Legambo	50	2900-3230	1216.98	912.72	20.00	6.36	20.93	7.04
Woreilu	40	2647-2861	1051.23	809.23	21.67	8.12	22.88	9.94
Tenta	50	2436- 3007	1203.06	896.16	20.47	6.92	21.64	7.45
Kelala	60	2426–2663	1007.96	761.03	23.33	10.38	24.60	11.58

*Average rainfall, and maximum and minimum temperatures of surveyed locations were obtained from respective districts' meteorological stations (<https://power.larc.nasa.gov/data-access-viewer/>) and Altitude ranges of surveyed fields were measured by a global positioning system (GPS) (NASA, 2025).

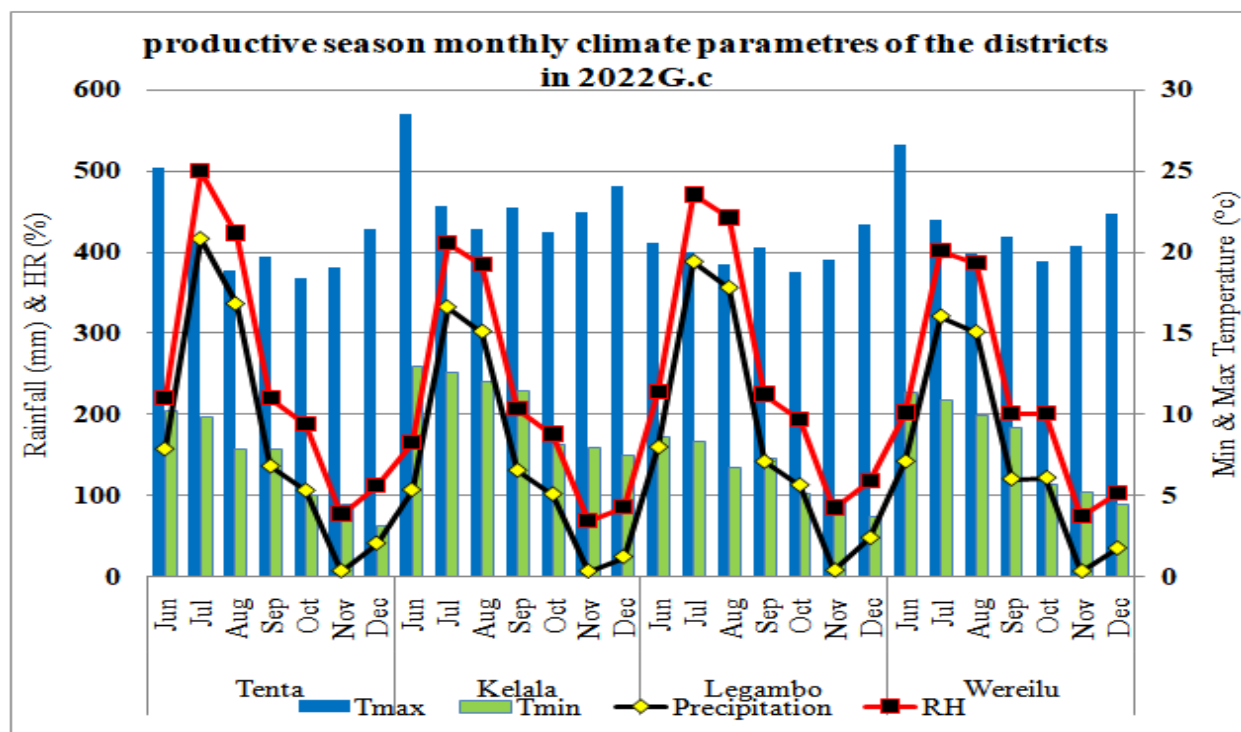
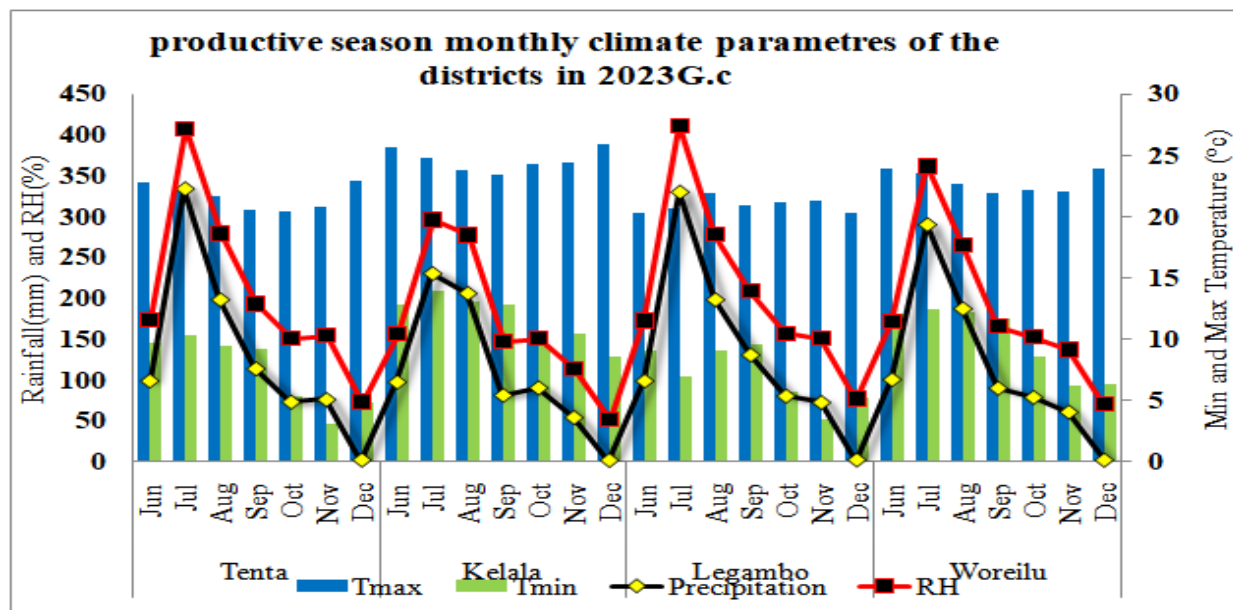


Figure 3. 2. Rainfall, maximum and minimum temperatures, and relative humidity of surveyed districts in north-eastern Ethiopia during the 2022 and 2023 faba bean-growing seasons.

3.2.2 Sampling Procedures and Disease Assessment

Within each selected *Kebele*, up to five farmer fields were assessed, depending on field availability at the time of the survey. Fields were selected randomly along accessible roads at intervals of approximately 5–10 km, following standard plant disease survey methods.

In each field, observations were taken at five sampling points arranged diagonally in an “X” pattern. At each sampling point, a 1 m² quadrat was placed for plant and disease assessment following the field sampling procedure described by Abera Merkuz and Semagn Meseret, 2022. All faba bean plants within each quadrat were counted and examined for typical symptoms of faba bean gall disease. The total number of plants and the numbers of infected and healthy plants were recorded separately for each quadrat.

In addition, farmers were interviewed using a structured questionnaire to collect information on locality, field history, previous crop, altitude, weed presence, soil type, faba bean variety, cropping system, planting date, weeding practices, field slope, drainage status, fungicide application method, disease management practices, and fertilizer use. These agro-ecological and crop management variables were subsequently used to examine their association with the occurrence and intensity of faba bean gall disease.

3.2.3 Data Collection

Disease Prevalence (%): The geographical distribution of Faba Bean Gall within each district was determined as the proportion of fields showing symptoms

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

Disease Incidence (%): Disease incidence was computed by counting diseased and healthy plants in each quadrat. disease incidence was computed according to the following equation.

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

Disease Severity (%): Disease severity was assessed on five randomly selected plants per quadrat using the 0–9 scale of (Ding *et al.*, 1993), where: 0 = no symptom; 1 = very small and few green lesions on leaves; 2 = very small, green, sunken lesions; 3 = many green, small sunken lesions; 4 = many small lesions and few large lesions turning brown; 5 = many large brown lesions; 6 = brown lesions starting to coalesce; 7 = large coalescing brown lesions; 8 = plants darkened and stem collapsed; and 9 = dead plants. Severity scores were then converted into a Percent Severity Index (PSI) following Wheeler (1969):

$$PSI = \frac{Snr}{Npr \times MSC} \times 100$$

Where Snr is the sum of numerical ratings, Npr is the number of plants rated, and MSC is the maximum score of the scale. Means of the severity from each quadrat were used in data analysis.

3.2.4 Data Analysis

Descriptive statistics were used to summarize the prevalence, incidence, and severity of faba bean gall disease across districts and in relation to different biophysical factors. Means, percentages, and graphical presentations were generated using SPSS software to describe and illustrate the spatial distribution of disease occurrence.

The associations between disease parameters (incidence and severity) and environmental and agronomic factors were assessed using logistic regression analysis in SAS version 9.4 (SAS Institute Inc., Cary, NC, USA). The proportional odds assumption was assessed prior to model fitting where ordinal logistic regression was considered appropriate. For the regression analysis, disease incidence was categorized into two classes: $\leq 75\%$ as moderate incidence and $> 75\%$ as high incidence. Similarly, the percent severity index (PSI) was classified into two categories: $\leq 50\%$ as low severity and $> 50\%$ as high severity. These thresholds were used to convert the disease variables into biologically meaningful binary categories suitable for binomial logistic regression analysis. Importantly, this categorization applies only to the logistic regression

models; the original continuous PSI values were retained for all other analyses, including ANOVA, correlation, and regression analyses.

The categorization facilitated the identification of factors associated with fields experiencing relatively high levels of disease incidence and severity, thereby allowing clearer interpretation of the effects of environmental and agronomic variables on faba bean gall disease occurrence.

Model development followed a stepwise approach. Each independent variable was first evaluated in single-variable ordinal logistic regression models. Variables showing significant or strong associations were included in a full multivariable model, and a reduced final model was derived by retaining only those variables that remained significant based on likelihood ratio tests (LRTs) and overall model fit statistics. For variables retained in the final model, parameter estimates, standard errors, and odds ratios (ORs) were calculated. Odds ratios, obtained by exponentiating regression coefficients, represent the odds of a field being in a higher disease category compared with the reference group (Zelege Tekalign *et al.*, 2023). Because faba bean gall disease was common (>50% incidence) in the study area, Interpreted directly as odds of higher disease occurrence. This approach avoids overestimation of effect sizes that would occur under the rare disease assumption.

Model fit and the contribution of individual variables were assessed using likelihood ratio tests and residual deviance, with additional goodness-of-fit metrics, including the Hosmer-Lemeshow test, used to validate model adequacy. Contingency chi-square (χ^2) tests were also performed to compare the frequency distributions of disease categories across explanatory variables, and statistical significance was set at $p < 0.05$. This analytical approach follows the methodologies outlined in previous studies (Yuen, 2006; McCullagh and Nelder, 1989; Sahile Samuel *et al.*, 2008; Yitayih Getnet *et al.*, 2021; Bitew Beyene *et al.*, 2021; Abera Merkuz and Semagn Meseret, 2022), ensuring a comprehensive evaluation of the relationships between faba bean gall occurrence and key environmental and agronomic factors.

3.3 Results and Discussion

3.3.1 Faba Bean Gall Prevalence, Incidence, and Severity

This study confirms that faba bean gall, caused by *Physoderma viciae*, has become a major constraint to faba bean production in the highlands of north-eastern Ethiopia. The disease was widely distributed across all surveyed districts and cropping seasons, with substantial spatial and temporal variation in prevalence, incidence, and severity. These variations were largely driven by agro-ecological conditions and were further modified by agronomic and crop management practices.

Overall disease intensity was markedly higher during the 2022 cropping season than in 2023 (Table 3. 1 and Figure 3. 2). This difference is likely attributable to higher rainfall and elevated relative humidity during the vegetative and flowering stages in 2022, conditions that enhance leaf wetness and favour zoospore release, dispersal, and infection. Similar associations between high moisture and severe faba bean gall epidemics have been reported previously(Bitew Beyene *et al.*, 2021; Ali Bereket and Terefe Habtamu, 2021). In contrast, lower rainfall, reduced humidity, and relatively higher temperatures during the podding stage in 2023 likely suppressed disease development (Anteneh Ademe *et al.*, 2018). These findings underscore the strong dependence of faba bean gall epidemics on seasonal weather conditions. Faba bean gall was detected at all crop growth stages and affected multiple plant organs, including leaves, stems, petioles, flowers, and pods(Figure 3. 3 and Appendix Figure 3. 2). While earlier studies primarily reported symptoms on vegetative tissues (Yan and Hua 2012), the occurrence of symptoms on reproductive organs in the present study may reflect increased disease pressure, greater pathogen aggressiveness, or improved detection of disease expression under favourable environmental.



Figure 3. 3. Collection of plant disease parameters and physical factors from farmers' fields during the 2022 and 2023 main cropping season.

Disease prevalence was highest in Legambo, Tenta, Woreilu, and Kelala districts, all of which received more than 1030 mm of rainfall during the 2022 main rainy season (). This pattern is consistent with the pathogen's preference for high relative humidity (80–100%) and moderate temperatures (10–20°C) (Yan and Hua, 2012).

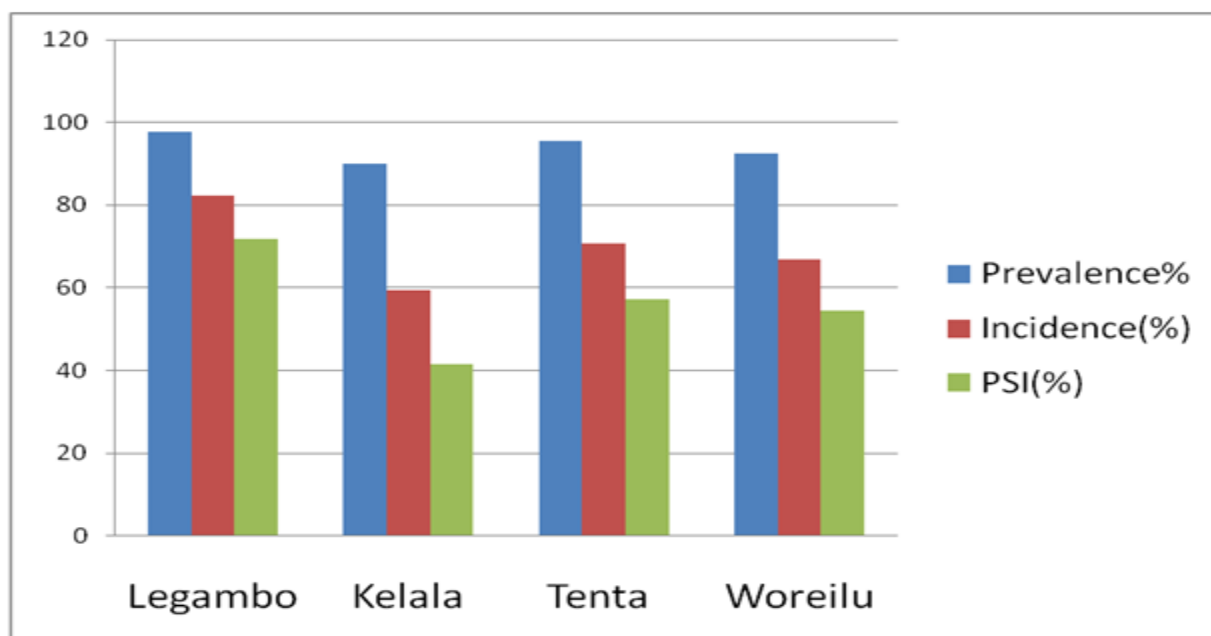


Figure 3. 4. Mean of faba bean gall disease (Prevalence, Incidence, and Percentage Severity index) across four districts in 2022 and 2023

Among the surveyed districts, Legambo recorded the highest disease prevalence (97.60%), followed by Tenta (95.60%), whereas lower prevalence was observed in Woreilu (92.50%) and Kelala (90.00%). Disease incidence ranged from 0% to 100% across fields, with Legambo exhibiting the highest mean incidence (82.26%) and severity (71.92%), followed by Tenta (70.85% incidence and 57.14% severity). In contrast, Kelala showed the lowest incidence (59.41%) and severity (41.45%); while Woreilu displayed intermediate levels (66.99% incidence and 54.56% severity) (Figure 3. 4 and

). Under favourable environmental conditions and on susceptible varieties, yield losses may reach 100%, leading some farmers to abandon faba bean cultivation altogether(Abebe Teklay *et al.*, 2014; Gezahegne Getaneh *et al.*, 2014; Bitew Beyene *et al.*, 2021; Yitayih Getnet and Azmeraw Yehizbalem, 2017).

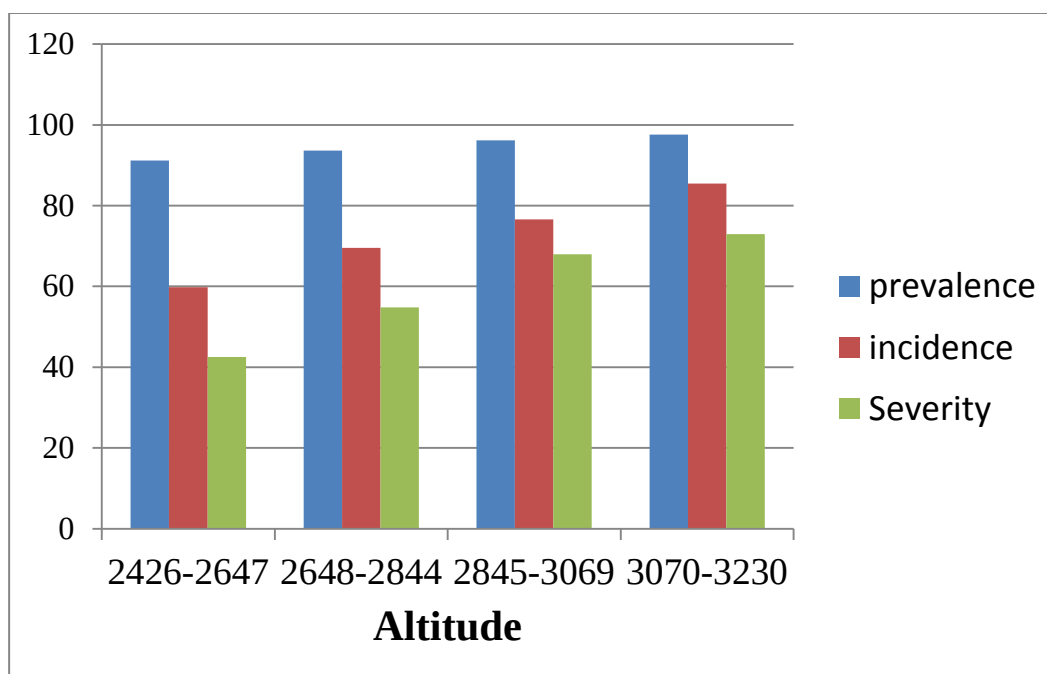


Figure 3. 5. Mean of faba bean gall disease prevalence, incidence and percentage severity index on different altitudes in 2022 and 2023 cropping seasons.

Altitude significantly influenced disease distribution, with higher prevalence, incidence, and severity recorded between 2426 and 3230 m a.s.l. (Figure 3. 5). This finding agrees with earlier reports (Yan and Hua 2012; Gezahegne Getaneh *et al.*, 2014; Hailemariam Bogale *et al.*, 2016; Bitew Beyene *et al.*, 2021; Gezahegne Getaneh *et al.*, 2014; Yitayih Getnet *et al.*, 2021; Yitayih Getnet *et al.*, 2023) suggesting that altitude indirectly affects disease development through its influence on temperature, humidity, and soil moisture. Fields located in poorly drained areas, near furrows, trees, or shaded zones exhibited more severe disease, likely due to increased moisture retention and reduced air circulation (Hailemariam Bogale *et al.*, 2016).

Clear seasonal differences were observed. During the 2022 cropping season, mean faba bean gall incidence and severity reached 74.81% and 64.01%, respectively, compared with 64.17% incidence and 47.21% severity in 2023. This further highlights the strong influence of inter-annual climatic variability on disease occurrence. The faba bean gall disease epidemiology was significantly influenced by faba bean varieties.

Fields planted with the improved variety Wolkie showed lower mean incidence (62.23%) and severity (48.31%) compared with fields planted with local varieties (73.57% incidence and

63.52% severity). This association suggests that Wolkie may possess partial tolerance, although the number of Wolkie fields surveyed was limited, and other farm management practices may have contributed to the observed differences. The lack of fully resistant faba bean varieties in Ethiopia remains a major challenge, despite the identification of several moderately tolerant lines (Bitew Beyene, 2012; Wondwosen Wulita, 2015 ; Yitayih Getnet and Azmeraw Yehizbalem, 2017; Hussen Seid *et al.*, 2025). Similar results have been reported elsewhere, where variation among breeding lines exists but complete resistance has not been achieved (Yan and Hua, 2012).

The faba bean gall disease epidemiology was significantly affected by soil type. Vertisols exhibited the highest disease prevalence (94.53%), incidence (71.76%), and severity (58.44%), followed by Nitisols (93.50%, 62.97%, and 53.90%, respectively) (

Table 3. 2). Arenosols recorded the lowest prevalence (89.78%), incidence (61.58%), and severity (44.00%). These associations may be related to variations in moisture retention, drainage, and soil structure. The high water-holding capacity and poor aeration of Vertisols may create conditions that are favourable for pathogen survival and plant stress. The high water-holding capacity and poor aeration of Vertisols create favourable conditions for pathogen survival and plant stress, whereas the better drainage of Arenosols may reduce infection factor (Bitew Beyene *et al.*, 2021). Although *Physoderma viciae* has been confirmed as the causal agent of faba bean gall in Ethiopia (You *et al.*, 2021), its survival mechanisms in different soil types remain poorly understood, representing an important research gap.

Agronomic practices were also associated with disease intensity. Fields that were not weeded showed higher incidence (78.24%) and severity (63.52%) than fields weeded twice (63.41% incidence and 50.49% severity). Poor weed management likely increased disease severity by creating humid microclimates and reducing crop vigour (Yimer Sultan *et al.*, 2018); (Bitew Beyene *et al.*, 2021). Proper land preparation improved soil aeration and drainage, while fertilizer application enhanced plant vigour and tolerance to infection (Öborn *et al.*, 2003; Amalero *et al.*, 2003; Veresoglou and Rillig, 2012; Mengesha and Yetayew, 2018).

Disease incidence and severity were highest during the vegetative and flowering stages, peaking at flowering. This stage coincides with rapid cell division in meristematic tissues, increasing

susceptibility to zoospore penetration and gall formation. However, the apparent increase in severity at flowering was largely mediated by seasonal and environmental conditions rather than crop phenology alone. The planting method significantly influenced disease development. Broadcast sowing resulted in higher disease prevalence, incidence, and severity than row planting.

Row planting reduced disease incidence by 62.68% and severity by 48.64%, likely due to improved air circulation and reduced leaf wetness (Pande and Rao, 2002; Wakweya *et al.*, 2016). Fertilizer application, particularly NPS applied at sowing, was associated with lower disease incidence (65.41%) and severity (50.21%) compared with unfertilized fields. Similarly, fungicide-treated fields showed lower incidence (61.78%) and severity (50.25%) than untreated fields (72.42% and 57.64%, respectively) (Appendix Table 3. 1).

Crop rotation also influenced disease levels. Fields previously rotated with legumes exhibited higher incidence (76.80%) and severity (76.20%) than fields rotated with cereals (69.34% incidence and 55.16% severity) (

Table 3. 2). This pattern suggests that cereal rotations reduce pathogen buildup in the soil, whereas legume rotations favour the persistence of resting spores and subsequent disease development (Gezahegne Getaneh *et al.*, 2018; Zeleke Tekalign *et al.*, 2023). Disease pressure was also higher in shaded or waterlogged micro-environments, reinforcing the importance of field drainage and site selection.

Table 3. 2. Prevalence, incidence, and severity (Mean $\pm$ SE) of faba bean gall across different independent variables in north-eastern Ethiopia during the 2022 and 2023 cropping seasons.

Variables	Variable class	No. of fields	Prevalence %	Incidence%	Percentage Severity index%
District	Legambo	50	97.60	82.26 $\pm$ 1.05	71.92 $\pm$ 0.66
	Kelala	60	90.00	59.41 $\pm$ 1.54	41.45 $\pm$ 2.02
	Tenta	50	95.60	70.85 $\pm$ 1.67	57.14 $\pm$ 2.02
	Woreilu	40	92.50	66.99 $\pm$ 1.46	54.56 $\pm$ 1.98
Year	2022	100	97.41	74.81 $\pm$ 1.14	64.01 $\pm$ 0.9
	2023	100	90.19	64.17 $\pm$ 1.33	47.21 $\pm$ 1.88
Altitude	2426-2647	70	91.16	59.81 $\pm$ 1.47	42.54 $\pm$ 1.94
	2648-2844	60	93.63	69.56 $\pm$ 1.33	54.80 $\pm$ 1.69
	2845-3069	50	96.18	76.56 $\pm$ 1.36	67.96 $\pm$ 1.01
	3070-3230	20	97.60	85.50 $\pm$ 0.99	72.93 $\pm$ 1.33
Soil type	Vertisol	95	94.53	71.76 $\pm$ 1.27	58.44 $\pm$ 1.63
	Arenosol	8	89.78	61.58 $\pm$ 5.48	44.00 $\pm$ 7.81

Variety	Nitisol	97	93.50	62.97 ± 1.41	53.90 ± 1.72
	Wolkie	96	92.64	62.23 ± 1.19	48.31 ± 1.66
	Local	104	95.06	77.36 ± 1.00	63.52 ± 1.33
Planting method	Broadcast planting	93	94.94	77.33 ± 1.03	63.63 ± 1.35
	Row planting	107	92.81	62.68 ± 1.19	48.64 ± 1.63
Weeding frequency	Unwedded	44	95.31	78.24 ± 1.58	63.52 ± 2.10
	Once	86	93.16	69.96 ± 1.46	55.73 ± 1.94
	Two times weeding	70	93.63	63.41 ± 1.40	50.49 ± 1.85
Land preparations	Once plowing	82	94.97	76.69 ± 1.67	62.89 ± 1.45
	Two times plowing	55	93.59	67.81 ± 1.67	54.95 ± 2.37
	Three times	63	92.46	61.58 ± 1.61	46.77 ± 2.09
	plowing				
Field size	0.25-0.5	162	93.90	70.45 ± 1.05	56.43 ± 1.32
	0.5-1	36	93.43	65.23 ± 2.11	52.06 ± 2.77
	1-1.5	2	92.31	68.50 ± 19.7	53.20 ± 23.00
Growth stage	Flowering	158	94.00	70.01 ± 1.05	56.47 ± 1.32
	Podding	42	93.04	67.54 ± 2.21	52.38 ± 2.77
Previous crop	Cereals	167	93.90	69.34 ± 1.03	55.16 ± 1.28
	Vegetable	31	93.16	69.84 ± 2.57	55.45 ± 3.45
	Legume	2	95.20	76.80 ± 6.00	76.20 ± 2.00
Fertilizer	Fertilized	55	93.26	65.41 ± 2.07	50.21 ± 2.54
	Unfertilized	155	94.01	71.04 ± 1.02	57.66 ± 1.31
Fungicide	Sprayed	55	93.78	61.78 ± 1.48	50.25 ± 2.10
	Unsprayed	145	93.81	72.42 ± 1.09	57.64 ± 1.41
Drainage	Excellent	35	92.07	56.87 ± 1.96	43.27 ± 2.83
	Good	60	93.34	66.67 ± 1.49	55.46 ± 2.05
	Poor	105	94.64	75.14 ± 1.13	60.95 ± 1.48

Remark: - SE= standard error

3.3.2 Association of Faba Bean Gall with Agro-Ecological Factors

The relationships between faba bean gall incidence and severity and various agro-ecological and management factors were examined using logistic regression analyses (Table 3.4. And Table 3.4). Both Type I (variables entered first, VEF) and Type III (variables entered last, VEL) analyses were conducted, with the Type III models providing the most reliable estimates of each variable's independent effect. For disease incidence, the Type I analysis identified district, year, altitude, soil type, variety, growth stage, land preparation, previous crop, fungicide application, and field drainage as significant contributors to deviance reduction.

In the Type III analysis, district, year, altitude, variety, previous crop, fungicide application, and drainage consistently retained significance, whereas variables such as soil type, planting method, field size, and growth stage lost significance. This indicates that the apparent effects of these variables were largely mediated by dominant environmental factors.

District, year, and altitude emerged as the strongest predictors of disease incidence (Appendix Table 3. 2). For percent severity index, a similar pattern was observed. In the VEF analysis, district, year, altitude, soil type, variety, Growth stage, land preparation, previous crop, fertilizer use, fungicide application, and drainage significantly influenced disease levels (Figure 3. 4). In the Type III model, district, year, altitude, variety, planting method, weeding frequency, previous crop, fertilizer use, fungicide application, and drainage remained significant. District, year, and altitude were again the most influential factors, while management practices had secondary, though still significant, effects. Management practices, particularly variety, previous crop, fertilizer use, fungicide application, and drainage, were significantly associated with disease severity, whereas growth stage did not retain independent significance after accounting for environmental factors. Particularly, variety, previous crop, land preparation, fungicide application, and drainage remained strongly linked to disease incidence regardless of entry order.

Table 3. 3. Logistic regression model for mean faba bean gall disease incidence and severity, and likelihood ratio test on independent variables during the 2022 and 2023 main rainy seasons.

Variable	DF	Faba bean gall disease incidence, LRT*				Faba bean gall disease severity LRT*			
		Type 1 analysis		Type 3 analysis		Type 1 analysis		Type 3 analysis	
		DR	Pr > χ^2	DR	Pr > χ^2	DR	Pr > χ^2	DR	Pr > χ^2
District	3	715.26	<.0001	57.74	<.0001	1054.05	<.0001	60.14	<.0001
Year	1	277.82	<.0001	194.57	<.0001	606.96	<.0001	477.72	<.0001
Altitude	3	75.26	<.0001	41.67	<.0001	111.71	<.0001	74.30	<.0001
Soil	2	7.30	0.0259	4.21	0.1217	9.71	0.0078	1.65	0.4385
Variety	1	249.14	<.0001	6.89	0.0087	136.96	<.0001	4.23	0.0398
Planting method	1	16.02	<.0001	0.84	0.3581	20.49	<.0001	8.02	0.0046
Weeding	2	4.62	0.0990	3.48	0.1755	2.80	0.2470	6.88	0.0321
Land	2	8.79	0.0123	8.34	0.0154	8.23	0.0163	2.92	0.2322
Field Size	2	4.08	0.1303	0.47	0.7900	1.38	0.5026	0.18	0.9141
Growth stage	1	2.12	0.1450	0.34	0.5605	1.21	0.2710	0.62	0.4327
Previous	2	6.24	0.0441	8.61	0.0135	21.37	<.0001	18.99	<.0001
Fertilizer	1	3.19	0.0743	0.18	0.6679	9.99	0.0016	4.88	0.0272
Fungicide	1	45.76	<.0001	36.58	<.0001	10.26	0.0014	6.39	0.0115
Drainage	2	13.90	0.0010	13.90	0.0010	10.36	0.0056	10.36	0.0056

Remark: - *LRT: Likelihood ratio test; VEF: variable entered first in the model; VEL: variable entered last in the model; DR: deviance reduction; and Pr: probability of a χ^2 value exceeding the deviance reduction; χ^2 : Chi-square; DF: degrees of freedom; PSI: percent severity index.

Some variables, including fungicide use, remained statistically significant regardless of entry order, whereas others, such as weeding frequency, were significant mainly for disease severity.

Additionally, Year and district remained consistently significant predictors for both incidence and severity. Growth stage did not retain independent significance in the Type III models, indicating that its apparent effects were largely mediated through seasonal and environmental factors. Variables such as field size and crop growth stage did not show statistically significant associations with either disease outcome in the final reduced model, whereas previous crop retained a significant association, particularly with disease severity. The results reinforce the need for integrated disease management strategies that are context-specific and adapted to local agro-ecological conditions. Further analysis of variable deviance, parameter estimates, and standard errors from reduced models (Table 3.4 and Table 3.5) Provides detailed insights into the strength and direction of association for each variable and their respective classes in relation to faba bean gall incidence and severity.

Results from the reduced logistic regression models clarified the direction and magnitude of these associations. Disease incidence varied significantly among districts, with higher odds in Legambo and lower odds in Kelala relative to Woreilu. The odds of high disease incidence were 1.62 times higher in 2022 compared to 2023. The 2022 season exhibited significantly higher odds of disease incidence than 2023, reflecting inter-annual climatic variability (Appendix Table 3. 1). Disease incidence declined progressively at lower altitude ranges relative to the highest elevation category. Improved varieties showed lower odds of infection than local varieties, while fields rotated with cereals or vegetables had lower disease incidence than those following legumes (Appendix Table 3. 3). Fungicide application and good field drainage were also associated with reduced disease incidence, although these results should be interpreted cautiously due to limited detail on fungicide use. Farmers reported using commonly available fungicides, including Mancozebe (1.5 kg ha¹), Ridomil (2.5 kg ha¹), Matco (1.8 kg ha¹), and Noble 25 WP, consistent with previous reports (Beyene Bitew and Abiro Tigabie, 2016;Hailemariam Bogale *et al.*, 2017; Bekele Belachew *et al.*, 2018; Kebede Wulita *et al.*, 2019; Kassa Yehuala *et al.*, 2020). However, inadequate knowledge of application rates, timing, and target diseases may limit fungicide effectiveness (Abebe Teklay *et al.*, 2014). Well-drained fields consistently exhibited lower disease pressure, emphasizing the importance of water management.

Table 3. 4. Analysis of Deviance, Natural Logarithms of Odds Ratios, and Standard Errors for Faba Bean Gall Disease Incidence Based on a Reduced Logistic Regression Model.

Variable	Residual deviance	DF	DR	Pr > χ^2	Variable Class	Estimate	SE	Odds ratio
District	1029.17	3	57.74	<.0001	Intercept	0.99	0.29	2.69
					Kelala	-0.15	0.06	0.86
					Legambo	0.51	0.08	1.67
					Tenta	0.10	0.06	1.10
					Woreilu	0.00	0.00	1.00
Year	751.35	1	194.57	<.0001	2022	0.48	0.03	1.62
					2023	0.00	0.00	1.00
Altitude	676.09	3	41.67	<.0001	2426-2647	-0.55	0.11	0.57
					2648-2844	-0.29	0.11	0.74
					2845-3069	-0.29	0.08	0.75
					3070-3230	0.00	0.00	1.00
Soil	668.79	2	4.21	0.1217	Nitisol	-0.08	0.04	0.92
					Arenosol	0.01	0.10	1.01
					Vertisol	0.00	0.00	1.00
Variety	419.65	1	6.89	0.0087	Wolkie	-0.19	0.07	0.83
					Local	0.00	0.00	1.00
Planting method	403.63	1	0.84	0.3581	Broadcast	0.10	0.11	1.10
					Row	0.00	0.00	1.00
Weeding	399.00	2	3.48	0.1755	No weeding	0.09	0.06	1.09
					One times	-0.01	0.05	0.99
					Two times	0.00	0.00	1.00
Land	390.21	2	8.34	0.0154	One plowing	0.18	0.07	1.20
					Two plowing	0.03	0.05	1.03
					Three plowing	0.00	0.00	1.00
					0.25-0.5	0.07	0.18	1.08
Field Size	386.13	3	0.47	0.7900	0.5-1	0.05	0.18	1.05
					1-1.5	0.00	0.00	1.00
					Flowering	-0.02	0.04	0.98
Growth stage	384.01	1	0.34	0.5605	Podding	0.00	0.00	1.00
					Cereal	-0.02	0.18	0.98
					Vegetable	-0.17	0.18	0.84
Previous crop	377.77	2	8.61	0.0135	Legume	0.00	0.00	1.00
					Fertilized	-0.02	0.04	0.98
					Unfertilized	0.00	0.00	1.00
Fertilizer	374.58	1	0.18	0.6679	Spraying	-0.25	0.04	0.78
					Unsprayed	0.00	0.00	1.00
Fungicide	328.82	1	36.58	<.0001	Excellent	-0.18	0.07	0.84
					Good	0.00	0.07	1.00
					Poor	0.00	0.00	1.00
Drainage	314.92	2	13.90	0.0010				

Remark: - Residual deviance: unexplained variation after fitting the model;
LRT: likelihood ratio test; DR: deviance reduction; Pr: probability of chi-square value exceeding the deviance reduction; χ^2 : Chi-square; SE: standard error and DF: degrees of freedom.

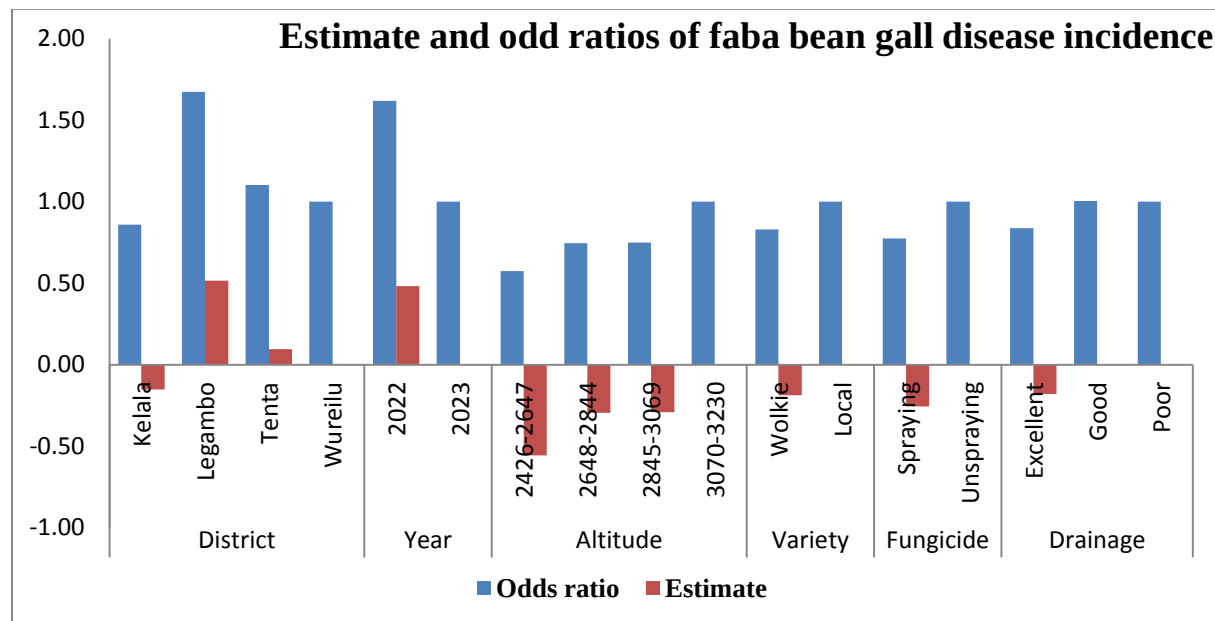


Figure 3. 6. Summarizing odds ratios from the reduced logistic regression model showing the effects of district, year, altitude, variety, fungicide application, and field drainage on faba bean gall disease incidence.

Disease severity followed similar spatial and temporal trends. Severity was significantly higher in Legambo and lower in Kelala relative to Woreilu and was markedly higher in 2022 than in 2023. Severity declined at lower altitudes and was significantly influenced by variety, cropping pattern, previous crop, fertilizer use, fungicide application, and drainage. Fields planted with Wolkie varieties and those rotated with cereals exhibited lower severity than fields following vegetables (Table 3. 5 and Appendix Table 3. 4). In contrast, soil type, land preparation, field size, and crop growth stage did not show independent effects in the reduced model. Overall, logistic regression analysis confirmed that faba bean gall incidence and severity are primarily driven by agro-ecological factors, particularly district, year, and altitude, while management practices such as variety selection, crop rotation, planting method, drainage, fertilizer use, weeding, and fungicide application play important modifying roles(

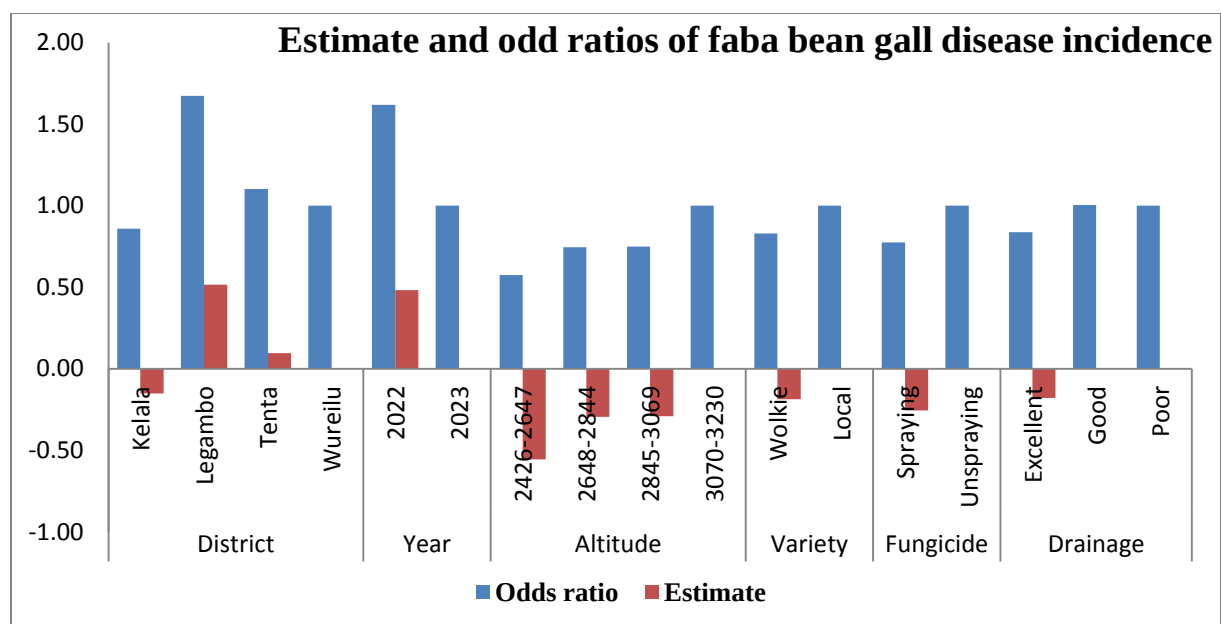


Figure 3. 6 and Figure 3. 7). some factors influenced disease incidence more strongly, whereas others had a greater effect on disease severity, indicating differential responses of disease components to environmental and agronomic variables.

Table 3. 5. Analysis of Deviance, Natural Logarithms of Odds Ratios, and Standard Errors for Faba Bean Gall Disease Severity Based on a Reduced Logistic Regression Model

Variable	Residual deviance	DF	LRT DR	Pr > χ^2	Variable class	Estimate	SE	Odds Ratio
District	1327.21	3	60.14	<.0001	Intercept	0.82	0.28	2.27
					Kelala	-0.25	0.06	0.78
					Legambo	0.39	0.07	1.47
					Tenta	0.07	0.05	1.07
					Woreilu	0.00	0.00	1.00
Year	720.26	1	477.72	<.0001	2022	0.70	0.03	2.01
					2023	0.00	0.00	1.00
Altitude	608.55	3	74.30	<.0001	2426-2647	-0.57	0.10	0.56
					2648-2844	-0.28	0.09	0.75
					2845-3069	-0.01	0.07	0.99
					3070-3230	0.00	0.00	1.00
Soil	598.84	2	1.65	0.4385	Nitisol	-0.05	0.04	0.95
					Arenosol	-0.03	0.09	0.97
					Vertisol	0.00	0.00	1.00
					Wolkie	-0.13	0.07	0.87
Variety	461.88	1	4.23	0.0398	Local	0.00	0.00	1.00
					Broadcast	0.28	0.10	1.32
Planting method	441.38	1	8.02	0.0046	Row	0.00	0.00	1.00
					No weeding	-0.14	0.06	0.87
					One times	-0.11	0.04	0.90
Weeding	438.59	2	6.88	0.0321	Two times	0.00	0.00	1.00

Land	430.35	2	2.92	0.2322	One plowing	0.09	0.06	1.10
					Two plowing	0.06	0.04	1.07
					Three plowing	0.00	0.00	1.00
Field Size	428.98	3	0.18	0.9141	0.25-0.5	0.07	0.17	1.07
					0.5-1	0.07	0.17	1.07
					1-1.5	0.00	0.00	1.00
Growth stage	427.77	1	0.62	0.4327	Flowering	-0.03	0.04	0.97
					Podding	0.00	0.00	1.00
Previous crop	406.40	2	18.99	<.0001	Cereal	-0.67	0.18	0.51
					Vegetable	-0.75	0.18	0.47
					Legume	0.00	0.00	1.00
Fertilizer	396.41	1	4.88	0.0272	Fertilized	-0.08	0.04	0.92
					Unfertilized	0.00	0.00	1.00
Fungicide	386.15	1	6.39	0.0115	Spraying	-0.10	0.04	0.90
					Unsprayed	0.00	0.00	1.00
Drainage	375.79	2	10.36	0.0056	Excellent	-0.12	0.07	0.89
					Good	0.05	0.07	1.05
					Poor	0.00	0.00	1.00

Residual deviance = unexplained variation after fitting the model; LRT = likelihood ratio test; DR = deviance reduction; Pr = probability of chi-square value exceeding the deviance reduction; χ^2 = Chi-square; SE = standard error; and df = degrees of freedom.

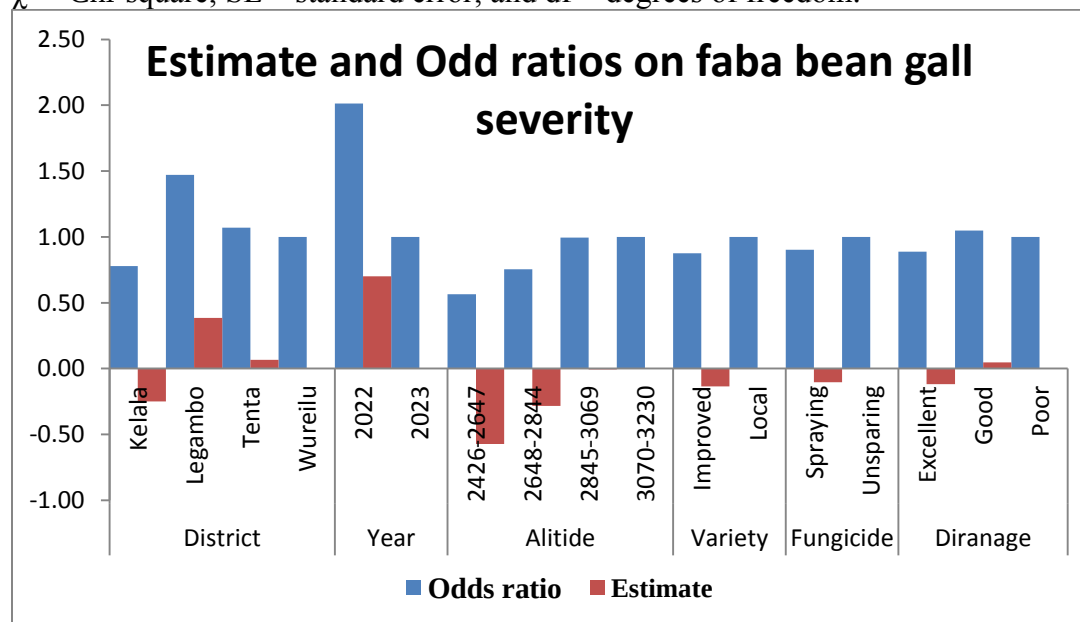


Figure 3. 7. Summarizing odds ratios and estimate from the reduced logistic regression model showing the effects of district, year, altitude, variety, fungicide application, and field drainage on faba bean gall disease severity.

3.4 Conclusion

This study provides evidence that faba bean gall, caused by *Physoderma viciae*, is a widespread and serious constraint to faba bean production in Ethiopia's highland regions. The disease was consistently observed across all surveyed districts in South Wollo, northeastern Ethiopia during both cropping seasons, with higher incidence and severity in areas of high altitude, increased rainfall, high relative humidity, and cooler temperatures.

Disease severity peaked at the flowering stage and was consistently associated with dense weeds, poor drainage, and suboptimal agronomic practices in the surveyed fields. Although some variation in susceptibility existed among genotypes, no complete resistance was identified, and the repeated use of susceptible local varieties contributes to the persistence and spread of the disease. Biophysical factors such as district, year, and altitude, together with agronomic practices including variety selection, crop rotation, planting method, drainage, fertilizer application, weeding, and fungicide use, were all found to influence disease incidence and severity. Logistic regression analysis confirmed that these factors interact to determine the occurrence and intensity of epidemics.

These findings highlight the urgent need for integrated disease management strategies. Breeding programs should focus on developing resistant or tolerant varieties. Farmers should adopt improved agronomic practices, including row planting, timely weeding, proper land preparation, and appropriate fertilizer use. Crop rotation with cereals or non-legume crops, along with well-drained fields and avoidance of shaded or waterlogged areas, can further reduce disease pressure. Judicious fungicide use, strengthened seed systems, and increased farmer awareness and training are also essential for sustainable management. Overall, the study demonstrates that faba bean gall is a persistent and serious disease in Ethiopia's highlands. Adoption of integrated, location-specific management practices will be critical to reduce yield losses, maintain faba bean production, and ensure food security in these farming systems.

3.5 Recommendations

Based on the findings of this study, integrated and location-specific management strategies are strongly recommended to reduce the impact of faba bean gall in northeastern Ethiopia. Priority should be given to the development and dissemination of faba bean varieties with improved resistance or tolerance to *Physoderma viciae*. In the absence of fully resistant varieties, moderately tolerant cultivars such as Wolkie should be promoted as part of an integrated management approach rather than as a standalone solution. Strengthening seed systems to improve farmers' access to quality and certified seed is also essential for sustaining productivity and enhancing disease management. Crop rotation, particularly with non-host cereal crops, should be emphasized to reduce soil-borne inoculum and disrupt the pathogen's life cycle. Improved field drainage and proper land preparation are critical, especially in high-altitude and high-rainfall areas where waterlogging and prolonged leaf wetness favour disease development. Farmers should avoid poorly drained fields and adopt practices that enhance soil aeration and reduce moisture accumulation.

Optimizing agronomic practices can further reduce disease pressure and improve crop resilience. Row planting should be encouraged to improve air circulation, while timely and adequate weed management helps minimize humid microclimates around plants. Balanced fertilizer application, including NPS at sowing, can enhance plant vigour and tolerance to infection. Fungicides may be used as supplementary tools during high-disease seasons, but their use should be judicious and supported by farmer training on correct product selection, application rates, timing, and target diseases.

Finally, continued research is needed to improve understanding of the biology, survival mechanisms, and environmental interactions of *P. viciae*, particularly its persistence in different soil types. Long-term, multi-location studies evaluating integrated disease management packages under diverse agro-ecological conditions are essential for developing sustainable and effective strategies to control faba bean gall and safeguard faba bean production in Ethiopia.

Chapter 4. Histopathological and Molecular Characterization of *Physoderma viciae* Associated with Faba Bean Gall Disease in Ethiopia

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Abstract

Faba bean gall disease has emerged as an important constraint to faba bean (Vicia faba L.) production in Ethiopia. This study was conducted to identify and characterize the organism associated with gall formation using an integrated approach involving field symptom assessment, histopathological examination, cultural isolation, and molecular detection. Field surveys conducted in major faba bean-growing areas of South Wollo, namely Legambo, Kelala, Woreilu, and Tenta, revealed characteristic symptoms of faba bean gall disease. Histopathological examination of infected tissues revealed severe cellular disorganization and structures characteristic of Physoderma infection, including thick-walled resting spores, turbinate cells, and epibiotic zoosporangia. Culture-based methods yielded only saprophytic fungi with morphological characteristics of Alternaria-like fungi, which were not amplified by Physoderma-specific primers, indicating that they were associated microorganisms rather than the pathogen responsible for gall formation. Molecular detection using the Physoderma-specific primer pairs Physo1 and Physo D' detected P. viciae-specific DNA in 24 of 40 symptomatic samples that yielded DNA of sufficient quality for PCR analysis, representing 60% of the samples tested. Twelve samples (30%) were positive with Physo1, and a different 12 samples (30%) were positive with Physo D'. Overall, the integration of histopathological and molecular evidence provides strong evidence for the association of Physoderma viciae with faba bean gall disease in Ethiopia. The failure to recover P. viciae on artificial media indicates that

conventional culture-based methods are unsuitable for its detection under the conditions used in this study. These findings highlight the value of combining histopathological examination with direct molecular detection for the identification of faba bean gall-associated P. viciae. Further studies involving sequencing of PCR products and phylogenetic analysis are recommended to provide sequence-level confirmation and to characterize the genetic diversity of P. viciae populations in Ethiopia.

Keywords: faba bean gall, histopathology, molecular detection, obligate pathogen, *Physoderma viciae*

4.1 Introduction

Faba bean (*Vicia faba* L.), believed to have originated in the Near East, is among the earliest domesticated legume crops, following chickpea and pea (Kadam and Salunkhe, 1989). Globally, it ranks as the fourth most important pulse crop, with China as the leading producer, followed by Ethiopia, Egypt, Italy, and Morocco (Sainte, 2011). In Ethiopia, faba bean is the most widely cultivated food legume and plays a crucial role in the livelihoods of smallholder farmers. Owing to its high protein content (20–41%), it serves as an important source of dietary protein and a valuable meat extender or substitute (Sainte, 2011; Sarker *et al.*, 2014). In addition to its nutritional value, the faba bean has significant economic, agronomic, and ecological importance. It provides a major source of income for farming households and contributes to national foreign exchange earnings (Thijs *et al.*, 2015). Agronomically, faba bean is an excellent rotational crop and plays a vital role in enhancing soil fertility through biological nitrogen fixation, thereby improving the sustainability of cereal-based cropping systems (Ronner and Giller, 2012).

Despite these advantages, faba bean productivity and yield stability in Ethiopia are severely constrained by a range of abiotic and biotic stresses (Shifa Hassen *et al.*, 2011). Recently, a destructive gall-forming disease caused by *Physoderma viciae* has emerged as a major threat to faba bean production. The disease is characterized by green, sunken lesions on the upper leaf surface that bulge on the lower surface and subsequently develop into light brown, chlorotic galls. These galls enlarge and coalesce into irregular circular or elliptical spots, leading to leaf distortion, premature senescence, and reduced yield (Gezahegne Getaneh *et al.*, 2014).

Previously, Ethiopian studies based on field symptoms and microscopic observations misidentified the causal agent as *Olpidium viciae* Kusano, a pathogen primarily reported from Japan and China (Hailemariam Bogale *et al.*, 2016; Gezahegne Getaneh *et al.*, 2018; Yan and Hua, 2012). However, recent morphological and molecular investigations by You *et al.* (2021) conclusively demonstrated that the pathogen responsible for faba bean gall disease is *Physoderma viciae*, not *O. viciae*. This re-identification has profound implications for understanding disease epidemiology and for developing effective management strategies in Ethiopia. Despite the increasing importance of faba bean gall disease, substantial knowledge gaps remain in Ethiopia regarding the biological characteristics of the pathogen and effective disease suppression strategies. Therefore, the present study aimed to identify and characterize the organism associated with faba bean gall disease in major faba bean-growing areas of South Wollo, Ethiopia, using symptomatological, histopathological, cultural, and molecular approaches.

4.2 Materials and Methods

4.2.1 Sample Collection

A total of 160 symptomatic faba bean leaf and stem samples were collected from farmers' fields in four districts of South Wollo Zone, namely Legambo, Woreilu, Kelala, and Tenta. The samples comprised 60 from Legambo, 40 from Woreilu, 30 from Kelala, and 30 from Tenta. Simple random sampling was used to obtain representative symptomatic plants from different locations within each field. Plant tissues exhibiting characteristic gall-like swellings and lesions were carefully excised using sterile instruments to minimize cross-contamination. Each sample was placed in a sterile polyethylene bag and labelled with relevant information, including district, sampling site, and date of collection. Samples were immediately placed in an ice box and transported to the Plant Pathology Laboratory at Ambo Agricultural Research Center for further processing.

4.2.2 Histopathological Examination

Histopathological examination was conducted using symptomatic leaf and stem tissues collected from faba bean plants exhibiting typical gall symptoms.

Small tissue sections (approximately 5 × 5 mm) were carefully excised from infected regions using a sterile razor blade and hand-sectioned into thin transverse sections under aseptic conditions. For general microscopic observation, tissue sections were mounted on clean glass slides containing a drop of lactophenol cotton blue. Additional sections were stained with safranin to enhance visualization of host tissue damage and pathogen structures. The prepared slides were covered with cover slips and examined under a microscope at magnifications of 100×, 200×, and 400×.

Microscopic observations focused on identifying histopathological alterations and diagnostic structures associated with *Physoderma* infection, including cellular disorganization, plasmolysis, resting spores, turbinate cells (specialized, swollen, short, and irregularly shaped vegetative cells typical of *Physoderma* development within host tissues), and epibiotic zoosporangia. Photomicrographs of representative structures were captured using a digital camera mounted on the microscope.

4.2.3 Isolation of Microorganisms from Faba Bean Gall Tissues

Isolation of microorganisms associated with faba bean gall tissues was conducted using symptomatic leaf and stem samples collected from infected plants. All laboratory procedures were performed under aseptic conditions. Freshly infected tissues showing active gall symptoms and healthy-looking margins were selected and cut into small pieces (approximately 3 × 3 mm) using a sterile scalpel. The tissue fragments were surface-sterilized by immersion in 70% ethanol for 30 seconds, followed by immersion in 2% sodium hypochlorite (NaClO) solution for 3–5 minutes. The sterilized tissues were then rinsed three times with sterile distilled water to remove residual disinfectants and dried on sterile filter paper under a laminar airflow cabinet.

The sterilized tissue pieces were aseptically transferred onto 90-mm Petri dishes containing sterilized Coon's medium composed of 4 g L⁻¹ maltose, 2 g L⁻¹ KNO₃, 1.2 g L⁻¹ MgSO₄ · 7H₂O, 2.68 g L⁻¹ KH₂PO₄, and 20 g L⁻¹ agar, supplemented with 50 mg L⁻¹ chloramphenicol to suppress bacterial contamination. To enhance fungal sporulation, one to two sterile filter paper pieces (approximately 1 cm²; Whatman No. 1) were placed on the surface of the culture medium following the methods described (Dugassa Alemayehu *et al.*, 2021 and Caiazza *et al.*, 2006).

The effectiveness of surface sterilization was verified by plating 0.1 mL of the final rinse water onto Coon's medium and monitoring for microbial growth. All inoculated plates were incubated at $23 \pm 2^{\circ}\text{C}$ for 14 days and examined daily for colony development. Emerging fungal colonies were sub-cultured onto fresh Coon's medium for purification using the single hyphal-tip technique as described by Ahmed and El-Fiki (2017). Pure cultures were subsequently transferred onto potato dextrose agar (PDA) slants and stored at 4°C for further cultural and morphological characterization. Since *Physoderma viciae* is considered an obligate pathogen, the recovered isolates were regarded as associated microorganisms or secondary colonizers rather than the primary causal agent of faba bean gall disease.

4.2.4 Cultural and Morphological Characterization of Recovered Isolates

Cultural and morphological characterization of the microorganisms recovered from faba bean gall tissues was conducted using Coon's medium, Potato Dextrose Agar (PDA), and Malt Extract Agar (MEA). PDA and MEA were prepared according to the manufacturer's instructions, while Coon's medium was prepared as described in Section 4.2.3. All procedures were carried out under aseptic conditions.

A 4 mm diameter mycelial disc was aseptically taken from the actively growing margin of each purified fungal isolate and placed at the center of a 90 mm Petri dish containing solidified culture medium. The inoculated plates were incubated at $23 \pm 2^{\circ}\text{C}$ for 14 days. Colony characteristics, including colony color, texture, margin shape, pigmentation, growth pattern, and sporulation, were visually assessed and recorded during the incubation period. Colony diameter was measured at two-day intervals starting from the fourth day after inoculation until the fungal growth covered the Petri dish surface. Three replicate plates were maintained for each isolate on each medium. Radial growth rate was calculated based on colony diameter increase over time.

For microscopic characterization, fungal structures were mounted in distilled water or lactophenol cotton blue on clean glass slides. Microscopic observations were performed using a compound light microscope at magnifications of $40\times$ and $100\times$.

Structures such as pycnidia, chlamydospores, and conidia were examined and photographed following the method described by Ahmadpour *et al.* (2017). The recovered isolates were morphologically compared with descriptions of common saprophytic and plant-associated fungi.

Since *Physoderma viciae* is considered an obligate pathogen that cannot be cultured on artificial media, the observed morphological characteristics were used only to describe associated fungal isolates and not for definitive identification of the causal agent of faba bean gall disease.

4.2.5 Molecular Identification of Faba Bean Gall

4.2.6 Collection of Faba Bean Gall (FBG) Samples for DNA Analysis

The 160 symptomatic samples collected during the field survey were used as the source material for molecular analysis. From these samples, 100 were selected for DNA extraction. Following extraction and quality assessment, DNA from 40 samples was of sufficient quality and quantity for PCR amplification. Thus, PCR-based molecular detection was conducted on 40 symptomatic samples. For molecular analysis, DNA was extracted directly from symptomatic gall tissues rather than from cultured fungal isolates. In addition, DNA was extracted from representative fungal isolates recovered from diseased tissues to determine whether the cultured microorganisms belonged to *Physoderma*. Before DNA extraction, we surface-cleaned symptomatic tissues with 70% ethanol, excised gall tissues with sterile scalpels, macerated them, and transferred them individually into sterile 1.5-mL Eppendorf tubes. Actively growing mycelia from 14-day-old cultures were similarly collected for DNA extraction.

4.2.7 DNA Extraction and PCR Conditions

DNA was extracted from symptomatic faba bean gall tissues using a modified(Dellaporta *et al.*, 1983) protocol. Approximately 1 g of infected tissue was ground in a mortar containing 500 μ L of extraction buffer. From the homogenate, 0.5 mL was transferred to a sterile 1.5-mL microcentrifuge tube, followed by the addition of 33 μ L of 20% SDS. Samples were mixed thoroughly and incubated at 65°C for 10 min. Subsequently, 0.5 mL of 5 M potassium acetate (KOAc) was added, and samples were incubated on ice for 20 min. Samples were centrifuged at 13,000 rpm for 10 min, and approximately 400–450 μ L of the clarified supernatant was transferred to new sterile tubes. DNA was precipitated by adding one-half volume of isopropanol, followed by vortexing and incubation at –20°C for 1 h. Samples were then centrifuged at 13,000 rpm for 15 min, and the DNA pellet was resuspended in 0.7 mL EB2 buffer and incubated overnight at 4°C. Extracted DNA was stored at –20°C until PCR analysis.

The quality of extracted DNA was assessed by agarose gel electrophoresis. Of the 100 samples from which DNA was extracted, 40 yielded DNA of sufficient quality and quantity for PCR amplification. PCR reactions were performed in a final volume of 25 µL containing 12.5 µL of DreamTaq Green PCR Master Mix (2×), 0.5 µM of each primer, 1 µL of template DNA, and 10.5 µL of nuclease-free water. Two *Physoderma viciae*-specific primer pairs, Physo1 and Physo D', were used for molecular detection (Table 4.1)

For each PCR assay, appropriate controls were included to verify the validity of amplification and to detect possible contamination. A positive control containing DNA previously confirmed to contain *P. viciae* was included to verify that the PCR reagents and amplification conditions were capable of detecting the target DNA. A negative control containing all PCR components except template DNA, with nuclease-free water used in place of DNA was included to monitor for contamination and nonspecific amplification. The positive control was expected to produce the characteristic amplification product, whereas the negative control was expected to show no amplification. For Physo1, PCR was performed with an initial denaturation at 95°C for 2 min, followed by 38 cycles of denaturation at 95°C for 30 s, annealing at 61.7°C for 1 min, and extension at 72°C for 1 min, followed by a final extension at 72°C for 10 min. For Physo D', the PCR program consisted of an initial denaturation at 95°C for 2 min, followed by 38 cycles of denaturation at 95°C for 1 min, annealing at 63.2°C for 1 min, and extension at 72°C for 1 min, followed by a final extension at 72°C for 10 min, according to You *et al.*(2022).

PCR products were separated by electrophoresis on 1% agarose gels containing 0.1% GelRed and visualized under UV illumination. Samples were considered positive when an amplification product of the expected size was observed in association with a positive control that produced the expected band and a negative control that showed no amplification.

Table 4. 1. *Physoderma viciae*-specific primers.

Primer name	Sequence (5'→3')
Physo1 F	ATCGGTCGATGGTGCAAAC
Physo1 R	CTTCCGTCTTCTTGCCCCCTT
Physo D F	GAGCCTCCACCAGAGTTTCC
Physo D R	CTTCCGTCTTCTTGCCCCCTT

* F= forward; R= reverse Source; (You *et al.*, 2022).

4.2.8 Statistical data analysis

Data on colony diameter and radial growth of the fungal isolates recovered from faba bean gall tissues were analyzed using SPSS version 20. One-way analysis of variance (ANOVA) was used to determine whether the culture medium significantly affected final colony diameter after 14 days of incubation. When significant differences were detected among treatment means, means were separated using the Least Significant Difference (LSD) test at the 5% significance level ($P \leq 0.05$). Results were expressed as mean $\pm$ standard deviation (SD) based on three replications. Colony growth over the incubation period was presented descriptively using changes in colony diameter at the recorded observation times. Radial growth rate was calculated based on the change in colony radius over the corresponding incubation period.

4.3 Results and Discussion

4.3.1 Symptoms of Faba Bean Gall Disease

Faba bean gall (FBG) disease, associated with *Physoderma viciae*, was observed on faba bean (*Vicia faba* L.) plants at all growth stages, including seedling, vegetative, flowering, podding, and maturity stages. The disease primarily affected leaves and stems, although occasional symptoms were also observed on pods during field surveys. Early symptoms appeared on the abaxial surface of young leaves as small, chlorotic, sunken galls. As the disease progressed, these galls enlarged, became light brown, and developed into circular to elliptical rough patches. Adjacent lesions frequently coalesced, leading to severe leaf distortion, curling, and abnormal leaf development (Figure 4. 1). At advanced stages, the galls darkened to brown or black and often ruptured, forming necrotic lesions. Severely infected leaves became blighted, wilted, and abscised prematurely. Plants under heavy infection showed stunted growth, crumpled foliage, reduced flowering, and poor pod formation, and in severe cases, complete yield loss was observed. The symptom progression observed in this study initially chlorotic and sunken galls that enlarge, coalesce, and later darken, closely resembles previous descriptions of broad bean blister disease reported in earlier studies (Xing, 1984; Li-Juan *et al.*, 1993; Dereje Gorfu and Beshir Tesfay, 1994; Yan and Hua, 2012; Gezahegne Getaneh *et al.*, 2014).

Furthermore, the disease was predominantly observed in highland areas above 2400 m a.s.l., suggesting a possible association with cool and humid agro-ecological conditions that may

favour pathogen development and disease progression. Although faba bean gall disease in Ethiopia was previously attributed to *Olpidium viciae* based mainly on field symptoms and limited microscopic observations (Gorfu Dereje and Beshir Tesfay 1994; Gezahegne Getaneh *et al.*, 2014), the symptoms recorded in the present study were consistent with those reported for *Physoderma viciae* in more recent studies. However, symptom expression alone is insufficient for definitive pathogen identification; therefore, further histopathological, and molecular analyses were conducted to confirm the identity of the causal organism.

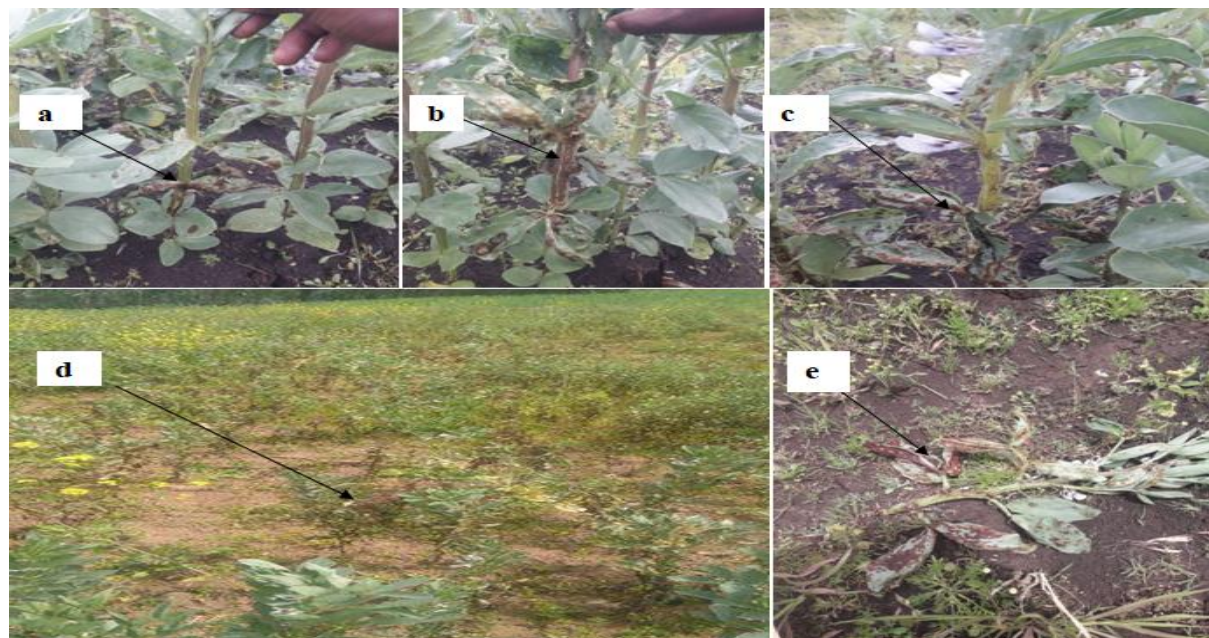


Figure 4. 1. Faba bean gall symptoms on the lower side of faba bean leaves (a-c), poor plant growth and major foliage death in a severely infested field (d-e)

4.3.2 Histopathological Detection of *Physoderma viciae* in Gall Tissues

Histopathological examination of symptomatic faba bean tissues revealed severe disruption of host cellular organization, including plasmolysis and degeneration of mesophyll cells within gall regions. Transverse sections of infected leaves showed dark brown necrotic areas corresponding to sites of pathogen colonization (Figure 4. 2). Microscopic observations revealed large masses of thick-walled resting spores embedded within gall tissues.

These structures were also detected in senesced plant residues, suggesting their role as survival structures in the disease cycle and potential contribution to pathogen persistence in the field.

In addition, turbinate cells (specialized, swollen, short, and irregularly shaped vegetative cells characteristic of *Physoderma* development within host tissues) and epibiotic zoosporangia containing zoospores were observed on infected tissue surfaces. The zoosporangia exhibited discharge openings consistent with zoospore release (Figure 4. 2). These histopathological structures are characteristic of *Physoderma* species and are distinct from those typically reported for *Olpidium* spp., particularly the absence of typical *Olpidium* resting sporangia and discharge tubes. The observed features, therefore, provide strong histological evidence supporting the association of *Physoderma viciae* with gall formation in Ethiopian faba bean fields (**Error! Reference source not found.**). These findings are consistent with recent reports by You *et al.*(2021, 2022), which clarified that faba bean gall disease previously attributed to *Olpidium viciae* is instead associated with *Physoderma viciae*.

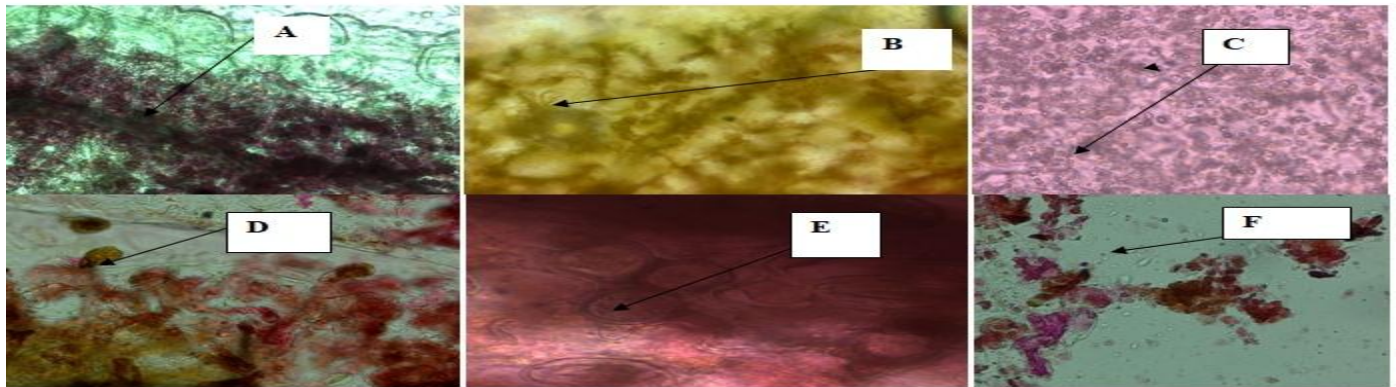


Figure 4. 2. Histopathological features associated with faba bean gall disease caused by *Physoderma viciae*. (a) Gall-associated tissue discoloration and necrosis; (b) thick-walled resting spores within infected tissue; (c) resting spores in senescent infected plant residue; (d) turbinate cells within infected tissue; (e) epibiotic zoosporangia on the infected tissue surface; and (f) zoosporangium containing zoospores with a discharge opening. Arrows indicate diagnostic pathogen structures. Scale bars are shown in each panel.

4.3.3 Isolation and Characterization of Gall-Associated Saprophytic Fungi

Attempts were made to isolate the causal organism of faba bean gall disease from symptomatic leaf and stem tissues using Coon's medium, Potato Dextrose Agar (PDA), and Malt Extract Agar (MEA). Several fungal colonies were recovered and purified; however, none exhibited morphological characteristics consistent with *Physoderma* species.

The recovered isolates exhibited morphological characteristics consistent with *Alternaria*-like fungi, including pigmented, septate, multicellular conidia with transverse and longitudinal septa.

However, because species-level identification was based only on morphology and no molecular identification of the cultured isolates was performed, the isolates are referred to here as *Alternaria*-like saprophytic fungi rather than being assigned definitively to *Alternaria alternata*.

4.3.4 Growth Characteristics of Gall-Associated Saprophytic Isolates on Different Media

Fungal isolates recovered from symptomatic faba bean gall tissues were successfully cultured on Coon's medium, Potato Dextrose Agar (PDA), and Malt Extract Agar (MEA). All media supported mycelial growth; however, significant differences ($P \leq 0.05$) in colony diameter were observed after 14 days of incubation (Table 4. 2). Colony diameter ranged from 51.8 mm on MEA to 61.5 mm on Coon's medium. Coon's medium supported the highest radial growth (61.5 ± 2.7 mm), followed by PDA (52.9 ± 3.4 mm), while MEA showed comparatively slower vegetative growth (51.8 ± 2.6 mm). In contrast, MEA enhanced sporulation, allowing clearer observation of reproductive structures.

The variation in colony growth among media is likely associated with differences in nutrient composition, particularly carbon and nitrogen availability, which influence fungal metabolism, biomass accumulation, and sporulation patterns. Accordingly, Coon's medium appeared to provide a more favourable nutritional environment for vegetative growth compared with PDA and MEA. Despite the successful in vitro growth of the recovered isolates, molecular analysis using *Physoderma*-specific primer pairs (Physo1 and Physo D') did not amplify DNA from any cultured isolate. In contrast, DNA extracted directly from symptomatic field tissues consistently yielded positive amplification. This clear contrast indicates that the cultured fungi were not *Physoderma viciae*, but rather saprophytic or secondary colonizers associated with diseased plant tissues. Therefore, the observed cultural and growth characteristics represent saprophytic fungal communities rather than the causal agent of faba bean gall disease.

Table 4. 2. Evaluation of different culture media on colony diameter (mm) and growth rate (mm/day) of saprophytic fungi isolated from faba bean gall tissues incubated at 23 ± 2 °C.

Medium type	Mean diameter $\pm$ SD of colony growth (mm) after different incubation periods (hr)													Radia	
	48	72	96	120	144	168	192	216	240	264	288	312	336	(mm/day)	R ²
Coon	9.4+0.2	12.7+1.3	18.2+1.7	20.9+3.2	27.9+1.6	31.1+1.9	39.5+1.7	43.1+2.9	47.3+3.3	50.4+2.1	53.7+3.3	56.9+2.2	61.5+2.7	4.48	0.98
MEA	7.7+0.8	11.5+0.4	15.6+3.1	18.9+1.6	24.8+3.6	26.7+4.3	30.0+3.8	34.5+2.1	37.6+1.7	41.5+3.7	42.7+1.9	45.7+1.2	51.8+2.6	3.54	0.97
PDA	8.3+1.2	11.8+0.6	15.8+2.1	19.8+3.5	26.3+3.8	29.2+3.7	35.3+4.5	38.3+4.6	40.3+3.0	43.5+4.8	45.8+3.3	47.8+3.99	52.9+3.4	3.71	0.94
Average	8.5	12.01	16.54	19.87	26.31	28.98	34.94	38.63	41.7	45.13	47.38	50.14	55.39	3.91	0.96
CV (%)	9.62	7.23	14.21	14.5	11.98	11.85	10.13	8.65	6.58	8.26	6.19	5.4	5.24	12.81	2.21

Means of mycelial growth followed by a different letter (s) in the same column are significantly ($p \leq 0.05$) different, MEA: Malt Extract Agar, PDA: Potato Dextrose Agar, R2: Coefficient of determination, SD: Standard deviation

4.3.5 Morphological Characteristics of Gall-Associated Saprophytic Isolates

Fungal isolates obtained from faba bean gall tissues exhibited relatively consistent colony morphology across culture media, with variation influenced by medium composition. On Coon's medium, colonies developed fast-growing, cottony to woolly mycelium with distinct concentric ring patterns. Potato Dextrose Agar (PDA) supported dense, velvety colonies with dark pigmentation developing centrally as cultures aged, whereas Malt Extract Agar (MEA) produced comparatively lighter, more compact colonies with reduced aerial mycelium.

Overall colony characteristics were consistent with previous reports by Dugassa Alemayehu *et al.* (2021), who documented substantial morphological variation among fungi isolated from symptomatic faba bean tissues across different media. Together, these observations support the interpretation that fungi recovered from gall-affected tissues are likely secondary colonizers associated with senescing or diseased plant material rather than primary causal agents of gall formation.

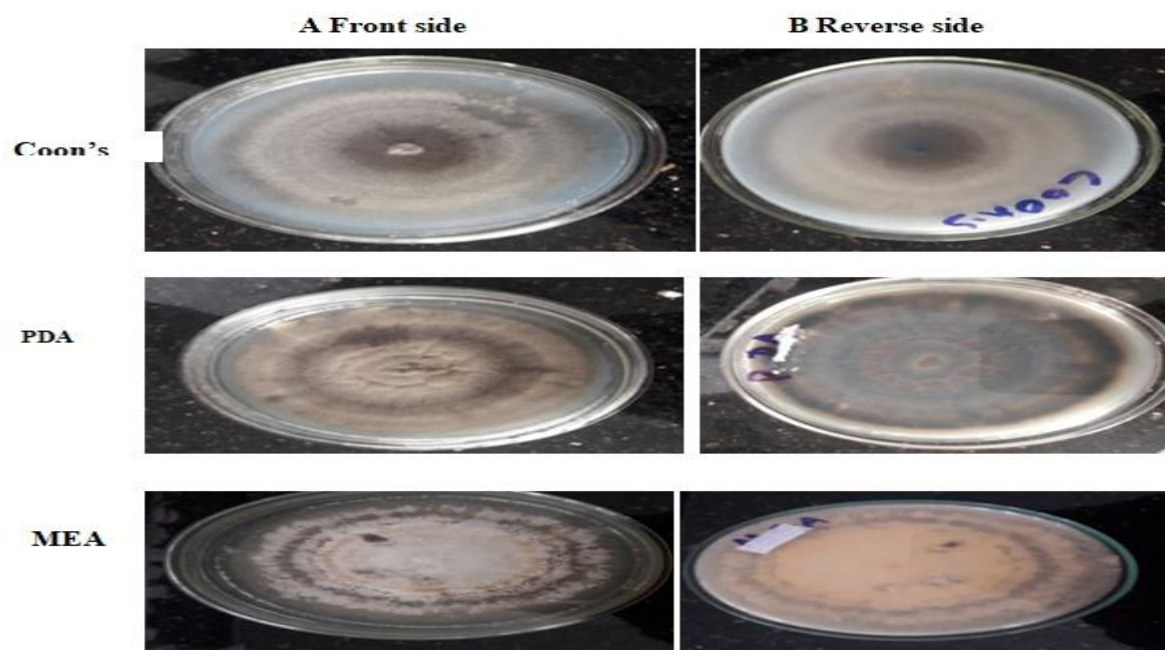


Figure 4. 3. Colony morphology of saprophytic fungi isolated from faba bean gall tissues on different media after 14 days of incubation at $23 \pm 2^{\circ}\text{C}$.

Table 4. 3. Colony morphology and growth characteristics of saprophytic fungi isolated from faba bean gall tissues

Medium	Conidia	Colony color	Margin	Colony texture	pigmentation	Mycelial growth
Coon's	++	Whitish	Regular	Cottony	Grayish white	Good
MEA	+	Dark gray	Regular	Felty	Pale yellow	Low
PDA	++	Dark gray to black	Regular	Velvety	Black	Good

Microscopic examination revealed pigmented, septate, multicellular conidia with both transverse and longitudinal septa. Conidia were produced singly or in short chains and ranged from ovoid to obclavate in shape, with most being ovoid to ellipsoidal and bearing short cylindrical beaks and distinct septation(Figure 4. 4).

These morphological features are consistent with descriptions of *Alternaria* species, particularly *Alternaria alternata*, which is commonly associated with senescing or decaying plant tissues. The observed characteristics, including conidial shape, septation pattern, beak structure, and conidiophore morphology, align with diagnostic criteria described by Simmons (1999), Rotem (1994) and Cooke *et al.* (1998) where conidial morphology is a primary basis for species-level identification within the genus *Alternaria*. Importantly, no structures typical of *Physoderma* species, such as resting spores, turbinate cells, or epibiotic zoosporangia, were observed in culture. This further supports that the cultured isolates represent saprophytic fungi rather than the causal agent of faba bean gall disease.

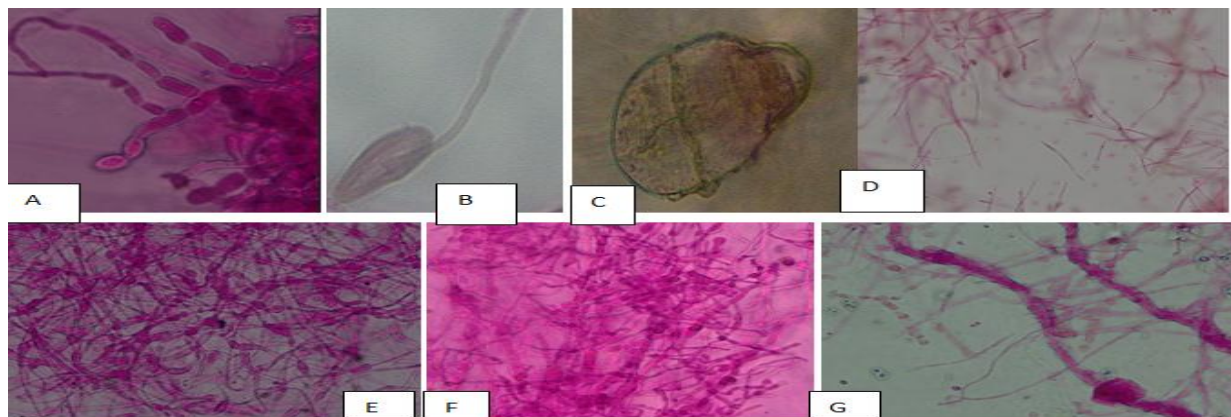


Figure 4. 4. Microscopic morphology of *Alternaria*-like isolates different medium (a–g) the view under the microscope (40×)

4.3.6 Molecular Detection of *Physoderma viciae* in Symptomatic Faba Bean Tissues

Molecular detection using the *Physoderma viciae*-specific primer pairs Physo1 and Physo D' successfully amplified DNA from symptomatic faba bean gall tissues collected directly from the field. The PCR assays included both positive and negative controls. The positive controls produced amplification products of the expected size, confirming that the PCR reagents and amplification conditions were functional for detection of the target DNA. In contrast, the negative controls showed no amplification, indicating that there was no detectable contamination or nonspecific amplification in the PCR reactions.

Of the 40 symptomatic samples that yielded DNA of sufficient quality and quantity for PCR analysis, 24 (60%) produced positive amplification with at least one of the two *Physoderma*-specific primer pairs. Twelve samples (30%) were positive with the Physo1 primer pair, while a different 12 samples (30%) were positive with the Physo D' primer pair. Thus, assuming that there was no overlap between the samples detected by the two primer pairs, the two assays collectively detected *Physoderma*-specific DNA in 24 of the 40 PCR-tested symptomatic samples (60%). The expected amplification products were approximately 300–400 bp for Physo1 and 400–500 bp for Physo D' (Figure 4. 5 and Figure 4. 6).

No amplification was obtained from DNA extracted from the fungal isolates recovered on artificial media using either of the two *Physoderma*-specific primer pairs. This result, together with the absence of characteristic *Physoderma* structures in culture, indicates that the fungi recovered on artificial media were not *P. viciae*. Rather, they were more likely saprophytic or secondary colonizers associated with diseased or senescing plant tissues. Therefore, the culture-based method used in this study did not confirm or recover *P. viciae* under the conditions tested. In contrast, amplification of *Physoderma*-specific DNA directly from symptomatic field-collected tissues provides molecular evidence supporting the presence and association of *P. viciae* with faba bean gall disease. The reliability of these PCR results was further supported by the successful amplification of the positive controls and the absence of amplification in the negative controls.

The molecular findings were consistent with the histopathological observations, which revealed thick-walled resting spores, turbinate cells, and epibiotic zoosporangia characteristic of *Physoderma*. The results are also consistent with the molecular diagnostic approach described by You *et al.*(2022), who developed the Physo1 and Physo D' primer pairs for the detection of *P. viciae*. The agreement between the characteristic histopathological structures and detection of *Physoderma*-specific DNA provides complementary evidence supporting the involvement of *P. viciae* in faba bean gall disease in the study areas.

Overall, the combined histopathological and molecular evidence strongly supports the associations of *P. viciae* with faba bean gall disease, whereas conventional culturing under the conditions used in this study failed to recover the pathogen and instead yielded associated saprophytic fungi. Nevertheless, PCR amplification alone does not provide sequence-level confirmation. Therefore, sequencing of the PCR products and subsequent phylogenetic analysis are recommended to provide independent species-level confirmation and to determine the genetic relationships of Ethiopian *P. viciae* populations with populations reported from other geographical regions.

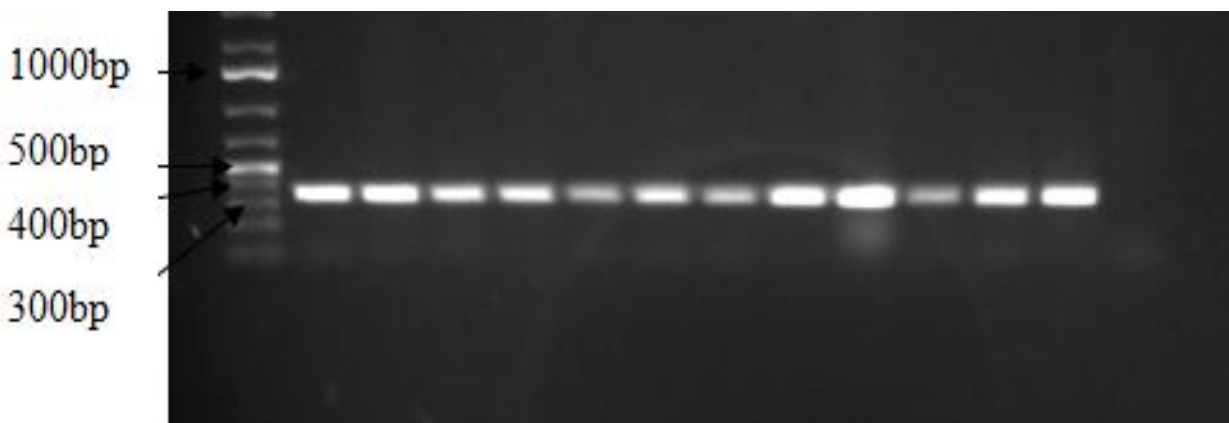


Figure 4. 5. PCR amplification of *Physoderma viciae* using the Physo1 primer pair. Amplification products of approximately 300–400 bp were detected in DNA extracted directly from symptomatic faba bean gall tissues

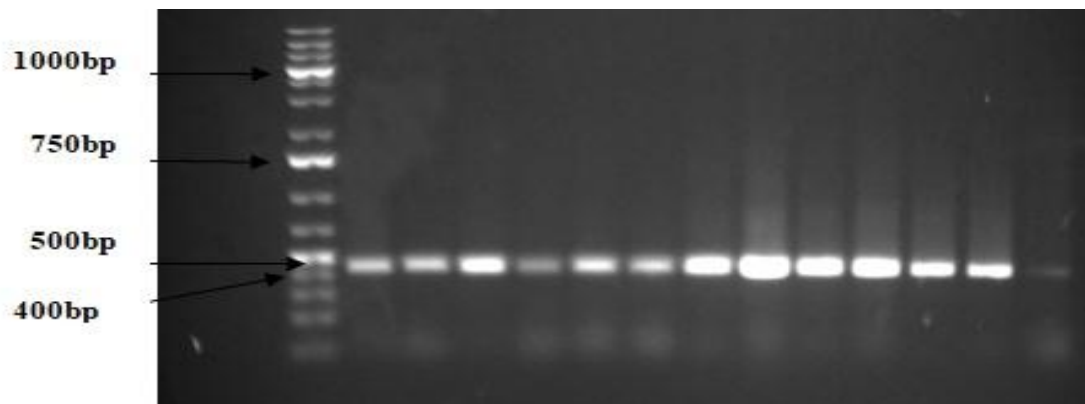


Figure 4. 6. PCR amplification of *Physoderma viciae* using the Physo D' primer pair. Amplification products of approximately 400–500 bp were detected in DNA extracted directly from symptomatic faba bean gall tissues.

4.4 Conclusion

This study provides complementary microscopic and molecular evidence for the association of *Physoderma viciae* with faba bean gall disease in the surveyed areas of South Wollo, Ethiopia. Microscopic examination of symptomatic tissues revealed resting spores, turbinate cells, and epibiotic zoosporangia consistent with *Physoderma*. In addition, *Physoderma*-specific PCR assays detected target DNA in a proportion of symptomatic field samples, whereas fungi recovered on artificial media were not amplified by the *Physoderma*-specific primers. These findings indicate that the culturable fungi were not the target organism and that direct molecular detection is more suitable than conventional culturing for detecting the gall-associated organism under the conditions used in this study. Nevertheless, because the PCR products were not sequenced and pathogenicity was not experimentally demonstrated, the findings should be interpreted as strong evidence of association rather than definitive sequence-level confirmation of *P. viciae* as the causal agent. Sequencing of PCR products, phylogenetic analysis, improved sampling across agroecological zones, and studies of pathogen survival, epidemiology, and host resistance are recommended for further confirmation and disease-management development.

4.5 Recommendation

Based on the findings of this study, molecular diagnostic methods using the *Physoderma*-specific primer pairs Physo1 and Physo D' should be considered for detecting *P. viciae* in symptomatic faba bean tissues, particularly when conventional culturing fails to recover the organism. Future studies should sequence PCR products obtained from symptomatic tissues and conduct phylogenetic analyses to provide sequence-level confirmation of pathogen identity and to determine the genetic diversity and relationships of *P. viciae* populations in Ethiopia and other regions.

Further research is needed to clarify the survival, epidemiology, and soil ecology of *P. viciae*, particularly the potential role of resting spores in infected crop residues and soil as sources of primary inoculum. Studies should also determine the environmental conditions, including temperature and moisture, which favour pathogen survival, infection, and disease development. Such information would contribute to the development of effective disease forecasting and management strategies.

Resistance screening of faba bean varieties should preferably be conducted under natural field conditions in locations with a known history of faba bean gall disease. Because reliable artificial inoculation methods for this apparently host-dependent pathogen remain limited, field-based screening may provide a more realistic assessment of varietal responses to natural infection. Research should therefore focus on developing reliable inoculation and disease-assessment methods that can be used for resistance screening under controlled and field conditions. Integrated disease management practices should also be investigated, including field sanitation, removal or proper management of infected crop residues, crop rotation with suitable non-host crops, and avoidance of continuous faba bean cultivation. These practices should be evaluated for their effectiveness in reducing pathogen inoculum and disease pressure under Ethiopian production conditions. Finally, further studies should investigate the distribution and prevalence of *P. viciae* in other faba bean-producing regions of Ethiopia and determine whether pathogen populations differ genetically or epidemiologically among agroecological zones. The resulting information would support the development of appropriate diagnostic, resistance-breeding, and integrated disease-management strategies for faba bean gall disease in Ethiopia.

Chapter 5. Evaluation of Faba Beans (*Vicia faba* L.) Genotypes against Faba Bean Gall (*Physoderma viciae*) in the Highlands of South Wollo, North-Eastern Ethiopia

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Abstract

*Faba bean (*Vicia faba* L.) is one of the most important food legumes worldwide, and Ethiopia is the second-largest producer after China. However, its production is constrained by several diseases, including faba bean gall caused by *Physoderma viciae*. This study evaluated faba bean genotypes against faba bean gall disease under field conditions in the highlands of South Wollo, Ethiopia, during the 2022 and 2023 main cropping seasons. Twenty-eight faba bean genotypes were evaluated at Legambo and Tenta districts using a randomized complete block design with three replications under natural disease infection. Disease incidence, percentage severity index, area under the disease progress curve, and yield and yield components were assessed at 10-day intervals and at harvest, respectively. Combined analysis of variance revealed significant differences among genotypes in disease incidence, PSI, and AUDPC at both locations and in both cropping seasons. The lowest disease incidence, PSI, and AUDPC were consistently recorded for Dosha, Obse, Wolkie, and FB-26869. In contrast, EH96048-1, EH00102-8-1, EH97091-2, Gora, and the local genotype generally recorded higher disease development and AUDPC values. The highest grain yields were obtained from Dosha, Obse, and Wolkie at both Legambo and Tenta. Grain yield was negatively and significantly correlated with disease parameters across locations and seasons, indicating that increased disease intensity was associated with reduced productivity. Regression analysis further showed that grain yield*

decreased by approximately $0.031\text{--}0.04\text{ t ha}^{-1}$ for every 1% increase in disease severity. The results identified Dosha, Obse, Wolkie, and FB-26869 as promising genotypes with relatively lower disease development and good agronomic performance under natural infection. These genotypes could be considered for further multi-location verification and as potential sources of resistance in faba bean gall disease management and breeding programs.

Keywords: AUDPC, disease severity, faba bean, genotype, *Physoderma viciae*, yield

5.1 Introduction

Faba bean (*Vicia faba* L.) is the first largest produced food legume in the world (Gaur *et al.*, 2010), and Ethiopia is the second-largest producer of faba bean in the world next to China (Abebe Teklay *et al.*, 2014). (Jensen *et al.*, 2010) found that faba beans play a critical role in the sustainability of cropping systems and provide food and feed rich in protein, especially for poorer sections of the population (Crépon *et al.*, 2010). Faba bean is by far the most important and single subsistence crop in Ethiopia after the staple cereals (Abera Merkuz and Semagn Meseret, 2022; MoANR, 2016). As the faba bean is familiar in Ethiopian feeding culture, most of the seed produced would be consumed domestically. Only a smaller percentage of the crop is delivered to the export market. Despite the small share of global export volume, Ethiopia ranks among the top exporters of broad beans worldwide (Bereda Biruk, 2009). The Amhara and Oromia are the major faba bean-producing regions. Within the regions, some zones, such as West Showa, North Showa, South Wollo, and East Gojjam, are identified as major production areas of faba beans (Bereda Biruk, 2009).

Faba bean is subjected to attack by numerous pathogenic fungi wherever the crop is grown. Fungal diseases like chocolate spot caused by *Botrytis fabae*, rust (*Uromyces vicia fabae*), black root rot (*Fusarium solani*), and rot (*Fusarium avenaceum*) are major factors behind the low productivity of the crop (Tadesse Negussie *et al.*, 2006; Berhanu Bekele *et al.*, 2003; Abera Merkuz and Semagn Meseret, 2022).

Furthermore, a newly emerging disease known as faba bean gall incited by the pathogen *Physoderma viciae* causes up to complete crop failure over wide areas within a short time and aggravates the diminution of yield to maximum nationwide (Dereje Gorfu *et al.*, 2012). Faba

bean gall infection starts at the seedling stage and continues through the flowering stage. Its symptoms mainly appear on leaves and stems (Dereje Gorfu *et al.*, 2012; Abebe Teklay *et al.*, 2014). Additionally, faba bean gall has the potential to cause quick, extensive crop failure and drastically lower yields across the country (Dereje Gorfu *et al.*, 2012). Efforts to control faba bean gall, using fungicide sprays, have been made (Alehegn Mastewal *et al.*, 2018; Abera Merkuz and Semagn Meseret, 2022).

However, due to the high cost, health concerns, and environmental impacts of fungicides, using resistant genotypes is considered the most effective, economical, and environmentally friendly method for managing gall disease. However, in Ethiopia, particularly in the Amhara region, inadequate information is available, or no attempts have been made in the past to identify useful resistance in faba bean genotypes against faba bean gall disease. Although faba bean gall is a newly emerging and widespread disease in South Wollo, no attempt has so far been made to manage the disease. Therefore, this study was aimed at evaluating faba bean genotypes for resistance to gall disease across locations and seasons in major faba bean-growing areas of South Wollo, Ethiopia.

5.2 Materials and Methods

5.2.1 Description of the Study Area

The experiments were conducted at Tenta and Legambo districts in South Wollo, during the main cropping seasons of 2022 and 2023. Legambo is located in the South Wollo Zone of the Amhara Regional State, approximately 501 km from Addis Ababa. It is situated at a latitude of 11°00'N and a longitude of 39°00'E, with an elevation ranging from 1,500 to 3,700 meters above sea level in the rift valley. The district experiences annual rainfall between 700 mm and 1,200 mm, and temperatures ranging from below 0°C to 13°C. The climate of the district is predominantly categorized into three agro-ecological zones: 2.6% “Wurch” (Frost), 48.4% Dega (Highland), and 49% Weina Dega (Temperate). Legambo is known for its high crop production potential, particularly for barley, faba bean, and pea.

Whereas Tenta, is located in the South Wollo zone of the Amhara Regional state, with 520 km north of Addis Ababa and 120 km from Dessie. It lies at 11°19'N latitude and 39°15'E longitude, with elevations ranging from 1,300 to 4,000 meters above sea level. The climate in Tenta is dry, with temperatures ranging from 4°C to 40°C. The district receives 700 to 1,100 mm of annual

rainfall, distributed across two rainy seasons: June to August and February to April (Teferi, 2013). The terrain in Tenta consists of 54% mountainous areas, 32% plains, and 14% undulating hills and valleys.

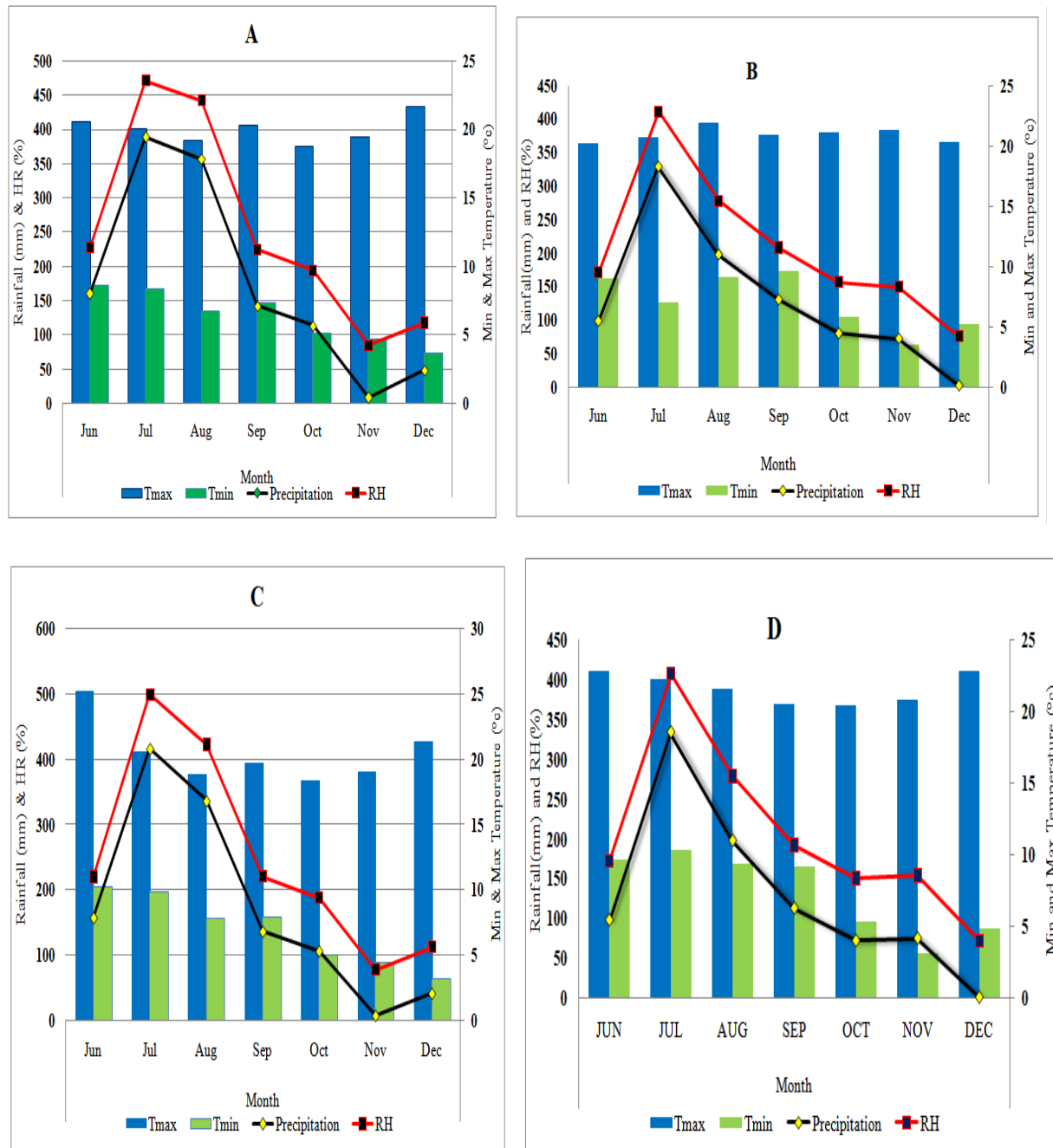


Figure 5. 1. Monthly weather conditions at Legambo (a, b) and Tenta (c, d) during the 2022 and 2023 faba bean growing seasons.

5.2.2 Treatments and Experimental Design

The experiments consisted of twenty-eight faba bean genotypes (Table 5. 1 and Appendix Figure 5. 1). The faba bean genotypes were obtained from Holeta Agricultural Research Center and Ethiopia Biodiversity Institute and evaluated for their reaction to faba bean gall under natural conditions.

The experiment was laid out in a randomized complete block design (RCBD) with three replications (Appendix Figure 5. 1). The spacing between plots and blocks were adjusted at 0.5 meters and 1 meter respectively. There were five rows per plot, and the space between the plants and the row was 0.1 meters and 0.4 meters, respectively. The size of each plot was 2 meters long and 1.6 meters wide, and the total area was 3.2 m². Disease, yield, and yield component data were taken from three central rows of plants. The rest of the agronomic practices were applied as the recommended package for the faba bean crop.



Figure 5. 2. Photo demonstrating field experiment data collection

Table 5. 1. Faba bean genotypes evaluated for their reaction against the faba bean gall in the 2022 and 2023 main cropping seasons.

No	Name of Genotype	Collected from
1	FB-26872	Ethiopian Biodiversity Institute
2	FB-26873	Ethiopian Biodiversity Institute
3	Local	---
4	FB-26885	Ethiopian Biodiversity Institute
5	FB-26869	Ethiopian Biodiversity Institute
6	Obse(EH95073-1)	Holeta Agricultural Research Center
7	EH09007-4	Holeta Agricultural Research Center
8	EH06088-6	Kulmsa Agriculture Research Center
9	EH96048-1	Holeta Agricultural Research Center
10	EH09004-2	Holeta Agricultural Research Center
11	EH06007-4	Kulmsa Agriculture Research Center
12	EH011038-3	Holeta Agricultural Research Center
13	EH920070	Holeta Agricultural Research Center
14	EH00102-8-1	Holeta Agricultural Research Center
15	EH98097-1	Kulmsa Agriculture Research Center
16	EH06007-2	Holeta Agricultural Research Center
17	EH010010-1	Kulmsa Agriculture Research Center
18	EH09046-3	Kulmsa Agriculture Research Center
19	EH09028-3	Kulmsa Agriculture Research Center
20	EH97091-2	Holeta Agricultural Research Center
21	EH07015-7	Holeta Agricultural Research Center
22	EH011025-1	Kulmsa Agriculture Research Center
23	EH011018-5	Holeta Agricultural Research Center
24	EH07005	Holeta Agricultural Research Center
25	EH011016-2	Holeta Agricultural Research Center
26	Dosha(COLL-155/00-3)	Holeta Agricultural Research Center
27	Wolkie(EH96049-2)	Holeta Agricultural Research Center
28	Gora	Holeta Agricultural Research Center

5.2.3 Data Collection

5.2.4 Disease assessment

Disease incidence (number of plants infected) and criticality of faba bean gall were assessed as of the disease onset at 10-day intervals from pre-tagged 10 plants in three central rows of each plot. The total number of plants that displayed the symptoms of faba bean gall was counted, and the percentage of disease incidence (PDI) was enumerated based on the formula by Wheeler (1969).

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

Disease severity: Disease severity was recorded on 10 randomly selected plants in the three central rows of each plot, starting from the onset of the disease and repeated at every 10- day intervals. A 0-9 scale was used where 0 = no disease symptom observed, 1 = < 2% plant parts infected, 2 = 2– 5% plant parts infected, 3 = 6 – 10% plant parts infected, 4 = 11 - 25% plant parts infected, 5 = 26 – 50% plant parts infected, 6 = 51 – 75% plant parts infected, 7 = 76 – 90% plant parts infected, 8 = 91 - 99% plant parts infected, 9 = 100% plant parts infected (Ding *et al.*,1993). Disease severity scores will be converted into a percentage severity index (PSI) for analysis(Wheeler, 1969).

$$\text{PSI} = \frac{\text{Sum of numerical rating} \times 100}{\text{Number of plants scored} \times \text{Maximum score on scale}}$$

The area under the disease progress curve (AUDPC): AUDPC was calculated for each plot using the formula of Shaner and Finney (1977) and expressed in %-days.

$$\text{AUDPC} = \sum_{i=1}^{n-1} 0.5(x_{i+1} + x_i)(t_{i+1} - t_i)$$

Where x_i is the cumulative disease severity at the i^{th} observation, t_i is the time (days after sowing) at the i^{th} observation and n is the total number of observations.

5.2.5 Yield and Yield Component Data

Plant height, number of pods per plant, number of seeds per pod, 100 seed weight, and total grain yield were recorded.

5.2.6 Data Analysis

The collected data on disease parameters, yield, and yield components were analyzed using the General Linear Model (GLM) framework for analysis of variance (ANOVA). Prior to analysis, the assumptions of normality and homogeneity of variance were assessed. For each location and cropping season, genotype was considered as the treatment factor, while block was included in the model to account for the randomized complete block design (RCBD).

For the combined analysis across locations and cropping seasons, the effects of genotype, location, year, and their interactions were evaluated. Treatment means were separated using Duncan's Multiple Range Test (DMRT) at a significance level of $p \leq 0.05$. The coefficient of variation (CV) and block effect were calculated to assess experimental variability and the contribution of blocking to experimental precision. Pearson's correlation analysis was conducted using R statistical software to determine the relationships among disease parameters, yield, and yield components. Regression analysis was performed to evaluate the relationship between percentage severity index (PSI) and grain yield of the faba bean genotypes. Disease reaction was assessed based on the mean observations recorded from individual plants within each experimental unit.

5.3 Results and Discussions

5.3.1 Faba Bean Gall Incidence

Faba bean gall incidence differed significantly among the evaluated genotypes at both locations and in both cropping seasons ($p < 0.05$). At Legambo, disease incidence ranged from 74.39% to 88.33% in 2022, with a mean of 79.48%, and from 72.53% to 85.67% in 2023, with a mean of 76.89%. At Tenta, incidence ranged from 71.17% to 84.33% in 2022, with a mean of 75.76%, and from 65.08% to 80.00% in 2023, with a mean of 70.86% (

Table 5. 2; Table 5. 3 and Appendix Table 5. 3). Genotypic differences were consistent across locations and years. Dosha, Obse, Wolkie, and FB-26869 generally had the lowest disease incidence, whereas EH96048-1, EH00102-8-1, EH97091-2, and the local genotype generally showed higher disease incidence. The relatively lower incidence in the former genotypes indicates a comparatively reduced response to gall disease under natural infection conditions (Appendix Table 5. 4 and Appendix Table 5. 5). Disease incidence was generally higher at Legambo than at Tenta. This difference may be associated with variation in rainfall, relative humidity, and other environmental conditions that influence pathogen development. Environmental effects on faba bean gall disease development and genotype-by-environment interactions have also been reported by Yan and Hua (2012), Alehegn Mastewal *et al.*(2018), Wondwosen Wulita *et al.* (2019). Overall, the results demonstrate substantial variation among genotypes in their response to faba bean gall disease. Dosha, Obse, Wolkie, and FB-26869

showed comparatively lower disease incidence and therefore warrant further evaluation as potential sources of resistance.

Table 5. 2. Faba bean gall disease incidence, Severity, and AUDPC on different faba bean genotypes at Legambo district in the 2022 and 2023 cropping seasons.

Faba bean Variety	DI%		PSI%		AUDPC %-days	
	2022	2023	2022	2023	2022	2023
FB-26872	83.67 ^{a-e}	81.00 ^{a-e}	64.67 ^{a-e}	63.67 ^{a-f}	1720.31 ^{a-c}	1676.41 ^{a-d}
FB-26873	81.33 ^{a-f}	76.33 ^{a-e}	64.33 ^{a-e}	63.28 ^{a-f}	1544.56 ^{d-h}	1494.52 ^{d-i}
Local	85.83 ^{a-d}	83.68 ^{a-d}	67.72 ^{ab}	67.95 ^{a-c}	1746.97 ^{ab}	1709.75 ^{a-c}
FB-26885	79.67 ^{b-f}	76.33 ^{a-e}	65.00 ^{a-d}	66.25 ^{a-d}	1531.22 ^{d-h}	1494.52 ^{d-i}
FB-26869	75.67 ^{ef}	73.67 ^e	57.00 ^{de}	57.30 ^{d-f}	1385.48 ^{i-k}	1368.82 ^{i-k}
FB-Obse	75.33 ^{ef}	73.00 ^e	56.67 ^{de}	54.97 ^f	1362.82 ^k	1350.48 ^{jk}
EH09007-4	78.33 ^{d-f}	76.00 ^{a-e}	65.67 ^{a-d}	65.26 ^{a-e}	1534.56 ^{d-h}	1494.52 ^{d-h}
EH06088-6	76.67 ^{ef}	74.62 ^{de}	63.33 ^{a-e}	62.22 ^{a-f}	1487.89 ^{t-k}	1481.19 ^{f-j}
EH96048-1	88.33 ^a	85.33 ^{ab}	66.33 ^{a-c}	69.11 ^a	1770.31 ^a	1759.75 ^a
EH09004-2	76.33 ^{ef}	75.32 ^{c-e}	65.00 ^{a-d}	64.33 ^{a-f}	1469.22 ^{g-k}	1471.19 ^{f-k}
EH06007-4	79.00 ^{c-f}	75.67 ^{b-e}	64.00 ^{a-e}	60.56 ^{a-f}	1580.31 ^{d-g}	1599.75 ^{b-g}
EH011038-3	77.33 ^{ef}	74.67 ^{de}	60.67 ^{a-e}	60.33 ^{a-f}	1511.22 ^{e-i}	1477.86 ^{f-j}
EH920070	77.00 ^{ef}	74.67 ^{de}	62.00 ^{a-e}	60.44 ^{a-f}	1522.56 ^{e-h}	1477.86 ^{f-j}
EH00102-8-1	87.33 ^{ab}	85.67 ^a	66.33 ^{a-c}	68.89 ^{ab}	1766.97 ^a	1756.41 ^a
EH98097-1	79.00 ^{c-f}	76.33 ^{a-e}	63.67 ^{a-e}	61.56 ^{a-f}	1631.22 ^{b-e}	1621.19 ^{a-e}
EH06007-2	77.00 ^{ef}	73.67 ^e	60.67 ^{a-e}	59.67 ^{a-f}	1613.64 ^{c-f}	1609.75 ^{b-f}
EH010010-1	79.33 ^{b-f}	76.33 ^{a-e}	63.00 ^{a-e}	61.67 ^{a-f}	1657.89 ^{a-d}	1627.86 ^{a-e}
EH09046-3	76.33 ^{ef}	74.33 ^{de}	59.33 ^{b-e}	58.67 ^{c-f}	1491.17 ^{t-k}	1485.62 ^{e-j}
EH09028-3	77.33 ^{ef}	74.67 ^{de}	61.67 ^{a-e}	58.93 ^{b-f}	1544.56 ^{d-h}	1527.86 ^{d-h}
EH97091-2	86.67 ^{a-c}	84.67 ^{a-c}	67.67 ^{ab}	67.22 ^{a-d}	1763.64 ^a	1756.41 ^a
EH07015-7	77.67 ^{d-f}	75.67 ^{b-e}	60.00 ^{b-e}	59.32 ^{a-f}	1587.84 ^{d-g}	1568.96 ^{c-g}
EH011025-1	80.33 ^{a-f}	77.67 ^{a-e}	62.00 ^{a-e}	60.33 ^{a-f}	1529.22 ^{d-h}	1517.86 ^{d-h}
EH011018-5	78.26 ^{def}	76.67 ^{a-e}	65.33 ^{a-d}	63.56 ^{a-f}	1571.17 ^{d-g}	1552.29 ^{c-h}
EH07005	79.33 ^{b-f}	76.67 ^{a-e}	65.67 ^{a-d}	64.33 ^{a-f}	1501.22 ^{e-j}	1451.19 ^{g-k}
EH011016-2	78.67 ^{c-f}	76.33 ^{a-e}	64.67 ^{a-e}	63.11 ^{a-f}	1514.56 ^{e-i}	1484.52 ^{e-j}
Dosha	74.39 ^f	72.53 ^e	55.67 ^e	54.33 ^f	1378.82 ^{jk}	1343.82 ^k
Wolkie	76.22 ^{ef}	73.50 ^e	57.92 ^{c-e}	55.83 ^{ef}	1411.22 ^{h-k}	1427.86 ^{h-k}
Gora	83.1 ^{a-e}	78.00 ^{a-e}	69.17 ^a	65.72 ^{a-e}	1731.17 ^{a-c}	1718.96 ^{ab}
MSE	23.23	24.14	22.59	25.37	4230.12	20749.26
CV	6.06	6.39	7.50	8.11	9.93	9.35
Mean	79.48	76.89	63.35	62.10	1567.68	1540.95
P value	0.0250	0.0446	0.0223	0.0225	0.0426	0.0098

MSqE=Mean square of error; CV=Coefficient of variation; DI=Disease Incidence; Percentage severity index; AUDPC=Area under disease progress curve. Treatments with the same letter are not significantly different.

5.3.2 Disease Severity

Disease severity varied significantly among genotypes at both locations and during both cropping seasons ($p < 0.05$). At Legambo, PSI ranged from 55.67% to 69.17% in 2022, with a mean of 63.35%, and from 54.33% to 69.11% in 2023, with a mean of 62.10%. At Tenta, PSI ranged from 50.00% to 64.33% in 2022, with a mean of 57.91%, and from 47.48% to 61.67% in 2023, with a mean of 54.79 % (

Table 5. 2 and Table 5. 3). Dosha and Obse recorded the lowest disease severity at Legambo, while Dosha, Obse, Wolkie, and FB-26869 generally showed the lowest severity at Tenta. In contrast, EH96048-1, EH00102-8-1, the local genotype, and, in some environments, EH97091-2 and Gora recorded relatively higher disease severity.

Disease severity was generally lower at Tenta than at Legambo. The difference may be related to environmental conditions, particularly rainfall and humidity during crop development. Favourable moisture conditions can enhance pathogen development and disease progression. The observed variation among genotypes is also consistent with previous reports that resistance to faba bean gall is influenced by both genotype and environment (Rhaïem *et al.*, 2002 ; Tivoli *et al.*, 1996; Bekele Belachew *et al.*, 2018; Wondwosen Wulita *et al.*, 2019; Yitayih Getnet and Azmeraw Yehizbalem, 2017). The differences in disease severity between Legambo and Tenta highlight the significant role of environmental conditions, particularly rainfall and humidity during critical growth stages, in pathogen proliferation (Figure 5. 1).

The variable resistance observed across genotypes further supports previous reports of genotype-by-environment interactions in gall disease expression (Yitayih Getnet and Azmeraw Yehizbalem, 2017; Tiruneh Belachew, 2016). For instance, (Belachew Bekele *et al.*, 2016 and Tiruneh Belachew, 2016) noted that under natural infection, the Local genotype showed the highest severity, while Gora had the lowest. The consistently lower disease severity of Dosha, Obse, Wolkie, and FB-26869 indicates that these genotypes have comparatively better tolerance or resistance to gall disease under the conditions of the present study.

Table 5. 3. Faba bean gall disease incidence, Severity, and AUDPC on different faba bean genotypes in 2022 and 2023 cropping seasons at Tenta district.

Faba bean variety	DI%		PSI%		AUDPC(%-days	
	2022	2023	2022	2023	2022	2023
FB-26872	80.67 ^{a-c}	78.33 ^{a-d}	60.67 ^{a-e}	57.36 ^{a-g}	1635.21 ^{a-c}	1559.77 ^{a-d}
FB-26873	75.87 ^{a-c}	70.50 ^{a-f}	60.56 ^{a-e}	57.00 ^{a-g}	1435.11 ^{d-g}	1381.69 ^{e-i}
Local	79.06 ^{a-c}	77.46 ^{a-e}	63.83 ^{ab}	60.73 ^{a-c}	1668.55 ^{ab}	1609.77 ^{a-c}
FB-26885	75.33 ^{a-c}	69.67 ^{b-f}	61.33 ^{a-d}	59.33 ^{a-e}	1485.11 ^{c-g}	1365.02 ^{f-i}
FB-26869	72.00 ^c	67.33 ^{ef}	54.00 ^{e-g}	48.56 ^{ij}	1331.48 ^{fg}	1303.23 ^{hi}
Obse	72.33 ^c	67.00 ^f	51.53 ^{fg}	49.22 ^{h-j}	1328.15 ^{fg}	1291.23 ⁱ
EH09007-4	75.67 ^{a-c}	69.67 ^{b-f}	60.33 ^{a-e}	58.11 ^{a-f}	1501.77 ^{b-f}	1398.36 ^{d-i}
EH06088-6	72.67 ^c	68.33 ^{c-f}	57.33 ^{a-f}	54.67 ^{b-i}	1438.44 ^{d-g}	1381.69 ^{e-i}
EH96048-1	84.33 ^a	80.00 ^a	64.33 ^a	61.67 ^a	1715.21 ^{ab}	1649.77 ^{ab}
EH09004-2	72.80 ^c	67.50 ^{ef}	60.00 ^{a-e}	51.56 ^{f-j}	1434.11 ^{d-g}	1377.02 ^{e-i}
EH06007-4	72.83 ^c	69.00 ^{c-f}	58.67 ^{a-e}	52.33 ^{f-j}	1556.88 ^{a-d}	1543.11 ^{a-e}
EH011038-3	74.67 ^{bc}	69.00 ^{c-f}	55.67 ^{d-g}	53.22 ^{d-j}	1436.11 ^{d-g}	1398.36 ^{d-i}
EH920070	73.67 ^c	69.00 ^{c-f}	55.67 ^{d-g}	53.56 ^{d-j}	1443.77 ^{d-g}	1395.02 ^{d-i}
EH00102-8-1	84.00 ^{ab}	79.67 ^{ab}	64.00 ^{ab}	61.11 ^{ab}	1721.88 ^a	1643.11 ^{ab}
EH98097-1	75.33 ^{a-c}	69.67 ^{b-f}	57.00 ^{c-f}	54.22 ^{c-i}	1578.44 ^{a-d}	1528.36 ^{a-f}
EH06007-2	73.67 ^c	67.67 ^{ef}	55.00 ^{d-g}	52.89 ^{e-j}	1568.55 ^{a-d}	1523.11 ^{a-f}
EH010010-1	75.33 ^{a-c}	69.67 ^{b-f}	57.67 ^{a-f}	54.67 ^{b-i}	1601.77 ^{a-d}	1531.69 ^{a-f}
EH09046-3	72.33 ^c	68.00 ^{d-f}	54.00 ^{e-g}	51.22 ^{g-j}	1454.51 ^{d-g}	1382.57 ^{e-i}
EH09028-3	73.67 ^c	69.20 ^{c-f}	54.67 ^{d-g}	51.67 ^{f-j}	1485.11 ^{c-g}	1435.02 ^{d-i}
EH97091-2	83.67 ^{ab}	78.67 ^{a-c}	62.33 ^{a-c}	59.89 ^{a-d}	1718.55 ^a	1676.44 ^a
EH07015-7	74.67 ^{bc}	69.67 ^{b-f}	54.33 ^{e-g}	52.22 ^{f-j}	1554.51 ^{a-d}	1482.57 ^{b-g}
EH011025-1	77.00 ^{a-c}	71.67 ^{a-f}	55.67 ^{d-g}	53.33 ^{d-j}	1493.77 ^{b-g}	1431.69 ^{d-i}
EH011018-5	75.33 ^{a-c}	70.00 ^{b-f}	59.67 ^{a-e}	56.22 ^{a-g}	1521.17 ^{b-e}	1465.91 ^{c-h}
EH07005	75.67 ^{a-c}	70.00 ^{b-f}	60.00 ^{a-e}	57.00 ^{a-g}	1435.11 ^{d-g}	1365.02 ^{f-i}
EH011016-2	75.67 ^{a-c}	70.00 ^{b-f}	58.67 ^{a-e}	55.67 ^{a-h}	1493.77 ^{b-g}	1418.36 ^{d-i}
Dosha	71.17 ^c	65.08 ^f	50.00 ^f	47.48 ^j	1314.82 ^g	1281.23 ⁱ
Wolkie	72.50 ^c	67.22 ^{ef}	51.83 ^{fg}	48.85 ^{ij}	1361.77 ^{efg}	1318.36 ^{ghi}
Gora	80.17 ^{a-c}	75.22 ^{a-f}	62.50 ^{abc}	59.71 ^{a-d}	1667.84 ^{ab}	1636.57 ^{ab}
MSE	22.73	28.23	26.08	26.30	20926.26	20078.27
CV	6.29	7.50	8.82	9.36	9.56	9.72
Mean	75.76	70.86	57.91	54.79	1513.62	1457.44
P value	0.0287	0.0259	0.0389	0.0257	0.0146	0.0232

MSqE=Mean square of error; CV=Coefficient of variation; DI=Disease Incidence; Percentage severity index; AUDPC=Area under disease progress curve. Treatments with the same letter are not significantly different.

5.3.3 Area Under Disease Progress Curve

The AUDPC differed significantly among genotypes, locations, and cropping seasons ($p < 0.05$), demonstrating variation in the rate and extent of disease development. At Legambo, AUDPC ranged from 1,362.82 to 1,770.31 %-days in 2022, with a mean of 1,567.68 %-days, and from 1,343.82 to 1,759.75 %-days in 2023, with a mean of 1,540.95 %-days. The lowest AUDPC values were generally recorded for Obse, Dosha, FB-26869, and Wolkie, whereas EH96048-1, EH00102-8-1, EH97091-2, and the local genotype generally had higher values (Figure 5.3 and Table 5.2). At Tenta, AUDPC ranged from 1,314.82 to 1,721.88 %-days in 2022, with a mean of 1,513.62 %-days, and from 1,281.23 to 1,676.44 %-days in 2023, with a mean of 1,457.44 %-days. Dosha, Obse, FB-26869, and Wolkie consistently recorded relatively low AUDPC values, while EH96048-1, EH00102-8-1, EH97091-2, Gora, and the local genotype showed relatively high disease progression (Appendix Figure 5. 2).

The lower AUDPC values observed for Dosha, Obse, Wolkie, and FB-26869 indicate slower and/or less extensive disease development throughout the crop growth period. Their consistent performance across environments strengthens their potential as sources of moderate resistance to faba bean gall disease. The generally lower AUDPC at Tenta than at Legambo agrees with the lower disease incidence and severity observed at Tenta. This suggests that environmental conditions contributed substantially to disease development. Genotype-by-environment interactions may also explain differences in the relative performance of some genotypes between locations.

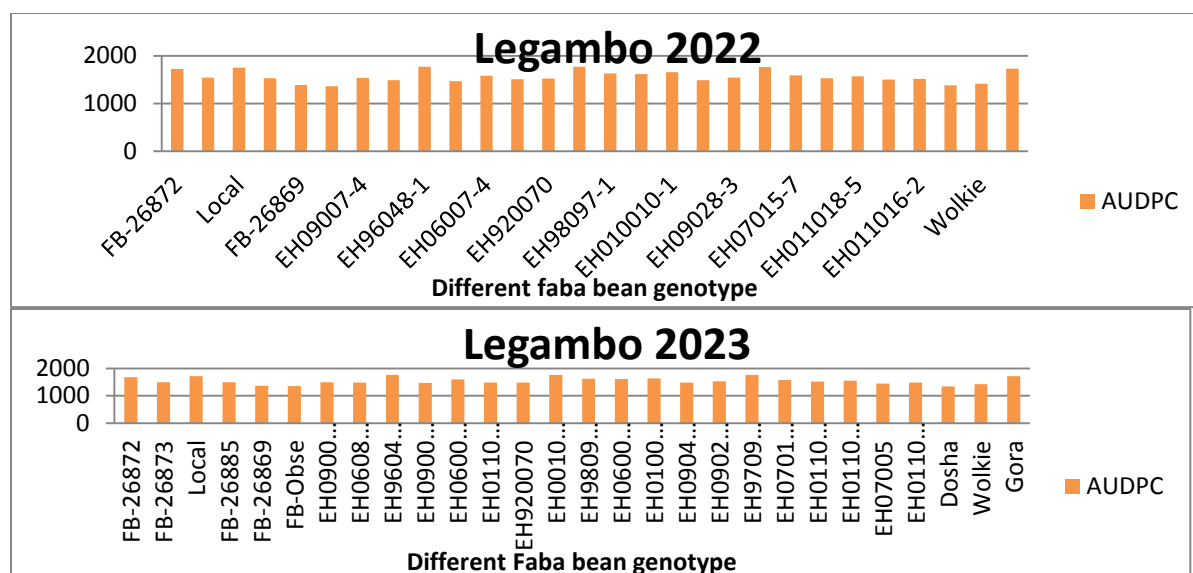


Figure 5. 3. Area under the disease progress curve (AUDPC) of faba bean genotypes evaluated against faba bean gall disease at Legambo during the 2022 (a) and 2023 (b) main cropping seasons.

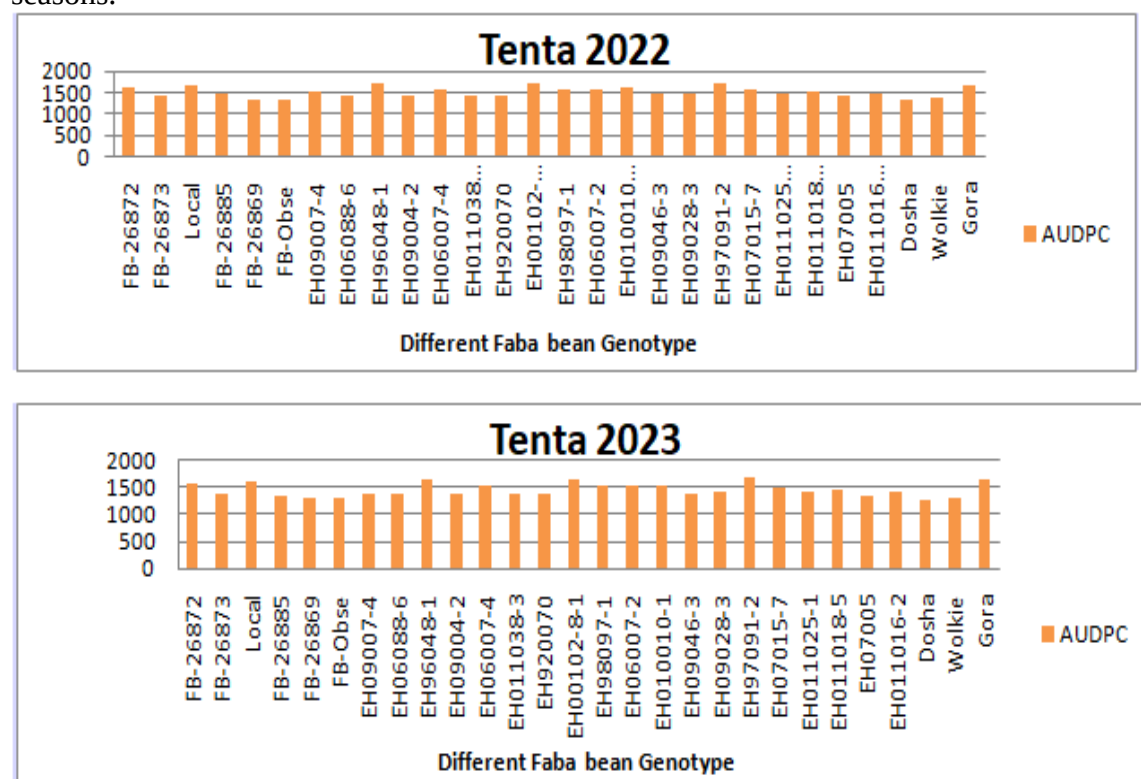


Figure 5. 4. Area under the disease progress curve (AUDPC) of faba bean genotypes evaluated against faba bean gall disease at Tenta during the 2022 (a) and 2023 (b) main cropping seasons.

5.3.4 Yield and Yield Components

Significant differences were observed among genotypes for grain yield and several yield components across locations and cropping seasons. Plant height, number of pods per plant, number of seeds per pod, and hundred seed weight also varied significantly among genotypes (Tables 5.4 - 5.6). Dosha consistently showed superior agronomic performance. It produced the tallest plants and the highest number of pods per plant at both locations. Wolkie and Obse also showed relatively high values for important yield components. In contrast, EH96048-1 and EH00102-8-1 generally had lower values for plant height, pod number, and seeds per pod.

The superior performance of Dosha, Obse, and Wolkie in several yield components may have contributed to their higher grain yields. However, the relationship between plant height and yield should be interpreted together with other yield components because plant height alone does not necessarily determine grain productivity. The relatively consistent performance of these genotypes across locations and seasons indicates their potential adaptation to the environments represented by Legambo and Tenta. Similar importance of plant architecture and yield components in determining faba bean productivity has been reported by Yirga Kindie and Zinabu Nigusie (2019).

5.3.5 Plant Height, Pods per Plant, and Seeds per Pod

Plant height differed significantly among genotypes at both locations ($p < 0.05$). At Legambo, plant height ranged from 54.67 to 73.78 cm in 2022 and from 57.93 to 76.40 cm in 2023, while the corresponding means were 66.09 and 66.23 cm. At Tenta, plant height ranged from 59.40 to 74.85 cm in 2022 and from 60.67 to 78.73 cm in 2023, with means of 68.46 and 69.73 cm, respectively. Dosha consistently produced the tallest plants at both locations and in both seasons. Wolkie and Obse also produced relatively tall plants. The greater plant height of these genotypes may reflect their genetic growth habit and adaptation to the tested environments.

Table 5. 4. Mean yield components of faba bean genotypes evaluated for faba bean disease under field conditions in the 2022 and 2023 cropping seasons at Legambo.

Faba bean variety	PH(cm)	PH(cm)	NPP ⁻¹	NPP ⁻¹	SPP ⁻¹	SPP ⁻¹
	2022	2023	2022	2023	2022	2023
FB-26872	62.40 ^{c-e}	59.27 ^{fg}	10.60 ^{b-d}	11.27 ^{b-e}	2.45 ^{cd}	2.67 ^{c-e}
FB-26873	64.80 ^{a-d}	64.50 ^{c-f}	10.47 ^{b-e}	11.60 ^{b-d}	2.63 ^{a-c}	2.57 ^{d-f}
Local	61.29 ^{c-e}	61.40 ^{d-g}	9.45 ^{b-f}	10.45 ^{c-e}	2.43 ^{cd}	2.52 ^{e-g}
FB-26885	66.83 ^{a-d}	66.33 ^{b-e}	9.67 ^{b-f}	11.87 ^{b-d}	2.57 ^{bc}	2.6 ^{c-f}
FB-26869	72.53 ^a	70.07 ^{bc}	11.67 ^{a-c}	12.93 ^{a-c}	2.75 ^{a-c}	2.79 ^{a-d}
FB-Obse	69.67 ^{a-c}	69.87 ^{bc}	11.73 ^{a-c}	13.63 ^{ab}	2.78 ^{a-c}	2.85 ^{a-c}
EH09007-4	66.20 ^{a-d}	64.27 ^{c-f}	9.87 ^{b-f}	12.07 ^{b-d}	2.56 ^{bc}	2.6 ^{c-f}
EH06088-6	67.93 ^{a-c}	68.13 ^{bc}	10.60 ^{b-d}	12.47 ^{b-d}	2.67 ^{a-c}	2.66 ^{c-e}
EH96048-1	54.67 ^e	57.93 ^g	7.13 ^f	10.00 ^{de}	2.13 ^d	2.37 ^{fg}
EH09004-2	68.67 ^{a-c}	68.53 ^{bc}	11.40 ^{a-c}	12.20 ^{b-d}	2.60 ^{a-c}	2.68 ^{c-e}
EH06007-4	68.73 ^{a-c}	67.40 ^{b-d}	10.93 ^{b-d}	11.80 ^{b-d}	2.60 ^{a-c}	2.61 ^{c-e}
EH011038-3	66.67 ^{a-d}	67.07 ^{b-d}	10.73 ^{b-d}	10.67 ^{c-e}	2.73 ^{a-c}	2.76 ^{a-e}
EH920070	64.87 ^{a-d}	63.73 ^{c-g}	10.53 ^{b-d}	11.33 ^{b-e}	2.60 ^{a-c}	2.64 ^{c-e}
EH00102-8-1	61.13 ^{c-e}	58.07 ^g	7.50 ^{ef}	8.93 ^e	2.40 ^{cd}	2.33 ^g
EH98097-1	66.00 ^{a-d}	66.00 ^{c-e}	10.67 ^{b-d}	11.47 ^{b-d}	2.60 ^{a-c}	2.6 ^{c-f}
EH06007-2	65.27 ^{a-d}	64.27 ^{c-f}	9.47 ^{b-f}	11.47 ^{b-d}	2.67 ^{a-c}	2.68 ^{c-e}
EH010010-1	62.67 ^{b-d}	64.67 ^{c-f}	10.07 ^{b-f}	11.20 ^{b-e}	2.40 ^{cd}	2.6 ^{c-f}
EH09046-3	67.73 ^{a-d}	68.00 ^{bc}	10.85 ^{b-d}	11.90 ^{b-d}	3.0 ^a	2.64 ^{c-e}
EH09028-3	66.80 ^{a-d}	67.20 ^{b-d}	9.53 ^{b-f}	11.70 ^{b-d}	2.56 ^{bc}	2.61 ^{c-f}
EH97091-2	58.53 ^{de}	60.60 ^{e-g}	7.93 ^{d-f}	10.20 ^{de}	2.47 ^{cd}	2.55 ^{d-g}
EH07015-7	66.73 ^{a-d}	68.03 ^{bc}	10.93 ^{b-d}	11.27 ^{b-e}	2.60 ^{a-c}	2.69 ^{b-e}
EH011025-1	67.07 ^{a-d}	68.33 ^{bc}	8.13 ^{d-f}	10.73 ^{c-e}	2.67 ^{a-c}	2.68 ^{c-e}
EH011018-5	65.13 ^{a-d}	67.60 ^{b-d}	8.87 ^{c-f}	11.60 ^{b-d}	2.67 ^{a-c}	2.73 ^{a-e}
EH07005	68.07 ^{a-c}	69.40 ^{bc}	10.25 ^{b-e}	12.07 ^{b-d}	2.73 ^{a-c}	2.77 ^{a-e}
EH011016-2	65.60 ^{a-d}	66.20 ^{b-e}	10.73 ^{b-d}	11.67 ^{b-d}	2.67 ^{a-c}	2.75 ^{a-e}
Dosha	73.78 ^a	76.40 ^a	14.02 ^a	15.03 ^a	2.93 ^{ab}	2.94 ^a
Wolkie	71.98 ^{ab}	72.65 ^{ab}	12.01 ^{ab}	13.46 ^{ab}	2.90 ^{ab}	2.93 ^{ab}
Gora	68.87 ^{a-c}	67.59 ^{b-d}	10.65 ^{b-d}	11.90 ^{b-d}	2.63 ^{a-c}	2.61 ^{c-f}
MSE	24.52	25.09	3.32	1.58	0.05	0.03
CV	7.49	7.56	17.83	10.75	8.33	6.55
Mean	66.09	66.23	10.23	11.67	2.62	2.66
P value	0.0135	0.0100	0.0231	0.0010	0.0188	0.0313

PH = Plant height; NPPP = Number of pods per plant; and SPP = Number of seeds per pod. MSE= mean square of error, CV=Coefficient of variation

The number of pods per plant also differed significantly among genotypes. Dosha recorded the highest number of pods per plant at both locations, followed by Obse and Wolkie. Conversely,

EH96048-1 and EH00102-8-1 generally produced fewer pods. The greater pod production of Dosha, Obse, and Wolkie likely contributed to their superior grain yield.

Similarly, the number of seeds per pod differed significantly among genotypes. Dosha and Wolkie generally recorded higher values, whereas EH96048-1 and EH00102-8-1 recorded lower values. The combination of greater pod number and seeds per pod provided an important yield advantage for the better-performing genotypes.

Table 5. 5. Mean of yield components of faba bean genotype evaluated for faba bean disease under field conditions in the 2022 and 2023 cropping seasons at Tenta.

Faba bean genotype	PH (cm)	PH(cm)	NPP ⁻¹	NPP ⁻¹	SPP ⁻¹	SPP ⁻¹
	2022	2023	2022	2023	2022	2023
FB-26872	66.73 ^{a-e}	73.53 ^{a-c}	10.53 ^{e-h}	12.40 ^{c-e}	2.48 ^{c-e}	2.76 ^{c-g}
FB-26873	69.13 ^{a-d}	68.53 ^{c-e}	12.13 ^{b-e}	12.93 ^{b-e}	2.56 ^{b-e}	2.71 ^{d-h}
Local	63.51 ^{b-e}	63.07 ^{ef}	10.66 ^{d-h}	11.79 ^{de}	2.54 ^{c-e}	2.53 ^{gh}
FB-26885	67.97 ^{a-e}	71.33 ^{b-d}	11.87 ^{b-f}	13.07 ^{b-e}	2.61 ^{a-e}	2.67 ^{d-h}
FB-26869	71.40 ^{ab}	72.67 ^{a-c}	13.40 ^{a-c}	14.00 ^{a-c}	2.79 ^{a-c}	2.88 ^{b-d}
Obse	73.00 ^b	73.67 ^{a-c}	13.60 ^{ab}	14.39 ^{ab}	2.80 ^{a-c}	2.88 ^{b-d}
EH09007-4	67.80 ^{a-e}	72.33 ^{b-d}	11.87 ^{b-f}	13.00 ^{b-e}	2.60 ^{a-e}	2.67 ^{d-h}
EH06088-6	69.93 ^{a-d}	70.00 ^{b-d}	12.93 ^{a-e}	13.20 ^{b-e}	2.75 ^{a-d}	2.67 ^{d-h}
EH96048-1	59.40 ^e	60.67 ^f	9.27 ^{gh}	9.47 ^f	2.30 ^e	2.47 ^h
EH09004-2	72.33 ^{ab}	72.00 ^{b-d}	13.20 ^{a-d}	13.40 ^{b-d}	2.76 ^{a-d}	2.76 ^{c-g}
EH06007-4	70.53 ^{a-d}	69.67 ^{b-d}	12.53 ^{b-e}	13.30 ^{b-d}	2.71 ^{a-d}	2.63 ^{e-h}
EH011038-3	68.87 ^{a-d}	69.33 ^{b-e}	12.47 ^{b-e}	12.27 ^{c-e}	2.74 ^{a-d}	2.81 ^{b-e}
EH920070	67.07 ^{a-e}	70.60 ^{b-d}	11.67 ^{b-g}	12.07 ^{de}	2.63 ^{a-e}	2.80 ^{b-e}
EH00102-8-1	62.27 ^{cde}	67.27 ^{c-e}	9.00 ^g	9.31 ^f	2.40 ^{de}	2.57 ^{f-h}
EH98097-1	67.60 ^{a-e}	68.67 ^{c-e}	12.27 ^{b-e}	12.67 ^{b-e}	2.60 ^{a-e}	2.75 ^{c-g}
EH06007-2	67.40 ^{a-e}	70.67 ^{b-d}	12.93 ^{a-e}	12.33 ^{c-e}	2.71 ^{a-d}	2.75 ^{c-g}
EH010010-1	66.93 ^{a-e}	67.33 ^{c-e}	10.73 ^{d-h}	11.93 ^{de}	2.60 ^{a-e}	2.65 ^{e-h}
EH09046-3	70.93 ^{abc}	71.67 ^{b-d}	13.13 ^{a-d}	13.47 ^{b-d}	2.78 ^{a-d}	2.80 ^{b-e}
EH09028-3	69.33 ^{a-d}	70.00 ^{b-d}	12.67 ^{a-e}	12.73 ^{b-e}	2.61 ^{a-e}	2.73 ^{d-g}
EH97091-2	61.53 ^{de}	65.67 ^{d-f}	9.40 ^{f-h}	11.40 ^e	2.53 ^{c-e}	2.67 ^{d-h}
EH07015-7	68.73 ^{a-d}	70.60 ^{b-d}	12.00 ^{b-e}	11.47 ^e	2.67 ^{a-e}	2.73 ^{d-g}
EH011025-1	68.93 ^{a-d}	70.67 ^{b-d}	10.87 ^{c-h}	12.87 ^{b-e}	2.67 ^{a-e}	2.97 ^{bc}
EH011018-5	68.33 ^{a-d}	70.07 ^{b-d}	11.67 ^{b-g}	13.60 ^{a-d}	2.73 ^{a-d}	2.80 ^{b-e}
EH07005	69.67 ^{a-d}	73.33 ^{a-c}	11.73 ^{b-f}	12.07 ^{de}	2.64 ^{a-d}	2.81 ^{b-e}
EH011016-2	68.60 ^{a-d}	68.67 ^{c-e}	11.80 ^{b-f}	12.00 ^{de}	2.63 ^{a-e}	2.77 ^{c-f}
Dosha	74.85 ^a	78.73 ^a	15.03 ^a	15.23 ^a	2.96 ^a	3.20 ^a
Wolkie	74.10 ^a	75.87 ^{ab}	13.59 ^{ab}	14.45 ^{ab}	2.92 ^{ab}	3.00 ^b
Gora	66.50 ^{a-e}	70.80 ^{b-d}	11.85 ^{b-f}	12.91 ^{b-e}	2.52 ^{c-e}	2.67 ^{d-h}
MSE	21.15	21.75	1.99	2.81	0.04	0.03
CV	6.72	6.69	11.91	13.26	7.14	6.57

Mean	68.46	69.73	11.83	12.65	2.65	2.75
P value	0.0346	0.0467	0.0019	0.0341	0.0483	0.0159

PH = Plant height; NPPP = Number of pods per plant; and SPP = Number of seeds per pod. MSE= mean square of error, CV=Coefficient of variation

5.3.6 Hundred Seed Weight and Yield

Hundred seed weight differed significantly among genotypes at both locations and in both cropping seasons ($p < 0.05$). At Legambo, values ranged from 43.67 to 69.00 g in 2022 and from 46.00 to 71.00 g in 2023, with means of 59.70 and 62.36 g, respectively. At Tenta, hundred seed weight ranged from 46.67 to 72.33 g in 2022 and from 44.00 to 73.00 g in 2023, with means of 63.19 and 63.83 g, respectively Table 5.6). Dosha consistently recorded the highest hundred seed weight at both locations, followed by Wolkie and, in some environments, Gora and Obse. EH97091-2 and EH96048-1 generally had the lowest seed weight.

Grain yield also differed significantly among genotypes. At Legambo, grain yield ranged from 1.25 to 1.92 t ha⁻¹ in 2022 and from 1.29 to 2.04 t ha⁻¹ in 2023, with mean yields of 1.48 and 1.58 t ha⁻¹, respectively. At Tenta, yield ranged from 1.54 to 2.19 t ha⁻¹ in 2022 and from 1.57 to 2.27 t ha⁻¹ in 2023, with means of 1.76 and 1.83 t ha⁻¹, respectively. Dosha produced the highest grain yield at both locations and in both seasons. At Legambo, it yielded 1.92 and 2.04 t ha⁻¹ in 2022 and 2023, respectively, while at Tenta it yielded 2.19 and 2.27 t ha⁻¹. Obse and Wolkie also produced relatively high grain yields. In contrast, EH96048-1 and the local genotype generally produced lower yields.

The superior yield of Dosha appears to be associated with its favourable combination of plant height, pod number, seeds per pod, and hundred seed weight. The relatively large seed size of Dosha, Wolkie, and other high-performing genotypes may also be advantageous for market and consumption preferences. Similar importance of seed size in faba bean production and marketing has been reported by Gereziher Teame *et al.*(2018).

Table 5. 6. Yields and hundred seed weights of faba bean genotypes at Legambo and Tenta in the 2022 and 2023 main cropping seasons.

Faba bean variety	Legambo				Tenta			
	Yield (t ha ⁻¹)	Yield (t ha ⁻¹)	HSW (g)	HSW (g)	Yield (t ha ⁻¹)	Yield (t ha ⁻¹)	HSW (g)	HSW (g)
FB-26872	1.33 ^{j-m}	1.52 ^{c-f}	55.00 ^{fg}	58.67 ^{e-h}	1.65 ^{d-g}	1.71 ^{i-l}	59.33 ^{de}	61.00 ^{de}
FB-26873	1.4 ^{h-m}	1.5 ^{c-g}	56.00 ^{e-g}	57.20 ^{f-i}	1.75 ^{c-g}	1.92 ^{d-i}	59.00 ^{de}	60.0 ^e
Local	1.25 ^m	1.33 ^{gh}	51.00 ^g	53.00 ^{ij}	1.60 ^{e-g}	1.62 ^{kl}	53.07 ^f	54.33 ^f
FB-26885	1.37 ^{i-m}	1.49 ^{c-g}	57.00 ^{d-f}	59.33 ^{d-g}	1.68 ^{d-g}	1.96 ^{c-e}	60.67 ^{c-e}	61.00 ^{de}
FB-26869	1.60 ^{b-e}	1.76 ^b	61.3 ^{b-e}	65.33 ^{a-c}	1.89 ^{b-d}	2.14 ^{a-c}	65.67 ^{bc}	66.00 ^{b-d}
Obse	1.90 ^a	2.04 ^a	64.67 ^{a-c}	65.67 ^{a-c}	2.17 ^a	2.16 ^{ab}	67.66 ^{ab}	68.00 ^{ab}
EH09007-4	1.42 ^{i-k}	1.54 ^{c-f}	57.67 ^{d-f}	65.67 ^{a-c}	1.68 ^{d-g}	1.83 ^{e-j}	67.33 ^{ab}	65.3 ^{b-e}
EH06088-6	1.60 ^{b-e}	1.65 ^{b-d}	64.00 ^{a-c}	66.00 ^{a-c}	1.88 ^{b-d}	1.93 ^{d-h}	66.33 ^b	67.00 ^{bc}
EH96048-1	1.28 ^{k-m}	1.29 ^h	45.67 ^h	48.00 ^{jk}	1.54 ^g	1.57 ^l	48.33 ^g	52.33 ^f
EH09004-2	1.38 ^{i-m}	1.66 ^{b-d}	62.00 ^{b-d}	64.67 ^{b-d}	1.84 ^{b-e}	2.11 ^{a-d}	65.00 ^{bc}	66.00 ^{b-d}
EH06007-4	1.64 ^{bc}	1.62 ^{c-e}	62.00 ^{b-d}	65.33 ^{a-c}	1.95 ^{a-c}	1.98 ^{b-e}	67.00 ^{ab}	66.93 ^{bc}
EH011038-3	1.47 ^{e-j}	1.52 ^{c-f}	64.33 ^{a-c}	66.33 ^{a-c}	1.66 ^{d-g}	1.69 ^{j-l}	66.33 ^b	67.33 ^{a-c}
EH920070	1.40 ^{g-l}	1.56 ^{b-f}	64.67 ^{a-c}	66.67 ^{ab}	1.76 ^{b-g}	1.94 ^{d-g}	67.00 ^{ab}	68.33 ^{ab}
EH00102-8-1	1.39 ^{h-m}	1.35 ^{f-h}	51.00 ^g	53.30 ^{hi}	1.59 ^{e-g}	1.72 ^{g-l}	53.67 ^f	54.20 ^f
EH98097-1	1.61 ^{b-d}	1.68 ^{bc}	64.00 ^{a-c}	66.00 ^{a-c}	1.62 ^{d-g}	1.83 ^{e-j}	66.33 ^b	67.00 ^{bc}
EH06007-2	1.53 ^{b-h}	1.6 ^{b-e}	64.67 ^{a-c}	67.00 ^{ab}	1.81 ^{b-g}	1.82 ^{e-k}	67.33 ^{ab}	67.67 ^{ab}
EH010010-1	1.51 ^{c-i}	1.49 ^{c-g}	64.33 ^{a-c}	67.67 ^{ab}	1.75 ^{b-g}	1.82 ^{e-k}	68.00 ^{ab}	68.33 ^{ab}
EH09046-3	1.55 ^{b-g}	1.62 ^{b-d}	62.33 ^{b-d}	65.33 ^{a-c}	1.82 ^{b-f}	1.95 ^{c-f}	66.00 ^b	66.33 ^{b-d}
EH09028-3	1.44 ^{f-j}	1.58 ^{b-e}	64.33 ^{a-c}	67.00 ^{ab}	1.7 ^{c-g}	1.75 ^{f-l}	68.00 ^{ab}	68.53 ^{ab}
EH97091-2	1.26 ^{lm}	1.4 ^{e-h}	43.67 ^h	46.00 ^k	1.55 ^{fg}	1.62 ^{j-l}	46.67 ^g	44.00 ^g
EH07015-7	1.41 ^{f-k}	1.54 ^{c-f}	53.67 ^{fg}	56.00 ^{g-i}	1.67 ^{d-g}	1.68 ^{j-l}	57.00 ^{ef}	61.00 ^{de}
EH011025-1	1.49 ^{d-i}	1.58 ^{b-e}	55.33 ^{fg}	60.3 ^{c-g}	1.74 ^{c-g}	1.77 ^{e-l}	60.67 ^{c-e}	61.67 ^{c-e}
EH011018-5	1.56 ^{b-f}	1.59 ^{b-e}	62.00 ^{b-d}	63.7 ^{b-e}	1.75 ^{c-g}	1.77 ^{e-l}	65.00 ^{bc}	65.3 ^{b-e}
EH07005	1.33 ^{j-m}	1.46 ^{d-h}	62.00 ^{b-d}	64.0 ^{b-e}	1.64 ^{d-g}	1.73 ^{g-l}	65.00 ^{bc}	65.3 ^{b-e}
EH011016-2	1.49 ^{d-i}	1.5 ^{c-g}	58.67 ^{c-f}	62.3 ^{b-f}	1.64 ^{d-g}	1.67 ^{ijkl}	63.00 ^{b-d}	63.6 ^{b-e}
Dosha	1.92 ^a	2.04 ^a	69.00 ^a	71.00 ^a	2.19 ^a	2.27 ^a	72.33 ^a	73.00 ^a
Wolkie	1.66 ^b	1.94 ^a	66.27 ^{ab}	67.17 ^{ab}	2.01 ^{ab}	2.17 ^{ab}	68.17 ^{ab}	68.67 ^{ab}
Gora	1.44 ^{f-j}	1.53 ^{c-f}	65.70 ^{ab}	67.67 ^{ab}	1.69 ^{d-g}	1.72 ^{h-l}	67.83 ^{ab}	68.96 ^{ab}
MSE	0.04	0.05	51.79	29.09	0.04	0.07	54.10	32.32
CV	13.87	14.21	12.06	8.65	11.41	14.30	11.64	8.91
Mean	1.48	1.58	59.70	62.36	1.76	1.83	63.19	63.83
P value	0.0294	0.0138	0.0067	<.0001	0.0135	0.0452	0.0047	<.0001

HSW = hundred seed weight

5.3.7 Association of Disease Parameters with Yield

Disease parameters were negatively associated with grain yield at both locations and in both cropping seasons (Table 5.7 and Table 5.8). At Legambo in 2022, the correlation coefficients

between grain yield and disease incidence, PSI, and AUDPC were -0.28 , -0.45 , and -0.54 , respectively. In 2023, the corresponding correlations were -0.29 , -0.44 , and -0.22 . At Tenta, grain yield was also negatively correlated with disease incidence, PSI, and AUDPC. In 2022, correlation coefficients were -0.26 , -0.36 , and -0.32 , respectively; while in 2023 they were -0.27 , -0.25 , and -0.45 , respectively.

The consistently negative relationships indicate that increased disease development was generally associated with reduced grain yield in the observed data. The stronger negative association observed for PSI and AUDPC in several environments suggests that disease severity and cumulative disease development may be more closely related to yield reduction than disease incidence alone. These findings agree with previous reports that increased faba bean gall disease severity is associated with reduced grain yield and that genotypes with lower disease intensity tend to maintain better productivity (Kassa Yehuala et al. 2020; Bitew Beyene et al., 2022)

Table 5. 7. Correlation coefficients (r) of disease parameters with yield at Legambo district

Parameters	2022				2023			
	DI	PSI	AUDPC	Yield	DI	PSI	AUDPC	Yield
DI	-				-			
PSI	0.25*	-			0.37***	-		
AUDPC	0.54***	0.37***	-		0.46***	0.32**	-	
Yield	-0.28*	-0.45**	-0.54***	-	-0.29**	-0.44***	-0.22*	-

Table 5. 8. Correlation coefficients (r) of disease parameters with yield at Tenta in districts

Parameter	2022				2023			
	DI	PSI	AUDPC	Yield	DI	PSI	AUDPC	Yield
DI	-				-			
PSI	0.44***	-			0.30**	-		
AUDPC	0.44***	0.28*	-		0.27*	0.36***	-	
Yield	-0.26*	-0.36***	-0.32**	-	-0.27*	-0.25*	-0.45***	-

PSI = Percent severity index, AUDPC = Area under disease progress curve; HSW = Hundred seed weight. *** = Very highly significant; ** = highly significant; * = Significant; and ns = non-significant at $p \leq 0.001$, $p \leq 0.01$, $p \leq 0.05$ and $p > 0.05$, respectively.

5.3.8 Regression Analysis of Yield with Percentage Gall Severity Index

Regression analysis was conducted to examine the relationship between faba bean grain yield and percentage gall severity index (PSI) measured at the final assessment date. Across both

locations and cropping seasons, grain yield was negatively associated with disease severity ($p < 0.001$).

At Legambo in 2022, the regression equation was $Y = -0.035x + 3.70$ ($R^2 = 0.57$, $p < 0.001$) (Appendix Figure 5. 4); at Tenta in 2022, $Y = -0.031x + 3.57$ ($R^2 = 0.55$, $p = 0.001$) (Appendix Figure 5. 5); at Legambo in 2023, $Y = -0.039x + 4.02$ ($R^2 = 0.74$, $p = 0.001$) (Appendix Figure 5. 6).; and at Tenta in 2023, $Y = -0.04x + 3.75$ ($R^2 = 0.56$, $p = 0.001$) (Appendix Figure 5. 7). The regression coefficients indicate that grain yield decreased by approximately 0.031 to 0.04 t ha⁻¹ for every 1% increase in disease severity. The R^2 values ranged from 0.55 to 0.74, indicating that disease severity explained 55–74% of the variation in grain yield in the observed data. These results demonstrate a consistent negative association between disease severity and grain yield across locations and seasons.

However, these relationships should be interpreted as predictive associations rather than definitive evidence of causation. The observational nature of the data means that other environmental and management factors not included in the model, such as soil fertility, rainfall distribution, temperature, and genotype $\times$ environment interactions, may also contribute to yield variation. The regression coefficients reflect the magnitude of association in the observed dataset, not a direct causal effect. Nevertheless, the consistency and strength of the negative associations across two locations and two seasons, together with the biological plausibility that disease reduces photosynthetic leaf area and limits grain filling, suggest that faba bean gall disease is an important factor associated with reduced productivity. Genotypes such as Dosha, Obse, and Wolkie, which showed lower disease severity and higher grain yields, may be suitable candidates for cultivation in disease-prone areas.

5.4 Conclusion

This study demonstrated significant variation among the evaluated faba bean genotypes in response to faba bean gall disease across locations and cropping seasons. Disease incidence, percent severity index (PSI), and AUDPC differed significantly among genotypes, indicating the presence of genetic variability for resistance to faba bean gall disease.

Across both years and locations, Dosha, Obse, Wolkie, and FB-26869 consistently exhibited lower disease incidence, severity, and AUDPC values compared with the other tested genotypes.

At Legambo, Dosha recorded the lowest disease severity (55.67% in 2022 and 54.33% in 2023) and AUDPC values (1,378.82 and 1,343.82 %-days, respectively), while similar trends were observed at Tenta, with disease severity values of 50.00% and 47.48% in 2022 and 2023, respectively. In contrast, EH96048-1, EH00102-8-1, EH97091-2, and the local variety consistently showed higher disease incidence, severity, and AUDPC values, indicating susceptibility to faba bean gall disease. Disease pressure was relatively higher at Legambo than at Tenta, suggesting that environmental conditions such as rainfall and relative humidity favoured disease development at Legambo. The higher disease severity and AUDPC recorded at Legambo confirm the influence of the environment on disease progression. Significant differences were also observed among genotypes for grain yield and yield-related traits. The moderately resistant genotypes Dosha, Obse, and Wolkie produced superior agronomic performance across locations and years.

Dosha gave the highest grain yield at locations, producing 1.92 and 2.04 t ha⁻¹ at Legambo and 2.19 and 2.27 t ha⁻¹ at Tenta during the 2022 and 2023 cropping seasons, respectively. Obse and Wolkie also produced consistently higher yields compared with susceptible genotypes. These genotypes further showed better performance in plant height, number of pods per plant, seeds per pod, and hundred seed weight.

Correlation analysis confirmed that disease incidence, PSI, and AUDPC were negatively associated with grain yield, indicating that increased disease intensity was associated with reduced productivity. Regression analysis further showed that grain yield declined by approximately 0.031–0.04 t ha⁻¹ for every 1% increase in disease severity. These results demonstrate the considerable association between faba bean gall disease and yield reduction.

Overall, the study identified Dosha, Obse, Wolkie, and FB-26869 as promising genotypes with moderate resistance to faba bean gall disease and superior yield performance under natural infection conditions. These genotypes can serve as important genetic resources for faba bean production and future resistance breeding programs in gall-prone areas of Ethiopia.

5.5 Recommendations

Based on the findings of this study, Dosha, Obse, and Wolkie are recommended as promising genotypes for cultivation in faba bean gall-prone areas of South Wollo and similar agro-ecological zones. These genotypes consistently showed lower disease incidence, severity, and AUDPC, together with higher grain yield across locations and cropping seasons. FB-26869 also showed relatively lower disease development and good yield performance and should be included in further evaluation. These genotypes should be tested through multi-location and multi-season trials to confirm their disease response, yield stability, and adaptability before wider dissemination. Furthermore, Dosha, Obse, Wolkie, and FB-26869 should be considered as potential parental materials in breeding programs aimed at developing faba bean varieties with improved gall disease resistance and high yield potential. Future studies should also investigate the influence of environmental factors, particularly rainfall and humidity, on disease development to support effective management of faba bean gall disease.

Chapter 6. Faba Bean Gall (*Physoderma viciae*) Disease Management through Faba Bean Varieties and Fungicides in the Highlands of South Wollo, Northeastern Ethiopia

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Abstract

Faba bean (Vicia faba L.) is an important food and cash crop in Ethiopia, but its productivity is constrained by several biotic and abiotic factors, including faba bean gall disease caused by Physoderma viciae. This study evaluated the effectiveness of combining faba bean varieties and fungicides for managing faba bean gall disease in Tenta and Legambo districts of South Wollo, northeastern Ethiopia, during the 2022 and 2023 cropping seasons. Four faba bean varieties (Gora, Dosha, Wolkie, and Local) were evaluated in combination with four fungicides (Mancozebe 80% WP, Matco, Noble 25 WP, and Ridomil Gold MZ 68 WG) and an untreated control. The 20 treatment combinations were arranged in a factorial experiment using a randomized complete block design with three replications. Disease incidence, disease severity, area under the disease progress curve, yield and yield components, relative yield loss, and economic returns were assessed. Variety, fungicide, and their interaction significantly influenced faba bean gall disease and grain yield across the study environments. The combination of Dosha with Noble 25 WP resulted in the lowest disease intensity and the highest grain yields (3.79 t ha⁻¹), with the highest net benefit (US\$ 2,293.63–4,168.20 ha⁻¹).

Therefore, the Doshia variety combined with Noble 25 WP is recommended as an effective and economically viable management option for faba bean gall disease in the study areas and similar agro-ecological zones. Further multi-location and multi-season studies are needed to validate the effectiveness, economic feasibility, and adaptability of this promising variety–fungicide combination under diverse production conditions.

Keywords: AUDPC, disease incidence, faba bean varieties, foliar spray, fungicides, *Physoderma viciae*

6.1 Introduction

Faba bean (*Vicia faba* L.) has been cultivated since the dawn of agriculture and remains an important crop for human nutrition and animal feed worldwide (Zohary and Hopf 2000). In Ethiopia, faba bean is a staple food, consumed in various forms, including boiled immature green beans (Tiru Melkamu, 2018; Abera Merkuz and Semagn Meseret, 2022). Faba bean is the most widely grown legume crop, surpassing other pulses in area coverage and production. Despite its importance, however, the average productivity of the faba bean is low (2.1 t/ha^{-1}) as compared to soybean (2.44 t/ha^{-1}) and grass pea (2.12 t/ha^{-1}) (CSA, 2022). Despite its significant importance, faba bean productivity in Ethiopia lags behind the crop potential (Abera Merkuz and Semagn Meseret, 2022). Faba bean gall (blister) disease was first reported on *Vicia unijuga* in Japan in 1912 (Kusano 1912). Subsequent studies confirmed that this fungus causes gall formation on faba bean (Kusano, 1936). The disease has since been reported in China (Xing, 1984) and Ethiopia, where it was first detected in North Shewa in 2010 (Dereje Gorfu *et al.*, 2012). Recent molecular evidence, however, has re-identified the causal agent as *Physoderma viciae*, correcting the long-standing misidentification (You *et al.*, 2021). The disease, known as Qormid in North Showa and South Wollo, Kolsim and Kortim in North Gondar, Aqorfid in East Gojam, and Chimid and Kurnchit in South Gondar, is most commonly called Qormid due to its distinctive leaf symptoms (Gezahegne Getaneh *et al.*, 2014).

Faba bean gall infection occurs at temperatures between 10°C and 25°C under high humidity conditions. Zoospores are released from resting sporangia in the presence of free water and can germinate between 5 and 30°C (Yan and Hua, 2012).

Resting spores can survive in soil and on crop debris for up to two years, serving as the primary inoculum for subsequent seasons. The disease is more prevalent and causes greater yield losses at altitudes above 2400 m a.s.l., where cooler temperatures and higher humidity favour its spread (Gezahegne Getaneh *et al.*, 2014).

Disease severity can reach 100%, resulting in complete crop failure across extensive areas within a single growing season (Abebe Teklay *et al.*, 2014). The disease has spread rapidly and aggressively throughout the northern and central highlands of Ethiopia, affecting all above-ground plant parts, including leaves, stems, and pods (Dereje Gorfu *et al.*, 2012).

Several factors contribute to the severity of faba bean gall epidemics. The widespread use of old, low yielding local varieties and the lack of access to improved, resistant varieties are primary contributing factors (Anteneh Ademe *et al.*, 2018). Additionally, limited use of inorganic fertilizers negatively affects soil nutrient status and overall crop productivity (Asfaw Solomon *et al.*, 2011), while the recent emergence of gall disease has compounded these challenges (Anteneh Ademe *et al.*, 2018; Wondwosen Wulita, 2015; Gezahegne Getaneh *et al.*, 2014).

In China, crop rotation with non-host cereals for three years and intercropping have been shown to reduce FBG incidence (Li-Juan *et al.*, 1993). Field sanitation practices, including residue removal, weed management, and stubble burning, are also recommended to minimize disease spread and severity (Yan and Hua, 2012).

Several studies have demonstrated the effectiveness of fungicides such as Bayleton 25 WP and Ridomil Gold MZ 68 WG in controlling faba bean gall (Teferi Teklay *et al.*, 2018; Hailemariam Bogale *et al.*, 2017; and Beyene Bitew and Abiro Tigabie, 2016). In the South Gonder Zone of northwestern Ethiopia, foliar application of Bayleton at 1.5 kg a.i. ha⁻¹ combined with varieties such as Adet-Hana, Bulga70, CS20DK, NC58, and Kasa reduced disease intensity and increased yields (Yitayih Getnet and Azmeraw Yehizbalem, 2017). Although farmers currently use fungicides to manage faba bean gall, frequent applications are required, which poses economic challenges for low-income farmers (Teferi Teklay *et al.*, 2018). Recent research suggests that integrated disease management is gaining recognition as a sustainable approach for controlling faba bean gall (Yitayih Getnet *et al.*, 2023).

Integrated disease management combining host resistance, cultural practices, and targeted fungicide application is the most effective strategy for reducing yield losses caused by faba bean gall. However, limited research has focused on the impact of combining faba bean varieties with foliar fungicide applications, specifically in South Wollo, northeastern Ethiopia. Therefore, this study was conducted to evaluate the effectiveness of integrating fungicides with different faba bean varieties for the management of faba bean gall disease under field conditions in South Wollo.

6.2 Materials and Methods

6.2.1 Description of the Study Area

The experiment was conducted in Tenta and Legambo districts, South Wollo, North-Eastern Ethiopia, during the 2022 and 2023 growing seasons. Legambo is one of the districts found in the South Wollo Zone, Amhara regional state, about 501 km away from Addis Ababa. Legambo, located at 10° 53' 56" N and 39° 3' 58" E, has an altitude ranging from 1,500 to 3,700 meters above sea level. The district experiences annual rainfall between 700 mm and 1,200 mm, with temperatures ranging from below 0°C to 13°C (LDANRDO 2023). Its climate consists of approximately 2.6% Wurchi, 48.4% Dega, and 49% Weina Dega. Legambo is known for its high yield production potential, especially for barley, faba beans, and peas.

Whereas Tenta district is found in North-Eastern Ethiopia, Amhara Regional State, and South Wollo Zone. It is 120 kilometers from Dessie, the zonal administrative centre, and 520 kilometers north of Addis Ababa. Its latitude is 11°19'N, its longitude is 39°15' E, and its typical elevation is between 1300 and 4000 meters above sea level. The region's typical temperature ranges from 4 to 40 °C. There is 700–1100 mm of annual rainfall on average, making for a dry environment. Therefore, there are two main rainy seasons (June to August and February to April) and bimodal rainfall (Teferi, 2013).

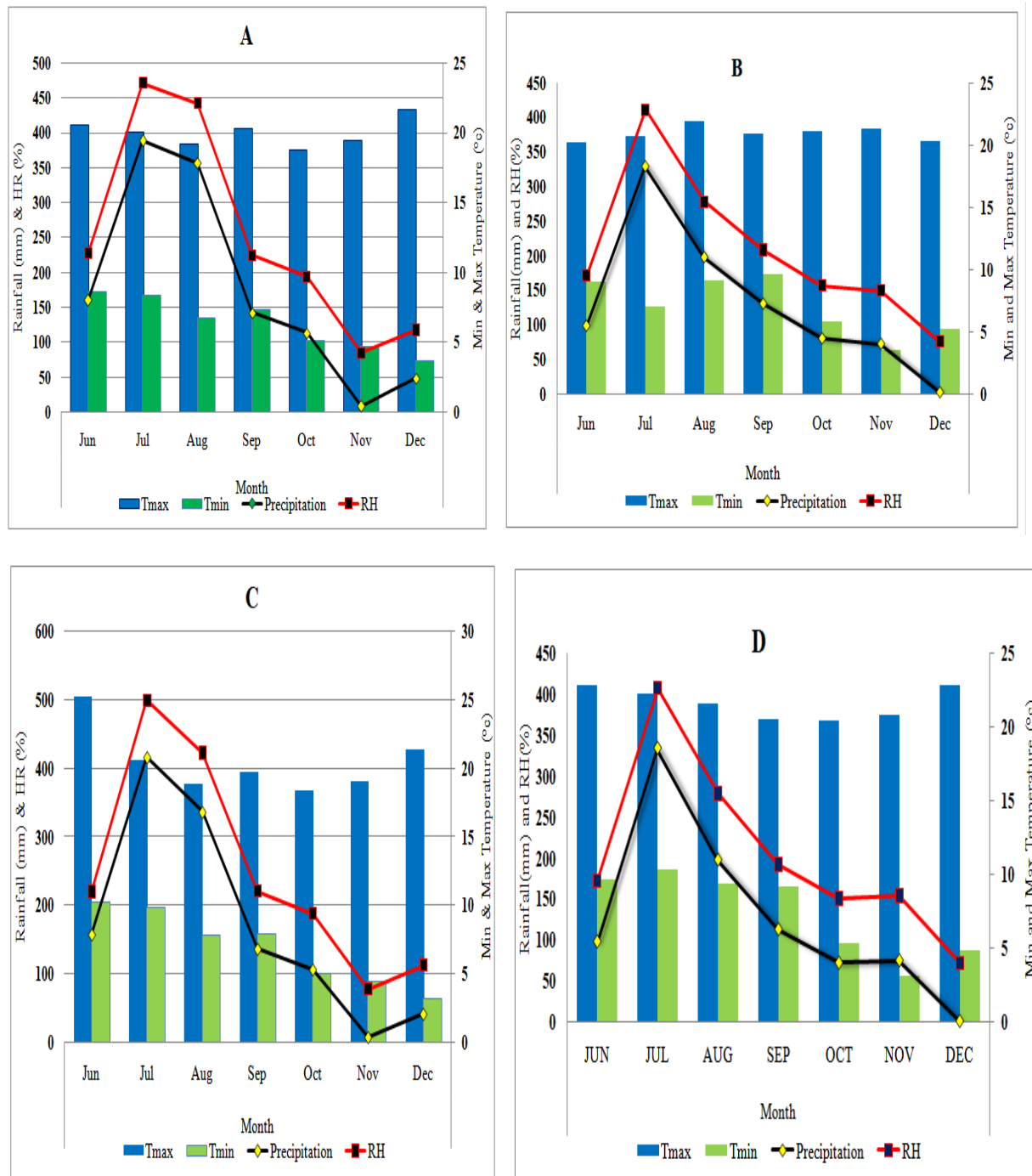


Figure 6. 1. The average annual maximum temperature, minimum temperature, and Relative humidity and mean monthly rainfall of 2 years at Legambo 2022(a) and 2023 (b) and Tenta 2022(c) and 2023(d) respectively.

6.2.2 Agronomic procedures and plant material.

The experimental field was prepared for faba bean seeding using conventional ploughing methods. All plots were weeded, fertilized with NPS, and managed according to recommended agronomic practices.

The study evaluated four fungicides, including an untreated control, applied to four faba bean varieties three improved (Dosha, Gora, and Wolkie) and one local check (Table 6. 1). The objective was to assess the interaction effects of fungicide treatments and faba bean varieties on the control of faba bean gall disease during the main cropping seasons of 2022 and 2023 at two experimental sites.

Table 6. 1 Description of Faba bean varieties

No	Faba bean varieties	Year of Release	Altitude (m.a.s.l.)	Annual rainfall (mm)		Yield(t) Research field
1	Dosha	2000	2050-2800	700-1000	Moderately resistance for Chocolate spot and Rust	2.8-6.2
2	Gora	2013	2000- 2800	700-1100	High yield, disease resistance and big seed size	4.41
3	Wolkie	2008	1900-2800	700-1000	High yield, resistance and big seed size	2.4-5.2
4	Local	Ns	Ns	Ns	Ns	Ns

Source: (MoARD, 2008), Variety Registration Book, Issue numbers 5-13N; Ns: Not specified

6.2.3 Experimental Design and Layout

The experiment was conducted using a factorial treatment arrangement in a randomized complete block design (RCBD) with three replications (Appendix Table 6. 1) The treatments consisted of four faba bean varieties (Gora, Dosha, Wolkie, and Local) combined with five fungicide treatments: Mancozebe 80% WP, Matco, Noble 25 WP, Ridomil Gold MZ 68 WG, and an untreated control. Thus, a total of 20 treatment combinations (4 varieties × 5 fungicide treatments) were evaluated (Table 6. 1 and Table 6. 2). Each experimental plot measured 2 m × 2 m, giving a total plot area of 4 m².

The spacing between plots and blocks was 0.5 m and 1.0 m, respectively. Plants were spaced 10 cm apart within rows, with 40 cm between rows. Fungicides were applied as foliar sprays at the recommended rates presented in Table 6. 1Table 6. 2.

Table 6. 2. Fungicides dose and mode of application used

Trade Name	Common Name	Dose	Mode of application
Mancozebe 80 WP	Mancozebe 80 WP	2kg/ha ⁻¹	Foliar spray
Matco	Meta laxyl 8% + Mancozebe 64% WP	2.5 kg/ha ⁻¹	Foliar spray
Ridomil Gold MZ 68WG	Meta laxilM40 g/kg +Mancozebe 640 g/kg	2.5kg/ha ⁻¹	Foliar spray
Noble 25 WP	Triadimefon 250 g/l	1.5kg/ha ⁻¹	Foliar spray

Source (Kebede Earecho, 2019) and (Kassa Yehuala *et al.*, 2020).

6.2.4 Data Collation

Disease incidence and severity data were collected from ten pre-tagged plants selected from the two central rows of each plot. The initial disease assessment was conducted at 40 days after sowing (DAS), when the first symptoms of faba bean gall disease were observed. Subsequent assessments were conducted at 10-day intervals until the end of the assessment period. The same tagged plants were used throughout the assessment period to monitor disease development and progression.

6.2.5 Disease-related parameters

Disease incidence was assessed at 10-day intervals starting at 40 DAS, when the first symptoms of faba bean gall disease were observed. Disease incidence was expressed as the percentage of plants showing visible disease symptoms relative to the total number of plants assessed and was calculated using the following formula:

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

Disease severity was assessed by estimating the percentage of leaf and stem area affected, using the 0-9 disease-scoring scale (Ding *et al.*, 1993). The following categories applied to the infection levels: 0, no visible infection on the leaves; 1, a few lesions that resemble dots and

make up less than 5% of the entire leaf area; 3–4, distinct galls, each smaller than 2 mm in diameter, that seize 6–25% of the leaf surface; 5, a large number of dispersed, somewhat linked galls that are 3–5 mm in diameter and cover 26–50% of the leaf surface with little to no defoliation; 6, confluent galls with considerable gall formation and roughly half of the leaves dead or defoliated, making up 51–75% of the leaf/stem area; 7, severe damage to larger leaves, with abundant gall formation covering over 76% of the leaf area; 8, 80% of the leaves defoliated, resulting in darkened and dead plants; and 9, disease affecting more than 80% of the foliar tissue, causing heavy defoliation and darkened and dead plants. For analysis, the severity ratings were transformed into a Percentage Severity Index (PSI) according to Wheeler (1969).

$$PSI = \frac{\text{Sum of numerical rating} \times 100}{\text{Number of plants scored} \times \text{Maximum score on scale}}$$

Area under the disease progress curve and the rate at which the disease progresses. According to Campbell and Madden (1990), the Area under Disease Progress Curve (AUDPC) was calculated using the PSI data and recorded at each assessment date.

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

The variables "xi" indicate the percentage of the disease's severity at the ith evaluation, "ti" indicates the time interval in days from the initial assessment date, and "n" indicates the total number of evaluations. Since time (t) was given in days and severity (x) was expressed in percentages, the AUDPC was calculated as a percentage per day. Disease severity was assessed at 10-day intervals from 40 DAS onward to quantify disease development over time. The AUDPC was expressed as percentage-days.

The disease progression parameters from each treatment were estimated using the Gompertz $-\ln [-\ln(Y)]$ (Berger, 1981) and logistic $\ln (Y/1-Y)$ (Van der Plank, 1969) models. The coefficient of determination (R^2) was used to assess the goodness of fit of the models. Next, the intercept of the curve and the apparent rate of disease increase (r) were calculated using the appropriate model. The factors were compared using analysis of variance (ANOVA) to evaluate the disease progression across the treatments.

6.2.6 Agronomic parameters

At maturity, the height of the plant was measured from the ground to the tips of ten selected random plants. One hundred seeds were randomly selected from each plot, and their weights were recorded. The grain yield per plot, which was then converted into a yield per hectare basis, was recorded using the two central rows (Birru, 1979).

6.2.7 Relative Yield Loss

The yield difference between the lower treatments and the basic treatment (plots with all treatment combinations) was calculated using the formula (Ararsa *et al.*, 2018) to determine the relative yield loss.

$$RYL = (Y_{bt} - Y_{lt} / Y_{bt}) \times 100$$

Where RYLP is the relative yield loss percentage, Y_{bt} yield of basic treatment (treatment plots with all treatments), and Y_{lt} is the yield from the lower treatment.

6.2.8 Cost-benefit analysis

The cost of the products for each treatment was computed on a per hectare basis, and the price of faba bean seeds (\$/kg) was determined based on local market values. Input costs, such as labour and fungicides, were converted to a per-hectare basis based on their frequency of use. Since the mean yields of the treatments varied significantly, a partial budget analysis was conducted using the marginal rate of return (MRR) to evaluate the data. Marginal analysis was used to evaluate the impact of small changes in input combinations on net returns.

According to (CIMMYT, 1988), the marginal rate of return is a measure used to examine how new management changed net returns relative to the previous one. The average yields for all treatments are known as the unadjusted grain yield (UGY) (ton/ha^{-1}). Adjusted grain yield (AGY) (ton/ha^{-1}): The yield gap refers to the difference between the experimental yield obtained under improved management practices and the yield that farmers usually achieve under their local farming conditions.

The average grain yield obtained from each treatment was reduced by 10% to account for the difference between experimental yields and the yields typically achieved by farmers under field conditions. The adjusted grain yield (AGY) was then multiplied by the farm gate price, which refers to the price farmers receive when selling their produce, to estimate the Gross Field Benefit (GFB) expressed in $\$/\text{ha}^{-1}$

$$\text{GFB} = \text{AGY} \times \text{Farm Gate Price}$$

The Total Variable Cost (TVC) was calculated by combining the costs of fungicides and the labour expenses associated with fungicide application in Tenta and Legambo districts, expressed in $\$/\text{ha}^{-1}$.

Across all treatments or plots, the expenses of other inputs and production techniques, including labour for preparing the soil, sowing, and weeding, applying NPS fertilizer, harvesting, and threshing, were constant. The net benefit (NB) in \$ dollars per hectare was calculated by subtracting the total variable costs (TVC) from the gross field benefits (GFB) for each treatment. $\text{NB} = \text{GFB} - \text{TVC}$. The Marginal Rate of Return (MRR) was calculated to assess the economic advantage obtained from additional investment in a treatment. It measures the increase in net benefit associated with an increase in total variable cost and is expressed as a percentage. The MRR helps determine whether the additional cost incurred by a treatment results in a proportionally higher economic return.

$$\text{MRR \%} = \Delta \text{NB} / \Delta \text{TVC} * 100$$

Where: MRR, marginal rate of return; **NB**, variation in net benefit; TVC, total variable cost.

6.3 Statistical Analysis

Disease parameters (disease incidence, percent severity index, area under the disease progress curve), seed yield, and yield components (number of pods per plant, seeds per pod, and 100-seed weight) were analyzed using the software analysis of variance (ANOVA) to assess the effects of the main treatments and their interactions. All data analysis was conducted using R software, version 4.4.1 (R Core Team, 2024).

Separating treatment means was done using the Duncan multiple range tests at a 5% probability level (Gomez and Gomez, 1984). Pearson correlation coefficients were calculated to assess the strength and direction of the relationships among the measured parameters.

6.4 Results and Discussion

6.4.1 Disease Parameters

The combined analysis of variance revealed highly significant differences ($p < 0.001$) in disease incidence (DI), disease severity (percentage severity index, PSI), and the area under the disease progress curve (AUDPC) among treatments across the 2022 and 2023 cropping seasons in Tenta and Legambo districts (Appendix Table 6. 3, Appendix Table 6. 4, and Appendix Table 6. 5). Among the fungicides tested, Noble 25 WP was the most effective in reducing both disease incidence and severity compared to other fungicides and the untreated control.

Gall disease prevalence was higher, and grain yield was lower in both districts during the 2022 season compared to 2023. Across both seasons, Tenta consistently recorded higher yields and lower disease incidence than Legambo. Environmental conditions, including temperature, rainfall, and relative humidity, significantly influenced disease progression. In 2022, the combination of low temperature, high humidity, and frequent rainfall likely created favourable conditions for spore germination and infection. Similar relationships between high humidity, frequent rainfall, and increased pathogen infection have been reported in previous studies conducted in other areas (Yitayih Getnet *et al.*, 2023; Teferi Teklay *et al.*, 2018; Bitew Beyene *et al.*, 2023).

Table 6. 3. Mean squares analysis of location, year, varieties, fungicide and the combined effect on faba bean gall disease incidence, severity and AUDPC at Legambo and Tenta in 2022 and 2023 main growing seasons.

Source	DF	DI (%)	PSI (%)	AUDPC(%-days)
Block	2	2.09ns	1.86ns	551.59ns
Loc	1	42.99*	33.44*	14634.69*
Year	1	123.01**	117.68**	82231.05***
Loc*Year	1	3.07ns	1.06ns	80.37ns
Variety	3	517.11***	525.94***	546382.71***
Fungicide	4	12250.83***	9696.77*****	4607679.05***

Variety*Fungicide	12	39.80***	32.05***	15854.43ns
Year*Variety	3	0.031ns	0.39ns	68.58ns
Year*Fungicide	4	0.43ns	0.23ns	143.52ns
Year*Variety*Fungicide	12	0.98ns	0.46ns	137.40ns
Loc*Variety	3	0.32ns	0.79ns	91.31ns
Loc*Fungicide	4	0.23ns	0.37ns	97.73ns
Loc*Variety*Fungicide	12	0.23ns	0.52ns	76.42ns
Loc*Year*Variety	3	0.31ns	0.39ns	82.44ns
Loc*Year*Fungicide	4	0.42ns	0.35ns	99.20ns
Loc*Year*Variety*Fungicide	12	0.32ns	0.49ns	88.22ns
Residuals	158	6.2	4.2	2061
Mean		49.52	32.43	996.62
Coefficient of Variance		6.68	8.87	6.11

I=Disease Incidence, PSI=Percentage Severity, AUDPC=Area under Disease Progress

Curve*, ** and *** refer to level of significance at $p \leq 0.05$, 0.01 and 0.001.

6.4.2 Disease incidence

Disease incidence varied ($p < 0.001$) across all faba bean varieties, locations, and cropping seasons (Table 6. 3). Disease incidence was significantly affected by the interaction between faba bean variety and fungicide treatment ($p < 0.001$), indicating that the effectiveness of fungicides varied depending on the variety used. Disease incidence was assessed at 10-day intervals starting from 40 days after sowing (DAS), when the first symptoms of faba bean gall disease were observed, and continued throughout the disease assessment period. The variety $\times$ fungicide interaction showed substantial differences in disease incidence among treatment combinations. The lowest disease incidence (38.78%) was recorded in Dosha treated with Noble 25 WP, whereas the highest incidence (84.59%) occurred in the untreated local variety (Table 6. 4).

This result indicates that the effectiveness of fungicide application was enhanced when combined with a variety with relatively better resistance to faba bean gall disease. In contrast, the local variety without fungicide protection was highly affected by the disease.

The lower disease incidence observed in Dosha combined with Noble 25 WP suggests that integrating host resistance with effective fungicide protection provided greater suppression of faba bean gall disease than either component alone. The response of the varieties to fungicide

application was not uniform, demonstrating the importance of selecting an appropriate combination of variety and fungicide for effective disease management (Appendix Table 6. 6).

The significant variety $\times$ fungicide interaction is consistent with previous studies reporting differences in varietal response to faba bean gall disease and variation in fungicide effectiveness. Abebe Teklay *et al.* (2014) reported disease incidence ranging from 5% to 100% among faba bean fields in Tigray, while Yitayih Getnet and Azmeraw Yehizbalem (2017) reported considerable variation in the response of faba bean varieties to gall disease. Likewise, Kebede Wulita *et al.* (2019) found that fungicides such as Bayleton and Ridomil Gold reduced faba bean gall disease severity. These findings support the importance of integrating relatively resistant varieties with effective fungicides for improved management of faba bean gall disease. Similarly, (Teferi Teklay *et al.*, 2018) reported that Bayleton and Ridomil Gold effectively reduced faba bean gall severity in northern Ethiopia. Other studies also demonstrated that appropriate fungicide application methods and rates can reduce disease severity and improve yield performance (Li-Juan *et al.*, 1993; Beyene Bitew and Abiro Tigabie, 2016; Hailemariam Bogale *et al.*, 2017).

Overall, the significant variety $\times$ fungicide interaction demonstrates that fungicide effectiveness was variety-dependent. Among the treatment combinations evaluated, Dosha + Noble 25 WP was the most effective combination for reducing disease incidence, and therefore it could be considered a promising integrated management option for faba bean gall disease under the conditions of the present study.

Table 6. 4. Interaction effect of fungicide treatments and faba bean varieties on faba bean gall disease incidence (%) at Legambo and Tenta districts during the 2022 and 2023 main cropping seasons.

Variety	Variety*fungicide				
	Control	Mancozebe	Noble	Matco	Ridomil
Dosha	72.29 ^c	40.90 ^{ij}	38.78 ^j	40.77 ^{ij}	40.31 ^{ij}
Wolkie	73.53 ^c	42.35 ^{g-i}	39.31 ^j	41.83 ^{hi}	40.52 ^{ij}
Gora	81.54 ^b	45.59 ^{d-f}	40.75 ^{ij}	44.38 ^{e-g}	43.65 ^{f-h}
Local	84.59 ^a	46.9 ^d	42.36 ^{g-i}	46.36 ^{de}	43.66 ^{f-h}

6.4.3 Disease Severity

The interaction between faba bean variety and fungicide treatment had a highly significant effect on disease severity ($p < 0.001$), indicating that the effectiveness of fungicides varied among varieties (**Table 6. 3**). The lowest percentage severity index (PSI) was recorded in Dosha treated with Noble 25 WP (21.08%), followed by Wolkie treated with Noble 25 WP (23.40%) and Gora treated with Noble 25 WP (23.96%) (Table 6. 5). In contrast, the highest disease severity was recorded in the untreated local variety (64.31%), followed by the untreated Gora (59.61%), Wolkie (54.28%), and Dosha (52.20%) treatments. These results demonstrate that the response to fungicide application differed among varieties and that the combination of a relatively resistant variety with an effective fungicide provided greater suppression of disease severity.

Across fungicide treatments, Noble 25 WP consistently produced low disease severity when combined with the improved varieties, particularly Dosha and Wolkie. The relatively low PSI observed in Dosha + Noble 25 WP suggests that host resistance and fungicide protection complemented each other in suppressing disease development. In contrast, the high PSI recorded in the untreated varieties, particularly the local variety, indicates greater disease susceptibility in the absence of fungicide protection. Therefore, the significant variety $\times$ fungicide interaction supports the use of specific variety–fungicide combinations rather than relying on either host resistance or fungicide application alone.

Disease severity was higher in 2022 than in 2023 and was also greater at Legambo than at Tenta (Figure 6. 1). These differences may be associated with variation in environmental conditions between seasons and locations, particularly temperature, relative humidity, and rainfall, which can influence the development and spread of faba bean gall disease. However, these environmental effects should be interpreted cautiously unless the corresponding weather data statistically support the observed differences.

Noble 25 WP, containing triadimefon, was among the most effective fungicide treatments in reducing disease severity. Triadimefon belongs to the triazole group of fungicides and acts by inhibiting sterol biosynthesis, thereby interfering with fungal growth and development.

The relatively low disease severity observed with Noble 25 WP across the tested varieties indicates its potential for reducing faba bean gall disease under the conditions of the present study. The present findings are consistent with previous studies showing that faba bean varieties differ in their response to gall disease and that fungicide application can reduce disease severity.

These findings align with previous studies (Abebe Teklay *et al.*, 2014 and Yitayih Getnet and Azmeraw Yehizbalem, 2017) reported that resistant faba bean varieties generally exhibit lower disease severity than susceptible varieties.. Similarly, Beyene Bitew and Abiro Tigabie (2016) and Teferi Teklay *et al.* (2018) reported that fungicide applications, including Ridomil Gold, reduced faba bean gall disease. The present study further demonstrates that fungicide effectiveness depends on the variety with which it is combined. Overall, the significant variety $\times$ fungicide interaction indicates that Dosha + Noble 25 WP were the most effective treatment combination for reducing faba bean gall disease severity. This combination therefore represents a promising integrated disease management option under the agro-ecological conditions of South Wollo.

Table 6. 5. Interaction effect of fungicide treatments and faba bean varieties on percentage severity index (PSI) of faba bean gall disease at Legambo and Tenta districts during the 2022 and 2023 main cropping seasons.

Variety	Variety*fungicide				
	Control	Mancozebe	Noble	Matco	Ridomil
Dosha	52.20 ^d	24.98 ^h	21.08 ⁱ	24.24 ^h	23.62 ^h
Wolkie	54.28 ^c	26.74 ^g	23.4 ^h	26.64 ^g	23.91 ^h
Gora	59.61 ^b	29.88 ^{ef}	23.96 ^h	28.93 ^f	24.82 ^h
Local	64.31 ^a	31.06 ^e	24.96 ^h	30.71 ^{ef}	29.12 ^f

6.4.4 Area under Disease Progress Curve (AUDPC)

The analysis of variance showed that year, variety, fungicide, and the variety $\times$ fungicide interaction significantly affected the area under the disease progress curve (AUDPC) ($p < 0.001$) (Table 6. 6). The significant variety $\times$ fungicide interaction indicates that the effectiveness of fungicides in reducing disease progression depended on the faba bean variety. Therefore, the interaction effect is more informative for evaluating the effectiveness of integrated varietal and fungicide management than the individual main effects.

The combined effect of variety and fungicide showed substantial differences in disease progression (Table 6. 6). The highest AUDPC (1721.26 %-days) was recorded for the untreated local variety, indicating prolonged and severe disease development throughout the assessment period. In contrast, Dosha treated with Noble 25 WP recorded the lowest AUDPC (653.99 %-days), followed by Wolkie treated with Noble 25 WP (780.07 %-days) and Dosha treated with Ridomil Gold (780.32 %-days). The lower AUDPC values obtained from these combinations indicate that disease development was suppressed more effectively when a relatively resistant variety was combined with an effective fungicide. Conversely, the high AUDPC recorded in untreated varieties, particularly the local variety, indicates greater disease accumulation in the absence of both host resistance and fungicide protection.

The difference between the best and poorest treatment combinations demonstrates the importance of integrating host resistance with fungicide application. The AUDPC of the untreated local variety was approximately 2.6 times higher than that of Dosha treated with Noble 25 WP.

This indicates that the combined use of a moderately resistant variety and an effective fungicide can substantially reduce the amount of disease accumulated during the crop-growing period. The relatively low AUDPC values recorded for Dosha and Wolkie when treated with Noble 25 WP also suggest that these varieties responded favourably to fungicide protection. Thus, the significant interaction observed in this study provides strong evidence that disease management should be based on appropriate combinations of variety and fungicide rather than relying on either component alone.

The local variety recorded the highest AUDPC value (1107.93 %-days), whereas Dosha showed the lowest AUDPC (889.13 %-days), indicating that host resistance plays an important role in reducing disease development (Figure 6. 3.). Fungicide treatments, particularly Noble 25 WP and Ridomil Gold, also reduced AUDPC values across both seasons, demonstrating their effectiveness in managing faba bean gall disease (Kassa Yehuala *et al.*, 2020; Bitew Beyene *et al.*, 2022). Disease progression also differed between cropping seasons and locations. The higher AUDPC recorded in 2022 than in 2023 indicates greater cumulative disease pressure during the

2022 season. Similarly, Legambo consistently exhibited higher disease incidence, severity, and AUDPC than Tenta.

These differences may be related to variation in temperature, rainfall, relative humidity, and leaf-wetness conditions between the two environments. Such conditions can influence the availability of free water required for infection and the subsequent development and spread of *Physoderma viciae*. The greater disease pressure at Legambo therefore suggests that environmental conditions at this site were more favourable for disease development, increasing the importance of effective host and fungicide combinations.

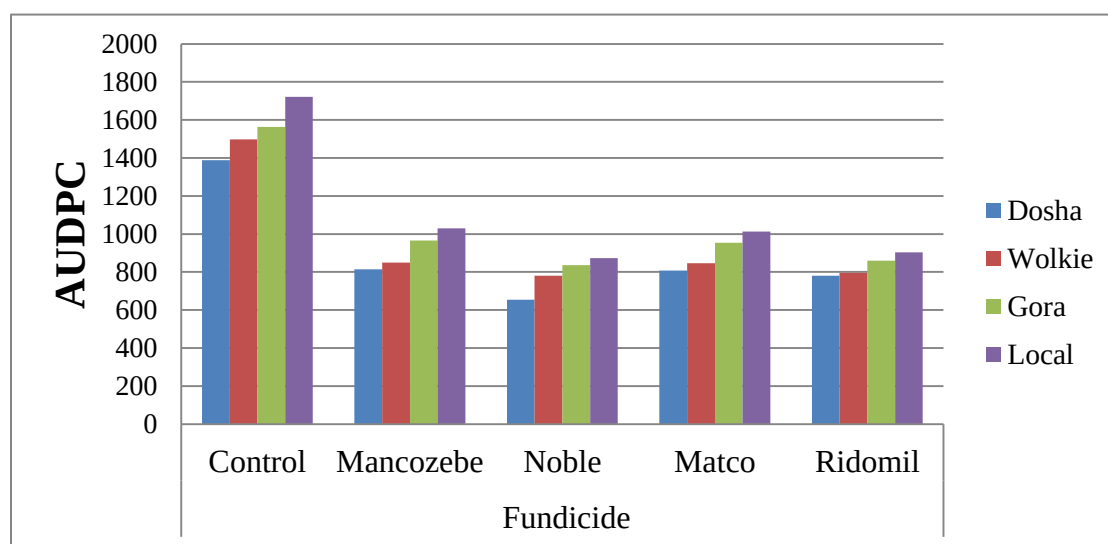


Figure 6. 2. Area under the disease progress curve (AUDPC) as affected by variety $\times$ fungicide combinations for faba bean gall disease at Legambo and Tenta during the 2022 and 2023 cropping seasons.

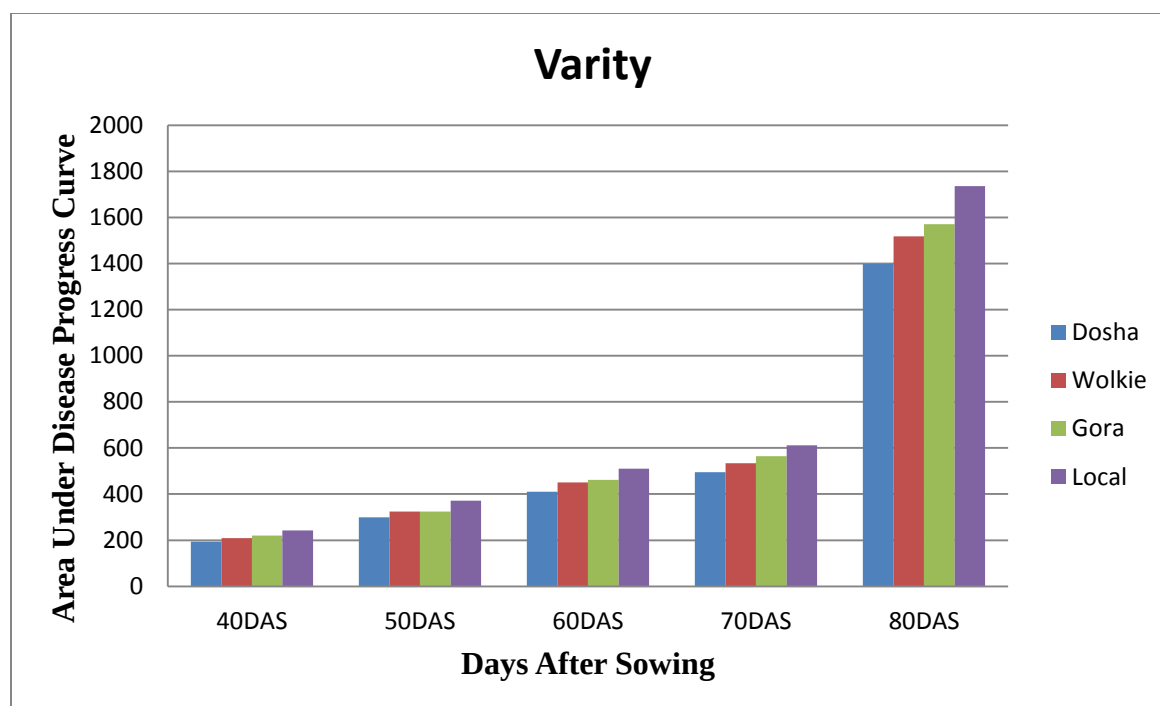


Figure 6. 3. Area under the disease progress curve (AUDPC) of faba bean varieties for faba bean gall disease at Legambo and Tenta during the 2022 and 2023 cropping seasons.

The present findings are consistent with previous studies reporting that varietal resistance and fungicide application can reduce faba bean gall disease development under field conditions (Kebede Wulita *et al.*, 2019; Teferi Teklay *et al.*, 2018; Yitayih Getnet and Azmeraw Yehizbalem, 2017; Yirga Kindie and Zinabu Nigusie, 2019; Gereziher Teame *et al.*, 2018). Previous reports also confirmed that fungicides such as Bayleton and Ridomil Gold effectively reduced faba bean gall disease and improved yield performance under field conditions (Teferi Teklay *et al.*, 2018; Bekele Belachew *et al.*, 2018; Wondwosen Wulita, 2015; Kebede Wulita *et al.*, 2019). However, the present study further demonstrates that the response to fungicide application was influenced by the variety used. The superior performance of the Dosha × Noble 25 WP combination suggests that integrating a moderately resistant variety with an effective fungicide can provide more effective suppression of disease progression than using susceptible varieties or untreated plants.

Overall, AUDPC results demonstrate that the Dosha × Noble 25 WP combination was the most effective treatment for reducing cumulative faba bean gall disease development under the conditions of this study. Therefore, this combination should be given priority for management of

faba bean gall, particularly in high disease-pressure environments such as Legambo. Further evaluation across additional locations and seasons would be useful to confirm the consistency of this treatment under diverse environmental conditions.

Table 6. 6. Interaction effect of fungicide treatments and faba bean varieties on area under the disease progress curve (AUDPC) of faba bean gall disease at Legambo and Tenta districts during the 2022 and 2023 main cropping seasons.

Variety	Variety*Fungicide				
	Control	Mancozebe	Noble	Matco	Ridomil
Dosha	1388.00 ^d	815.06 ^{ij}	653.99 ^k	808.26 ^{ij}	780.32 ^j
Wolkie	1498.14 ^c	848.78 ^{hi}	780.07 ^j	846.07 ^{hi}	795.29 ^j
Gora	1563.47 ^b	965.01 ^f	836.39 ^{hi}	954.77 ^f	859.11 ^h
Local	1721.26 ^a	1028.98 ^e	872.69 ^{gh}	1013.03 ^e	903.66 ^g

The means indicated by the same letters did not differ significantly from each other. MSqE, Means square of error, and CV, coefficient of variance.

6.4.5 Progression Rate of Faba Bean Gall Disease

Disease progression rates were estimated using both the logistic and Gompertz models. The logistic model consistently produced higher coefficients of determination (R^2) than the Gompertz model across all disease severity assessments. Therefore, logistic-derived rates were used to compare epidemic development among variety–fungicide combinations across locations and cropping seasons. Disease progression rates varied significantly among treatments, locations, and cropping seasons. During the 2022 cropping season, the highest disease progression rates were recorded in untreated local variety plots at Tenta and Legambo, with rates of 0.059 and 0.053 logit day⁻¹, respectively. In contrast, Dosha treated with Noble 25 WP showed the lowest epidemic rates, recording 0.013 logit day⁻¹ at Tenta and 0.017 logit day⁻¹ at Legambo (

Table 6. 7). Similarly, in the 2023 cropping season, the untreated local variety again exhibited the highest disease progression rates, with values of 0.054 logit day⁻¹ at Tenta and 0.052 logit day⁻¹ at Legambo. The lowest progression rates were recorded from Dosha treated with Noble 25 WP, with values of 0.012 and 0.011 logit day⁻¹ at Tenta and Legambo, respectively (

Table 6. 7).

Fungicide application substantially reduced disease progression across both locations and cropping seasons. At Legambo, Noble 25 WP-treated Dosha plots reduced disease progression rates by 90.1% in 2022 and 80% in 2023 (Appendix Table 6. 7). At Tenta, reductions were even greater, reaching 98.3% in 2022 and 96.6% in 2023. Across all treatments, Noble 25 WP consistently performed better than Ridomil Gold in reducing epidemic development (Table 6. 6). The superior performance of Noble 25 WP may be attributed to its systemic mode of action. The fungicide is absorbed and translocated within plant tissues, providing both preventive and curative protection against faba bean gall disease. In contrast, Ridomil Gold is a semi-systemic fungicide composed of Metalaxyl, which provides systemic activity, and Mancozebe, which acts as a contact fungicide. Since Mancozebe remains on the plant surface, it is more susceptible to wash-off by rainfall or irrigation and therefore may require repeated applications. These differences in fungicide properties likely contributed to the higher effectiveness of Noble 25 WP in suppressing disease progression. Among the tested treatments, Dosha combined with Noble 25 WP consistently resulted in the lowest disease progression rates across locations and seasons. Specifically, at Legambo, Noble 25 WP reduced disease progression in Dosha plots by 98.1% in 2022 and 96.1% in 2023 (Appendix Table 6. 7.). Similarly, at Tenta, reductions reached 96.6% in 2022 and 95.5% in 2023. These findings demonstrate that integrating moderately resistant varieties such as Dosha with systemic fungicides like Noble 25 WP provides an effective strategy for slowing epidemic development and minimizing the impact of faba bean gall disease. The present findings are consistent with previous studies conducted in other faba bean-growing areas of Ethiopia. Yitayih Getnet and Azmeraw Yehizbalem (2017) reported that integrating resistant varieties with fungicide application significantly reduced disease development and epidemic progression. Similarly, Teferi Teklay *et al.* (2018) and Kebede Wulita *et al.* (2019) demonstrated that fungicides such as Bayleton and Ridomil Gold effectively suppressed faba bean gall epidemics under field conditions. Other studies also indicated that disease progression and fungicide effectiveness vary across locations and seasons depending on environmental conditions and varietal response (Gereziher Teame *et al.*, 2018; Yirga Kindie and Zinabu Nigusie, 2019).

Although these studies were conducted in different locations, they support the general consistency of the present findings regarding the integrated management of faba bean gall disease.

Table 6. 7. Adjusted coefficient of determination (R²) and faba bean gall progression rate (r) in logit per day for faba bean varieties combined with fungicide in Legambo and Tenta districts during the 2022 and 2023 growing seasons.

Variety	Fungicide	Legambo				Tenta			
		2022		2023		2022		2023	
		R ²	Rate(r)	R ²	Rate(r)	R ²	Rate(r)	R ²	Rate(r)
Dosha	Control	98.1	0.048	96.1	0.046	96.6	0.048	95.5	0.046
	Mancozebe	94.4	0.023	91.8	0.016	91.3	0.018	91.3	0.015
	Noble	90.1	0.017	80.0	0.011	84.1	0.013	78.2	0.012
	Matco	93.5	0.023	91.3	0.016	89.9	0.017	89.6	0.018
	Ridomil	93.2	0.017	90.4	0.017	89.3	0.017	88.7	0.017
Wolkie	Control	98.2	0.054	98.3	0.048	96.8	0.045	96.7	0.049
	Mancozebe	95.0	0.023	93.2	0.018	93.5	0.018	91.7	0.016
	Noble	92.3	0.018	90.4	0.013	87.5	0.014	87.2	0.012
	Matco	94.7	0.022	92.6	0.019	93.4	0.019	90.1	0.019
	Ridomil	93.3	0.017	90.7	0.014	89.4	0.015	89.5	0.014
Gora	Control	98.9	0.053	98.9	0.049	97.9	0.050	97.9	0.049
	Mancozebe	95.0	0.021	94.4	0.015	94.4	0.015	93.1	0.016
	Noble	94.4	0.013	93.0	0.013	92.4	0.013	89.3	0.012
	Matco	94.7	0.017	93.4	0.015	93.4	0.015	93.0	0.014
	Ridomil	93.9	0.013	93.2	0.012	94.8	0.015	90.1	0.013
Local	Control	99.6	0.059	99.2	0.054	98.3	0.053	98.4	0.052
	Mancozebe	96.1	0.022	95.7	0.018	95.7	0.018	94.1	0.018
	Noble	94.1	0.017	94.4	0.012	90.9	0.014	92.7	0.016
	Matco	95.8	0.019	95.0	0.017	95.0	0.017	93.9	0.016
	Ridomil	95.5	0.018	91.9	0.013	92.1	0.014	92.0	0.013

R² Coefficient of determination for the Logistic epidemiological model a Disease progress rate obtained from regression line of disease severity against time of disease assessment

6.4.6 Crop Yield Parameter

The combined analysis of variance showed that year, location, variety, and fungicide application significantly affected most of the measured agronomic traits and grain yield of faba bean (Table 6. 8). More importantly, the variety × fungicide interaction was significant for plant height, number of pods per plant, seeds per pod, and grain yield, indicating that the response of the varieties to fungicide application differed.

Therefore, the interaction effect is considered in interpreting these traits. In contrast, the variety $\times$ fungicide interaction was not significant for hundred-seed weight, indicating that the effect of fungicide treatment on seed weight was relatively consistent among varieties.

Table 6. 8. Analysis of the combined effects of year, location, fungicide, and variety on faba bean yield and yield components in Tenta and Legambo during the 2022 and 2023 growing seasons.

Source	DF	PH	NPP	SPP	Yield	HSW
Block	2	12.48ns	11.44**	0.02ns	0.04ns	13.55ns
Loc	1	63.49**	7.79*	0.52***	0.55***	462.79***
Year	1	123.44***	23.66***	2.78***	2.26***	452.51***
Loc*Year	1	0.65ns	0.01ns	0.06ns	0.08ns	179.07**
Variety	3	1308.67***	44.91***	2.08***	3.78***	612.07***
Fungicide	4	2857.02***	67.27***	5.99***	17.90***	3541.42***
Variety*Fungicide	12	11.03*	2.59*	0.05**	0.09*	15.20
Year*Variety	3	5.54ns	0.16ns	0.02ns	0.03ns	6.65ns
Year*Fungicide	4	0.87ns	0.46ns	0.03ns	0.03ns	1.15ns
Year*Variety*Fungicide	12	1.27ns	0.30ns	0.02ns	0.01ns	1.21ns
Loc*Variety	3	1.01ns	0.01ns	0.002ns	0.01ns	3.14ns
Loc*Fungicide	4	0.56ns	0.12ns	0.01ns	0.01ns	3.54ns
Loc*Variety*Fungicide	12	0.54ns	0.04ns	0.01ns	0.01ns	1.42ns
Loc*Year*Variety	3	0.31ns	0.09ns	0.03ns	0.004ns	1.31ns
Loc*Year*Fungicide	4	0.27ns	0.04ns	0.01ns	0.01ns	3.22ns
Loc*Year*Variety*Fungicide	12	0.39ns	0.12ns	0.01ns	0.01ns	2.24ns
Residuals	158	3.60	0.494	0.027	0.039	24.8
Coefficient of Variance		3.07	7.97	4.46	6.9	7.11
Mean		80.08	14.87	3.23	2.88	70.04

PH, plant height; NPP, number of pods per a plant; SPP, seed per pod; and HSW, hundred seed weight. *, ** and *** refer to level of significance at $p \leq 0.05$, 0.01 and 0.001

6.4.7 Plant height of faba bean

Plant height was significantly affected by variety, fungicide treatment, year, and location ($p < 0.001$) (Table 6. 8). The significant variety $\times$ fungicide interaction ($p \leq 0.05$) indicates that the effect of fungicide application on plant growth varied among varieties. The tallest plants (94.18 cm) were recorded from Dosha treated with Noble 25 WP, whereas the shortest plants (62.90 cm) were observed in the untreated local variety (Table 6. 9). The greater plant height obtained from the Dosha $\times$ Noble 25 WP combination may be associated with the combined contribution of varietal performance and effective suppression of faba bean gall disease. Severe disease can reduce functional leaf area and photosynthetic activity, thereby limiting assimilate production and plant growth. The untreated local variety had greater disease incidence, severity, and

AUDPC in the preceding disease assessments, which may have contributed to its reduced growth.

The substantially greater plant height of fungicide-treated plants, particularly Dosha treated with Noble 25 WP, therefore suggests that effective disease suppression helped maintain vegetative growth. Similar findings were reported by Bitew *et al.* (2022), who reported that faba bean gall disease adversely affected plant growth and yield components under Ethiopian field conditions. The results further indicate that combining a relatively better-performing variety with an effective fungicide can provide greater protection of plant growth than using either component alone.

Table 6. 9. Interaction effect of fungicide and varieties on plant height of faba bean over years and locations.

Varity	Variety *Fungicide				
	Control	Mancozebe	Noble	Matco	Ridomil
Dosha	73.58 ^h	87.18 ^{bc}	94.18 ^a	87.25 ^{bc}	88.66 ^b
Wolkie	69.32 ⁱ	83.75 ^{de}	88.92 ^b	83.99 ^{de}	87.58 ^{bc}
Gora	66.27 ^j	77.10 ^{fg}	85.79 ^{cd}	78.51 ^f	84.12 ^{de}
Local	62.90 ^k	75.71 ^g	82.88 ^e	77.14 ^{fg}	78.76 ^f

Mean values in the same column with different letters represent significant variation at a 5% probability level. PH plant height

6.4.8 Seeds per pod and number of pods per plant

The number of pods per plant was significantly affected by year, location, variety, and fungicide treatment ($p < 0.001$) (Table 6. 8). The variety $\times$ fungicide interaction was also significant ($p \leq 0.05$), demonstrating that pod production responded differently to fungicide treatment depending on the variety. The highest number of pods per plant (18.01) was recorded from Dosha treated with Noble 25 WP, whereas the lowest value (12.81) occurred in the untreated local variety (Table 6. 10). The greater pod production in the Dosha $\times$ Noble 25 WP treatment may be explained by the lower disease pressure observed in this combination. Reduced disease damage can preserve photosynthetically active leaf area and improve assimilate production during the reproductive stage, thereby supporting pod initiation and development.

In contrast, the high disease pressure in the untreated local variety may have restricted reproductive development, resulting in fewer pods per plant. Thus, the significant interaction

demonstrates that the benefit of fungicide protection was dependent on the genetic background of the variety.

Table 6. 10. Interaction effect of fungicide and varieties on number of pods per plant of faba bean over years and locations.

Variety	Variety *Fungicide				
	Control	Mancozebe	Noble	Matco	Ridomil
Dosha	13.37 ^{jk}	15.61 ^{de}	18.01 ^a	15.77 ^{cde}	16.30 ^c
Wolkie	13.31 ^{jk}	15.19 ^{ef}	17.12 ^b	13.84 ^{ij}	16.10 ^{cd}
Gora	13.12 ^k	14.05 ^{hi}	15.87 ^{cd}	14.47 ^{d-g}	14.73 ^{fg}
Local	12.81 ^k	13.82 ^{ij}	14.58 ^{fgh}	14.38 ^{ghi}	14.46 ^{ghi}

Seeds per pod were also significantly affected by variety and fungicide treatment ($p < 0.001$), while the variety $\times$ fungicide interaction was significant ($p \leq 0.01$) (Table 6. 8). The highest number of seeds per pod (3.77) was recorded from Dosha treated with Noble 25 WP, whereas the lowest value (2.57) was observed in the untreated local variety (Table 6. 11). The greater number of seeds per pod under effective fungicide protection may indicate improved reproductive development resulting from reduced disease stress during flowering and pod formation.

The observed varietal differences in pods per plant and seeds per pod may also reflect genetic differences among the varieties. Similar varietal variation in faba bean yield components has been reported (Tafere Mulualem *et al.*, 2012 and Gerezihir Teame, 2018) However, the significant variety $\times$ fungicide interaction in the present study indicates that genetic potential alone did not determine reproductive performance; disease protection through appropriate fungicide treatment also contributed to the expression of yield components.

Table 6. 11. Interaction effect of fungicide and varieties on a seed per pod of faba bean over years and locations.

Variety	Variety *Fungicide				
	Control	Mancozebe	Noble	Matco	Ridomil
Dosha	2.804 ^f	3.31 ^{cd}	3.77 ^a	3.56 ^b	3.73 ^a
Wolkie	2.73 ^{fg}	3.303 ^{cd}	3.74 ^a	3.32 ^{cd}	3.56 ^b
Gora	2.61 ^{gh}	3.01 ^e	3.45 ^{bc}	3.06 ^e	3.28 ^d
Local	2.57 ^h	2.99 ^e	3.44 ^{bc}	3.01 ^e	3.27 ^d

6.4.9 Faba bean grain yield

Grain yield was highly significantly affected by year, location, variety, and fungicide treatment ($p < 0.001$) (Table 6. 8). However, because the variety $\times$ fungicide interaction was significant ($p \leq 0.05$), the combined response of variety and fungicide provides the most relevant basis for interpreting yield performance.

The variety $\times$ fungicide interaction showed clear differences among treatment combinations (Table 6. 12). The highest grain yield (3.79 t ha^{-1}) was obtained from Dosha treated with Noble 25 WP, followed by Wolkie treated with Noble 25 WP (3.68 t ha^{-1}) and Dosha treated with Ridomil Gold (3.57 t ha^{-1}). In contrast, the lowest grain yield (1.64 t ha^{-1}) was recorded from the untreated local variety, followed by untreated Gora (1.67 t ha^{-1}). The yield advantage of the Dosha $\times$ Noble 25 WP combination corresponds with its lower disease intensity and AUDPC observed in the disease assessments, suggesting that effective disease suppression contributed to improved yield formation.

The large difference between the highest-yielding combination (Dosha $\times$ Noble 25 WP) and the untreated local variety demonstrates the importance of integrating varietal selection with fungicide application. Faba bean gall disease can reduce functional leaf area and photosynthetic activity, thereby restricting assimilate production and allocation to reproductive structures and developing seeds. Consequently, the lower disease pressure obtained from the Dosha $\times$ Noble 25 WP combination likely allowed better vegetative growth, pod formation, seed development, and ultimately greater grain yield.

The present findings agree with Yitayih Getnet and Azmeraw Yehizbalem (2017) who reported improved faba bean grain yield following fungicide application and demonstrated the importance of combining host resistance with chemical disease management. The current study further indicates that the magnitude of yield improvement depends on the variety–fungicide combination. The superior yield of Dosha when treated with Noble 25 WP, together with its relatively lower disease incidence, severity, and AUDPC, demonstrates the potential of this combination for integrated management of faba bean gall disease.

The higher grain yield recorded in 2023 (2.97 t ha⁻¹) than in 2022 (2.78 t ha⁻¹), and in Tenta (2.92 t ha⁻¹) than in Legambo (2.83 t ha⁻¹), further indicates that environmental conditions influenced overall crop productivity.

However, the absence of significant location × variety, location × fungicide, year × variety, year × fungicide, and higher-order interactions suggests that the relative performance of the tested variety × fungicide combinations was generally consistent across the evaluated environments. This consistency strengthens the potential of effective combinations, particularly Dosha × Noble 25 WP, for managing faba bean gall disease and improving productivity under the study conditions.

Table 6. 12. Interaction effect of fungicide and varieties on a yield of faba bean over years and locations.

Variety	Variety*Fungicide				
	Control	Mancozebe	Noble	Matco	Ridomil
Dosha	2.12 ^h	3.09 ^{de}	3.79 ^a	3.10 ^{de}	3.57 ^b
Wolkie	1.98 ^h	3.07 ^{de}	3.68 ^{ab}	3.11 ^{de}	3.38 ^c
Gora	1.67 ⁱ	2.80 ^{fg}	3.21 ^d	2.88 ^{fg}	2.95 ^{ef}
Local	1.64 ⁱ	2.72 ^g	3.11 ^{de}	2.75 ^g	2.89 ^{fg}

Mean values in the same column with different letter represent significant variation at 5% probability level.

6.4.10 Relative yield loss due to faba bean gall epidemic

Relative yield loss was calculated by comparing the grain yield obtained from each variety–fungicide treatment combination with that of the corresponding Noble 25 WP-treated plot, which was used as the reference treatment (Table 6. 13). Accordingly, the relative yield-loss values represent the percentage reduction in grain yield relative to the Noble 25 WP treatment and should therefore not be interpreted as absolute disease-induced yield loss. The results showed considerable variation in relative yield loss among varieties and fungicide treatments, indicating that both host genotype and disease-management practices influenced grain yield under faba bean gall (FBG) disease pressure. The untreated control plots exhibited the greatest relative yield losses for all varieties. The highest loss was recorded for Gora (47.98%), followed by Local (47.27%), Wolkie (46.20%), and Dosha (44.06%). These results demonstrate that, in the absence of fungicide protection, FBG disease was associated with substantial reductions in grain yield.

The differences among varieties also indicate that their responses to disease pressure were not uniform. Gora and Local showed the greatest yield deficits relative to the Noble-treated reference, whereas Dosha showed the lowest. This variation may reflect differences in the level of resistance or tolerance among varieties, as host genotype is an important component of integrated disease management in faba bean.

The substantial yield reduction observed in untreated plots is consistent with previous studies reporting that FBG disease can cause serious yield losses in faba bean when susceptible varieties are grown without effective disease-management measures (Appendix Table 6. 11). (Bekele Belachew *et al.*, 2018; Teferi Teklay *et al.*, 2018 reported significant effects of FBG disease on faba bean growth and grain yield, emphasizing the importance of using disease-resistant or moderately resistant varieties as a component of disease management. Similarly Kebede Wulita *et al.*, 2019 reported differences among faba bean genotypes in their response to disease pressure, supporting the present observation that the magnitude of yield loss differed among varieties. Application of fungicides markedly reduced relative yield loss compared with the untreated controls. Ridomil Gold produced the lowest relative yield losses among the fungicide treatments, with losses of 5.80% for Dosha, 8.15% for Wolkie, 8.10% for Gora, and 7.07% for Local. The corresponding grain yields were 3.57, 3.38, 2.95, and 2.89 t ha⁻¹, respectively. These results indicate that Ridomil Gold was highly effective in reducing the yield penalty associated with FBG disease under the conditions of the present study. The small yield differences between Ridomil-treated plots and the Noble-treated reference plots further suggest that these two treatments provided comparatively effective protection of grain yield. The effectiveness of fungicide application in maintaining grain yield agrees with previous studies that demonstrated the importance of chemical disease management for reducing the adverse effects of faba bean diseases.

Bogale Girma *et al.*, (2021) reported that fungicide application contributed to improved disease management and grain yield in faba bean, while Bitew Beyene *et al.*, 2022 also demonstrated the value of fungicide-based management in reducing disease-related yield losses. More recently, Yitayih Getnet *et al.*, (2023) reported that combining improved varieties with appropriate fungicide protection enhanced disease management and grain yield compared with poorly protected or susceptible treatments.

These findings support the present result that fungicide application substantially reduced the yield disadvantage observed in untreated plots. In contrast, Mancozebe-treated plots showed comparatively greater relative yield losses, ranging from 12.54% in Local to 18.47% in Dosha. Matco-treated plots showed intermediate performance, with relative yield losses ranging from 10.28% in Gora to 18.15% in Dosha. Although both fungicides reduced yield loss compared with the untreated controls, their performance was generally inferior to that of Ridomil Gold and the Noble reference treatment. This result suggests that differences in fungicide efficacy, disease suppression, application performance, or the interaction between fungicide and host genotype may have contributed to the observed variation in yield response. However, fungicide efficacy should not be inferred solely from yield loss; disease severity, disease incidence, application timing, and environmental conditions should also be considered when evaluating fungicide performance.

The effect of disease management is further demonstrated by the difference in grain yield between untreated and fungicide-treated plots. For example, grain yield of Dosha increased from 2.12 t ha^{-1} in the untreated control to 3.57 t ha^{-1} with Ridomil Gold, representing an increase of 1.45 t ha^{-1} . Similarly, yield increased from 1.98 to 3.38 t ha^{-1} in Wolkie, from 1.67 to 2.95 t ha^{-1} in Gora, and from 1.64 to 2.89 t ha^{-1} in Local. These increases provide clear evidence that effective disease management substantially improved grain production under the conditions of the experiment. The magnitude of the response also indicates that the benefit of disease management was not restricted to a single variety, although the extent of yield improvement differed among genotypes.

Overall, the present findings demonstrate that the integration of improved varieties with effective fungicide protection is more advantageous for minimizing yield losses associated with FBG disease than reliance on untreated varieties alone. The consistently low relative yield losses obtained with Noble 25 WP and Ridomil Gold indicate that these treatments provided the greatest protection of grain yield in the present experiment. This finding is in agreement with previous studies emphasizing integrated disease management, in which the use of improved or disease-tolerant varieties together with appropriate fungicide application was more effective in reducing disease effects and maintaining faba bean productivity than individual management

practices alone(Bekele Belachew *et al.*, 2018; Teferi Teklay *et al.*, 2018; Kebede Wulita *et al.*, 2019; Bogale Girma *et al.*, 2021; Bitew Beyene *et al.*, 2022; Yitayih Getnet *et al.*, 2023).

Table 6. 13. The combined impact of a fungicide-treated faba bean variety on yield loss due to faba bean gall disease in Legambo district, North-Eastern Ethiopia, during the main growing seasons of 2022 and 2023.

Variety	Fungicide	Yield(t/ha ⁻¹)	Relative Yield loss (%)
Dosha	Control	2.12	44.06
	Mancozebe	3.09	18.47
	Noble	3.79	0.00
	Matco	3.10	18.15
	Ridomil	3.57	5.80
Wolkie	Control	1.98	46.20
	Mancozebe	3.07	16.58
	Noble	3.68	0.00
	Matco	3.11	15.60
	Ridomil	3.38	8.15
Gora	Control	1.67	47.98
	Mancozebe	2.80	12.77
	Noble	3.21	0.00
	Matco	2.88	10.28
	Ridomil	2.95	8.10
Local	Control	1.64	47.27
	Mancozebe	2.72	12.54
	Noble	3.11	0.00
	Matco	2.75	11.58
	Ridomil	2.89	7.07

6.5 Cost–Benefit Analysis

The partial budget analysis showed clear differences in economic performance among treatments (Table 6. 14 and Table 6. 15). In both years, Dosha treated with Noble 25 WP produced the highest net benefit: US\$2,293.63 ha⁻¹ in 2022 and US\$4,168.20 ha⁻¹ in 2023. The same treatment also had the highest marginal rate of return, reaching 4,187.94% in 2022 and 5,410.40% in 2023. In 2022, the net benefit of this treatment was 123.3% higher than the best untreated control (Gora, US\$1,027.24 ha⁻¹) and 0.8% higher than the next-best fungicide treatment (Wolkie + Noble 25 WP, US\$2,274.49 ha⁻¹). In 2023, it was 128.1% higher than the untreated control (US\$1,827.00 ha⁻¹) and 3.7% higher than the next-best treatment (Wolkie + Noble 25 WP, US\$4,018.00 ha⁻¹).

ha⁻¹). These results indicate that the combination of Dosha and Noble 25 WP was the most economically advantageous option under the conditions of this study. In contrast, the lowest net benefits were recorded in untreated controls. In 2022, the local variety without fungicide produced only US\$995.34 ha⁻¹, followed by untreated Gora with US\$1,027.24 ha⁻¹. In 2023, both untreated Gora and Local generated US\$1,827.00 ha⁻¹. These treatments had no fungicide expenditure and therefore an MRR of 0%, but their low net benefits resulted from substantially lower grain yields under disease pressure. The difference between the highest and lowest treatments demonstrates the economic importance of effective FBG management.

The higher economic performance of the integrated treatment is consistent with previous studies in Ethiopia. Kassa Yehuala *et al.*, 2020 reported that combining improved faba bean varieties with Noble 25 WP increased grain yield and economic return under FBG pressure. Similarly, Kebede Wulita *et al.* (2019), Bogale Girma *et al.* (2021), ; Teferi Teklay *et al.* (2018), and Yitayih Getnet *et al.* (2023) emphasized the economic and agronomic benefits of integrating host resistance with appropriate disease-management practices. Overall, Dosha + Noble 25 WP were the most economically beneficial treatment in both years, whereas untreated Local and Gora had the lowest economic returns. This indicates that effective FBG management can substantially improve the profitability of faba bean production under the conditions of the study area.

Table 6. 14. Cost benefits analysis for managing faba bean gall disease in Legambo and Tenta for the cropping seasons of 2022 using various varieties and fungicides.

Variety	Fungicide	UGY (tha ⁻¹)	AGY (t/ha ⁻¹)	Bean (\$/t ⁻¹)	GFB (\$ ha ⁻¹)	PC (\$ha ⁻¹)	MC (\$ha ⁻¹)	TVC (\$ha ⁻¹)	NB (\$ha ⁻¹)	MB (\$ ha ⁻¹)	MRR (%)
Dosha	Noble	3.62	3.258	714.29	2327.16	17.45	16.07	33.52	2293.63	992.03	4187.94
	Ridomil	3.48	3.13	714.29	2237.16	16.78	29.46	46.24	2190.92	889.32	2442.99
	Matco	2.95	2.66	714.29	1896.44	14.22	29.02	43.24	1853.20	551.60	1651.11
	Mancozebe	2.94	2.65	714.29	1890.01	14.18	25.00	39.18	1850.84	549.24	1872.01
	Control	2.04	1.84	714.29	1311.44	9.84	0.00	9.84	1301.60	0	0.00
Wolkie	Noble	3.59	3.23	714.29	2307.87	17.31	16.07	33.38	2274.49	1068.60	4403.60
	Ridomil	3.35	3.02	714.29	2153.58	16.15	29.46	45.61	2107.97	902.08	2471.49
	Mancozebe	3.07	2.76	714.29	1973.58	14.80	25.00	39.80	1933.78	727.89	2371.79
	Matco	2.94	2.65	714.29	1890.01	14.18	29.02	43.20	1846.82	640.92	1880.50
	Control	1.89	1.70	714.29	1215.01	9.11	0.00	9.11	1205.89	0	0.00
Gora	Noble	3.08	2.77	714.29	1980.01	14.85	16.07	30.92	1949.09	921.85	3980.78
	Ridomil	2.88	2.59	714.29	1851.44	13.89	29.46	43.35	1808.09	780.85	2194.43
	Matco	2.81	2.53	714.29	1806.44	13.55	29.02	42.57	1763.87	736.63	2116.40
	Mancozebe	2.73	2.46	714.29	1755.01	13.16	25.00	38.16	1716.85	689.60	2268.44
	Control	1.61	1.45	714.29	1035.01	7.76	0.00	7.76	1027.24	0	0.00
Local	Noble	2.97	2.67	714.29	1909.30	14.32	16.07	30.39	1878.91	883.57	3863.73
	Ridomil	2.81	2.53	714.29	1806.44	13.55	29.46	43.01	1763.43	768.09	2164.44
	Mancozebe	2.68	2.41	714.29	1722.87	12.92	25.00	37.92	1684.95	689.60	2268.44
	Matco	2.67	2.40	714.29	1716.44	12.87	29.02	41.89	1674.55	679.20	1976.05
	Control	1.56	1.44	714.29	1002.86	7.52	0.00	7.52	995.34	0	0.00

UGY, unadjusted grain yield; AGY, adjusted grain yield; GFB, gross field benefit; PC, Production Cost; MC, Marginal cost; TVC, total variable cost; NB, net benefit; MB, Marginal benefit; MRR, marginal rate of return. The unite price of yield per kilogram during 2022 was\$0.714(at an exchange rate of 1\$=ETB 56) at the time of yield selling, and the price of fungicides Mancozabe, Noble, Matco and Ridomil were 12.5\$, 10.71\$, 11.61\$, 11.79\$, respectively.

Table 6. 15. Cost benefits analysis for managing faba bean gall disease in Legambo and Tenta for the cropping seasons of 2023 using various varieties and fungicides.

Variety	Fungicide	UGY (t/ha ⁻¹)	AGY (t/ha ⁻¹)	Bean (price)	GFB (ha ⁻¹)	PC (\$/ha ⁻¹)	MC (\$ha ⁻¹)	TVC (\$ha ⁻¹)	NB (\$ha ⁻¹)	MB (\$ ha ⁻¹)	MRR (%)
Dosha	Noble	3.95	3.56	1184.2	4209.8	14.0	27.6	41.7	4168.2	1831.3	5410.4
	Ridomil	3.66	3.29	1184.2	3900.8	13.0	62.5	75.5	3825.3	1488.4	2198.9
	Matco	3.25	2.93	1184.2	3463.8	11.5	72.4	83.9	3379.9	1043.0	1370.5
	Mancozebe	3.24	2.92	1184.2	3453.1	11.5	55.3	66.8	3386.4	1049.5	1780.1
	Control	2.2	1.98	1184.2	2344.7	7.8	0.0	7.8	2336.9	0.0	0.0
Wolkie	Noble	3.77	3.39	1184.2	4018.0	13.4	27.6	41.0	3977.0	1778.2	5281.2
	Ridomil	3.42	3.08	1184.2	3645.0	12.2	62.5	74.7	3570.3	1371.5	2038.0
	Matco	3.28	2.95	1184.2	3495.8	11.7	72.4	84.0	3411.7	1212.9	1582.0
	Mancozebe	3.16	2.85	1184.2	3367.9	11.2	55.3	66.5	3301.4	1102.6	1864.6
	Control	2.07	1.86	1184.2	2206.2	7.4	0.0	7.4	2198.8	0.0	0.0
Gora	Noble	3.34	3.01	1184.2	3559.7	11.9	27.6	39.5	3520.2	1693.2	5071.6
	Ridomil	3.03	2.73	1184.2	3229.3	10.8	62.5	73.3	3156.0	1329.0	1979.1
	Matco	2.94	2.65	1184.2	3133.4	10.4	72.4	82.8	3050.6	1223.5	1595.2
	Mancozebe	2.88	2.53	1184.2	3069.4	10.2	55.3	65.5	3004.0	1176.9	1982.0
	Control	1.72	1.55	1184.2	1833.1	6.1	0.0	6.1	1827.0	0.0	0.0
Local	Noble	3.24	2.92	1184.2	3453.1	11.5	27.6	39.1	3414.0	1587.0	4804.6
	Ridomil	2.98	2.63	1184.2	3176.0	10.6	62.5	73.1	3102.9	1275.9	1905.0
	Matco	2.84	2.56	1184.2	3026.8	10.1	72.4	82.5	2944.4	1117.3	1463.4
	Mancozebe	2.77	2.44	1184.2	2952.2	9.8	55.3	65.1	2887.1	1060.1	1797.0
	Control	1.72	1.55	1184.2	1833.1	6.1	0.0	6.1	1827.0	0.0	0.0

UGY, unadjusted grain yield; AGY, adjusted grain yield; GFB, gross field benefit; PC, Production Cost; MC, Marginal cost; TVC, total variable cost; NB, net benefit; MB, Marginal benefit; MRR, marginal rate of return. The unit price of yield per kilogram during 2022 was \$1.84 (at an exchange rate of \$1 = ETB 76) at the time of yield selling, and the price of fungicides Mancozabe, Noble, Matco, and Ridomil were 27.63\$, 18.42\$, 28.95\$, and 25\$, respective

6.6 Correlation of Disease Parameters with Yield and Yield Components

Correlation analysis showed that all relationships among disease parameters, grain yield, and hundred seed weight (HSW) were highly significant at both Legambo and Tenta and in both cropping seasons (Table 6. 16 and Table 6. 17). Disease parameters were consistently and negatively correlated with grain yield and HSW. Grain yield showed strong negative correlations with disease incidence (DI), percent severity index (PSI), and area under the disease progress curve (AUDPC). Similarly, HSW was negatively correlated with DI, PSI, and AUDPC. These results indicate that higher disease incidence, severity, and cumulative disease development were consistently associated with lower grain yield and seed weight. In contrast, grain yield and HSW showed strong positive correlations at both locations and across both seasons, indicating that treatments with greater hundred seed weight also tended to have greater grain yield. Disease parameters also showed strong positive correlations with one another. DI was positively correlated with PSI and AUDPC, while PSI was positively correlated with AUDPC (Appendix Table 6. 10 and Appendix Table 6. 11). Thus, higher disease incidence corresponded to greater disease severity and greater cumulative disease development over time.

Table 6. 16. Correlation coefficient (r) between yield and yield components and disease parameters at Legambo district in the crop seasons of 2022(Lower Diagonal) and 2023(Upper Diagonal).

Parameter	HSW	Yield	DI	PSI	AUDPC
HSW	1	0.87**	-0.90**	-0.89**	-0.93**
Yield	0.80**	1	-0.88**	-0.86**	-0.91**
DI	-0.92**	-0.82**	1	0.97**	0.97**
PSI	-0.91**	-0.81**	0.98**	1	0.96**
AUDPC	-0.94**	-0.82**	0.97**	0.96**	1

Table 6. 17. Correlation coefficient (r) between yield and yield components and disease parameters at Tenta district in the crop seasons of 2022(Lower diagonal) and 2023(Upper diagonal).

Parameter	HSW	Yield	DI	PSI	AUDPC
HSW	1	0.83**	-0.88**	-0.86**	-0.89**
Yield	0.88**	1	-0.88**	-0.86**	-0.92**
DI	-0.91**	-0.89**	1	0.96**	0.96**
PSI	-0.89**	-0.89**	0.97**	1	0.96**
AUDPC	-0.91**	-0.94**	0.97**	0.96**	1

HSW, hundred seed weight; DI, disease incidence; PSI, per cent severity index; AUDPC, area under disease progress curve; **, = highly significant difference at 0.01; *, significant difference at 0.05; and ns, non-significant difference at 0.05 probability level. Numbers presented below and above the diagonal are referring to the P-values and correlation coefficient, respectively.

6.7 Conclusion

This study showed that faba bean gall (FBG) disease caused by *Physoderma viciae* is an important constraint to faba bean production in Legambo and Tenta districts during the 2022 and 2023 cropping seasons. Disease incidence, percent severity index (PSI), area under the disease progress curve (AUDPC), and disease progress rate varied among varieties, fungicide treatments, locations, and cropping seasons. Disease levels were generally higher in 2022 and at Legambo than in 2023 and Tenta, indicating that seasonal and location-specific environmental conditions were associated with variation in disease development.

Among the varieties tested, Dosha showed a moderately resistant response and consistently recorded lower disease incidence, PSI, AUDPC, and disease progress rate than the local variety. The untreated local variety generally had the highest disease levels and the greatest relative yield loss. These results indicate that using a moderately resistant variety such as Dosha can contribute to reducing FBG intensity under the conditions of this study.

Fungicide application reduced disease parameters and was associated with improved grain yield and yield components. Noble 25 WP generally provided the best disease management. The combination of Dosha with Noble 25 WP consistently resulted in low disease incidence, severity, and AUDPC and produced high grain yield, hundred seed weight, number of pods per plant, and seeds per pod. In contrast, untreated plots generally recorded higher disease levels and lower yield performance.

Correlation analysis showed that disease incidence, PSI, and AUDPC were negatively associated with grain yield and hundred seed weight, while grain yield and hundred seed weight were positively associated. Disease parameters were also positively correlated with one another. These relationships were consistent at both locations and across the two cropping seasons, indicating a strong association between disease intensity and yield-related traits. However, because these are correlation results, they should be interpreted as associations rather than direct causal effects.

Relative yield loss, calculated relative to the Noble 25 WP-treated reference, was greatest in untreated treatments and lowest in Noble 25 WP treatments.

Economic analysis showed that the Dosha + Noble 25 WP combination generated the highest net benefit in both cropping seasons, indicating that this treatment was both agronomically effective and economically attractive under the conditions of this study.

Overall, integrating the moderately resistant Dosha variety with effective fungicide application, particularly Noble 25 WP, is a promising approach for managing FBG disease and improving faba bean productivity and economic returns in the study areas.

6.8 Recommendations

Based on the findings of this study, the Dosha variety is recommended for production in Legambo, Tenta, and similar agroecological areas due to its moderately resistant response to faba bean gall and relatively better yield performance. However, wider validation across additional environments and seasons is needed before broad recommendation. Among the fungicides tested, Noble 25 WP provided the most effective disease management and highest economic return under the conditions of this study. It can therefore be considered a promising option for FBG management, provided farmers follow registered label rates, recommended application methods, and safety precautions.

The results support an integrated disease management approach that combines a moderately resistant variety such as Dosha with effective fungicide application, rather than relying solely on fungicides or susceptible local varieties. Disease monitoring should guide timely management decisions, as disease development varied between locations and seasons. Future research should evaluate different fungicide application schedules and spray intervals, including preventive, disease-onset, and fixed-interval applications. Dose–response studies are also needed to determine the minimum effective rate that provides adequate control while reducing costs and environmental exposure. Further research should assess the durability of the moderately resistant response of Dosha and other promising varieties across multiple locations, seasons, and disease-pressure levels. Variety $\times$ fungicide compatibility should be evaluated to determine whether specific fungicides provide consistent benefits with different levels of host resistance. Finally, the most promising variety–fungicide combinations should be validated on-farm under farmer-managed conditions, comparing disease control, grain yield, production cost, net benefit, and marginal rate of return. This would provide stronger evidence for practical and economically feasible FBG management recommendations in northeastern Ethiopia.

Chapter 7. General Conclusion and Recommendations

7.1 Conclusion

Faba bean gall (FBG) disease, caused by *Physoderma viciae*, has become a major constraint to faba bean production in the highlands of South Wollo, northeastern Ethiopia. The disease was recorded in all surveyed districts during the 2022 and 2023 main cropping seasons, confirming its wide distribution and increasing economic importance. Disease prevalence, incidence, and percentage severity index (PSI) were higher in 2022 than in 2023 and were strongly associated with high-altitude environments, high rainfall, high relative humidity, and cool temperatures. Disease development was most severe at the flowering stage and was further intensified by poor field drainage, heavy weed infestation, and inadequate crop management practices. Logistic regression identified district, year, altitude, variety, previous crop, fungicide application, and field drainage as significant determinants of disease incidence and severity.

Histopathological and molecular investigations confirmed the association of *P. viciae* with FBG disease in the study areas. Histopathological examination revealed resting spores, turbinate cells, and epibiotic zoosporangia characteristic of *Physoderma*. Molecular detection using Physo1 and Physo D' primers successfully identified *P. viciae* directly from symptomatic field tissues. In contrast, culture-based methods yielded only saprophytic fungi that neither amplified with *Physoderma*-specific primers nor induced disease symptoms in greenhouse tests. The failure to culture *P. viciae* under artificial conditions, together with its detection only from naturally infected field tissues, suggests that the pathogen is highly host-dependent and likely obligate in nature. However, sequence-level confirmation and phylogenetic characterization remain necessary. Significant variation in disease response was observed among the 28 faba bean genotypes evaluated. No genotype showed complete resistance. Dosha, Obse, Wolkie, and FB-26869 consistently exhibited lower disease incidence, severity, and AUDPC values, together with superior grain yield across locations and seasons. In contrast, local varieties and genotypes EH96048-1, EH00102-8-1, EH97091-2, and Gora were more susceptible. These results indicate that moderate resistance combined with good agronomic performance is available for use in integrated management.

Integration of moderately resistant genotypes with fungicide application significantly reduced disease incidence, severity, and AUDPC and increased grain yield. The combination of Dosha with Noble 25 WP provided the greatest disease suppression, the highest grain yield (3.79 t ha⁻¹), and the highest net benefit. The strong negative association between disease intensity and grain yield confirms the substantial impact of FBG on productivity. However, because the data were observational, these relationships should be interpreted as associations rather than direct causation.

Overall, FBG disease is governed by complex interactions among host genotype, environmental conditions, and crop management practices. Sustainable management requires an integrated approach combining moderately resistant varieties, judicious fungicide application, improved field drainage, cereal-based crop rotation, field sanitation, and other appropriate agronomic practices. The study also highlights the value of integrating molecular diagnostics with histopathological analyses for accurate pathogen detection and disease diagnosis.

7.2 Recommendations

Based on the findings of this study, integrated disease management combining moderately resistant varieties, judicious fungicide application, and improved agronomic practices is recommended for sustainable management of faba bean gall (FBG) disease in South Wollo and similar highland agroecologies of Ethiopia. Farmers in gall-prone areas should cultivate the moderately resistant genotypes Dosha, Obse, Wolkie, and FB-26869, which consistently showed lower disease incidence, severity, and AUDPC values together with superior grain yield. However, because none of the evaluated varieties exhibited complete resistance, these genotypes should be used as part of an integrated management strategy rather than as a standalone control measure. The combination of Dosha with Noble 25 WP provided the greatest disease suppression and the highest economic return under the conditions of this study. Therefore, fungicide application should be initiated at the first appearance of symptoms and applied according to registered label rates and safety guidelines. Farmers should also adopt improved agronomic practices, including row planting, timely weeding, proper land preparation, balanced fertilizer application, field sanitation, and maintenance of adequate field drainage. Cultivation in poorly drained, shaded, or waterlogged fields should be avoided.

Crop rotation with cereals or other non-host crops for at least three consecutive years should be practiced to reduce the accumulation of *P. viciae* inoculum in the soil, and continuous faba bean cultivation should be avoided. The use of clean and certified seed obtained from reliable sources is also recommended to minimize the introduction and spread of the pathogen.

Agricultural extension services, in collaboration with NGOs, ATVET colleges, and research institutes, should strengthen farmer awareness and capacity through regular training programs focused on disease recognition, epidemiology, and timely implementation of management practices. Demonstration plots in disease-prone areas should be established to facilitate technology transfer and encourage wider adoption of the integrated package described above. Extension personnel should also improve farmers' access to improved seed and provide guidance on the safe and effective use of fungicides. The Ministry of Agriculture and the pesticide registration authority should register and recommend Noble 25 WP for FBG management at the registered label rate, while the Amhara Bureau of Agriculture and regional extension services should ensure that the package reaches farmers through demonstrations, field days, and farmer training.

Plant breeding programs at EIAR, regional agricultural research institutes, and universities should prioritize the development of faba bean varieties with durable and high levels of resistance to *P. viciae*. The promising genotypes identified in this study should be utilized as parental materials in resistance breeding efforts. Multi-location and multi-season screening of breeding materials should be strengthened to identify stable, high-yielding, and disease-resistant genotypes across diverse agroecological conditions. In addition, the *Physoderma*-specific molecular markers Physo1 and Physo D' validated in this study should be incorporated into breeding and screening programs to improve the efficiency and accuracy of resistance selection.

Further research is required to improve understanding of the biology, ecology, and epidemiology of *P. viciae*. Particular attention should be given to elucidating the pathogen's life cycle, mechanisms of survival as resting spores in soil, and environmental factors that trigger infection and disease development. Since greenhouse inoculation experiments failed to reproduce disease symptoms, future studies should focus on developing reliable field-based inoculation techniques

using naturally infested soil. Additional research is also needed to determine whether the pathogen is seed borne, identify potential alternative hosts, and investigate its survival and distribution in different soil types, particularly Vertisols, where disease severity is frequently high. Molecular studies involving sequencing of PCR amplicons and phylogenetic analyses are recommended to confirm the genetic identity of Ethiopian *P. viciae* populations and to assess their diversity and evolutionary relationships. Long-term epidemiological investigations examining pathogen variability, disease dynamics, and genotype $\times$ environment interactions should also be conducted, together with studies evaluating the potential role of biological control agents. Future research should specifically evaluate different fungicide application schedules and spray intervals, including early preventive application, disease-onset application, and subsequent applications at fixed intervals. Dose–response studies should also be conducted to determine the minimum effective fungicide rate that provides adequate disease control while reducing unnecessary production costs and environmental exposure. The durability of the moderately resistant response of the promising varieties should be evaluated across multiple locations, seasons, and disease-pressure levels, and variety $\times$ fungicide compatibility should be assessed. Finally, the most promising variety–fungicide combinations identified in this study should be subjected to on-farm validation under farmers’ field conditions, comparing disease control, grain yield, production cost, net benefit, and marginal rate of return under farmer-managed conditions.

Policymakers and agricultural development organizations should strengthen both formal and informal seed systems to facilitate the rapid multiplication and dissemination of improved and moderately resistant faba bean varieties. Increased investment is required in resistance breeding, disease surveillance, diagnostic capacity, and integrated disease management programs. Molecular diagnostic methods should be incorporated into routine disease monitoring, seed certification, and breeding activities. The establishment of national and regional disease surveillance networks would support early warning systems and enable timely responses to disease outbreaks. Policymakers should also strengthen extension services, support farmer training programs, and facilitate access to quality fungicides for resource-limited farmers while ensuring proper regulation, quality control, and safe-use practices.

Strengthening collaboration among researchers, plant breeders, extension personnel, policymakers, and farmers will be essential for the successful implementation of sustainable disease management strategies.

Overall, sustainable management of faba bean gall disease requires a comprehensive and integrated approach that combines moderately resistant varieties, improved agronomic practices, crop rotation, field sanitation, effective drainage management, accurate molecular diagnostics, and judicious fungicide use. Reliance on any single management strategy is unlikely to provide effective long-term control. The implementation of these recommendations will contribute to reducing yield losses, improving faba bean productivity, enhancing food security, and strengthening the livelihoods of smallholder farmers in the highland regions of Ethiopia

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APPENDIX

Distribution and Prevalence of Faba Bean Gall (*Physoderma viciae*) diseases in South Wollo, Ethiopia.

Survey data collection sheet for Faba bean gall diseases:

Date_____

Field Number: _____

I. General information

1. Location:

1.1. Region_____Zone:_____District:_____Kebele_____

1.2. GPS: W.P _____ Latitude (N) _____ Longitude (E) _____Altitude _____
m.a.s.l

1.3 Interviewee's name_____ gender: _____ age _____
duty_____

Level of education: _____

2. Question regarding the faba bean gall diseases.

2.1. Land area: _____ha. Soil type_____Ecology_____ Previous
crop_____

2.3. Agronomic practices: Residue clearance (yes/no) _____,

Tillage frequency: _____

Tillage time: _____,

Sowing Time: _____,

Sowing method: (Broadcasted/row planted/ transplanted),

Weeding freq.: _____,

Weeding time: _____, _____, _____

Seed type: (local/improved);

If improved, name_____, source: _____, s/rate: _____

Herbicide (yes/no); if yes, name: _____, rate: _____, time: _____

Fungicide (yes/no); if yes, name: _____, rate: _____, time: _____

Fertilizer (yes/no); Type 1: _____, rate: _____, time: _____ Type 2: rate: _____, time: _____

Crop growth stage: _____

3. Faba bean gall diseases incidence and severity

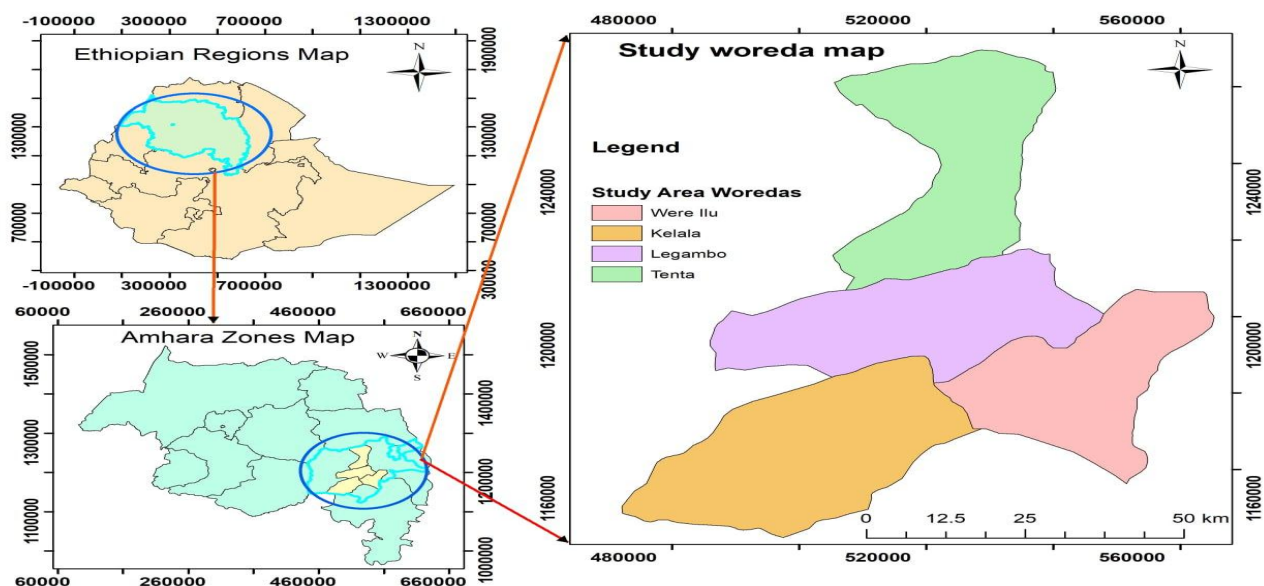
3.1. Do you ever notice this disease? Yes/No, if yes, when? _____, what was its impact? _____, what control measures? _____

3.2. Plant parts attacked: _____

3.3. Field management (poor, good, excellent)

3.4. Faba bean gall disease incidence and severity recording table

	Disease, Prevalence, Incidence and Severity (%)																	
Qt No	FBG		Disease severity										Other major disease1			Other major disease1		
	DP	DI	P1	P2	P3	P4	P5	P6	P7	P8	P9	10	DP	DI	DS	DP	DI	DS
1																		
2																		
3																		
4																		
5																		

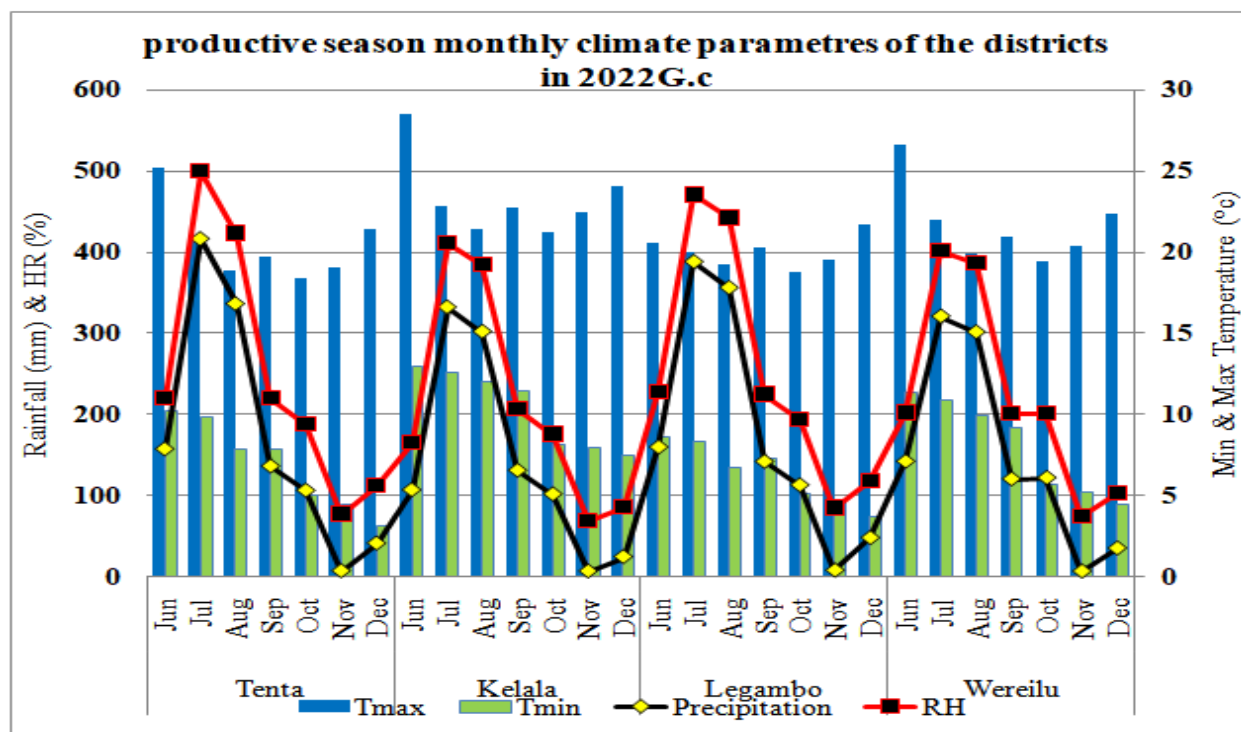
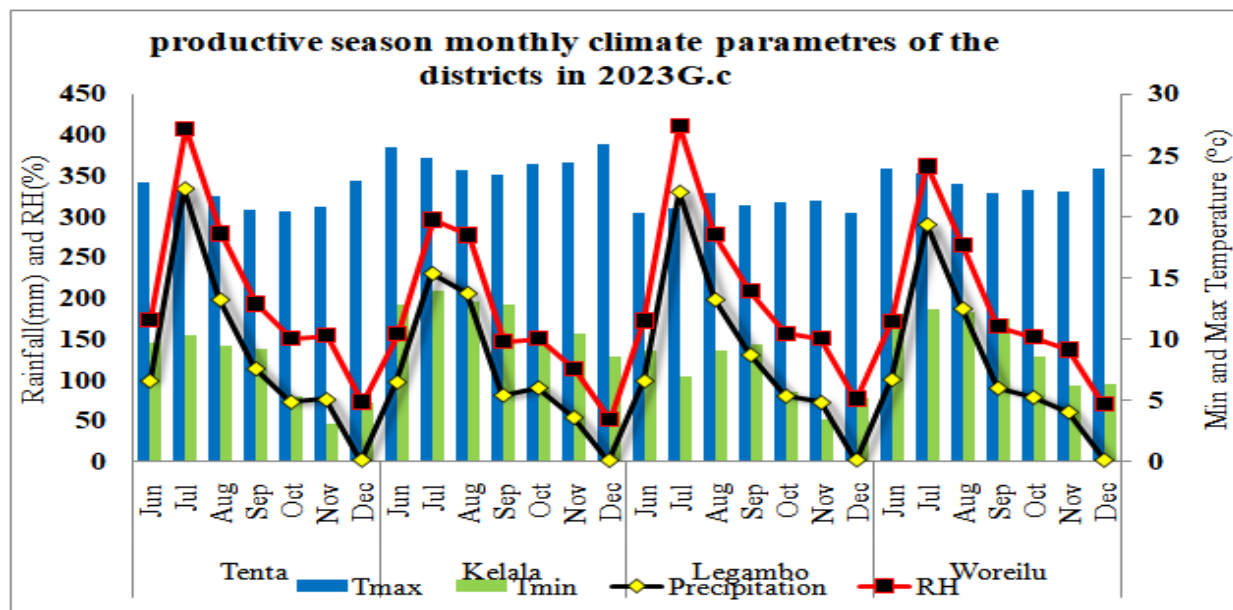


Appendix Figure 2. 1. Map showing surveyed districts for faba bean gall in South Wollo, North-Eastern Ethiopia, during the 2022 and 2023 cropping seasons.

Appendix Table 2. 1. Altitude and Weather Conditions of Faba Bean Gall Surveyed Districts in South Wollo zone, Eastern Amhara, Ethiopia.

District	Number of fields	Altitude (m a.s.l.)	Rainfall (mm)		Mean of Temperature ($^{\circ}$ C)			
			2022	2023	2022		2023	
					Maximum	Minimum	Maximum	Minimum
Legambo	50	2900-3230	1216.98	912.72	20.00	6.36	20.93	7.04
Woreilu	40	2647-2861	1051.23	809.23	21.67	8.12	22.88	9.94
Tenta	50	2436- 3007	1203.06	896.16	20.47	6.92	21.64	7.45
Kelala	60	2426–2663	1007.96	761.03	23.33	10.38	24.60	11.58

*Average rainfall, and maximum and minimum temperatures of surveyed locations were obtained from respective districts' meteorological stations (<https://power.larc.nasa.gov/data-access-viewer/>) and Altitude ranges of surveyed fields were measured by a global positioning system (GPS).



Appendix Figure 3. 1. Rainfall, maximum and minimum temperatures, and relative humidity of surveyed districts in north-eastern Ethiopia during the 2022 and 2023 faba bean-growing seasons.

Appendix Table 3. 1. Prevalence, incidence, and severity (Mean $\pm$ SE) of faba bean gall across different independent variables in north-eastern Ethiopia during the 2022 and 2023 cropping seasons.

Variables	Variable class	No. of fields	Prevalence %	Incidence%	Percentage Severity index%
District	Legambo	50	97.60	82.26 $\pm$ 1.05	71.92 $\pm$ 0.66
	Kelala	60	90.00	59.41 $\pm$ 1.54	41.45 $\pm$ 2.02
	Tenta	50	95.60	70.85 $\pm$ 1.67	57.14 $\pm$ 2.02
	Woreilu	40	92.50	66.99 $\pm$ 1.46	54.56 $\pm$ 1.98
Year	2022	100	97.41	74.81 $\pm$ 1.14	64.01 $\pm$ 0.9
	2023	100	90.19	64.17 $\pm$ 1.33	47.21 $\pm$ 1.88
Altitude	2426-2647	70	91.16	59.81 $\pm$ 1.47	42.54 $\pm$ 1.94
	2648-2844	60	93.63	69.56 $\pm$ 1.33	54.80 $\pm$ 1.69
	2845-3069	50	96.18	76.56 $\pm$ 1.36	67.96 $\pm$ 1.01
	3070-3230	20	97.60	85.50 $\pm$ 0.99	72.93 $\pm$ 1.33
Soil type	Vertisol	95	94.53	71.76 $\pm$ 1.27	58.44 $\pm$ 1.63
	Arenosol	8	89.78	61.58 $\pm$ 5.48	44.00 $\pm$ 7.81
	Nitisol	97	93.50	62.97 $\pm$ 1.41	53.90 $\pm$ 1.72
Variety	Wolkie	96	92.64	62.23 $\pm$ 1.19	48.31 $\pm$ 1.66
	Local	104	95.06	77.36 $\pm$ 1.00	63.52 $\pm$ 1.33
Planting method	Broadcast planting	93	94.94	77.33 $\pm$ 1.03	63.63 $\pm$ 1.35
	Row planting	107	92.81	62.68 $\pm$ 1.19	48.64 $\pm$ 1.63
Weeding frequency	Unwedded	44	95.31	78.24 $\pm$ 1.58	63.52 $\pm$ 2.10
	Once	86	93.16	69.96 $\pm$ 1.46	55.73 $\pm$ 1.94
	Two times weeding	70	93.63	63.41 $\pm$ 1.40	50.49 $\pm$ 1.85
Land preparations	Once plowing	82	94.97	76.69 $\pm$ 1.67	62.89 $\pm$ 1.45
	Two times plowing	55	93.59	67.81 $\pm$ 1.67	54.95 $\pm$ 2.37
	Three times plowing	63	92.46	61.58 $\pm$ 1.61	46.77 $\pm$ 2.09
Field size	0.25-0.5	162	93.90	70.45 $\pm$ 1.05	56.43 $\pm$ 1.32
	0.5-1	36	93.43	65.23 $\pm$ 2.11	52.06 $\pm$ 2.77
	1-1.5	2	92.31	68.50 $\pm$ 19.7	53.20 $\pm$ 23.00
Growth stage	Flowering	158	94.00	70.01 $\pm$ 1.05	56.47 $\pm$ 1.32
	Podding	42	93.04	67.54 $\pm$ 2.21	52.38 $\pm$ 2.77
Previous crop	Cereals	167	93.90	69.34 $\pm$ 1.03	55.16 $\pm$ 1.28
	Vegetable	31	93.16	69.84 $\pm$ 2.57	55.45 $\pm$ 3.45
	Legume	2	95.20	76.80 $\pm$ 6.00	76.20 $\pm$ 2.00
Fertilizer	Fertilized	55	93.26	65.41 $\pm$ 2.07	50.21 $\pm$ 2.54
	Unfertilized	155	94.01	71.04 $\pm$ 1.02	57.66 $\pm$ 1.31
Fungicide	Sprayed	55	93.78	61.78 $\pm$ 1.48	50.25 $\pm$ 2.10
	Unsprayed	145	93.81	72.42 $\pm$ 1.09	57.64 $\pm$ 1.41
Drainage	Excellent	35	92.07	56.87 $\pm$ 1.96	43.27 $\pm$ 2.83
	Good	60	93.34	66.67 $\pm$ 1.49	55.46 $\pm$ 2.05
	Poor	105	94.64	75.14 $\pm$ 1.13	60.95 $\pm$ 1.48

Remark: - SE= standard error

Appendix Table 3. 2. Logistic regression model for mean faba bean gall disease incidence and severity, and likelihood ratio test on independent variables during the 2022 and the 2023 main rainy seasons.

Variable	DF	Faba bean gall disease incidence, LRT*				Faba bean gall disease severity LRT*			
		Type 1 analysis		Type 3 analysis		Type 1 analysis		Type 3 analysis	
		DR	Pr > χ^2	DR	Pr > χ^2	DR	Pr > χ^2	DR	Pr > χ^2
District	3	715.26	<.0001	57.74	<.0001	1054.05	<.0001	60.14	<.0001
Year	1	277.82	<.0001	194.57	<.0001	606.96	<.0001	477.72	<.0001
Altitude	3	75.26	<.0001	41.67	<.0001	111.71	<.0001	74.30	<.0001
Soil	2	7.30	0.0259	4.21	0.1217	9.71	0.0078	1.65	0.4385
Variety	1	249.14	<.0001	6.89	0.0087	136.96	<.0001	4.23	0.0398
Planting method	1	16.02	<.0001	0.84	0.3581	20.49	<.0001	8.02	0.0046
Weeding	2	4.62	0.0990	3.48	0.1755	2.80	0.2470	6.88	0.0321
Land	2	8.79	0.0123	8.34	0.0154	8.23	0.0163	2.92	0.2322
Field Size	2	4.08	0.1303	0.47	0.7900	1.38	0.5026	0.18	0.9141
Growth stage	1	2.12	0.1450	0.34	0.5605	1.21	0.2710	0.62	0.4327
Previous	2	6.24	0.0441	8.61	0.0135	21.37	<.0001	18.99	<.0001
Fertilizer	1	3.19	0.0743	0.18	0.6679	9.99	0.0016	4.88	0.0272
Fungicide	1	45.76	<.0001	36.58	<.0001	10.26	0.0014	6.39	0.0115
Drainage	2	13.90	0.0010	13.90	0.0010	10.36	0.0056	10.36	0.0056

Remark: - *LRT: Likelihood ratio test; VEF: variable entered first in the model; VEL: variable entered last in the model; DR: deviance reduction; and Pr: probability of an χ^2 value exceeding the deviance reduction; χ^2 : Chi-square; DF: degrees of freedom; PSI: percent severity index.

Appendix Table 3. 3. Analysis of deviance, natural logarithms of odds ratios, and standard errors for faba bean gall disease incidence based on a reduced logistic regression model. Independent variables were evaluated using likelihood ratio tests during the 2022 and 2023 main cropping season.

Variable	Residual deviance	DF	DR	Pr > χ^2	Variable Class	Estimate	SE	Odds ratio
District	1029.17	3	57.74	<.0001	Intercept	0.99	0.29	2.69
					Kelala	-0.15	0.06	0.86
					Legambo	0.51	0.08	1.67
					Tenta	0.10	0.06	1.10
					Woreilu	0.00	0.00	1.00
Year	751.35	1	194.57	<.0001	2022	0.48	0.03	1.62
					2023	0.00	0.00	1.00
Altitude	676.09	3	41.67	<.0001	2426-2647	-0.55	0.11	0.57
					2648-2844	-0.29	0.11	0.74
					2845-3069	-0.29	0.08	0.75
					3070-3230	0.00	0.00	1.00
Soil	668.79	2	4.21	0.1217	Nitisol	-0.08	0.04	0.92
					Arenosol	0.01	0.10	1.01

Variety	419.65	1	6.89	0.0087	Vertisol	0.00	0.00	1.00
					Wolkie	-0.19	0.07	0.83
					Local	0.00	0.00	1.00
Planting method	403.63	1	0.84	0.3581	Broadcast	0.10	0.11	1.10
					Row	0.00	0.00	1.00
Weeding	399.00	2	3.48	0.1755	No weeding	0.09	0.06	1.09
					One times	-0.01	0.05	0.99
					Two times	0.00	0.00	1.00
Land	390.21	2	8.34	0.0154	One	0.18	0.07	
					plowing			1.20
					Two	0.03	0.05	
					plowing			1.03
Field Size	386.13	3	0.47	0.7900	Three	0.00	0.00	
					plowing			1.00
					0.25-0.5	0.07	0.18	1.08
					0.5-1	0.05	0.18	1.05
Growth stage	384.01	1	0.34	0.5605	1-1.5	0.00	0.00	1.00
					Flowering	-0.02	0.04	0.98
					Podding	0.00	0.00	1.00
Previous crop	377.77	2	8.61	0.0135	Cereal	-0.02	0.18	0.98
					Vegetable	-0.17	0.18	0.84
					Legume	0.00	0.00	1.00
Fertilizer	374.58	1	0.18	0.6679	Fertilized	-0.02	0.04	0.98
					Unfertilized	0.00	0.00	1.00
Fungicide	328.82	1	36.58	<.0001	Spraying	-0.25	0.04	0.78
					Unsprayed	0.00	0.00	1.00
Drainage	314.92	2	13.90	0.0010	Excellent	-0.18	0.07	0.84
					Good	0.00	0.07	1.00
					Poor	0.00	0.00	1.00

Remark: - Residual deviance: unexplained variation after fitting the model;

LRT: likelihood ratio test; DR: deviance reduction; Pr: probability of chi-square value exceeding the deviance reduction; χ^2 : Chi-square; SE: standard error and DF: degrees of freedom.

Appendix Table 3. 4. Analysis of deviance, natural logarithms of odds ratios, and standard errors for faba bean gall disease severity based on a reduced logistic regression model. Independent variables were evaluated using likelihood ratio tests during the 2022 and 2023 main cropping season

Variable	Residual deviance	DF	LRT DR	Pr > χ^2	Variable class	Estimate	SE	Odds Ratio
District	1327.21	3	60.14	<.0001	Intercept	0.82	0.28	2.27
					Kelala	-0.25	0.06	0.78
					Legambo	0.39	0.07	1.47
					Tenta	0.07	0.05	1.07
Year	720.26	1	477.72	<.0001	Woreilu	0.00	0.00	1.00
					2022	0.70	0.03	2.01
					2023	0.00	0.00	1.00
Altitude	608.55	3	74.30	<.0001	2426-2647	-0.57	0.10	0.56
					2648-2844	-0.28	0.09	0.75
					2845-3069	-0.01	0.07	0.99
					3070-3230	0.00	0.00	1.00
Soil	598.84	2	1.65	0.4385	Nitisol	-0.05	0.04	0.95
					Arenosol	-0.03	0.09	0.97
					Vertisol	0.00	0.00	1.00
Variety	461.88	1	4.23	0.0398	Wolkie	-0.13	0.07	0.87
					Local	0.00	0.00	1.00
Planting method	441.38	1	8.02	0.0046	Broadcast	0.28	0.10	1.32
					Row	0.00	0.00	1.00
Weeding	438.59	2	6.88	0.0321	No weeding	-0.14	0.06	0.87
					One times	-0.11	0.04	0.90
					Two times	0.00	0.00	1.00
Land	430.35	2	2.92	0.2322	One	0.09	0.06	
					plowing			1.10
					Two	0.06	0.04	
					plowing			1.07
Field Size	428.98	3	0.18	0.9141	Three	0.00	0.00	
					plowing			1.00
					0.25-0.5	0.07	0.17	1.07
					0.5-1	0.07	0.17	1.07
Growth stage	427.77	1	0.62	0.4327	1-1.5	0.00	0.00	1.00
					Flowering	-0.03	0.04	0.97
					Podding	0.00	0.00	1.00
Previous crop	406.40	2	18.99	<.0001	Cereal	-0.67	0.18	0.51
					Vegetable	-0.75	0.18	0.47
					Legume	0.00	0.00	1.00
Fertilizer	396.41	1	4.88	0.0272	Fertilized	-0.08	0.04	0.92
					Unfertilized	0.00	0.00	1.00
Fungicide	386.15	1	6.39	0.0115	Spraying	-0.10	0.04	0.90
					Unsprayed	0.00	0.00	1.00
Drainage	375.79	2	10.36	0.0056	Excellent	-0.12	0.07	0.89

Good	0.05	0.07	1.05
Poor	0.00	0.00	1.00

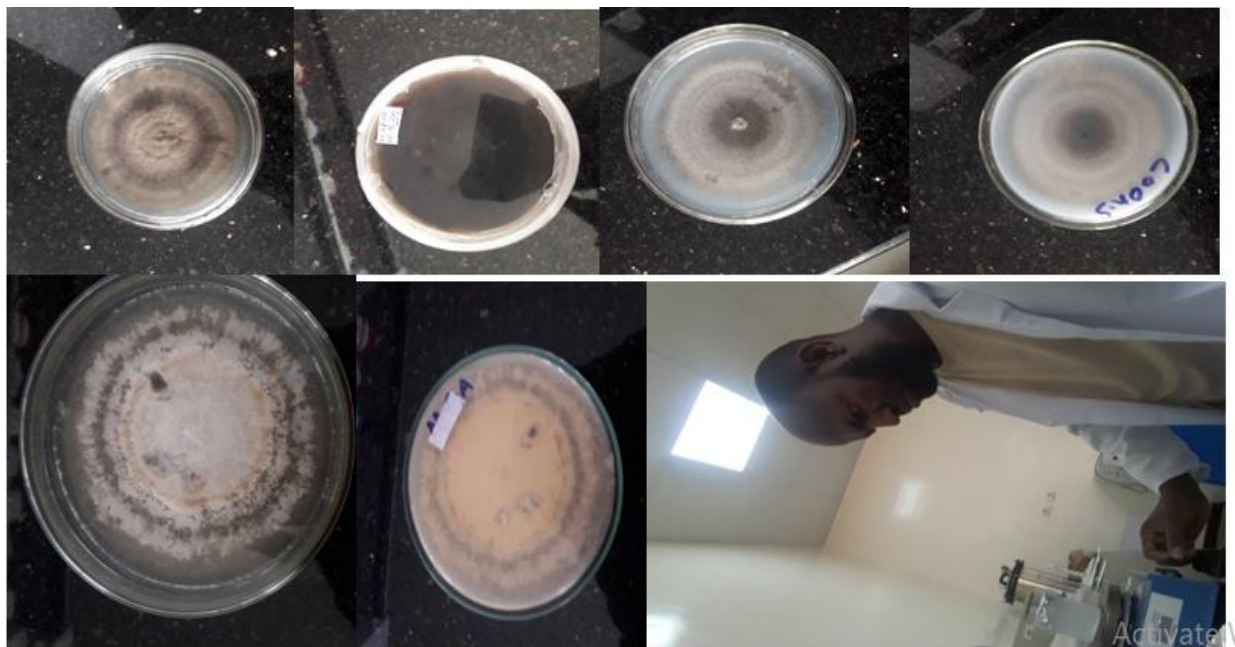
Residual deviance = unexplained variation after fitting the model; LRT = likelihood ratio test; DR = deviance reduction; Pr = probability of chi-square value exceeding the deviance reduction; χ^2 = Chi-square; SE = standard error; and df = degrees of freedom.



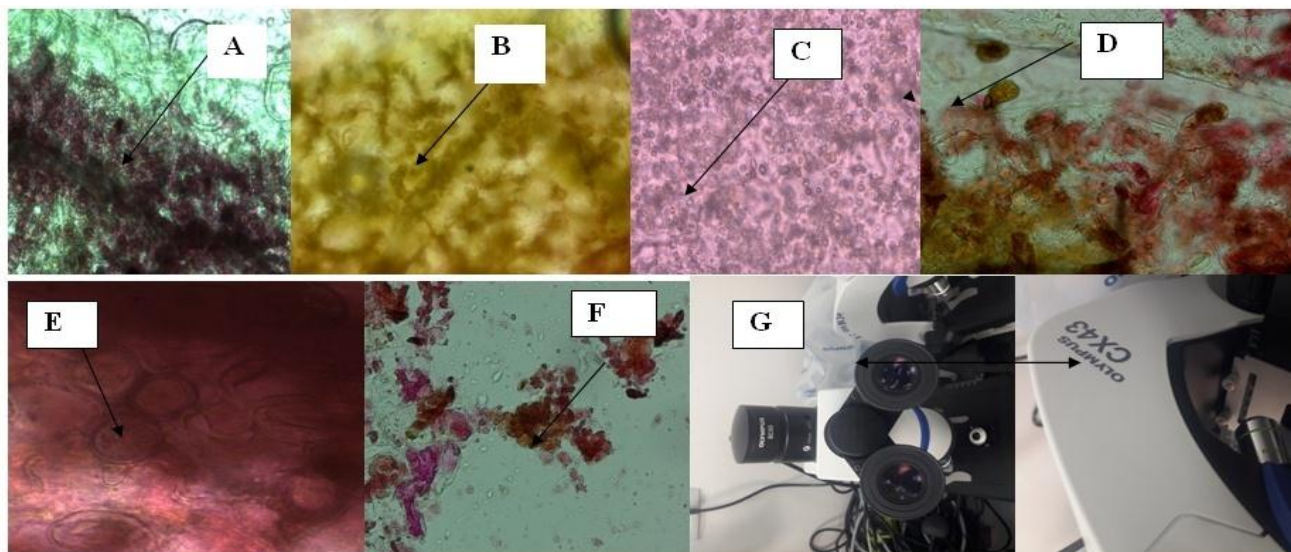
Appendix Figure 3. 2. Photographs showing data collection on disease parameters and physical factors during field surveys conducted in the 2022 and 2023 cropping seasons.



Appendix Figure 4. 1. Symptoms of faba bean gall disease at different growth stages, showing (a) gall symptoms at the seedling stage, (b) symptoms at the flowering stage, (c) gall development on the stem during the vegetative stage, and (d) severe gall infection on the leaf



Appendix Figure 4. 2. Photos demonstrating laboratory work on pathogen isolation and characterization.



Appendix Figure 4. 3. Typical cross section of a bean leaf with symptoms of faba bean gall disease showing dark brown regions (arrows) on underside of leaf gall (a), in which large masses of resting spores are produced (arrow) (b), and typical masses of resting spores in end.



Appendix Figure 4. 4. Photo showing the demonstration and observation of molecular materials during a laboratory experiment.

Appendix Table 5. 1. Treatment setup and randomization for evaluating different faba bean genotypes against faba bean gall disease at Legambo and Tenta Districts.

No plot	Treatment	Rep 1	Rep 2	Rep 3
1	FB-26872	10	38	76
2	FB-26873	5	39	60
3	Local	18	42	63
4	FB-26885	25	53	77
5	FB-26869	23	47	58
6	Obse	21	44	70
7	EH09007-4	17	35	64
8	EH06088-6	16	43	59
9	EH96048-1	24	52	61
10	EH09004-2	27	34	65
11	EH06007-4	12	50	62
12	EH011038-3	19	48	81
13	EH920070	14	32	83
14	EH00102-8-1	7	54	80
15	EH98097-1	22	29	67
16	EH06007-2	2	55	68
17	EH010010-1	15	40	71
18	EH09046-3	9	51	84
19	EH09028-3	20	36	79
20	EH97091-2	11	33	69
21	EH07015-7	3	31	72

22	EH011025-1	1	49	73
23	EH011018-5	8	30	74
24	EH07005	26	45	57
25	EH011016-2	28	56	82
26	Dosha	6	41	66
27	Wolkie	4	46	75
28	Gora	13	37	78

Appendix Table 5. 2. Faba bean genotypes evaluated for their reaction against the faba bean gall in the 2022 and 2023 main cropping seasons.

No	Name of Genotype	Collected from
1	FB-26872	Ethiopian Biodiversity Institute
2	FB-26873	Ethiopian Biodiversity Institute
3	Local	---
4	FB-26885	Ethiopian Biodiversity Institute
5	FB-26869	Ethiopian Biodiversity Institute
6	Obse(EH95073-1)	Holeta Agricultural Research Center
7	EH09007-4	Holeta Agricultural Research Center
8	EH06088-6	Kulmsa Agriculture Research Center
9	EH96048-1	Holeta Agricultural Research Center
10	EH09004-2	Holeta Agricultural Research Center
11	EH06007-4	Kulmsa Agriculture Research Center
12	EH011038-3	Holeta Agricultural Research Center
13	EH920070	Holeta Agricultural Research Center
14	EH00102-8-1	Holeta Agricultural Research Center
15	EH98097-1	Kulmsa Agriculture Research Center
16	EH06007-2	Holeta Agricultural Research Center
17	EH010010-1	Kulmsa Agriculture Research Center
18	EH09046-3	Kulmsa Agriculture Research Center
19	EH09028-3	Kulmsa Agriculture Research Center
20	EH97091-2	Holeta Agricultural Research Center
21	EH07015-7	Holeta Agricultural Research Center
22	EH011025-1	Kulmsa Agriculture Research Center
23	EH011018-5	Holeta Agricultural Research Center
24	EH07005	Holeta Agricultural Research Center
25	EH011016-2	Holeta Agricultural Research Center
26	Dosha(COLL-155/00-3)	Holeta Agricultural Research Center
27	Wolkie(EH96049-2)	Holeta Agricultural Research Center
28	Gora	Holeta Agricultural Research Center

Appendix Table 5. 3. Summary of analysis of variance mean squares for the effect of locations, year, treatments and their interactions on agronomic, yield, and disease parameters at Legambo and Tenta, north-eastern Ethiopia.

Source	DF	DI	PSI	AUDPC	PH	NPP	SPP	Yield	HSW
Block	2	50.02ns	13.66ns	11086.15ns	56.30*	1.12ns	0.01ns	0.01ns	10.53ns
Loc	1	1995.97***	3261.47***	433586.73***	867.54***	137.09***	0.34***	5.89***	510.35***
Year	1	1177.02***	349.68***	124008.62**	76.67*	106.29***	0.36***	0.74***	226.22**
Genotype	27	174.86***	171.73***	167858.45***	160.35***	18.22***	0.24***	0.33***	469.40***
Genotype*Loc	27	1.90ns	2.04ns	730.905ns	7.19ns	0.79ns	0.01ns	0.02ns	2.44ns
Genotype*Year	27	1.45ns	3.40ns	879.93ns	4.15ns	1.04ns	0.02ns	0.02ns	1.98ns
Year*Loc	1	111.63*	102.27*	30213.71ns	61.29ns	8.49*	0.10ns	0.003ns	84.50*
Genotype*Year*Loc	27	1.28ns	2.65ns	359.74ns	6.09ns	0.50ns	0.01ns	0.01ns	3.53ns
CV		6.37	7.73	6.43	5.96	11.27	6.15	7.98	7.29
Mean		75.75	59.46	1520.85	67.75	11.59	2.67	1.67	62.28

Appendix Table 5. 4. Faba bean gall disease incidence, Severity and AUDPC on different faba bean genotypes at Legambo district in the 2022 and 2023 cropping seasons.

Faba bean Variety	DI%		PSI%		AUDPC %-days	
	2022	2023	2022	2023	2022	2023
FB-26872	83.67 ^{a-e}	81.00 ^{a-e}	64.67 ^{a-e}	63.67 ^{a-f}	1720.31 ^{a-c}	1676.41 ^{a-d}
FB-26873	81.33 ^{a-f}	76.33 ^{a-e}	64.33 ^{a-e}	63.28 ^{a-f}	1544.56 ^{d-h}	1494.52 ^{d-i}
Local	85.83 ^{a-d}	83.68 ^{a-d}	67.72 ^{ab}	67.95 ^{a-c}	1746.97 ^{ab}	1709.75 ^{a-c}
FB-26885	79.67 ^{b-f}	76.33 ^{a-e}	65.00 ^{a-d}	66.25 ^{a-d}	1531.22 ^{d-h}	1494.52 ^{d-i}
FB-26869	75.67 ^{ef}	73.67 ^e	57.00 ^{de}	57.30 ^{d-f}	1385.48 ^{i-k}	1368.82 ^{i-k}
FB-Obse	75.33 ^{ef}	73.00 ^e	56.67 ^{de}	54.97 ^f	1362.82 ^k	1350.48 ^{ik}
EH09007-4	78.33 ^{d-f}	76.00 ^{a-e}	65.67 ^{a-d}	65.26 ^{a-e}	1534.56 ^{d-h}	1494.52 ^{d-i}
EH06088-6	76.67 ^{ef}	74.62 ^{de}	63.33 ^{a-e}	62.22 ^{a-f}	1487.89 ^{f-k}	1481.19 ^{f-j}
EH96048-1	88.33 ^a	85.33 ^{ab}	66.33 ^{a-c}	69.11 ^a	1770.31 ^a	1759.75 ^a
EH09004-2	76.33 ^{ef}	75.32 ^{c-e}	65.00 ^{a-d}	64.33 ^{a-f}	1469.22 ^{g-k}	1471.19 ^{f-k}
EH06007-4	79.00 ^{c-f}	75.67 ^{b-e}	64.00 ^{a-e}	60.56 ^{a-f}	1580.31 ^{d-g}	1599.75 ^{b-g}
EH011038-3	77.33 ^{ef}	74.67 ^{de}	60.67 ^{a-e}	60.33 ^{a-f}	1511.22 ^{e-i}	1477.86 ^{f-j}
EH920070	77.00 ^{ef}	74.67 ^{de}	62.00 ^{a-e}	60.44 ^{a-f}	1522.56 ^{e-h}	1477.86 ^{f-j}
EH00102-8-1	87.33 ^{ab}	85.67 ^a	66.33 ^{a-c}	68.89 ^{ab}	1766.97 ^a	1756.41 ^a
EH98097-1	79.00 ^{c-f}	76.33 ^{a-e}	63.67 ^{a-e}	61.56 ^{a-f}	1631.22 ^{b-e}	1621.19 ^{a-e}
EH06007-2	77.00 ^{ef}	73.67 ^e	60.67 ^{a-e}	59.67 ^{a-f}	1613.64 ^{c-f}	1609.75 ^{b-f}
EH010010-1	79.33 ^{b-f}	76.33 ^{a-e}	63.00 ^{a-e}	61.67 ^{a-f}	1657.89 ^{a-d}	1627.86 ^{a-e}
EH09046-3	76.33 ^{ef}	74.33 ^{de}	59.33 ^{b-e}	58.67 ^{c-f}	1491.17 ^{t-k}	1485.62 ^{e-j}
EH09028-3	77.33 ^{ef}	74.67 ^{de}	61.67 ^{a-e}	58.93 ^{b-f}	1544.56 ^{d-h}	1527.86 ^{d-h}
EH97091-2	86.67 ^{a-c}	84.67 ^{a-c}	67.67 ^{ab}	67.22 ^{a-d}	1763.64 ^a	1756.41 ^a
EH07015-7	77.67 ^{d-f}	75.67 ^{b-e}	60.00 ^{b-e}	59.32 ^{a-f}	1587.84 ^{d-g}	1568.96 ^{c-g}
EH011025-1	80.33 ^{a-f}	77.67 ^{a-e}	62.00 ^{a-e}	60.33 ^{a-f}	1529.22 ^{d-h}	1517.86 ^{d-h}
EH011018-5	78.26 ^{def}	76.67 ^{a-e}	65.33 ^{a-d}	63.56 ^{a-f}	1571.17 ^{d-g}	1552.29 ^{c-h}
EH07005	79.33 ^{b-f}	76.67 ^{a-e}	65.67 ^{a-d}	64.33 ^{a-f}	1501.22 ^{e-j}	1451.19 ^{g-k}
EH011016-2	78.67 ^{c-f}	76.33 ^{a-e}	64.67 ^{a-e}	63.11 ^{a-f}	1514.56 ^{e-i}	1484.52 ^{e-j}
Dosha	74.39 ^f	72.53 ^e	55.67 ^e	54.33 ^f	1378.82 ^{jk}	1343.82 ^k
Wolkie	76.22 ^{ef}	73.50 ^e	57.92 ^{c-e}	55.83 ^{ef}	1411.22 ^{h-k}	1427.86 ^{h-k}
Gora	83.1 ^{a-e}	78.00 ^{a-e}	69.17 ^a	65.72 ^{a-e}	1731.17 ^{a-c}	1718.96 ^{ab}
MSE	23.23	24.14	22.59	25.37	4230.12	20749.26
CV	6.06	6.39	7.50	8.11	9.93	9.35
Mean	79.48	76.89	63.35	62.10	1567.68	1540.95
P value	0.0250	0.0446	0.0223	0.0225	0.0426	0.0098

MSqE=Mean square of error; CV=Coefficient of variation; DI=Disease Incidence; Percentage severity index; AUDPC=Area under disease progress curve. Treatments with the same letter are not significantly different.



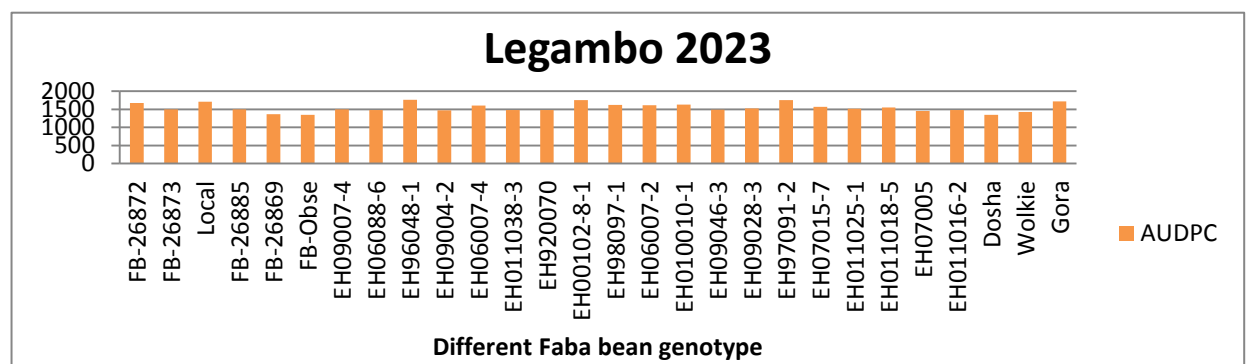
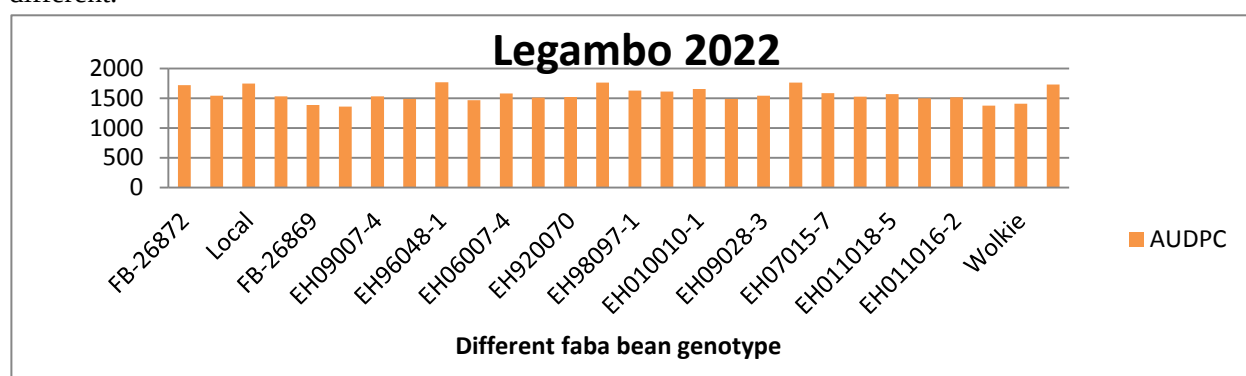
Appendix Figure 5. 1. Photographs showing land preparation, sowing, seedling, vegetative, flowering, podding, and harvesting stages during the field experiments conducted in the 2022 and 2023 cropping seasons.

Appendix Table 5. 5. Faba bean gall disease incidence, Severity and AUDPC on different faba bean genotypes in 2022 and 2023 cropping seasons at Tenta district.

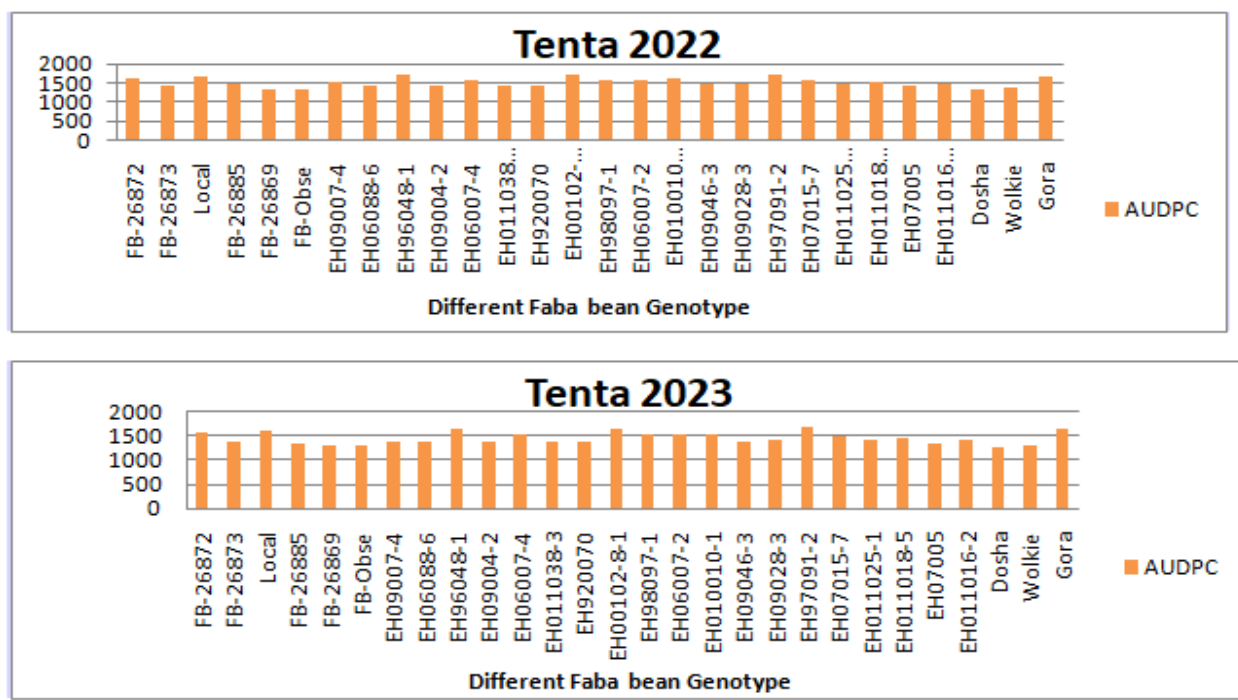
Faba bean variety	DI%		PSI%		AUDPC(%-days)	
	2022	2023	2022	2023	2022	2023
FB-26872	80.67 ^{a-c}	78.33 ^{a-d}	60.67 ^{a-e}	57.36 ^{a-g}	1635.21 ^{a-c}	1559.77 ^{a-d}
FB-26873	75.87 ^{a-c}	70.50 ^{a-f}	60.56 ^{a-e}	57.00 ^{a-g}	1435.11 ^{d-g}	1381.69 ^{e-i}
Local	79.06 ^{a-c}	77.46 ^{a-e}	63.83 ^{ab}	60.73 ^{a-c}	1668.55 ^{ab}	1609.77 ^{a-c}
FB-26885	75.33 ^{a-c}	69.67 ^{b-f}	61.33 ^{a-d}	59.33 ^{a-e}	1485.11 ^{c-g}	1365.02 ^{f-i}
FB-26869	72.00 ^c	67.33 ^{ef}	54.00 ^{e-g}	48.56 ^{ij}	1331.48 ^{fg}	1303.23 ^{hi}
Obse	72.33 ^c	67.00 ^f	51.53 ^{fg}	49.22 ^{h-j}	1328.15 ^{fg}	1291.23 ⁱ
EH09007-4	75.67 ^{a-c}	69.67 ^{b-f}	60.33 ^{a-e}	58.11 ^{a-f}	1501.77 ^{b-f}	1398.36 ^{d-i}
EH06088-6	72.67 ^c	68.33 ^{c-f}	57.33 ^{a-f}	54.67 ^{b-i}	1438.44 ^{d-g}	1381.69 ^{e-i}
EH96048-1	84.33 ^a	80.00 ^a	64.33 ^a	61.67 ^a	1715.21 ^{ab}	1649.77 ^{ab}
EH09004-2	72.80 ^c	67.50 ^{ef}	60.00 ^{a-e}	51.56 ^{f-j}	1434.11 ^{d-g}	1377.02 ^{e-i}
EH06007-4	72.83 ^c	69.00 ^{c-f}	58.67 ^{a-e}	52.33 ^{f-j}	1556.88 ^{a-d}	1543.11 ^{a-e}
EH011038-3	74.67 ^{bc}	69.00 ^{c-f}	55.67 ^{d-g}	53.22 ^{d-j}	1436.11 ^{d-g}	1398.36 ^{d-i}
EH920070	73.67 ^c	69.00 ^{c-f}	55.67 ^{d-g}	53.56 ^{d-j}	1443.77 ^{d-g}	1395.02 ^{d-i}
EH00102-8-1	84.00 ^{ab}	79.67 ^{ab}	64.00 ^{ab}	61.11 ^{ab}	1721.88 ^a	1643.11 ^{ab}
EH98097-1	75.33 ^{a-c}	69.67 ^{b-f}	57.00 ^{c-f}	54.22 ^{c-i}	1578.44 ^{a-d}	1528.36 ^{a-f}
EH06007-2	73.67 ^c	67.67 ^{ef}	55.00 ^{d-g}	52.89 ^{e-j}	1568.55 ^{a-d}	1523.11 ^{a-f}
EH010010-1	75.33 ^{a-c}	69.67 ^{b-f}	57.67 ^{a-f}	54.67 ^{b-i}	1601.77 ^{a-d}	1531.69 ^{a-f}
EH09046-3	72.33 ^c	68.00 ^{d-f}	54.00 ^{e-g}	51.22 ^{g-j}	1454.51 ^{d-g}	1382.57 ^{e-i}
EH09028-3	73.67 ^c	69.20 ^{c-f}	54.67 ^{d-g}	51.67 ^{f-j}	1485.11 ^{c-g}	1435.02 ^{d-i}
EH97091-2	83.67 ^{ab}	78.67 ^{a-c}	62.33 ^{a-c}	59.89 ^{a-d}	1718.55 ^a	1676.44 ^a
EH07015-7	74.67 ^{bc}	69.67 ^{b-f}	54.33 ^{e-g}	52.22 ^{f-j}	1554.51 ^{a-d}	1482.57 ^{b-g}
EH011025-1	77.00 ^{a-c}	71.67 ^{a-f}	55.67 ^{d-g}	53.33 ^{d-j}	1493.77 ^{b-g}	1431.69 ^{d-i}

EH011018-5	75.33 ^{a-c}	70.00 ^{b-f}	59.67 ^{a-e}	56.22 ^{a-g}	1521.17 ^{b-e}	1465.91 ^{c-h}
EH07005	75.67 ^{a-c}	70.00 ^{b-f}	60.00 ^{a-e}	57.00 ^{a-g}	1435.11 ^{d-g}	1365.02 ^{f-i}
EH011016-2	75.67 ^{a-c}	70.00 ^{b-f}	58.67 ^{a-e}	55.67 ^{a-h}	1493.77 ^{b-g}	1418.36 ^{d-i}
Dosha	71.17 ^c	65.08 ^f	50.00 ^f	47.48 ^j	1314.82 ^g	1281.23 ⁱ
Wolkie	72.50 ^c	67.22 ^{ef}	51.83 ^{fg}	48.85 ^{ij}	1361.77 ^{efg}	1318.36 ^{ghi}
Gora	80.17 ^{a-c}	75.22 ^{a-f}	62.50 ^{abc}	59.71 ^{a-d}	1667.84 ^{ab}	1636.57 ^{ab}
MSE	22.73	28.23	26.08	26.30	20926.26	20078.27
CV	6.29	7.50	8.82	9.36	9.56	9.72
Mean	75.76	70.86	57.91	54.79	1513.62	1457.44
P value	0.0287	0.0259	0.0389	0.0257	0.0146	0.0232

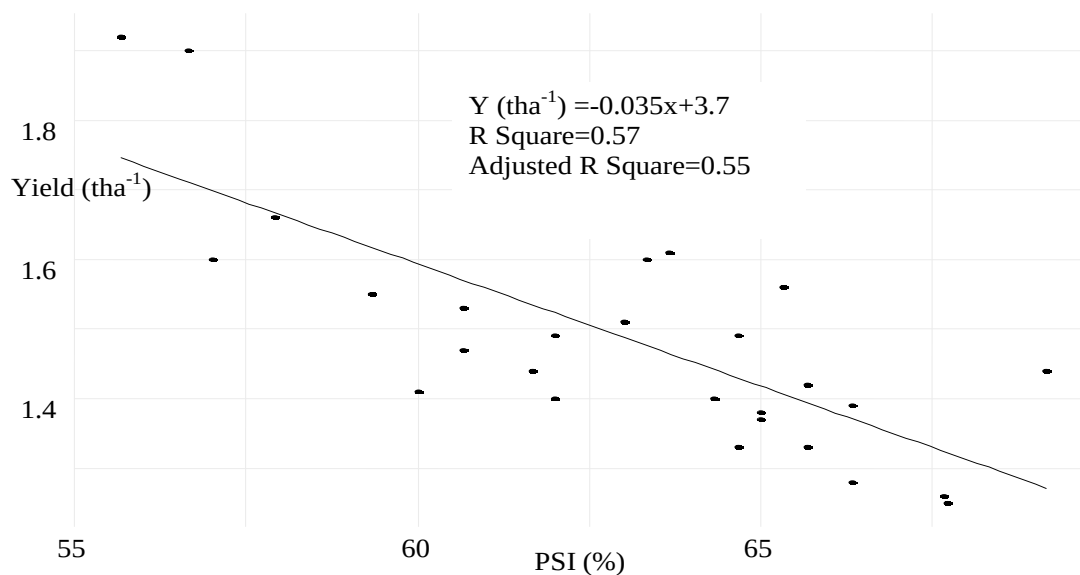
MSqE=Mean square of error; CV=Coefficient of variation; DI=Disease Incidence; Percentage severity index; AUDPC=Area under disease progress curve. Treatments with the same letter are not significantly different.



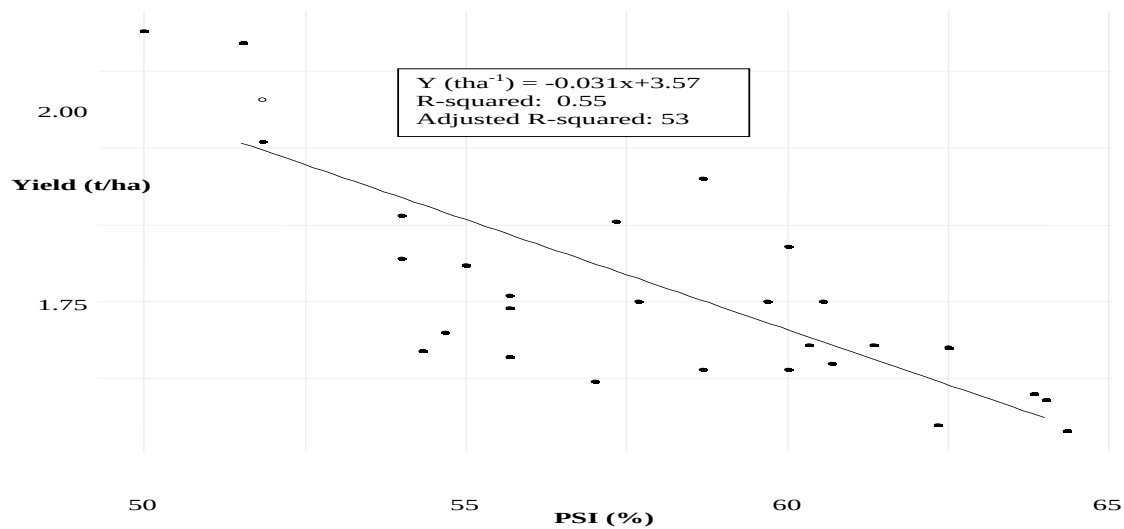
Appendix Figure 5. 2. Area under disease progress curve of the different faba bean genotype for the faba bean gall at Legambo in the 2022(a) and 2023(b) main cropping seasons.



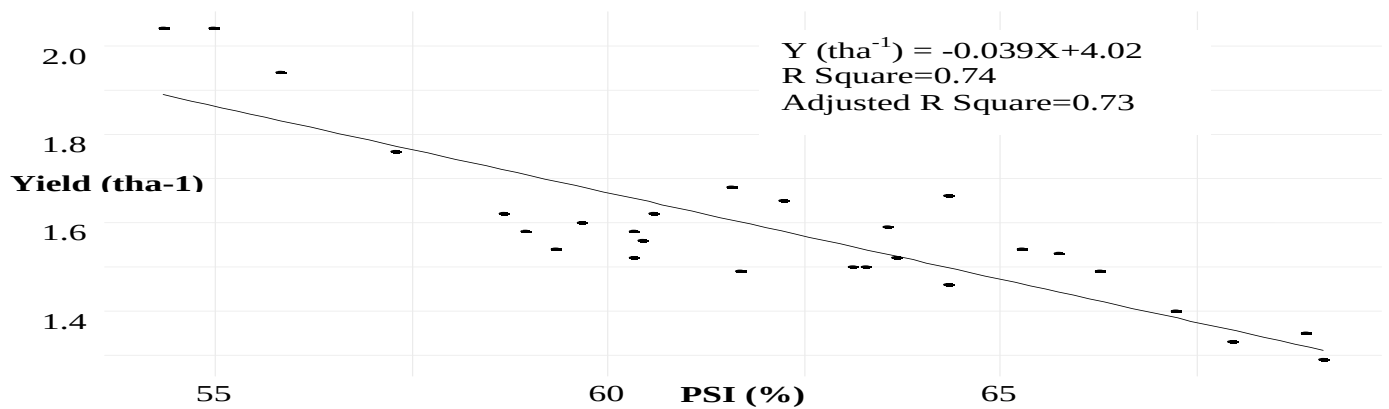
Appendix Figure 5. 3. Area under disease progress curve of the different faba bean genotype for the faba bean gall at Tenta in the 2022(c) and 2023(d) main cropping seasons.



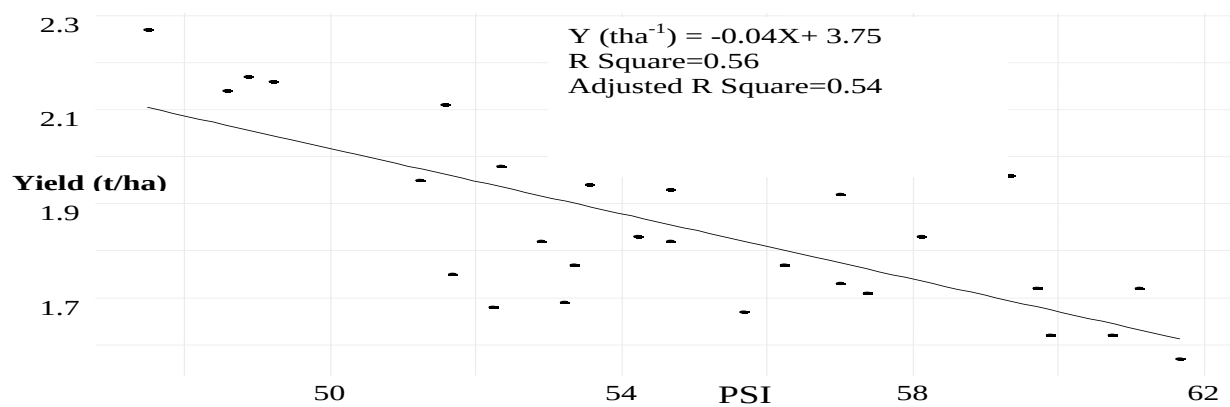
Appendix Figure 5. 4. Yield Vs PSI on faba bean gall disease at Legambo 2022



Appendix Figure 5. 5. Yield Vs PSI on faba bean gall disease at Tenta 2022



Appendix Figure 5. 6. Yield VS PSI on faba bean gall disease at Legambo 2023



Appendix Figure 5. 7. Yield VS PSI on faba bean gall disease at Tenta 2023.

Appendix Table 5. 6. Mean yield components of faba bean genotypes evaluated for faba bean disease under field conditions in the 2022 and 2023 cropping seasons at Legambo.

Faba bean variety	PH(cm)	PH(cm)	NPP ⁻¹	NPP ⁻¹	SPP ⁻¹	SPP ⁻¹
	2022	2023	2022	2023	2022	2023
FB-26872	62.40 ^{c-e}	59.27 ^{fg}	10.60 ^{b-d}	11.27 ^{b-e}	2.45 ^{cd}	2.67 ^{c-e}
FB-26873	64.80 ^{a-d}	64.50 ^{c-f}	10.47 ^{b-e}	11.60 ^{b-d}	2.63 ^{a-c}	2.57 ^{d-f}
Local	61.29 ^{c-e}	61.40 ^{d-g}	9.45 ^{b-f}	10.45 ^{c-e}	2.43 ^{cd}	2.52 ^{e-g}
FB-26885	66.83 ^{a-d}	66.33 ^{b-e}	9.67 ^{b-f}	11.87 ^{b-d}	2.57 ^{bc}	2.6 ^{c-f}
FB-26869	72.53 ^a	70.07 ^{bc}	11.67 ^{a-c}	12.93 ^{a-c}	2.75 ^{a-c}	2.79 ^{a-d}
FB-Obse	69.67 ^{a-c}	69.87 ^{bc}	11.73 ^{a-c}	13.63 ^{ab}	2.78 ^{a-c}	2.85 ^{a-c}
EH09007-4	66.20 ^{a-d}	64.27 ^{c-f}	9.87 ^{b-f}	12.07 ^{b-d}	2.56 ^{bc}	2.6 ^{c-f}
EH06088-6	67.93 ^{a-c}	68.13 ^{bc}	10.60 ^{b-d}	12.47 ^{b-d}	2.67 ^{a-c}	2.66 ^{c-e}
EH96048-1	54.67 ^e	57.93 ^g	7.13 ^f	10.00 ^{de}	2.13 ^d	2.37 ^{fg}
EH09004-2	68.67 ^{a-c}	68.53 ^{bc}	11.40 ^{a-c}	12.20 ^{b-d}	2.60 ^{a-c}	2.68 ^{c-e}
EH06007-4	68.73 ^{a-c}	67.40 ^{b-d}	10.93 ^{b-d}	11.80 ^{b-d}	2.60 ^{a-c}	2.61 ^{c-e}
EH011038-3	66.67 ^{a-d}	67.07 ^{b-d}	10.73 ^{b-d}	10.67 ^{c-e}	2.73 ^{a-c}	2.76 ^{a-e}
EH920070	64.87 ^{a-d}	63.73 ^{c-g}	10.53 ^{b-d}	11.33 ^{b-e}	2.60 ^{a-c}	2.64 ^{c-e}
EH00102-8-1	61.13 ^{c-e}	58.07 ^g	7.50 ^{ef}	8.93 ^e	2.40 ^{cd}	2.33 ^g
EH98097-1	66.00 ^{a-d}	66.00 ^{c-e}	10.67 ^{b-d}	11.47 ^{b-d}	2.60 ^{a-c}	2.6 ^{c-f}
EH06007-2	65.27 ^{a-d}	64.27 ^{c-f}	9.47 ^{b-f}	11.47 ^{b-d}	2.67 ^{a-c}	2.68 ^{c-e}
EH010010-1	62.67 ^{b-d}	64.67 ^{c-f}	10.07 ^{b-f}	11.20 ^{b-e}	2.40 ^{cd}	2.6 ^{c-f}
EH09046-3	67.73 ^{a-d}	68.00 ^{bc}	10.85 ^{b-d}	11.90 ^{b-d}	3.0 ^a	2.64 ^{c-e}
EH09028-3	66.80 ^{a-d}	67.20 ^{b-d}	9.53 ^{b-f}	11.70 ^{b-d}	2.56 ^{bc}	2.61 ^{c-f}
EH97091-2	58.53 ^{de}	60.60 ^{e-g}	7.93 ^{d-f}	10.20 ^{de}	2.47 ^{cd}	2.55 ^{d-g}
EH07015-7	66.73 ^{a-d}	68.03 ^{bc}	10.93 ^{b-d}	11.27 ^{b-e}	2.60 ^{a-c}	2.69 ^{b-e}
EH011025-1	67.07 ^{a-d}	68.33 ^{bc}	8.13 ^{d-f}	10.73 ^{c-e}	2.67 ^{a-c}	2.68 ^{c-e}
EH011018-5	65.13 ^{a-d}	67.60 ^{b-d}	8.87 ^{c-f}	11.60 ^{b-d}	2.67 ^{a-c}	2.73 ^{a-e}
EH07005	68.07 ^{a-c}	69.40 ^{bc}	10.25 ^{b-e}	12.07 ^{b-d}	2.73 ^{a-c}	2.77 ^{a-e}
EH011016-2	65.60 ^{a-d}	66.20 ^{b-e}	10.73 ^{b-d}	11.67 ^{b-d}	2.67 ^{a-c}	2.75 ^{a-e}
Dosha	73.78 ^a	76.40 ^a	14.02 ^a	15.03 ^a	2.93 ^{ab}	2.94 ^a
Wolkie	71.98 ^{ab}	72.65 ^{ab}	12.01 ^{ab}	13.46 ^{ab}	2.90 ^{ab}	2.93 ^{ab}
Gora	68.87 ^{a-c}	67.59 ^{b-d}	10.65 ^{b-d}	11.90 ^{b-d}	2.63 ^{a-c}	2.61 ^{c-f}
MSE	24.52	25.09	3.32	1.58	0.05	0.03
CV	7.49	7.56	17.83	10.75	8.33	6.55
Mean	66.09	66.23	10.23	11.67	2.62	2.66
P value	0.0135	0.0100	0.0231	0.0010	0.0188	0.0313

Appendix Table 5. 7. Mean of yield and yield components of faba bean genotype evaluated for faba bean disease under field conditions in the 2022 and 2023 cropping seasons at Tenta.

Faba bean genotype	PH(cm)	PH(cm)	NPP ⁻¹	NPP ⁻¹	SPP ⁻¹	SPP ⁻¹
	2022	2023	2022	2023	2022	2023
FB-26872	66.73 ^{a-e}	73.53 ^{a-c}	10.53 ^{e-h}	12.40 ^{c-e}	2.48 ^{c-e}	2.76 ^{c-g}
FB-26873	69.13 ^{a-d}	68.53 ^{c-e}	12.13 ^{b-e}	12.93 ^{b-e}	2.56 ^{b-e}	2.71 ^{d-h}
Local	63.51 ^{b-e}	63.07 ^{ef}	10.66 ^{d-h}	11.79 ^{de}	2.54 ^{c-e}	2.53 ^{gh}
FB-26885	67.97 ^{a-e}	71.33 ^{b-d}	11.87 ^{b-f}	13.07 ^{b-e}	2.61 ^{a-e}	2.67 ^{d-h}
FB-26869	71.40 ^{ab}	72.67 ^{a-c}	13.40 ^{a-c}	14.00 ^{a-c}	2.79 ^{a-c}	2.88 ^{b-d}
Obse	73.00 ^b	73.67 ^{a-c}	13.60 ^{ab}	14.39 ^{ab}	2.80 ^{a-c}	2.88 ^{b-d}
EH09007-4	67.80 ^{a-e}	72.33 ^{b-d}	11.87 ^{b-f}	13.00 ^{b-e}	2.60 ^{a-e}	2.67 ^{d-h}
EH06088-6	69.93 ^{a-d}	70.00 ^{b-d}	12.93 ^{a-e}	13.20 ^{b-e}	2.75 ^{a-d}	2.67 ^{d-h}
EH96048-1	59.40 ^e	60.67 ^f	9.27 ^{gh}	9.47 ^f	2.30 ^e	2.47 ^h
EH09004-2	72.33 ^{ab}	72.00 ^{b-d}	13.20 ^{a-d}	13.40 ^{b-d}	2.76 ^{a-d}	2.76 ^{c-g}
EH06007-4	70.53 ^{a-d}	69.67 ^{b-d}	12.53 ^{b-e}	13.30 ^{b-d}	2.71 ^{a-d}	2.63 ^{e-h}
EH011038-3	68.87 ^{a-d}	69.33 ^{b-e}	12.47 ^{b-e}	12.27 ^{c-e}	2.74 ^{a-d}	2.81 ^{b-e}
EH920070	67.07 ^{a-e}	70.60 ^{b-d}	11.67 ^{b-g}	12.07 ^{de}	2.63 ^{a-e}	2.80 ^{b-e}
EH00102-8-1	62.27 ^{cde}	67.27 ^{c-e}	9.00 ^g	9.31 ^f	2.40 ^{de}	2.57 ^{f-h}
EH98097-1	67.60 ^{a-e}	68.67 ^{c-e}	12.27 ^{b-e}	12.67 ^{b-e}	2.60 ^{a-e}	2.75 ^{c-g}
EH06007-2	67.40 ^{a-e}	70.67 ^{b-d}	12.93 ^{a-e}	12.33 ^{c-e}	2.71 ^{a-d}	2.75 ^{c-g}
EH010010-1	66.93 ^{a-e}	67.33 ^{c-e}	10.73 ^{d-h}	11.93 ^{de}	2.60 ^{a-e}	2.65 ^{e-h}
EH09046-3	70.93 ^{abc}	71.67 ^{b-d}	13.13 ^{a-d}	13.47 ^{b-d}	2.78 ^{a-d}	2.80 ^{b-e}
EH09028-3	69.33 ^{a-d}	70.00 ^{b-d}	12.67 ^{a-e}	12.73 ^{b-e}	2.61 ^{a-e}	2.73 ^{d-g}
EH97091-2	61.53 ^{de}	65.67 ^{d-f}	9.40 ^{f-h}	11.40 ^e	2.53 ^{c-e}	2.67 ^{d-h}
EH07015-7	68.73 ^{a-d}	70.60 ^{b-d}	12.00 ^{b-e}	11.47 ^e	2.67 ^{a-e}	2.73 ^{d-g}
EH011025-1	68.93 ^{a-d}	70.67 ^{b-d}	10.87 ^{c-h}	12.87 ^{b-e}	2.67 ^{a-e}	2.97 ^{bc}
EH011018-5	68.33 ^{a-d}	70.07 ^{b-d}	11.67 ^{b-g}	13.60 ^{a-d}	2.73 ^{a-d}	2.80 ^{b-e}
EH07005	69.67 ^{a-d}	73.33 ^{a-c}	11.73 ^{b-f}	12.07 ^{de}	2.64 ^{a-d}	2.81 ^{b-e}
EH011016-2	68.60 ^{a-d}	68.67 ^{c-e}	11.80 ^{b-f}	12.00 ^{de}	2.63 ^{a-e}	2.77 ^{c-f}
Dosha	74.85 ^a	78.73 ^a	15.03 ^a	15.23 ^a	2.96 ^a	3.20 ^a
Wolkie	74.10 ^a	75.87 ^{ab}	13.59 ^{ab}	14.45 ^{ab}	2.92 ^{ab}	3.00 ^b
Gora	66.50 ^{a-e}	70.80 ^{b-d}	11.85 ^{b-f}	12.91 ^{b-e}	2.52 ^{c-e}	2.67 ^{d-h}
MSE	21.15	21.75	1.99	2.81	0.04	0.03
CV	6.72	6.69	11.91	13.26	7.14	6.57
Mean	68.46	69.73	11.83	12.65	2.65	2.75
P value	0.0346	0.0467	0.0019	0.0341	0.0483	0.0159

PH = Plant height; NPPP = Number of pods per plant; and SPP = Number of seeds per pod. MSqE= mean square of error, CV=Coefficient of variation.

Appendix Table 5. 8. Yields and hundred seed weights of faba bean genotypes at Legambo and Tenta in the 2022 and 2023 main cropping seasons.

Faba bean variety	Legambo				Tenta			
	Yield (t/ha ⁻¹)	Yield (t/ha ⁻¹)	HSW (g)	HSW (g)	Yield (t/ha ⁻¹)	Yield (t/ha ⁻¹)	HSW (g)	HSW (g)
FB-26872	1.33 ^{j-m}	1.52 ^{c-f}	55.00 ^{fg}	58.67 ^{e-h}	1.65 ^{d-g}	1.71 ^{i-l}	59.33 ^{de}	61.00 ^{de}
FB-26873	1.4 ^{h-m}	1.5 ^{c-g}	56.00 ^{e-g}	57.20 ^{f-i}	1.75 ^{c-g}	1.92 ^{d-i}	59.00 ^{de}	60.0 ^e
Local	1.25 ^m	1.33 ^{gh}	51.00 ^g	53.00 ^{ij}	1.60 ^{e-g}	1.62 ^{kl}	53.07 ^f	54.33 ^f
FB-26885	1.37 ^{i-m}	1.49 ^{c-g}	57.00 ^{d-f}	59.33 ^{d-g}	1.68 ^{d-g}	1.96 ^{c-e}	60.67 ^{c-e}	61.00 ^{de}
FB-26869	1.60 ^{b-e}	1.76 ^b	61.3 ^{b-e}	65.33 ^{a-c}	1.89 ^{b-d}	2.14 ^{a-c}	65.67 ^{bc}	66.00 ^{b-d}
Obse	1.90 ^a	2.04 ^a	64.67 ^{a-c}	65.67 ^{a-c}	2.17 ^a	2.16 ^{ab}	67.66 ^{ab}	68.00 ^{ab}
EH09007-4	1.42 ^{f-k}	1.54 ^{c-f}	57.67 ^{d-f}	65.67 ^{a-c}	1.68 ^{d-g}	1.83 ^{e-j}	67.33 ^{ab}	65.3 ^{b-e}
EH06088-6	1.60 ^{b-e}	1.65 ^{b-d}	64.00 ^{a-c}	66.00 ^{a-c}	1.88 ^{b-d}	1.93 ^{d-h}	66.33 ^b	67.00 ^{bc}
EH96048-1	1.28 ^{k-m}	1.29 ^h	45.67 ^h	48.00 ^{jk}	1.54 ^g	1.57 ^l	48.33 ^g	52.33 ^f
EH09004-2	1.38 ^{i-m}	1.66 ^{b-d}	62.00 ^{b-d}	64.67 ^{b-d}	1.84 ^{b-e}	2.11 ^{a-d}	65.00 ^{bc}	66.00 ^{b-d}
EH06007-4	1.64 ^{bc}	1.62 ^{c-e}	62.00 ^{b-d}	65.33 ^{a-c}	1.95 ^{a-c}	1.98 ^{b-e}	67.00 ^{ab}	66.93 ^{bc}
EH011038-3	1.47 ^{e-j}	1.52 ^{c-f}	64.33 ^{a-c}	66.33 ^{a-c}	1.66 ^{d-g}	1.69 ^{j-l}	66.33 ^b	67.33 ^{a-c}
EH920070	1.40 ^{g-l}	1.56 ^{b-f}	64.67 ^{a-c}	66.67 ^{ab}	1.76 ^{b-g}	1.94 ^{d-g}	67.00 ^{ab}	68.33 ^{ab}
EH00102-8-1	1.39 ^{h-m}	1.35 ^{f-h}	51.00 ^g	53.30 ^{hi}	1.59 ^{e-g}	1.72 ^{g-l}	53.67 ^f	54.20 ^f
EH98097-1	1.61 ^{b-d}	1.68 ^{bc}	64.00 ^{a-c}	66.00 ^{a-c}	1.62 ^{d-g}	1.83 ^{e-j}	66.33 ^b	67.00 ^{bc}
EH06007-2	1.53 ^{b-h}	1.6 ^{b-e}	64.67 ^{a-c}	67.00 ^{ab}	1.81 ^{b-g}	1.82 ^{e-k}	67.33 ^{ab}	67.67 ^{ab}
EH010010-1	1.51 ^{c-i}	1.49 ^{c-g}	64.33 ^{a-c}	67.67 ^{ab}	1.75 ^{b-g}	1.82 ^{e-k}	68.00 ^{ab}	68.33 ^{ab}
EH09046-3	1.55 ^{b-g}	1.62 ^{b-d}	62.33 ^{b-d}	65.33 ^{a-c}	1.82 ^{b-f}	1.95 ^{c-f}	66.00 ^b	66.33 ^{b-d}
EH09028-3	1.44 ^{f-j}	1.58 ^{b-e}	64.33 ^{a-c}	67.00 ^{ab}	1.7 ^{c-g}	1.75 ^{f-l}	68.00 ^{ab}	68.53 ^{ab}
EH97091-2	1.26 ^{lm}	1.4 ^{e-h}	43.67 ^h	46.00 ^k	1.55 ^{fg}	1.62 ^{j-l}	46.67 ^g	44.00 ^g
EH07015-7	1.41 ^{f-k}	1.54 ^{c-f}	53.67 ^{fg}	56.00 ^{g-i}	1.67 ^{d-g}	1.68 ^{j-l}	57.00 ^{ef}	61.00 ^{de}
EH011025-1	1.49 ^{d-i}	1.58 ^{b-e}	55.33 ^{fg}	60.3 ^{c-g}	1.74 ^{c-g}	1.77 ^{e-l}	60.67 ^{c-e}	61.67 ^{c-e}
EH011018-5	1.56 ^{b-f}	1.59 ^{b-e}	62.00 ^{b-d}	63.7 ^{b-e}	1.75 ^{c-g}	1.77 ^{e-l}	65.00 ^{bc}	65.3 ^{b-e}
EH07005	1.33 ^{j-m}	1.46 ^{d-h}	62.00 ^{b-d}	64.0 ^{b-e}	1.64 ^{d-g}	1.73 ^{g-l}	65.00 ^{bc}	65.3 ^{b-e}
EH011016-2	1.49 ^{d-i}	1.5 ^{c-g}	58.67 ^{c-f}	62.3 ^{b-f}	1.64 ^{d-g}	1.67 ^{jkl}	63.00 ^{b-d}	63.6 ^{b-e}
Dosha	1.92 ^a	2.04 ^a	69.00 ^a	71.00 ^a	2.19 ^a	2.27 ^a	72.33 ^a	73.00 ^a
Wolkie	1.66 ^b	1.94 ^a	66.27 ^{ab}	67.17 ^{ab}	2.01 ^{ab}	2.17 ^{ab}	68.17 ^{ab}	68.67 ^{ab}
Gora	1.44 ^{f-j}	1.53 ^{c-f}	65.70 ^{ab}	67.67 ^{ab}	1.69 ^{d-g}	1.72 ^{h-l}	67.83 ^{ab}	68.96 ^{ab}
MSE	0.04	0.05	51.79	29.09	0.04	0.07	54.10	32.32
CV	13.87	14.21	12.06	8.65	11.41	14.30	11.64	8.91
Mean	1.48	1.58	59.70	62.36	1.76	1.83	63.19	63.83
P value	0.0294	0.0138	0.0067	<.0001	0.0135	0.0452	0.0047	<.0001

HSW = hundred seed weight

Appendix Table 5. 9. Correlation coefficients (r) of disease parameters with yield at Legambo district in 2022 and 2023 main cropping season.

Parameters	2022				2023			
	DI	PSI	AUDPC	Yield	DI	PSI	AUDPC	Yield
DI	-				-			
PSI	0.25*	-			0.37***	-		
AUDPC	0.54***	0.37***	-		0.46***	0.32**	-	
Yield	-0.28*	-0.45**	-0.54***	-	-0.29**	-0.44***	-0.22*	-

Appendix Table 5. 10. Correlation coefficients (r) of disease parameters with yield at Tenta districts in 2022 and 2023 main cropping seasons

Parameter	2022				2023			
	DI	PSI	AUDPC	Yield	DI	PSI	AUDPC	Yield
DI	-				-			
PSI	0.44***	-			0.30**	-		
AUDPC	0.44***	0.28*	-		0.27*	0.36***	-	
Yield	-0.26*	-0.36***	-0.32**	-	-0.27*	-0.25*	-0.45***	-

PSI = Percent severity index, AUDPC = Area under disease progress curve; HSW = Hundred seed weight. *** = Very highly significant; ** = highly significant; * = Significant; and ns = non-significant at $p \leq 0.001$, $p \leq 0.01$, $p \leq 0.05$ and $p > 0.05$, respectively.

Appendix Table 6. 1. Treatment setup and randomization for the integrated management of faba bean gall disease combining faba bean varieties and fungicides

Treatment	Treatment combination	Plot number		
		Rep-I	Rep-II	Rep-III
1	Dosha without spray	15	23	47
2	Dosha with Mancozebe	14	35	55
3	Dosha with Noble	19	29	42
4	Dosha with Matco	20	33	43
5	Dosha with Ridomil	2	34	52
6	Wolkie without spray	18	27	58
7	Wolkie with Mancozebe	8	36	51
8	Wolkie with Noble	17	21	44
9	Wolkie with Matco	6	26	45
10	Wolkie with Ridomil	1	40	50
11	Gora without spray	12	30	46
12	Gora with Mancozebe	7	37	56
13	Gora with Noble	11	25	41
14	Gora with Matco	10	38	49
15	Gora with Ridomil	16	24	57
16	Local with Mancozebe	5	22	60
17	Local with Matco	4	39	54
18	Local with Ridomil	3	32	48
19	Local without spray	9	31	59
20	Local with Noble	13	28	53

Appendix Table 6. 2. Description of Faba bean varieties

No	Faba bean varieties	Year of Release	Altitude (m.a.s.l.)	Annual rainfall (mm)	Characteristics	Yield(Q) Research field
1	Dosha	200	2050-2800	700-1000	Moderately resistance for Chocolate spot and Rust	28-62
2	Gora	2013	2000- 2800	700-1100	High yield, disease resistance and big seed size	44.1
3	Wolkie	2008	1900-2800	700-1000	High yield, resistance and big seed size	24-52
4	Local	Ns	Ns	Ns	Ns	Ns

Source: MoARD (208), Variety Registration Book, Issue numbers 5-13N; Ns: Not specified

Appendix Table 6. 3. Fungicides dose and mode of application were used

Trade Name	Common Name	Dose	Mode of application
Mancozebe 80 WP	Mancozebe 80 WP	2kg/ha ⁻¹	Foliar spray
Matco	Metalaxyl 8% + Mancozebe 64% WP	2.5 kg/ha ⁻¹	Foliar spray
Ridomil Gold MZ 68WG	MetalaxilM40 g/kg +Mancozebe 640 g/kg	2.5kg/ha ⁻¹	Foliar spray
Noble 25 WP	Triadimefon 250 g/l	1.5kg/ha ⁻¹	Foliar spray

Source Kebede Earecho (2019) and (Kassa Yehuala et al. 2020).

Appendix Table 6. 4. Mean squares analysis of location, year, varieties, fungicide and the combined effect on faba bean gall disease at Legambo and Tenta in 2022 and 2023 main growing seasons of disease Incidence, Severity and AUDPC.

Source	DF	DI (%)	PSI (%)	AUDPC(%-day)
Location	1	43.0**	34.2**	14635**
Year	1	123.0***	119.1***	82232***
Block	2	1.6ns	2.1ns	679ns
Variety	3	517.1***	526.9 ***	546382***
Fungicide	4	12250.8 ***	9684.2 ***	4607675***
Location: Variety	3	0.3ns	0.8ns	91ns
Location: Year	1	3.1ns	0.9ns	80ns
Year: Fungicide	4	0.4ns	0.3ns	144ns
Year: Variety	3	0.0ns	0.3ns	69ns
Variety: Fungicide	12	39.8***	32.4***	15854***
Location: Fungicide	4	0.2 ns	0.4ns	98ns
Location:Year:Variety	3	0.3ns	0.5ns	82ns
Location:Year:Fungicide	4	0.4ns	0.3ns	99ns
Year:Variety:Fingicide	12	1.0ns	0.5ns	137ns
Location: Variety: Fungicide	12	0.2ns	0.5ns	76ns

Location:Year:Variety: Fungicide	12	0.3 ns	0.5ns	88ns
Residuals	158	6.2	4.2	2061
Coefficient of Variance		5.03	6.32	4.56

I=Disease Incidence, PSI=Percentage Severity, AUDPC=Area under Disease Progress

Curve*, ** and *** refer to level of significance at $p \leq 0.05$, 0.01 and 0.001.

Appendix Table 6. 5. Adjusted coefficient of determination (R^2) and faba bean gall progression rate (r) in logit per day for faba bean varieties combined with fungicide in Legambo and Tenta districts during the 2022 and 2023 growing seasons.

Variety	Fungicide	Legambo				Tenta			
		2022 R^2	Rate(r)	2023 R^2	Rate(r)	2022 R^2	Rate(r)	2023 R^2	Rate(r)
Dosha	Control	98.1	0.048	96.1	0.046	96.6	0.048	95.5	0.046
	Mancozebe	94.4	0.023	91.8	0.016	91.3	0.018	91.3	0.015
	Noble	90.1	0.017	80.0	0.011	84.1	0.013	78.2	0.012
	Matco	93.5	0.023	91.3	0.016	89.9	0.017	89.6	0.018
	Ridomil	93.2	0.017	90.4	0.017	89.3	0.017	88.7	0.017
Wolkie	Control	98.2	0.054	98.3	0.048	96.8	0.045	96.7	0.049
	Mancozebe	95.0	0.023	93.2	0.018	93.5	0.018	91.7	0.016
	Noble	92.3	0.018	90.4	0.013	87.5	0.014	87.2	0.012
	Matco	94.7	0.022	92.6	0.019	93.4	0.019	90.1	0.019
	Ridomil	93.3	0.017	90.7	0.014	89.4	0.015	89.5	0.014
Gora	Control	98.9	0.053	98.9	0.049	97.9	0.050	97.9	0.049
	Mancozebe	95.0	0.021	94.4	0.015	94.4	0.015	93.1	0.016
	Noble	94.4	0.013	93.0	0.013	92.4	0.013	89.3	0.012
	Matco	94.7	0.017	93.4	0.015	93.4	0.015	93.0	0.014
	Ridomil	93.9	0.013	93.2	0.012	94.8	0.015	90.1	0.013
Local	Control	99.6	0.059	99.2	0.054	98.3	0.053	98.4	0.052
	Mancozebe	96.1	0.022	95.7	0.018	95.7	0.018	94.1	0.018
	Noble	94.1	0.017	94.4	0.012	90.9	0.014	92.7	0.016
	Matco	95.8	0.019	95.0	0.017	95.0	0.017	93.9	0.016
	Ridomil	95.5	0.018	91.9	0.013	92.1	0.014	92.0	0.013

R^2 Coefficient of determination for the Logistic epidemiological model a Disease progress rate obtained from regression line of disease severity against time of disease assessment

Appendix Table 6. 6. Analysis of the combined effects of year, location, fungicide, and variety on faba bean yield and components in Tenta and Legambo during the 2022 and 2023 growing seasons.

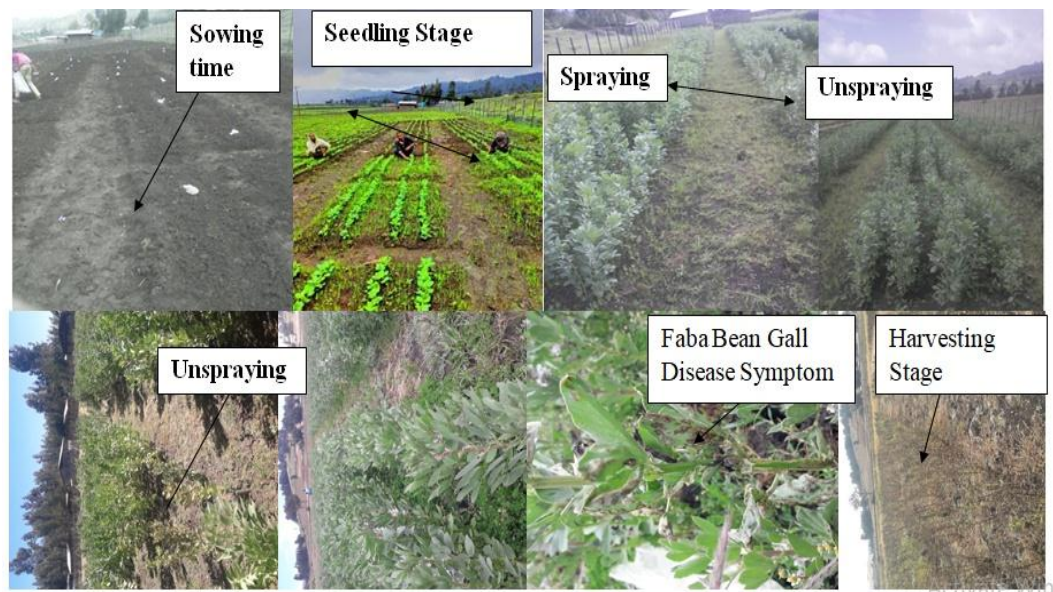
Source	DF	PH(cm)	NPP ⁻¹	SPP ⁻¹	Yield (t/ha ⁻¹)	HSW(g)
Location	1	65.6***	7.4***	0.5***	0.55***	462.8***
Year	1	117.8***	24.3***	2.8***	2.26***	452.5 ***
Block	2	2.15ns	2.2*	0.05ns	0.04ns	13.6ns
Variety	3	1309.9***	45.5***	2.08 ***	3.79***	612.1***
Fungicide	4	2859.4***	67.2***	5.99***	17.89***	3541***
Location: Variety	3	0.71ns	0.01ns	0.002ns	0.01ns	3.1ns

Location: Year	1	0.46ns	0.03ns	0.06ns	0.08ns	179.1**
Year: Fungicide	4	0.82ns	0.4ns	0.03ns	0.03ns	1.1ns
Year: Variety	3	5.66ns	0.16ns	0.02ns	0.03ns	6.6ns
Variety: Fungicide	12	11.24***	2.59***	0.05*	0.09*	15.2ns
Location: Fungicide	4	0.40ns	0.14ns	0.01ns	0.01ns	3.5ns
Location: Year: Variety	3	0.61ns	0.06ns	0.034ns	0.004ns	1.3ns
Location:Year:Fungicide	4	0.52ns	0.05ns	0.014ns	0.01ns	3.2ns
Year: Variety: Fungicide	12	1.03ns	0.29ns	0.015ns	0.01ns	1.2 ns
Location: Variety: Fungicide	12	0.44ns	0.05ns	0.007ns	0.01ns	1.4ns
Location: Year: Variety: Fungicide	12	0.39ns	0.11ns	0.008ns	0.01ns	2.2ns
Residuals	158	3.60	0.494	0.027	0.039	24.8
Coefficient of Variance		2.37	4.72	5.11	6.9	5.07

PH plant height NPP, number of pods per a plant, SPP seed per pod and HSW hundred seed weight. *, ** and *** refer to level of significance at $P \leq 0.05$, 0.01 and 0.001

Appendix Table 6. 7. The combined impact of a fungicide-treated faba bean variety on yield loss due to faba bean gall disease in Legambo district, north-eastern Ethiopia, during the main growing seasons of 2022 and 2023.

Variety	Fungicide	Yield	Relative yield loss (%)
Dosha	Control	2.12	44.06
	Mancozebe	3.09	18.47
	Noble	3.79	0.00
	Matco	3.10	18.15
	Ridomil	3.57	5.80
Wolkie	Control	1.98	46.20
	Mancozebe	3.07	16.58
	Noble	3.68	0.00
	Matco	3.11	15.60
	Ridomil	3.38	8.15
Gora	Control	1.67	47.98
	Mancozebe	2.80	12.77
	Noble	3.21	0.00
	Matco	2.88	10.28
	Ridomil	2.95	8.10
Local	Control	1.64	47.27
	Mancozebe	2.72	12.54
	Noble	3.11	0.00
	Matco	2.75	11.58
	Ridomil	2.89	7.07



Appendix Figure 6. 1. Field demonstration of faba bean gall disease management at Legambo and Tenta Districts.

Appendix Table 6. 8. Combined cost benefit analysis for managing faba bean gall disease at Legambo and Tenta for the cropping seasons of 2022 using various varieties and fungicides.

Variety	Fungicide	UGY (t/ha ⁻¹)	AGY (t/ha ⁻¹)	Bean (\$/t ⁻¹)	GFB (\$ha ⁻¹)	PC (\$ha ⁻¹)	MC (\$ha ⁻¹)	TVC (\$ha ⁻¹)	NB (\$ha ⁻¹)	MB (\$ha ⁻¹)	MRR (%)
Dosha	Noble	3.62	3.258	714.29	2327.16	17.45	16.07	33.52	2293.63	992.03	4187.94
	Ridomil	3.48	3.13	714.29	2237.16	16.78	29.46	46.24	2190.92	889.32	2442.99
	Matco	2.95	2.66	714.29	1896.44	14.22	29.02	43.24	1853.20	551.60	1651.11
	Mancozebe	2.94	2.65	714.29	1890.01	14.18	25.00	39.18	1850.84	549.24	1872.01
	Control	2.04	1.84	714.29	1311.44	9.84	0.00	9.84	1301.60	0	0.00
Wolkie	Noble	3.59	3.23	714.29	2307.87	17.31	16.07	33.38	2274.49	1068.60	4403.60
	Ridomil	3.35	3.02	714.29	2153.58	16.15	29.46	45.61	2107.97	902.08	2471.49
	Mancozebe	3.07	2.76	714.29	1973.58	14.80	25.00	39.80	1933.78	727.89	2371.79
	Matco	2.94	2.65	714.29	1890.01	14.18	29.02	43.20	1846.82	640.92	1880.50
	Control	1.89	1.70	714.29	1215.01	9.11	0.00	9.11	1205.89	0	0.00
Gora	Noble	3.08	2.77	714.29	1980.01	14.85	16.07	30.92	1949.09	921.85	3980.78
	Ridomil	2.88	2.59	714.29	1851.44	13.89	29.46	43.35	1808.09	780.85	2194.43
	Matco	2.81	2.53	714.29	1806.44	13.55	29.02	42.57	1763.87	736.63	2116.40
	Mancozebe	2.73	2.46	714.29	1755.01	13.16	25.00	38.16	1716.85	689.60	2268.44
	Control	1.61	1.45	714.29	1035.01	7.76	0.00	7.76	1027.24	0	0.00
Local	Noble	2.97	2.67	714.29	1909.30	14.32	16.07	30.39	1878.91	883.57	3863.73
	Ridomil	2.81	2.53	714.29	1806.44	13.55	29.46	43.01	1763.43	768.09	2164.44
	Mancozebe	2.68	2.41	714.29	1722.87	12.92	25.00	37.92	1684.95	689.60	2268.44
	Matco	2.67	2.40	714.29	1716.44	12.87	29.02	41.89	1674.55	679.20	1976.05
	Control	1.56	1.44	714.29	1002.86	7.52	0.00	7.52	995.34	0	0.00

UGY, unadjusted grain yield; AGY, adjusted grain yield; GFB, gross field benefit; PC, Production Cost; MC, Marginal cost; TVC, total variable cost; NB, net benefit; MB, Marginal benefit; MRR, marginal rate of return. The unite price of yield per kilogram during 2022 was\$0.714(at an exchange rate of 1\$=ETB 56) at the time of yield selling, and the price of fungicides Mancozabe, Noble, Matco and Ridomil were 12.5\$, 10.71\$, 11.61\$, 11.79\$, respectively.

Appendix Table 6. 9. Cost benefit analysis for managing faba bean gall disease in Legambo and Tenta for the cropping seasons of 2023 using various varieties and fungicides.

Variety	Fungicide	UGY (t/ha ⁻¹)	AGY (t/ha ⁻¹)	Bean (price)	GFB (ha ⁻¹)	PC (\$/ha ⁻¹)	MC (\$ha ⁻¹)	TVC (\$ha ⁻¹)	NB (\$ha ⁻¹)	MB (\$ ha ⁻¹)	MRR (%)
Dosha	Noble	3.95	3.56	1184.2	4209.8	14.0	27.6	41.7	4168.2	1831.3	5410.4
	Ridomil	3.66	3.29	1184.2	3900.8	13.0	62.5	75.5	3825.3	1488.4	2198.9
	Matco	3.25	2.93	1184.2	3463.8	11.5	72.4	83.9	3379.9	1043.0	1370.5
	Mancozebe	3.24	2.92	1184.2	3453.1	11.5	55.3	66.8	3386.4	1049.5	1780.1
	Control	2.2	1.98	1184.2	2344.7	7.8	0.0	7.8	2336.9	0.0	0.0
Wolkie	Noble	3.77	3.39	1184.2	4018.0	13.4	27.6	41.0	3977.0	1778.2	5281.2
	Ridomil	3.42	3.08	1184.2	3645.0	12.2	62.5	74.7	3570.3	1371.5	2038.0
	Matco	3.28	2.95	1184.2	3495.8	11.7	72.4	84.0	3411.7	1212.9	1582.0
	Mancozebe	3.16	2.85	1184.2	3367.9	11.2	55.3	66.5	3301.4	1102.6	1864.6
	Control	2.07	1.86	1184.2	2206.2	7.4	0.0	7.4	2198.8	0.0	0.0
Gora	Noble	3.34	3.01	1184.2	3559.7	11.9	27.6	39.5	3520.2	1693.2	5071.6
	Ridomil	3.03	2.73	1184.2	3229.3	10.8	62.5	73.3	3156.0	1329.0	1979.1
	Matco	2.94	2.65	1184.2	3133.4	10.4	72.4	82.8	3050.6	1223.5	1595.2
	Mancozebe	2.88	2.53	1184.2	3069.4	10.2	55.3	65.5	3004.0	1176.9	1982.0
	Control	1.72	1.55	1184.2	1833.1	6.1	0.0	6.1	1827.0	0.0	0.0
Local	Noble	3.24	2.92	1184.2	3453.1	11.5	27.6	39.1	3414.0	1587.0	4804.6
	Ridomil	2.98	2.63	1184.2	3176.0	10.6	62.5	73.1	3102.9	1275.9	1905.0
	Matco	2.84	2.56	1184.2	3026.8	10.1	72.4	82.5	2944.4	1117.3	1463.4
	Mancozebe	2.77	2.44	1184.2	2952.2	9.8	55.3	65.1	2887.1	1060.1	1797.0
	Control	1.72	1.55	1184.2	1833.1	6.1	0.0	6.1	1827.0	0.0	0.0

UGY, unadjusted grain yield; AGY, adjusted grain yield; GFB, gross field benefit; PC, Production Cost; MC, Marginal cost; TVC, total variable cost; NB, net benefit; MB, Marginal benefit; MRR, marginal rate of return. The unit price of yield per kilogram during 2022 was \$1.84 (at an exchange rate of \$1 = ETB 76) at the time of yield selling, and the price of fungicides Mancozabe, Noble, Matco, and Ridomil were 27.63\$, 18.42\$, 28.95\$, and 25\$, respectively

Appendix Table 6. 10. Correlation coefficient (r) between yield and yield components and disease characteristics at Legambo district in the crops seasons of 2022(Lower Diagonal) and 2023(upper diagonal).

Parameter	HSW	Yield	DI	PSI	AUDPC
HSW	1	0.87**	-0.90**	-0.89**	-0.93**
Yield	0.80**	1	-0.88**	-0.86**	-0.91**
DI	-0.92**	-0.82**	1	0.97**	0.97**
PSI	-0.91**	-0.81**	0.98**	1	0.96**
AUDPC	-0.94**	-0.82**	0.97**	0.96**	1

Appendix Table 6. 11. Correlation coefficient (r) between yield and yield components and disease characteristics at Tenta district in the crops seasons of 2022(Lower diagonal) and 2023(Upper diagonal).

Parameter	HSW	Yield	DI	PSI	AUDPC
HSW	1	0.83**	-0.88**	-0.86**	-0.89**
Yield	0.88**	1	-0.88**	-0.86**	-0.92**
DI	-0.91**	-0.89**	1	0.96**	0.96**
PSI	-0.89**	-0.89**	0.97**	1	0.96**
AUDPC	-0.91**	-0.94**	0.97**	0.96**	1

HSW= hundred seed weight, DI= disease incidence, PSI= per cent severity index, AUDPC= area under disease progress curve, ** = highly significant difference at 0.01, * = significant difference at 0.05 and ns = non-significant difference at 0.05 probability level. Numbers presented below and above the diagonal are referring to the P-values and correlation coefficient, respectively

BIOGRAPHY OF THE AUTHOR

The author was born in June 1992 G.C. in the Amhara National Regional State, South Wollo Zone, and Kelala District. He attended his elementary education at Kelala Primary School from 2000 to 2007 and completed his secondary and preparatory education at Kelala Senior Secondary and Preparatory School from 2008 to 2012.

After completing his high school education, he joined Woldia University in 2013 to pursue tertiary education and graduated with a Bachelor of Science (BSc) degree in Plant Science in June 2016. Following his graduation, he joined the postgraduate program at Debre Berhan University, where he pursued a Master of Science (MSc) degree in Plant Protection and successfully graduated on June 25, 2018.

After completing his master's degree, he worked as a lecturer at Mekdela Amba University for two years and six months, from July 1, 2018, to December 16, 2020. Subsequently, he joined the postgraduate program at Bahir Dar University, College of Agriculture and Environmental Sciences, to pursue a Doctor of Philosophy (PhD) degree in Plant Pathology

Published Article

This dissertation is submitted in fulfilment of the requirements for the degree of Doctor of Philosophy (PhD) in Plant Pathology at Bahir Dar University, College of Agriculture and Environmental Sciences, Bahir Dar, Ethiopia. The dissertation is based on three research papers published and one research paper submitted for publication.

1. Seid Hussen, Merkuz Abera, Berhanu Bekele, and Tesfaye Alemu. 2025. Survey on the Distribution and Epidemiology of Faba Bean Gall (*Physoderma viciae*) in South Wollo, North-Eastern Ethiopia: An Emerging Threat to Faba Bean Production. *International Journal of Phytopathology*, 14(2), 165-180. doi: <https://doi.org/10.33687/phytopath.014.02.5880> (Scopus and Web of Science indexed)
2. Seid Hussen, Merkuz Abera, Berhanu Bekele, and Tesfaye Alemu. 2026. Histopathological and Molecular Detection of *Physoderma viciae* Associated with Faba Bean Gall Disease in Ethiopia. *Scientific Reports*. Submitted. (Scopus and Web of Science indexed)
3. Seid Hussen, Merkuz Abera, Berhanu Bekele, and Tesfaye Alemu. 2025. Evaluation of faba bean (*Vicia faba* L.) genotypes against faba bean gall (*Physoderma viciae*) in highlands of South Wollo, North-Eastern Ethiopia. *Journal of Plant Pathology*, pp. 1-13. doi: 10.1007/s42161-025-02052-4 (Scopus and Web of Science indexed)
4. Seid Hussen, Merkuz Abera, Berhanu Bekele, and Tesfaye Alemu. 2026. Faba Bean Gall (*Physoderma viciae*) Disease Management through Varieties and Fungicides in the Highlands of South Wollo, Northeastern Ethiopia. *Plant Disease*, 110(4), 1312-1322. doi: 10.1094/PDIS-11-24-2294-RE (Scopus and Web of Science indexed)

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This certificate is awarded to Prof/Dr/Mr/Mrs **Seid Hussen** for presenting a talk **Evaluation of different Faba Bean Genotype against Faba Bean Gall (*Physoderma viciae*) hotspot areas of highland of South Wollo, Northeastern Ethiopia** on conference held at Mekdela Amba University, Tulu Awuliya, Ethiopia, on February 22– 23, 2025.


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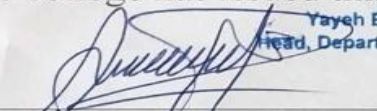


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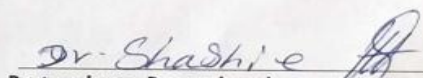
CERTIFICATE OF RECOGNITION

To: Mr. Seid Hussen Ahmed

The College of Agriculture and Environmental Sciences of Bahir Dar University would like to appreciate your contribution to our weekly seminar by presenting your seminar “**Faba Bean Gall (*Physoderma viciae*), a Fungal Disease: An Emerging Threat to Faba Bean (*Vicia faba* L.) Production in Ethiopia – A Review.**” in 2025. By recognizing your contribution, the college has issued this certificate.


Yareh Bitew Bantie (PhD)
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Dr. Shashie
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