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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

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ABSTRACT

Faba bean gall, a disease caused by *Physoderma viciae*, has emerged as a major constraint to faba bean production in the highland areas of northeastern Ethiopia. This study assessed the prevalence, incidence, and severity of faba bean gall across major faba bean-growing districts during the 2022 and 2023 cropping seasons. A total of 200 fields were surveyed, and disease parameters were recorded alongside agro-ecological and management-related variables. The results revealed that faba bean gall was widespread across all surveyed districts, with higher prevalence and severity recorded in 2022, coinciding with increased rainfall, humidity, and prolonged cloud cover. Disease incidence and severity were positively correlated with altitude, particularly in fields located above 2844 m above sea level and peaked during the flowering stage. Disease intensity was primarily driven by district, year, altitude, variety, and drainage, with agronomic practices exerting secondary modifying effects. Although Wolkie varieties showed slightly lower disease levels than local landraces, no cultivar displayed complete resistance. Logistic regression analysis identified district, year, altitude, variety, and field drainage as the most important independent predictors of faba bean gall incidence and severity, with agronomic practices exerting secondary modifying effects. The findings highlight the urgent need for integrated disease management strategies, emphasizing host resistance, improved drainage, crop rotation, and context-specific agronomic practices to mitigate the impact of faba bean gall in Ethiopia's highlands.

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INTRODUCTION

Faba bean (*Vicia faba* L.) is among the most widely produced food legumes globally. Ethiopia is the second-largest faba bean producer after China (FAOSTAT, 2018) and a secondary center of diversity for faba bean (Keneni *et al.*, 2005). Faba bean is produced by 4.1 million smallholders covering over 466,000 ha of land with a production of over a million tons of grain and average productivity of 2.2 t ha⁻¹

(CSA, 2021). Thus, it is a rich available source of food for both humans and animals (Sahile Samuel *et al.*, 2011; Merkuz and Semagne, 2022a). It also makes a significant contribution to soil fertility restoration as a suitable rotation crop that fixes atmospheric nitrogen and thereby reducing dependence on external fertilizer inputs. Furthermore, faba bean is an important source of income for farmers and

generates foreign currency for the country (Agegnehu and Fessehaie, 2006).

The productivity of faba bean in Ethiopia remains far below its potential due to multiple constraints, including biological factors such as the inherently low grain-yield potential of indigenous varieties and their high susceptibility to biotic and abiotic stresses (Mussa Jarso *et al.*, 2008). Among the biotic stresses, chocolate spot (*Botrytis fabae*), rust (*Uromyces vicia fabae*) and wilt/root rot complex highly contribute to the low productivity of the crop (Merkuz and Semagne, 2022a). Faba bean gall has recently emerged as a serious threat to faba bean production in Ethiopia and China, causing substantial yield losses. The disease was first reported in East Africa in 2012. In Ethiopia, the causal agent was initially identified as *Olpidium viciae* based on symptom similarity and the presence of resting spores within galls (Dereje Gorfu *et al.*, 2012; Earecho, 2019). However, early molecular studies conducted in Ethiopia were inconclusive and often showed similarity to unrelated fungi that do not induce typical faba bean gall symptoms. In contrast, studies from China confirmed *O. viciae* as the causal agent of faba bean blister disease (Yan, 2012).

Recent integrative morphological and molecular analyses have since clarified that the true causal agent of faba bean gall in Ethiopia is *Physoderma viciae*, not *Olpidium viciae*, thereby resolving the longstanding taxonomic confusion (You *et al.*, 2021). Accordingly, the disease previously referred to as *Olpidium viciae* infection is now correctly classified as faba bean gall caused by *Physoderma viciae*. This taxonomic clarification is critical for accurate interpretation of past studies and for the development of effective disease management strategies. This emerging disease can lead to severe epidemics, resulting in extensive yield losses and, in extreme cases, complete crop failure over large areas within a short period.

Faba bean gall is characterized by a wide range of symptoms and has been reported in several major faba bean-growing regions of Ethiopia, including North Shewa (Beyen, 2015), the Selale Highlands (Hailu *et al.*, 2014), and the Wollo Highlands (Bogale *et al.*, 2016)

Although the disease is spreading rapidly, there is insufficient information on its status. Survey data are useful for gaining insights into the occurrence, distribution and relative importance of different crop diseases (Sahiel Samuel *et al.*, 2008; Merkuz and Semagne, 2022a). Therefore, the objectives of this study were to assess the

distribution and intensity of the Faba bean gall disease in central and northern Faba bean growing areas of South Wollo, Eastern Amhara Region, Ethiopia.

MATERIAL AND METHODS

Survey Area

Field surveys were conducted during the main cropping seasons of 2022 and 2023 in the major faba bean-growing areas of four districts in the South Wollo Administrative Zone, Amhara Region, Ethiopia: Legambo, Tenta, Woreilu, and Kelala (Figure 1). These districts were purposively selected based on their faba bean production potential, accessibility, and area coverage. Within each district, five Kebeles (local administrative units) were randomly selected to obtain broad geographic and agro-ecological representation. This multistage sampling approach-purposive district selection followed by random Kebele selection, helped minimize selection bias and ensure logistical feasibility.

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 point, a 1 m² quadrat was placed for plant and disease assessment (Merkuz and Meseret, 2022b). The total number of plants, number of infected plants, and number of healthy plants within each quadrat were recorded. During the survey, farmers were also interviewed to collect information on locality name, field history, altitude, previous crop, weed presence, drainage condition, soil type, faba bean variety grown, cropping system, planting date, weeding practices, disease management practices, and fertilizer use (Merkuz and Meseret, 2022b).

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

Disease prevalence (%): (Number of infected fields / Total number of fields assessed) × 100

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

Disease incidence (%): (Number of diseased plants / Total number of plants assessed) × 100.

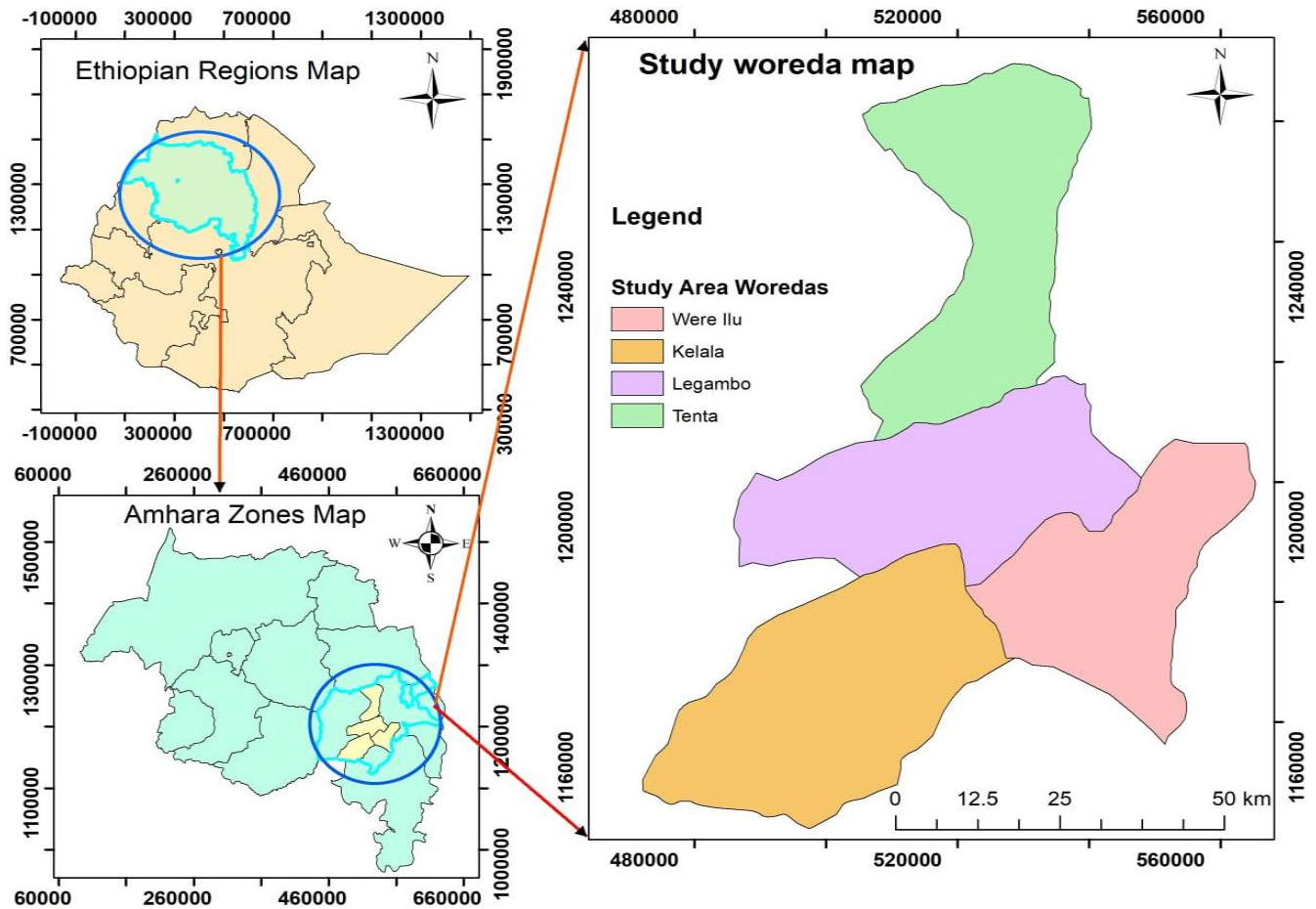


Figure 1. Map showing surveyed districts for faba bean gall in South Wollo, North Eastern Ethiopia, during the 2022 and 2023 cropping seasons.

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

District	Number of fields	Altitude	Rainfall (mm)		Mean of Temperature (°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).

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):

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

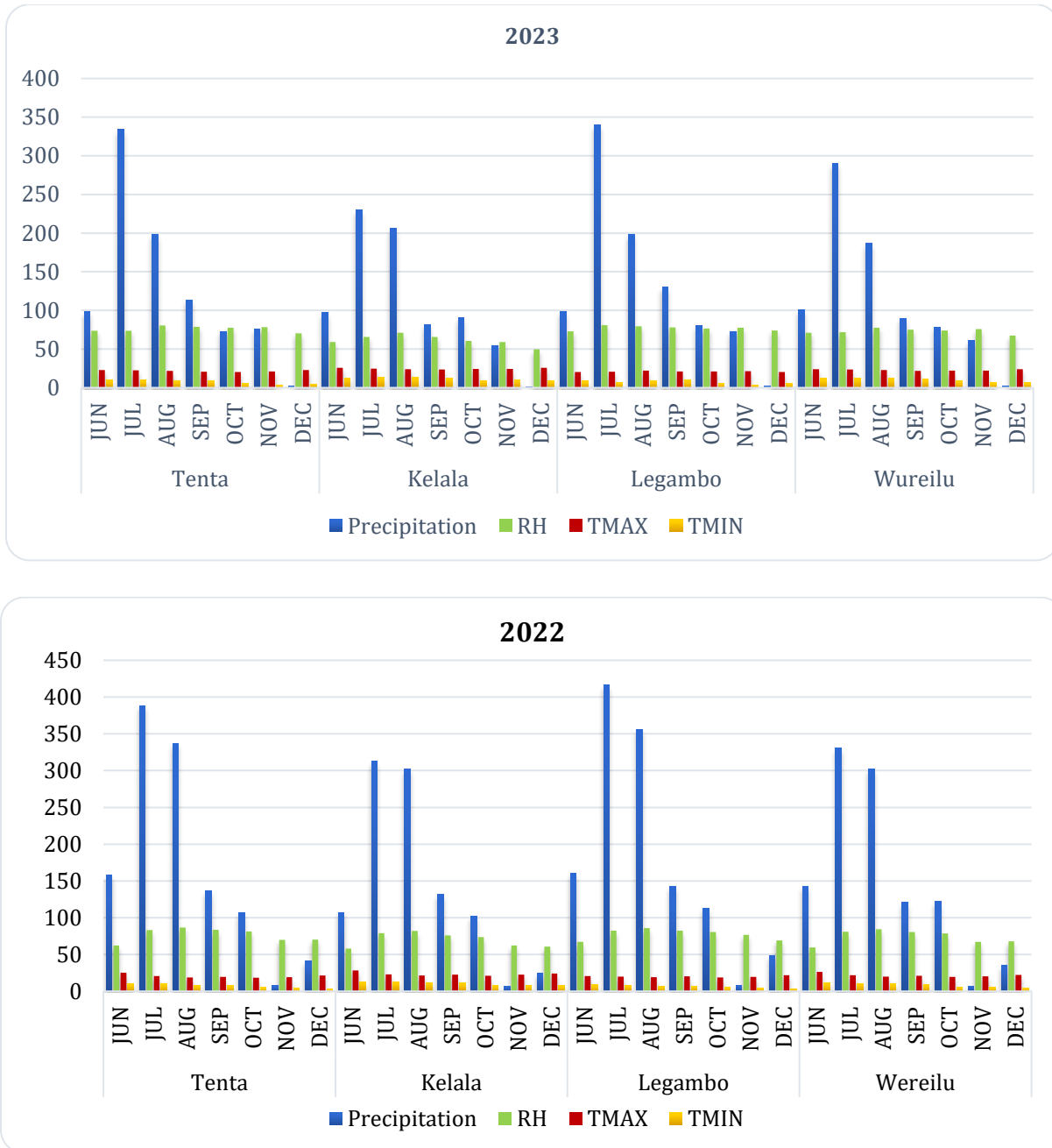


Figure 2. Rainfall, maximum and minimum temperatures, and relative humidity (mean ±SE) of surveyed districts in northeastern Ethiopia during the 2022 and 2023 faba bean-growing seasons (<https://power.larc.nasa.gov/data-access-viewer/>).

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

Data Analysis

Descriptive statistics were employed to summarize disease prevalence, incidence and severity. Descriptive

statistics, including means, percentages, and graphs, were generated using SPSS software to summarize the spatial distribution of faba bean gall incidence, severity, and prevalence. To explore the association between disease parameters (incidence and severity) and various biophysical factors, logistic regression analysis was conducted using the GENMOD procedure in SAS 9.4.

Initially, all independent variables were tested individually against disease incidence and severity (treated as binomial response variables) in single-variable models. Variables that showed strong or significant associations were then tested in a full multiple regression model, and those maintaining significance were included in a reduced multiple-variable model.

For each variable included in the reduced model, parameter estimates, standard errors, and odds ratios (ORs) were calculated (Zelege *et al.*, 2023). ORs, derived by exponentiation of the regression coefficients, were interpreted as relative risks when greater than one. Model fit and the contribution of each variable were evaluated using likelihood ratio tests (LRTs), compared against chi-square distributions. Deviance analysis was used to assess differences between models, and contingency chi-square (χ^2) tests were applied to compare the frequency distributions of categorical variables across disease incidence and severity classes. This analytical approach follows methodologies outlined by Yuen (2006), McCullagh and Nelder (1989), Sahile *et al.* (2008), Getnet *et al.* (2021), Bitew *et al.* (2021), and Merkez and Meseret (2022b), ensuring comprehensive statistical evaluation of the relationships between disease occurrence and key environmental and agronomic variables.

RESULTS

Faba Bean Gall Prevalence, Incidence, and Severity.

The distribution of faba bean gall varied significantly across geographical locations, seasons, faba bean varieties, soil types, and agronomic practices. Among the surveyed districts, Legambo recorded the highest disease prevalence (97.60%), followed by Tenta (95.60%). The lowest prevalence was observed in Woreilu (92.50%) and Kelala (90.00%). Disease incidence ranged from 0% to 100%, with Legambo showing the highest mean incidence (82.26%) and severity (71.92%), followed by Tenta (70.85% incidence and 57.14% severity). Kelala had the lowest incidence (59.41%) and severity (41.45%), while Woreilu showed slightly higher values (66.99% incidence and 54.56% severity).

Seasonal differences were notable. In the 2022 cropping season, disease pressure was higher than in 2023, with mean faba bean gall incidence and severity of 74.81%

and 64.01%, respectively, compared to lower values in 2023 (64.17% incidence and 47.21% severity), indicating a clear seasonal effect on disease occurrence. Varietal differences influenced disease intensity. Fields planted with Wolkie varieties showed lower mean incidence (62.23%) and severity (48.31%) compared to local varieties (73.57% incidence and 63.52% severity). However, the number of Wolkie variety fields was limited, highlighting the need for further evaluation to confirm potential resistance. Soil type significantly affected disease levels. Vertisol had the highest prevalence (94.53%), incidence (71.76%), and severity (58.44%), followed by Nitisols (93.50%, 62.97%, and 53.90%, respectively). Arenosol recorded the lowest values (89.78%, 61.58%, and 44.00%, respectively), likely due to differences in moisture retention, drainage, and soil structure. Agronomic practices were also associated with disease intensity. Fields without weeding exhibited higher incidence (78.24%) and severity (63.52%) than those weeded twice (63.41% and 50.49%, respectively). Disease was higher at the flowering stage than at the podding stage, suggesting increased susceptibility during flowering. Planting method affected disease development: broadcast sowing led to higher prevalence, incidence, and severity than row planting, which reduced incidence by 62.68% and severity by 48.64%. Fertilizer application, particularly NPS at sowing, was associated with reduced disease (65.41% incidence and 50.21% severity) compared to unfertilized fields. Similarly, fungicide-treated fields had lower incidence (61.78%) and severity (50.25%) than untreated fields (72.42% and 57.64%, respectively). Fields previously rotated with legumes had higher incidence (76.80%) and severity (76.20%) compared with fields rotated with cereals (69.34% incidence and 55.16% severity), indicating that cereal rotations may reduce pathogen buildup. Previous cropping history influenced incidence, with fields following cereals and vegetables exhibiting lower disease incidence than those following legumes. Altitude strongly correlated with disease intensity. Fields at higher elevations (3069–3230 m a.s.l.) had the highest prevalence (97.60%), incidence (85.50%), and severity (72.93%), with decreasing levels at lower altitudes. Micro-environmental conditions such as shaded areas, waterlogged zones, or furrows also promoted more severe infections, likely due to increased humidity and poor drainage.

Table 2. Prevalence, incidence, and severity (Mean \pm SE) of faba bean gall across different independent variables in northeastern 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
	2647-2844	60	93.63	69.56 \pm 1.33	54.80 \pm 1.69
	2844-3069	50	96.18	76.56 \pm 1.36	67.96 \pm 1.01
	3069-3230	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	Unweeded	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.

Association of Faba Bean Gall with Agro-Ecological Factors

The relationship between faba bean gall disease incidence and severity and various agro-ecological and management factors was analyzed using logistic regression (Tables 3–5).

Both Type I (variables entered first, VEF) and Type III (variables entered last, VEL) analyses were conducted, with Type III providing the most reliable assessment 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 factors significantly reducing deviance. In Type III models, district, year, altitude, variety, previous crop, fungicide application, and drainage consistently retained significance, whereas the effects of some management variables varied between incidence and severity. Among these, district, year, and altitude were consistently the strongest predictors, highlighting the dominant role of environmental and seasonal factors. Variables such as Planting method, soil type, field size, and growth stage lost significance in the Type III analysis, indicating that their apparent effects were largely influenced by these dominant factors.

For disease severity (measured as percent severity index, PSI), 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 (Table 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. 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.

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 (Tables 4 and 5) provide 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 model further clarified the direction and magnitude of these associations for disease incidence (Table 4; Figure 3). Disease incidence varied significantly among districts, with Legambo showing higher odds and Kelala lower

odds of infection relative to Woreilu. The 2022 season exhibited significantly higher odds of disease incidence than 2023, reflecting inter-annual variability in environmental conditions. Incidence declined progressively at lower altitude ranges compared with the highest elevation category. Among agronomic factors, varieties were associated with reduced odds of infection compared with local varieties. Previous cropping history influenced disease incidence, with fields following cereals and vegetables exhibiting lower disease incidence than those following legumes. Fungicide application and improved field drainage were associated with lower disease incidence; however, these relationships should be interpreted cautiously due to the limited resolution of fungicide-use data.

Table 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. Independent variables were evaluated using likelihood ratio tests during the 2022 and 2023 main rainy seasons.

Variable	Residual deviance	DF	DR	Pr > χ^2	Variable Class	Estimate	SE	Odds ratio
					Intercept	0.99	0.29	2.69
District	1029.17	3	57.74	<.0001	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
					2647-2844	-0.29	0.11	0.74
					2844-3069	-0.29	0.08	0.75
					3069-3230	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
Field Size	386.13	3	0.47	0.7900	0.25-0.5	0.07	0.18	1.08
					0.5-1	0.05	0.18	1.05
					1-1.5	0.00	0.00	1.00

Growth stage	384.01	1	0.34	0.5605	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.

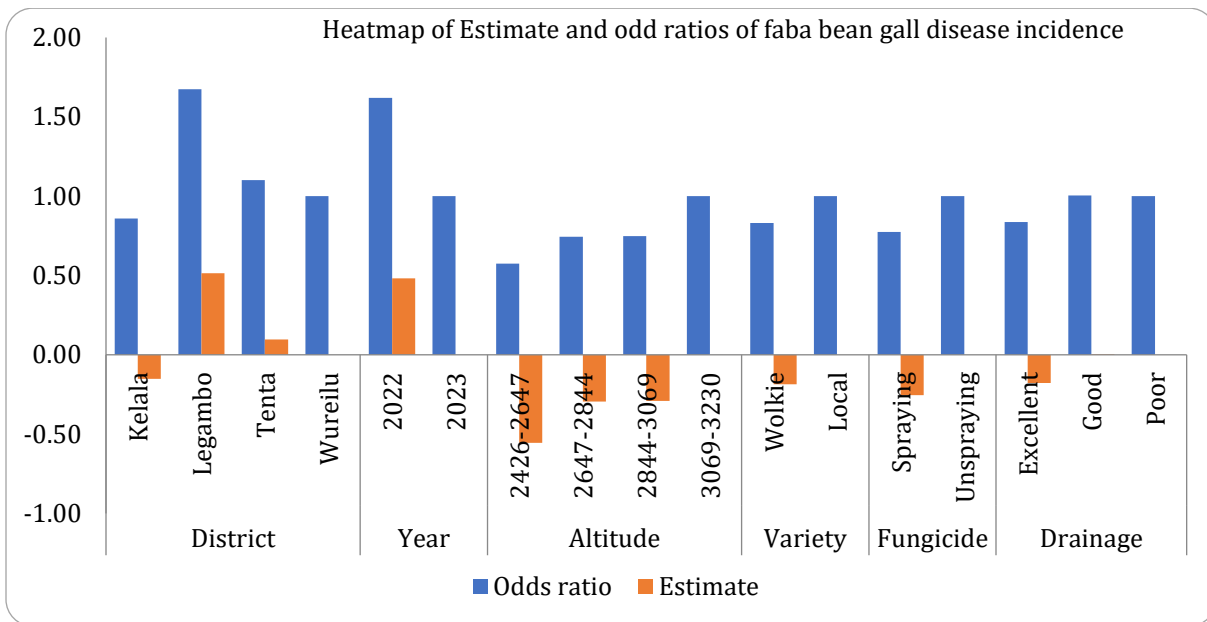


Figure 3. Heatmap summarizing odds ratios from the reduced logistic regression model showing the effects of district, year, altitude, variety, fungicide application, and field drainage on faba bean gall disease incidence.

For disease severity, similar spatial and temporal trends were observed (Table 5; Figure 4). Severity was significantly higher in Legambo and lower in Kelala relative to Woreilu, and markedly higher in the 2022 season compared with 2023. Disease severity decreased at lower altitudes relative to the highest elevation range. Several management practices were significantly associated with disease severity, including variety, cropping pattern, previous crop, fertilizer use, fungicide application, and drainage. Fields planted with Wolkie varieties and those rotated with cereals or legumes

exhibited substantially lower disease severity than fields following vegetables. Fertilizer use, fungicide application, and good drainage were associated with modest reductions in disease severity, whereas soil type, land preparation, field size, and crop growth stage did not show significant independent effects in the reduced model.

Overall, these results demonstrate that faba bean gall disease development is strongly driven by environmental and agro-ecological factors, particularly district, year, and altitude, while farm management

practices contribute secondary but meaningful influences, especially on disease severity. The findings underscore the multifactorial nature of faba bean gall epidemics and highlight the importance of integrated, location-specific disease management strategies adapted to local agro-ecological conditions.

Table 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. Independent variables were evaluated using likelihood ratio tests during the 2022 and 2023 main rainy seasons.

Variable	Residual deviance	DF	LRT		Variable class	Estimate	SE	Odds ratio
			DR	Pr > χ^2				
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
					2647-2844	-0.28	0.09	0.75
					2844-3069	-0.01	0.07	0.99
					3069-3230	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 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.

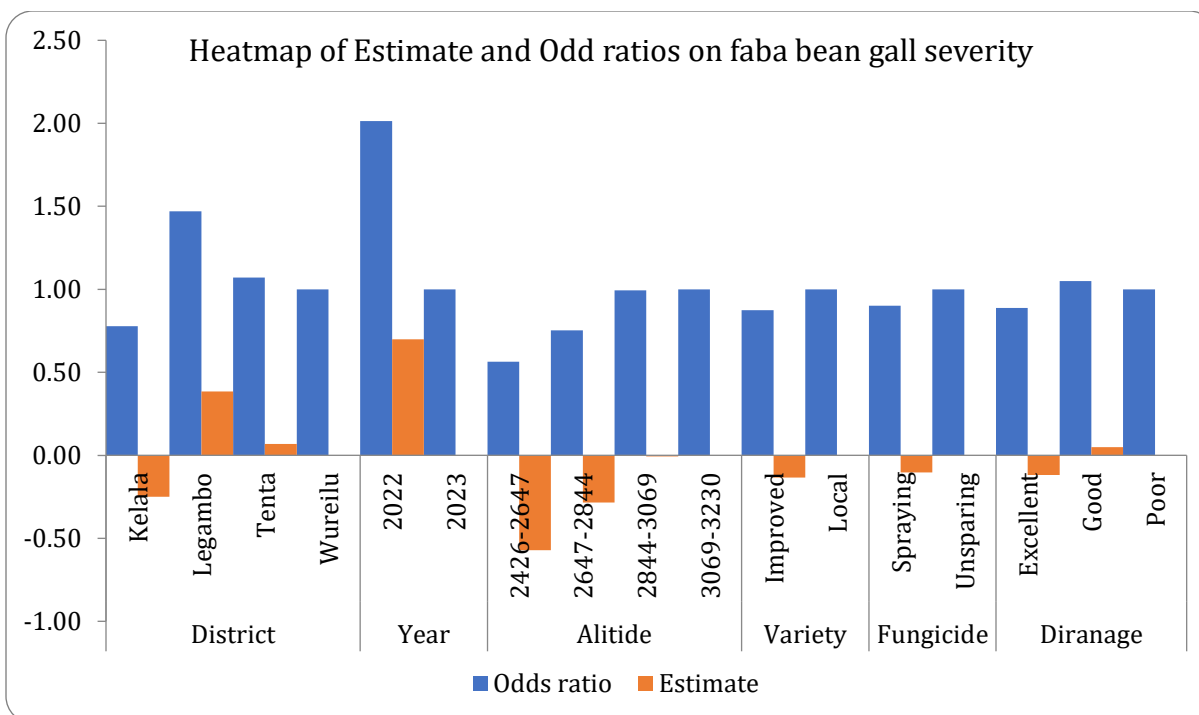


Figure 4. Heatmap summarizing odds ratios and estimate from the reduced logistic regression model showing the effects of district, year, altitude, variety, fungicide application, and field drainage on faba bean gall disease severity.

DISCUSSION

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

Faba bean gall intensity was notably higher during the 2022 cropping season than in 2023, likely due to higher rainfall, prolonged cloud cover, and increased relative humidity during the vegetative and flowering stages. Such conditions enhance leaf wetness and favor zoospore release, dispersal, and infection, as previously reported (Samuel *et al.*, 2008; Eshetu *et al.*, 2013; Getenet Yitayih *et al.*, 2021; Bereket and Habtamu, 2021; Bitew *et al.*, 2021). In contrast, lower rainfall, reduced humidity, and higher temperatures during the podding stage in 2023 likely suppressed disease development (Ademe *et al.*, 2018). These findings underscore the strong dependence of faba bean gall epidemics on seasonal weather conditions.

The disease was detected at all growth stages and

affected multiple plant organs, including leaves, stems, petioles, flowers, and pods. While earlier studies mainly reported symptoms on vegetative tissues (Yan, 2012), the presence of symptoms on reproductive organs in this study may indicate either increased pathogen aggressiveness or improved detection of disease expression. Disease prevalence was highest in districts such as Legambo, Tenta, Woreilu, and Kelala, which received over 1030 mm of rainfall during the 2022 main rainy season. This aligns with the pathogen's preference for high relative humidity (80–100%) and moderate temperatures (10–20°C) (Yan, 2012; Przetakiewicz, 2014).

Altitude significantly influenced disease distribution, with higher prevalence and severity recorded between 2426 and 3230 m.a.s.l. This is consistent with previous studies (Xing, 1984; Yan, 2012; Hailu *et al.*, 2014; Bogale *et al.*, 2016; Bitew *et al.*, 2021; Getnet Yitayih, 2023), indicating that altitude indirectly affects faba bean gall through its effects on temperature, humidity, and soil moisture. Fields located in poorly drained areas, near furrows, trees, or shaded zones exhibited more severe disease due to increased moisture retention and reduced air circulation (Bogale *et al.*, 2016).

Soil type also played a significant role in disease

dynamics. Vertisols recorded the highest disease prevalence and severity, followed by Nitisols, while sandy soils exhibited the lowest levels. The poor aeration and high moisture-holding capacity of Vertisols likely create favorable conditions for pathogen survival and plant stress, whereas Arenosols promote better drainage and reduce infection risk (Bitew *et al.*, 2021). Although *Physoderma viciae* is the confirmed causal agent of faba bean gall in Ethiopia (You *et al.*, 2021), its survival mechanisms in different soil types remain poorly understood, highlighting an important research gap.

Crop rotation clearly reduced disease. Fields rotated with cereals or other non-legume crops exhibited significantly lower faba bean gall incidence and severity than fields continuously planted with faba bean or other legumes. These findings underscore crop rotation as a practical and effective management option for smallholder farmers. The persistence of resting spores in soil likely explains the increased disease levels following legume rotations, whereas cereal rotations reduce inoculum density over time, disrupting the pathogen life cycle (Getaneh *et al.*, 2018; Zeleke *et al.*, 2023).

Disease incidence and severity were highest during the vegetative and flowering stages, peaking at flowering. This coincides with intense cell division in meristematic tissues, which may increase vulnerability to zoospore penetration and gall formation by *P. viciae*. Although severity was descriptively higher at flowering, growth stage did not retain independent significance in Type III models, suggesting that this pattern was largely mediated by seasonal and environmental conditions rather than plant phenology alone. Increased disease pressure at these stages may also be attributed to dense canopy development, prolonged leaf wetness, and higher physiological stress, while reduced disease during podding coincided with declining rainfall and humidity (Yan, 2012; Ademe *et al.*, 2018; Yitayih *et al.*, 2021).

Management practices significantly influenced disease outcomes. Row planting consistently reduced faba bean gall compared to broadcasting, likely due to improved airflow and light penetration that reduce canopy humidity (Pande and Narayana, 2002; Wakweya *et al.*, 2016). Weeding frequency and fertilizer use influenced disease severity but did not consistently retain independent significance for incidence once dominant environmental factors were accounted for. Poor weed management increased disease severity by creating

humid microclimates and weakening crop vigor (Yimer *et al.*, 2018; Bitew *et al.*, 2021). Proper land preparation improved soil aeration and drainage, while fertilizer application enhanced plant vigor and resistance to infection (Oborn *et al.*, 2003; Dordas, 2008; Veresoglou *et al.*, 2013; Mengesha and Yetayew, 2018).

Fields in which fungicides were applied generally showed lower mean disease incidence and severity. Farmers reported using commonly available fungicides, including Mancozeb (ethylene bisdithiocarbamate) at 1.5 kg ha⁻¹, Ridomil (Metalaxyl 40 g kg⁻¹ + Mancozeb 640 g kg⁻¹) at 2.5 kg ha⁻¹, Matco (Metalaxyl 8% + Mancozeb 64% WP) at 1.8 kg ha⁻¹, and Noble 25 WP (Triadimefon 250 g a.i. kg⁻¹) as foliar sprays. Similar fungicides, particularly Ridomil, Mancozeb, and Bayleton, have been frequently used by faba bean growers in previous studies (Bitew and Tigabie, 2016; Bogale *et al.*, 2017; Belachew *et al.*, 2018; Wondwosen Wulita *et al.*, 2019; Yehuala Kassa *et al.*, 2020).

Despite the association between fungicide application and reduced disease, caution is warranted in interpretation. Some farmers lacked adequate knowledge regarding recommended application rates, crop growth stages for spraying, and target diseases, which may reduce fungicide effectiveness (Teklay *et al.*, 2014). The fungicides reported by farmers included Mancozeb (FRAC M03), a multi-site contact fungicide; Ridomil and Matco, which contain Metalaxyl (FRAC 4), a phenylamide fungicide; and Triadimefon (FRAC 3), a sterol biosynthesis inhibitor (Fishel, 2009). Well-drained fields also exhibited lower disease pressure, highlighting the importance of water management (Bogale *et al.*, 2016).

Seed source and variety choice remain critical challenges. Most farmers rely on recycled local seed. Although Wolkie showed lower mean incidence and severity, the absence of complete resistance indicates it should be deployed as part of integrated management rather than as a standalone solution. No fully resistant faba bean variety is currently available in Ethiopia, though several moderately tolerant lines have been identified (Bitew, 2012; Wulita, 2015; Getenet and Yehizbalem, 2017; Seid *et al.*, 2025). Similar findings elsewhere show variation among breeding lines but no complete resistance (Yan, 2012), representing a major gap in national management efforts.

Logistic regression analysis confirmed that faba bean gall incidence and severity are primarily driven by agro-

ecological factors such as district, year, and altitude, with management practices-including variety selection, crop rotation, planting method, drainage, fertilizer use, weeding, and fungicide application-playing important modifying roles. Some factors influenced incidence more strongly, while others had greater effects on severity, indicating differential responses of disease components to environmental and agronomic variables.

Overall, this study demonstrates that faba bean gall is a serious and persistent threat to faba bean production in northeastern Ethiopia, with prevalence reaching up to 97.14% in some districts. Under favorable conditions and on susceptible varieties, yield losses may reach 100%, leading some farmers to abandon faba bean cultivation entirely (Abebe *et al.*, 2014; Hailu *et al.*, 2014; Bitew *et al.*, 2021; Yitayih and Azemraw, 2017). Priority interventions should focus on developing resistant varieties, promoting crop rotation, improving seed systems, optimizing agronomic practices, enhancing drainage, and applying fungicides judiciously. A deeper understanding of the biology of *Physoderma viciae*, its survival mechanisms, and environmental interactions is essential for sustainable long-term management.

CONCLUSION

The present study confirms that faba bean gall has become a widespread and serious constraint in Ethiopia's highland faba bean-producing regions. The disease was consistently observed across all surveyed districts during both the 2022 and 2023 cropping seasons, with higher incidence and severity associated with high-altitude areas, increased rainfall, higher relative humidity, and cooler temperatures. Disease severity peaked at the flowering stage and was further exacerbated by dense weed populations, poor drainage, and suboptimal agronomic practices. Although some variation in susceptibility was observed among genotypes, no fully resistant variety was identified, and the continued use of susceptible local varieties contributes to the persistence and spread of the disease. Logistic regression analysis confirmed that environmental factors such as district, year, and altitude, together with agronomic practices including variety selection, crop rotation, planting method, drainage, fertilizer use, weeding, and fungicide application, collectively influence disease incidence and severity.

These findings highlight the urgent need for integrated disease management strategies that combine host

resistance, improved agronomic practices, effective drainage, crop rotation, judicious fungicide use, and strengthened seed systems. Breeding programs should focus on developing resistant or tolerant varieties, while farmers should adopt row planting, timely weeding, proper land preparation, and appropriate fertilizer application to reduce disease pressure. Crop rotation with cereals or non-legume crops can help limit pathogen buildup in soils, and well-drained fields or avoidance of shaded or waterlogged areas can further reduce severity. In addition, continued research on the biology, epidemiology, and survival mechanisms of *Physoderma viciae*, along with increased farmer awareness and training, is essential for sustainable management. Adoption of these integrated, location-specific measures will be critical to safeguard faba bean production, minimize yield losses, and ensure food security in Ethiopia's highland farming systems.

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DATA AVAILABILITY

The datasets generated and/or analyzed during the current study are available from the corresponding author, Seid Hussen, upon reasonable request.

CONFLICT OF INTEREST

The authors declare that they have no competing interests.

ETHICS DECLARATION

Not applicable.

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