UDESC

Revista de Ciências Agroveterinárias
Universidade do Estado de Santa Catarina (UDESC)

Research Article

Response of improved fenugreek (*Trigonella foenum-graecum* L.) varieties to powdery mildew (*Erysiphe polygoni*) and its performance evaluation under natural field conditions in the Wolaita zone, South Ethiopia

Resposta de variedades aprimoradas de feno-grego (Trigonella foenum-graecum L.) ao oídio (erysiphe polygoni) e sua avaliação de desempenho em condições de campo naturais na zona de wolaita, no Sul da Etiópia

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Submission: January 9th, 2024 | Acceptance: February 1st, 2025

ABSTRACT

Powdery mildew is one of the most important diseases that constrain fenugreek production and productivity in fenugreek-growing areas of Ethiopia, where mid to high land environmental conditions prevail. Thus, this study was conducted to evaluate the performance and response of six fenugreek varieties to powdery mildew under field conditions in the Wolaita Zone, Southern Ethiopia, in the 2020/2021 cropping seasons. The treatments consisted of six released fenugreek varieties that were laid out in an RCBD with three replications. Disease severity was assessed as the proportion of leaf area affected by the disease in 10 randomly selected plants in the middle two rows. The AUDPC was estimated from the percent severity index. The results revealed that the terminal disease severity varied from 27.00 to 48.67PSI in Sodo Zuria; and 23.67 to 57.33PSI in Damot Gale, respectively. AUDPC varied from 530.80 to 907.07%-days in Sodo Zuria and from 341.80 to 668.50%-days in Damot Gale. The varieties Bishoftu, FG-10, and Challa exhibited high disease severity and high AUDPC and were categorized as susceptible fenugreek varieties. It is concluded that under field conditions, different fenugreek varieties responded differently to powdery mildew, and the disease severity was strongly affected by the use of different resistance levels of fenugreek varieties and differences in the environmental conditions. It is therefore promising to use the two varieties, such as Ebbisa and Hunda, which were considered resistant under field conditions and which are recommended for use by farmers in the study areas and other regions with similar agroecologies in Ethiopia.

KEYWORDS: AUDPC. Annual spices. Disease severity index. Pod. Pollination. Seed yield.

RESUMO

O oídio é uma das doenças mais importantes que limitam a produção e produtividade do feno-grego nas áreas de cultivo desse vegetal na Etiópia, onde prevalecem condições ambientais em regiões de média a alta altitude. Assim, este estudo foi conduzido para avaliar o desempenho e a resposta de seis variedades de feno-grego ao oídio em condições de campo na Zona de Wolaita, Sul da Etiópia, durante as safras de 2020/2021. Os tratamentos consistiram em seis variedades de feno-grego lançadas, dispostas em um delineamento de blocos casualizados com três repetições cada. A gravidade da doença foi avaliada como a proporção da área foliar afetada pela doença em dez plantas selecionadas aleatoriamente nas duas fileiras do meio. O AUDPC foi estimado a partir do índice percentual de gravidade. Os resultados revelaram que a gravidade final da doença variou de 27,00 a 48,67 PSI em Sodo Zuria e de 23,67 a 57,33 PSI em Damot Gale, respectivamente. A progressão da doença, medida pela Área Abaixo da Curva de Progresso da Doença, variou entre as localidades. Em Sodo Zuria, o AUDPC variou de 530,80 a 907,07%-dias,

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enquanto em Damot Gale, a variação foi de 341,80 a 668,50%-dias. As variedades Bishoftu, FG-10 e Challa apresentaram alta gravidade da doença e alto AUDPC, sendo categorizadas como variedades suscetíveis de feno-grego. Conclui-se que, em condições de campo, diferentes variedades de feno-grego responderam de maneira diferente ao oídio, e a gravidade da doença foi fortemente afetada pelo uso de diferentes níveis de resistência das variedades de feno-grego e diferenças nas condições ambientais. As variedades Ebbisa e Hunda demonstraram resistência promissora ao oídio em condições de campo, sendo altamente recomendadas para cultivo por agricultores nas áreas de estudo e em outras regiões da Etiópia com condições agroecológicas similares.

PALAVRAS-CHAVE: AUDPC. Especiarias anuais. Índice de gravidade da doença. Vagem. Polinização. Rendimento de sementes.

INTRODUCTION

Fenugreek (*Trigonella foenum-graecum* L.), which belongs to the family Fabaceae, is a diploid species with a chromosome number of 2n=16. The genus *Trigonella* is one of the largest genera of the tribe *Trifoliate* in the family *Fabaceae* and sub-family *Papilionaceae* (JYOTI et al. 2016). Among the species in the Trigonella genus, *Trigonella foenum-graecum*, commonly known as fenugreek, is an annual species with autogamous flowers that are occasionally visited by insects for pollination. While it originates from countries on the eastern shores of the Mediterranean, fenugreek is now extensively cultivated in India, Egypt, Ethiopia, Morocco, and sporadically in England (DAVOUD *et al.* 2010, MILLION 2012a, KASSA *et al.* 2020). In Ethiopia, fenugreek serves various essential purposes, including improving soil structure and fertility as a rotation crop, generating significant income for farmers and producers, and contributing to the flavor and texture of traditional bread (loaf) and "tef-injera", a staple food in cooler zones of the country (MILLION 2012b, ROBA *et al.* 2022). The flour of fenugreek is utilized in the production of various spices. For instance, when the powder is soaked overnight and the water is poured off the following morning, the remaining mixture, combined with honey, yields a delicious beverage. Additionally, in the absence of milk, fenugreek can serve as a substitute for infant feed.

Fenugreek holds significant importance as one of the primary spice crops cultivated in Ethiopia, both in terms of production volume and the extent of cultivation (TESHOME *et al.* 2020). This is attributed to the country's diverse agroecologies, which are conducive to the growth of a wide range of spice crops (TESFAYE & HAILESELASSIE 2019). Smallholder farmers in Ethiopia extensively cultivate various indigenous and exotic spice crops (MULUGETA 2021). As a result, Ethiopia benefits from favorable agroecologies that support the production of high-value, premium-quality spices and herbs used for enhancing flavor, seasoning, and shelf-life of processed and canned foods (MEKONNEN *et al.* 2022). The country's diverse agroecologies enable the cultivation and production of numerous spices, herbs, and medicinal plants, as well as the seamless incorporation of exotic spices (ABEBAW & BELAYNEH 2018). The utilization of spices and medicinal plants is widespread in Ethiopian cuisine, with virtually no local dish lacking a distinct spice ingredient (MEKONNEN 2020).

Fenugreek is one of the most important seed spice crops in Ethiopia (ROBA *et al.* 2022). Despite its importance, this crop is low-yielding due to multiple biotic and abiotic factors. Among the biotic factors, diseases are the principal threats limiting fenugreek production and productivity. The major diseases occurring on fenugreek are powdery mildew, damping off, collar rot, leaf spots, and rust. The three most prevalent fungal diseases affecting fenugreek are powdery mildew (caused by *Erysiphe polygoni*) and *Leveillula taurica*, *Cercospora* leaf spot, and downy mildew (caused by *Peronospora trigonallae*) (THOMAS *et al.* 2010, KRISHNENDU *et al.* 2014). Compared to other leaf diseases, powdery mildew is the most widely distributed, has high economic importance (JONGEBLOED 2004; GOJIYA & PANDYA 2019) and has the potential to affect biomass and seed yield in crops under moist agro-climatic conditions.

Understanding how a particular disease affects a specific crop is crucial for determining effective control measures (SMITH *et al.* 2020). However, the potential of the fenugreek sub-sector has not been fully realized, and the crop's production and utilization have not received adequate research and extension support (JOHNSON & LEE 2019). Furthermore, limited empirical information is available regarding the response of various fenugreek varieties to this disease (KUMAR *et al.* 2021). Additionally, the introduction of these high-value agricultural products significantly contributes to increasing the income of individual farmers, as well as meeting the demand for seasoning, flavoring agents, and condiments (PATEL & SINGH 2022).

This study aims to provide robust evidence regarding the favorable environments for cultivating fenugreek varieties, thereby enabling farmers and investors interested in fenugreek production in the Wolaita zone, south Ethiopia, and surrounding areas with similar agroecologies to make informed decisions. Therefore, the objective of this study is to evaluate the response of improved fenugreek varieties to powdery mildew under natural field conditions and to select adaptable, high-yielding varieties for production and crop improvement in breeding schemes.

MATERIAL AND METHODS

Description of the Experimental Sites

Field experiments were conducted during the 2020/21 cropping season in two locations namely: Sodo Zuria (Location 06^{o}52' N latitude and 37^{o}48' E longitude, altitude of 2162 masl,maximum temperature 21^{o}C and minimum 11.5^{o}C, annual average rainfall 1271 mm, soil type is clay loam textural class with soil pH of 5.36) and Damot Gale (Location 06^{o}83' N latitude and 37^{o}73' E longitude, altitude of 1907 masl,maximum temperature 21 ^{o}C and minimum 11.5 ^{o}C, annual average rainfall 1250 mm and soil type sandy loam with pH value of 7.6) (SIMON *et al.* 2020).

Treatment and Experimental Design

The experiment involved six released varieties of fenugreek (Bishofitu, Burqa, Chala, Ebbisa, FG-10, and Hunda) arranged in a randomized complete block design (RCBD) with three replications. Each plot measured 1.8 meters in width and 2 meters in length, resulting in a total gross area of 3.6 square meters. The experimental field was prepared by plowing, pulverizing, and leveling to create a smooth seedbed for planting. Seeds were manually planted, with two seeds sown per hill at a row spacing of 30 cm and a plant spacing of 10 cm. Thinning was conducted after emergence to ensure the proposed plant density per plot. The recommended fertilizer application included 20 kg/ha of P (Phosphorus) at planting in the form of Nitrogen, Phosphorus, and Sulfur (NPS), and 55 kg/ha of N (Nitrogen) in the form of urea based on crop-specific nutrient needs and local soil characteristics (ETHIOSIS 2014). Crop management activities, such as hoeing and weeding, were performed throughout the crop-growing season.

Disease Assessment

Field disease assessment at each location was assessed 6 times throughout the growing season from the onset of the disease until the fenugreek reached physiological maturity. Ten randomly taken plants in the two central rows were tagged and used for successive disease assessments.

Disease severity (%): Disease severity was rated using 0-5 scales described by PRAKASH & SAHARAN (2002). The scores were described as 0 = free from diseases; 1 = 1 to 10 % of leaf area infected; 2 = 10.1 to 25 % of leaf area infected; 3 = 25.1 to 50 % of leaf area infected; 4 = 50.1 to 75 % of leaves area infected and 5 = More than 75 % of leaf area infected. Rating started when obvious genotypic differences for diseases (powdery mildew) reaction became apparent and continued until leaves senesced. Disease severity scores were converted into percentage severity index (PSI) for analysis using Equation 1 suggested by WHEELER (1969). Equation1 is given below.

$$PSI = \frac{\text{Sum of all numerical ratings x 100}}{\text{Total no of plants rated x Maximum rating}} \qquad \text{Eq. (1)}$$

The disease progress rate (DPR) was calculated based on the linearized model (Equation 2; CAMPBELL & MADDEN 1990, VANDER-PLANK 1963), and the calculated values were analyzed by using SAS software:

$$r = ((Ln\ x / (1-x)) – (Ln\ x_o / (1- x_o))/t \qquad \text{Eq. (2)}$$

where: r = disease progress rate, X_o = initial disease severity, X = final disease severity, t = the duration of the epidemic, and Ln = Natural logarithm.

The area under the disease progress curve (AUDPC), which consists of proportions of diseased plants, was calculated from disease severity recorded at seven-day intervals starting from the onset of disease, six times in each location throughout the growing period and converted to the percent severity index. To ensure consistent disease evaluation in the field, the area under the disease progress curve was calculated. This curve was developed from seven days of disease severity reading in different locations. By constructing a curve, symptom development, and disease severities were compared over locations. AUDPC is used to quantify the suppression of the beginning of the epidemic and the time until the powdery mildew reaches a peak. The diseases for the whole plant were converted to AUDPC to compare relative levels of resistance and susceptible varieties (Equation 3). AUDPC was computed from severity data using the formula suggested by CAMPBELL & MADDEN (1990):

$$AUDPC = \Sigma\ [(x_i + x_i+1)/2]\ x\ (t_i+1 - t_i) \qquad \text{Eq. (3)}$$

Where: x_i is the disease severity expressed in percentage at i^{th} observation, t_i is time (days after sowing) at the i^{th} observation and n is the total number of days the disease was assessed.

Data Collection and Measurements

Analysis of variance was conducted for Powdery mildew severity, the area under disease progress curve (AUDPC) and disease progress rate at all plant growth stages were subjected to analysis of variance, and means were compared using the least significant difference (LSD) at $p \leq 0.05$ level of significance, and SAS Version 9.2 (SAS 2008) software was employed for the analysis. To determine the disease progress rate, a logistic growth model, ln [x/ (1-x)], (VANDER-PLANK 1963) was used to estimate the disease progression. The transformed data were regressed over time (DAS) to determine the disease progress rate. The AUDPC values and disease progress rate (r) were calculated for each tested variety, and data were analyzed by analysis of variance. The two locations were considered as different environments because of heterogeneity of variance as tested by Bartlett's test (GOMEZ & GOMEZ 1984) and F-test was significant for Powdery mildew reaction on fenugreek varieties under field conditions studied. Thus, the data were not combined for analyses.

This field experiment meticulously documented a range of key agronomic traits. Days to maturity were determined by calculating the number of days from the emergence of seedlings to the observation of flowering in 90% of the plants within each experimental plot. Plant height was assessed at maturity by measuring the distance from the ground to the apex of six randomly selected plants per experimental unit, with the average recorded. Branching architecture was characterized by counting the number of primary branches (emerging directly from the main stem) and secondary branches (emerging from primary branches) on six randomly chosen plants per experimental unit, again using the average for analysis.

The total number of pod-bearing branches originating from the main stem was also tallied using the same sampling method. Pod characteristics were assessed by measuring the average length of six randomly selected pods per plant and counting the total number of pods on six randomly chosen plants per experimental unit, expressing the latter as an average. To determine the number of seeds per pod, all pods from the six sampled plants were threshed, the seeds counted, and the total number of seeds divided by the total number of pods. Seed yield was evaluated at both the plant and plot level. For seed yield per plant, the average dry weight of seeds from six randomly selected plants per plot was calculated. Yield per plot was determined by harvesting and weighing the dry seeds from all harvestable rows within each experimental plot.

To complement these field observations, a laboratory analysis was conducted to determine the oil content of the fenugreek seeds. This involved a standardized procedure of grinding pre-cleaned and dried seeds, employing a solvent extraction method (utilizing solvents like hexane), and subsequently quantifying the extracted oil. Data were subjected to analysis of variance using the general linear model SAS version 9.2 (SAS 2008). Variance components due to genotype$(\sigma 2p)$ (Equation 4), phenotype$(\sigma 2p)$ (Equation 5), and the environment (Equation 6) are calculated by adopting the following formulas as suggested by BURTON & DEVANE (1953).

$$\text{Genotypic Variance, } \sigma^2_g = (MSg\text{-}MSe)/r \qquad \text{Eq. (4)}$$

$$Phenotypic\ variance\ (\sigma 2p)\ =\ \sigma 2g\ +\sigma 2e \qquad \text{Eq. (5)}$$

$$Environmental\ variance\ (\sigma 2e)\ =\ Error\ mean\ square \qquad \text{Eq. (6)}$$

where: MSg = mean square of genotype, MSe = mean square of error and r = number of replications.
According to (SIGN 2001) the phenotypic (Equation 7) and genotypic (Equation 8) coefficients of variances were expressed as:

$$PCV = \frac{\sqrt{Phenotypic\ variance}}{Population\ mean\ for\ trait}\ or \quad PCV\ =\ \frac{\sigma 2P}{X}\ x\ 100 \qquad \text{Eq. (7)}$$

$$GCV\ =\ \frac{\sqrt{Genotypic\ variance}}{Population\ mean\ for\ trait}\ or \quad GCV\ =\ \frac{\sigma 2g}{x}\ x\ 100 \qquad \text{Eq. (8)}$$

where PCV = phenotypic coefficient of variation; GCV = Genotypic coefficient of variation; and x = the grand mean of a character.

Heritability in a broad sense was calculated for each trait by using the Equation 9 (ALLARD 1960):

$$H^2\ (\%) = \frac{\sigma 2g}{\sigma 2p}\ x1oo \qquad \text{Eq. (9)}$$

where: H = Heritability in broad sense, σ^2g = genotypic variance and $\sigma^2{}_p$ = Phenotypic variance.

Genetic advance (GA) under selection, assuming the selection intensity of 5% was calculated according to Equation 19 as proposed by JOHNSON *et al.* (1955):

$$GA = K.\sqrt{\sigma 2p}.\frac{\sigma 2g}{\sigma 2p} = K.H^*\sqrt{\sigma 2p} \qquad \text{Eq. (10)}$$

where: GA = Expected genetic advance; K = The selection differential (K= 2.056 at 5% selection intensity)

Genetic advance as a percentage of the mean was calculated to compare the extent of predicted advances of different traits under selection, using Equation 11 given by FALCONER & MACKEY (1996):

$$GAM = \frac{GA}{X}x\ 100 \qquad \text{Eq. (11)}$$

where: GAM = Genetic advance as a percent of the mean; GA = Genetic advance under selection; and X = Mean value.

Analysis of variance was conducted for Powdery mildew severity, AUDPC, and disease progress rate at all plant growth stages, and phenological parameters, seed yield, oil contents, and variance components were subjected to analysis of variance using the statistical analysis system SAS Version 9.2 (SAS 2008). Significant treatment means were separated using the least significant difference (LSD) test at p≤0.05 probability level.

RESULTS AND DISCUSSIONS

Disease Development on Fenugreek Varieties under Field Conditions

Powdery Mildew (*Erysiphe polygoni)* Severity

The study found that powdery mildew symptoms appeared earlier on the highly susceptible variety compared to the improved fenugreek varieties in the 2020/2021 cropping seasons. This finding is consistent with numerous studies demonstrating the role of host plant resistance in managing powdery mildew diseases across various crops (LEBEDA *et al.* 2019). For instance, research on cucumber powdery mildew (caused by *Podosphaera xanthii*) has identified significant variations in disease resistance among different cultivars, with some exhibiting complete resistance due to the presence of specific resistance genes. Similarly, studies on pea powdery mildew (caused by *Erysiphe pisi*) have revealed that resistance is often conferred by single dominant genes, leading to distinct phenotypic differences between resistant and susceptible varieties (FONDEVILLA *et al.* 2012)**.** There were varying levels of powdery mildew severity recorded on the different fenugreek varieties under natural infections, and the significant variation in disease severity observed among the fenugreek varieties at both locations further emphasizes the role of genetic factors in disease development. This finding is corroborated by research on various crops, including wheat, barley, and grapevine, where significant differences in powdery mildew severity have been attributed to genotypic variations (LILLEMO *et al.* 2013).

The varieties displayed different responses to the disease, and the initial and terminal disease severity differed significantly ($p \leq 0.05$) among the varieties at both locations. According to the study (Table 1, Figure 1), the improved fenugreek varieties exhibited the lowest mean initial and terminal disease severity in both locations in the 2020/2021 cropping seasons, suggesting that these varieties possess mechanisms for both preventing infection and slowing down disease progression. This could be attributed to a combination of factors, including preformed defenses (resistant varieties may have higher constitutive levels of defense compounds, such as phenolic compounds, phytoalexins, or pathogenesis-related proteins, which can inhibit fungal growth and development and induced resistance (upon infection, resistant varieties may activate stronger and faster defense responses, including the hypersensitive response and the production of reactive oxygen species, effectively limiting fungal spread) (LILLEMO *et al.* 2013, LEBEDA *et al.* 2019). Furthermore, disease severity during the initial assessment varied significantly among the varieties in the Sodo Zuria testing site. Notably, higher initial disease severities were recorded for varieties Challa and FG-10, with values of 6.00 PSI and 8.33 PSI, respectively, in the Sodo Zuria district in the 2020/2021 cropping season. In contrast, lower initial disease severities were observed for varieties Burqa (5.33 PSI), Hunda (5.33 PSI), and Ebbissa (4.00 PSI) in the same district during the 2020/2021 cropping season. This information underscores the differential responses of the fenugreek varieties to powdery mildew and highlights the need for further investigation into the factors contributing to these varying responses.

The study found that disease severity at the terminal assessment, near crop physiological maturity, was significantly ($p \leq 0.05$) different among the varieties in the Sodo Zuria district during the 2020/2021 cropping seasons. Specifically, lower terminal disease severity was recorded for the variety Ebbissa, while the varieties Hunda and Burqa exhibited higher terminal disease severity in the Sodo Zuria district testing site (Table 1). The levels of terminal disease severities in the Ebbissa and Burqa varieties were significantly different from the other tested varieties. Additionally, these varieties showed a similar reaction at their early growth stages by having significantly lower initial powdery mildew severities. For instance, the initial disease severity of the Hunda and Burqa varieties was slightly higher (5.33 PSI) compared to the Ebbissa variety (4.00 PSI) during the Sodo Zuria district testing. These results underscore the variability in disease susceptibility and resistance among the fenugreek varieties, indicating the need for further exploration of the factors contributing to these varying responses at different growth stages and locations.

Table 1. Mean Initial ($PSI_{i)}$ and terminal (PSI_f) severity, AUDPC, and parameter estimates of Powdery mildew in six fenugreek varieties in Sodo Zuria and Damot Gale districts of Wolaita Zone in 2020/2021 cropping season.

Varieties	Sodo Zuria in 2020/2021				Damot Gale in 2020/2021			
	PSI_i	**PSI_t**	**AUDPC**	**DPR (Logit $days^{-1}$)**	**PSI_i**	**PSI_t**	**AUDPC**	**DPR (Logit $days^{-1}$)**
Bishoftu	8.33[a]	48.33[a]	907.70[a]	0.0663[bc]	3.00[ab]	57.33[a]	668.50[a]	0.1082[a]
Burqa	5.33[bc]	31.00[b]	617.20[b]	0.0580[cd]	2.33[bc]	26.33[d]	430.50[c]	0.0839[bc]
Challa	6.00[b]	48.67[a]	889.00[a]	0.0681[b]	2.67[b]	41.33[c]	536.70[b]	0.0889[bc]
Ebissa	4.00[c]	27.00[c]	530.80[c]	0.0656[b]	1.67[c]	23.67[d]	341.80[c]	0.0768[c]
Fg-10	6.00[b]	48.67[a]	893.70[a]	0.0807[a]	3.66[a]	49.67[b]	583.30[ab]	0.0932[ab]
Hunda	5.33[bc]	29.00[bc]	530.80[c]	0.0548[d]	1.67[c]	27.33[d]	416.50[c]	0.0804[bc]
CV (%)	16.90	3.20	3.20	8.20	17.90	3.95	11.00	9.50
LSD (5%)	1.789	2.27	42.33	0.0097	0.814	5.80	99.20	0.0154

Mean within a column followed by the same letters are not significantly different from each other according to LSD at a 5% probability level. LSD = Least Significant Difference, CV = Coefficient of Variation. PSIi and PSIt = Initial and terminal Percent Severity Index, respectively, AUDPC = Area under Disease Progress Curve, and DPR = Disease progress rate (Logit $days^{-1}$).

The contrasting performance of varieties such as Hunda and Burqa, which show similar initial resistance but different terminal severity, could be attributed to stage-specific resistance mechanisms. Some plant defense mechanisms are more active during specific growth stages. For instance, certain defense-related genes might be up-regulated during the early growth stages in Hunda and Burqa, explaining the lower initial severity, but their effectiveness might decline as the plant matures, leading to higher terminal severity (AGRIOS 2005).

Different powdery mildew pathotypes (strains with varying virulence) in Sodo Zuria could also contribute to the observed differences. A variety resistant to one pathotype might be susceptible to another. Further investigation into the genetic makeup of the powdery mildew population in the Sodo Zuria testing site could provide valuable insights (LILLEMO *et al*. 2013). While the study focuses on varietal differences, environmental factors like temperature, humidity, and light can significantly influence powdery mildew development. Microclimatic variations within the Sodo Zuria site might have influenced disease progression differently on each variety, contributing to the observed terminal severity differences (BURDON 2014).

In the Damot Gale district during the 2020/2021 cropping seasons, the study found that powdery mildew severity varied significantly ($p \leq 0.05$) among the different fenugreek varieties during the initial assessment, as shown in Table 1. Higher initial severities of 3.66 PSI and 3.00 PSI were recorded for the FG-10 and Bishoftu varieties, while significantly lower values of 1.67 PSI were observed for both the Hunda and Ebbissa varieties. Furthermore, disease severity at the terminal assessment near crop physiological maturity was also significantly ($p \leq 0.05$) different among the six varieties in the 2020/2021 cropping seasons in the Damot Gale district. The varieties Hunda, Burqa, and Ebbissa exhibited lower terminal disease severities, with recorded values of 27.33 PSI, 26.33 PSI, and 23.67 PSI, respectively, as detailed in Table 1. The levels of terminal disease severity for Hunda, Burqa, and Ebbissa were significantly different from the other fenugreek varieties tested, indicating distinct responses to the disease. These varieties also displayed similar reactions at their early growth stages, with significantly lower initial severity of the disease. Additionally, the initial disease severity of the Burqa variety was somewhat higher than that of Hunda and Ebbissa and was significantly different from the other varieties tested in the Damot Gale district during the 2020/2021 cropping season. These findings highlight the varying levels of disease severity among the fenugreek varieties in the Damot Gale district and the need for further investigation into the factors influencing these differential responses at different growth stages.

Area under Disease Progress Curve (AUDPC)

The study also computed the AUDPC from the severity data and found a highly significant ($p \leq 0.05$) difference among the six tested fenugreek varieties in both the Sodo Zuria and Damot Gale districts during the 2020/2021 cropping season, as detailed in Table 1. The AUDPC values varied between 530.80 and 907.70%-days in the Sodo Zuria district and between 341.80 and 668.50%-days in the Damot Gale district. Notably, the Bishoftu variety exhibited the highest AUDPC value of 907.70%-days, indicating its higher susceptibility to powdery mildew in the Sodo Zuria district, while the same variety had an AUDPC value of 668.50%-days in the Damot Gale district.

Conversely, the variety Ebbissa had the lowest AUDPC value, followed by the Hunda and Burqa varieties, indicating their resistance to powdery mildew int both locations during the 2020/2021 cropping season. Additionally, all varieties considered susceptible displayed consistently higher areas under the disease progress curve in the Sodo Zuria than in the Damot Gale district during the testing seasons. These results align with similar assessments and suggest a differential but stable reaction by the varieties to natural infection by powdery mildew in the Sodo Zuria and Damot Gale districts of the Wolaita Zone. These findings indicate the varying levels of resistance and susceptibility among the tested fenugreek varieties and provide valuable insights into their performance under natural infection by powdery mildew at different locations.

Disease Progress Rate (DPR)

The disease progress rates and parameter estimates due to Powdery mildew are presented in Table 1. In the 2020/2021 cropping season, variations in disease progress rates were observed among the six fenugreek varieties used in both Sodo Zuria and Damot Gale districts. The observed disease progress rates exhibited variations across the six fenugreek varieties, ranging from 0.0548 to 0.0807 units day-1 int Sodo Zuria and 0.0768 to 0.1082 units day-1 int Damot Gale (Table 1). Notably, the disease progress rate was found to be higher int Damot Gale compared to Sodo Zuria. Furthermore, the varieties Bishoftu, FG-10, and Challa demonstrated faster disease progression in both locations, while Hunda, Ebbissa, and Burqa exhibited relatively slower rates. The statistical analysis revealed significant differences in disease progress rates among the fenugreek varieties tested. The differences in disease progress rates among the fenugreek varieties tested were found to be statistically significant. Despite the highest AUDPC being observed in the Bishoftu variety, the FG-10 variety exhibited relatively faster mean disease progress rates (r = 0.0807) in the Sodo Zuria district during the 2020/2021 cropping season. Overall, these findings indicate the importance of considering the varietal differences in disease progress rates when developing strategies for managing Powdery mildew in fenugreek cultivation.

Phenological Parameters:

Days to maturity

The analysis of variance revealed significant ($p \leq 0.05$) differences among the fenugreek varieties in terms of days to maturity (as shown in Table 2). The days to maturity varied across different locations, with Sodo Zuria experiencing a range from 108.67 to 115.00 days, and Damot Gale ranging from 106.33 to 111.67 days, indicating differences of 6.33 and 5.34 days, respectively, between the longest and shortest maturity periods. Variety Hunda consistently took the longest time to reach maturity int both locations. Specifically, in Sodo Zuria, variety Hunda had the longest maturity period at 115.00 days, while FG-10 had the shortest at 106.33 days in Damot Gale, showing an 8.67-day difference between the longest and shortest maturity periods (Table 3). These findings imply a wide range of variability among the fenugreek varieties for days to maturity. This aligns with the findings of CHALA *et al.* (2021), who also observed significant differences among fenugreek varieties in terms of the number of days required to reach physiological maturity.

Plant Height

The analysis of variance revealed that the plant height of varieties was significantly ($p \leq 0.05$) influenced by the location, as shown in Table 2. On average, the plant height of varieties was greater in Sodo Zuria compared to Damot Gale. Additionally, significant differences in plant height were observed among the varieties, with plant heights ranging from 28.95 to 39.98 cm. Variety Ebbisa exhibited the tallest plants at 39.98 cm, followed by variety Hunda at 38.60 cm, while variety Bishofitu had the shortest plants at 28.95 cm (Table 3). These differences in plant height among the varieties are likely due to their distinct responses to their respective growing environments. This aligns with the findings of GÜZEL & ÖZYAZICI (2021), who also reported significant differences in plant height among fenugreek varieties. Interestingly, the interactions between locations and varieties did not have a significant effect on plant height, as indicated in Table 2.

Number of Branches

The analysis of variance revealed that the location had a significant ($p \leq 0.05$) impact on the number of primary, secondary, and total branches per plant, as detailed in Table 2. On average, Sodo Zuria exhibited a higher mean number of primary, secondary, and total branches per plant compared to Damot Gale. Furthermore, the main effect of varieties, when averaged across locations, showed significant differences in the number of secondary and total branches per plant (Table 2). In general, the number of secondary and total branches per plant for the varieties ranged from 2.15 to 3.60 and 4.92 to 7.15, respectively. Variety Ebbisa had the highest number of secondary branches per plant (3.60) and total branches per plant (7.15), followed by Hunda with a mean of 2.79 secondary branches per plant and 7.03 total branches per plant. Conversely, the variety Burqa had the lowest number of secondary branches per plant (2.15) and total branches per plant (4.73) (Table 3).

Table 2. Analysis of variance for ten traits of fenugreek varieties

Trait	Location	Variety	Location x variety	Error	CV (%)	Grand mean
Days to maturity	78.02*	49.96*	15.29*	2.92	1.56	109.53
Primary branches	19.36*	0.38^{NS}	0.63^{NS}	0.26	19.30	2.64
Secondary branches	21.01*	1.73*	3.86*	0.55	27.50	2.69
Total branches	70.56*	6.21*	4.74*	1.03	17.19	5.92
Plant height	96.37*	104.12*	19.07^{NS}	10.77	9.38	34.99
Pod length	0.23^{NS}	7.42*	0.18^{NS}	0.46	6.37	10.67
Pods per plant	484.00*	118.69*	7.71*	8.69	24.45	12.06
Seeds per pod	50.41*	4.24^{NS}	1.85^{NS}	2.17	14.14	10.41
Seed yield	10.29*	32.86*	1.98*	0.96	18.98	5.16
Oil content	0.06*	0.06*	0.00^{NS}	0.00	8.39	0.51

CV = Coefficient of Variation. *= significant at 5%, NS= not significant.

Table 3. Mean performance of fenugreek varieties for phenological and growth parameters.

Location	Varieties	Days to maturity	Plant height (cm)	Primary branches	Secondary branches	Total No branches
Sodo Zuria	Bishofitu	110.00^{b-d}	32.63	3.30	3.50^{a-c}	7.10^{bc}
	Burqa	111.00^{b-d}	33.57	2.87	2.23^{c-f}	5.33^{cd}
	Challa	110.00^{b-d}	37.00	3.77	3.23^{b-d}	7.30^{a-c}
	Ebbisa	108.67^{c-e}	41.03	3.13	4.50^{ab}	8.13^{ab}
	FG 10	111.33^{bc}	36.00	3.60	2.40^{c-e}	6.50^{b-d}
	Hunda	115.00^{a}	39.50	3.60	4.90^{a}	9.57^{a}
Damot Gale	Bishofitu	110.00^{b-d}	25.27	1.33	0.90^{f}	2.37^{e}
	Burqa	111.33^{bc}	31.53	1.87	2.07^{c-f}	4.50^{de}
	Challa	108.33^{de}	29.27	1.53	1.97^{d-f}	4.37^{de}
	Ebbisa	100.67^{f}	38.93	2.67	2.70^{cd}	6.17^{b-d}
	FG 10	106.33^{e}	37.40	1.97	2.93^{cd}	5.23^{cd}
	Hunda	111.67^{b}	37.70	2.10	1.03^{ef}	4.50^{de}
	LSD	2.93	NS	NS	1.45	2,33
Varieties mean	Bishofitu	110.00^{bc}	28.95^{d}	2.32	2.20^{b}	4.92^{b}
	Burqa	111.17^{b}	32.55^{cd}	2.37	2.15^{b}	4.73^{b}
	Chala	109.17^{bc}	33.13^{bc}	2.65	2.60^{ab}	5.83^{ab}
	Ebbisa	104.67^{d}	39.98^{a}	2.90	3.60^{a}	7.15^{a}
	FG 10	108.83^{c}	36.70^{ab}	2.78	2.67^{ab}	5.87^{ab}
	Hunda	113.33^{a}	38.60^{a}	2.85	2.97^{ab}	7.03^{a}
	LSD	2.07	3.87	NS	1.02	1.65
Location means	Sodo Zuria	111.00^{a}	36.62^{a}	3.38^{a}	3.46^{a}	7.32^{a}
	Damot Gale	108.06^{b}	33.35^{b}	1.91^{b}	1.93^{b}	4.52^{b}
	LSD	1.19	2.23	0.35	0.59	0.95
	CV (%)	1.56	9.38	19.30	27.50	17.19

Mean within a column followed by the same letters are not significantly different from each other according to LSD at a 5% probability level. LSD = Least Significant Difference, CV = Coefficient of Variation, and NS= not significant.

The interactions between locations and varieties resulted in significant ($p \leq 0.05$) differences in the number of secondary and total branches per plant, as shown in Table 2. The number of secondary branches per plant ranged from 0.90 to 4.90, while the total number of branches per plant ranged from 2.37 to 9.57. Varieties Hunda and Ebbisa produced a relatively higher number of secondary and total branches per plant in Sodo Zuria, while varieties FG-10 and Ebbisa yielded a greater number in Damot Gale. Overall, the greatest number of secondary branches per plant (4.90) and total branches per plant (9.57) were recorded for variety Hunda in Sodo Zuria, whereas the lowest number of secondary branches per plant (0.90) and total branches per plant (2.37) were obtained from variety Bishofitu in Damot Gale (Table 3). However, the main effect of varieties and their interactions with locations did not affect the number of primary branches per plant, as indicated in Table 2.

Figure 1. Vegetative performance of fenugreek genotypes (A), Symptom of Powdery mildew on fenugreek genotype (B), Seed yield of fenugreek (C), and Oil content extraction of fenugreek at Lab. (D)

Yield Components and Yield:

Pod length

Significant ($p \leq 0.05$) differences were observed as a result of the main effect of varieties on pod length, as indicated in Table 4. The pod length varied among varieties, ranging from 9.47 to 12.60 cm. Variety Ebbisa had the longest pod length at 12.60 cm, followed by variety Hunda with an average pod length of 11.27 cm. Conversely, the shortest pod length of 9.47 cm was recorded for the variety Bishofitu (Table 4). These findings highlight the significant inherent differences among the varieties in terms of pod length. However, the main effect of location and its interaction with varieties did not yield significant differences in pod length, as shown in Table 2.

Number of pods per plant and seeds per pod

The analysis of variance indicated that the location had a significant ($p \leq 0.05$) effect on the number of pods per plant and seeds per pod, as demonstrated in Table 4. It was observed that both the number of pods per plant and seeds per pod were higher in Sodo Zuria compared to Damot Gale, suggesting that the growing conditions in Sodo Zuria are more conducive to the growth and development of the crop. Similarly, the main effect of varieties led to significant differences in the number of pods per plant and seeds per pod (Table 4). Across the varieties, the number of pods per plant ranged from 7.92 to 20.27 and the seeds per pod ranged from 9.62 to 11.73. Variety Ebbisa exhibited the highest number of pods per plant (20.27) and seeds per pod (11.73), followed by variety FG-10 with an average number of pods per plant of 12.47 and seeds per pod of 10.98. Conversely, variety Chala had the lowest number of pods per plant (7.92) and seeds per pod (9.62) (Table 4).

Furthermore, the interactions between locations and varieties resulted in significant differences in the number of pods per plant and seeds per pod, as indicated in Table 2. Generally, the varieties produced a higher number of pods per plant and seeds per pod in Sodo Zuria compared to Damot Gale. Specifically, the highest number of pods per plant (24.13) and seeds per pod (12.03) were recorded for variety Ebbisa in Sodo Zuria, whereas the lowest values were observed for variety Bishofitu in Damot Gale (Table 4). These results reflect the varying responses of varieties to their respective growing environments in terms of pod production per plant and seeds per pod.

Seed Yield

The analysis of variance revealed that the seed yield significantly ($p \leq 0.05$) varied with the different locations, as indicated in Table 2 and Figure 1. A significantly higher seed yield was obtained from the Sodo Zuria location compared to Damot Gale. This disparity in performance among the varieties in Damot Gale may be attributed to unfavorable growing conditions, including biotic factors (diseases), soil type, and climatic factors that had a negative impact on crop performance. Similarly, the main effect of varieties had a significant impact on seed yield, as demonstrated in Table 2. The seed yield for the varieties averaged across locations, ranged from 2.07 to 8.60 kg/ha. Variety Ebbisa achieved the highest seed yield at 8.60 kg/ha, followed by variety Hunda with an average seed yield of 6.65 kg/ha, while variety Bishofitu had the lowest seed yield at 2.07 kg/ha (Table 3).

Additionally, the interactions between locations and varieties resulted in significant ($p \leq 0.05$) differences in seed yield, as indicated in Table 2. The investigation revealed that the fenugreek varieties Ebbisa, Hunda, and Burqa yielded higher in Sodo Zuria, whereas varieties Ebbisa, Hunda, and FG-10 performed better in Damot Gale. Notably, varieties Ebbisa and Hunda exhibited stable seed yields at both locations, with variety Ebbisa performing superiorly. In general, all varieties yielded higher inSodo Zuria compared to Damot Gale. Overall, the greatest seed yield of 8.83 kg/ha was recorded for variety Ebbisa in Sodo Zuria, followed by the same variety in Damot Gale with a mean seed yield of 8.36 kg/ha. Conversely, the lowest seed yield of 1.87 kg/ha was achieved by the variety Bishofitu i Damot Gale (Table 4).

Notably, the seed yield obtained from the Sodo Zuria experimental site was even higher than that of Damot Gale in the two cropping seasons. This indicates that the variety's reaction to disease severity was influenced by locations, suggesting that a variety considered as a high or low yielder in one location may perform differently in other locations, signifying differences in the reactions of the varieties across locations (Table 1).

Oil Content

The results from the analysis of variance indicate that the oil content was significantly influenced by location, variety, and their interaction ($p < 0.05$) (Table 2;

Figure 1). In Sodo Zuria, the varieties demonstrated better oil-yielding ability compared to Damot Gale. Across all locations, the oil content of the varieties ranged from 3.90% to 6.80%. Variety Burqa had the highest oil content at 6.80%, followed by variety Hunda at 5.40%, while variety Bishofitu had the lowest oil content at 3.90%.

The interaction between locations and varieties also had an impact on the oil content, with values ranging from 3.70% to 7.40%. Varieties Burqa, Ebbisa, and Hunda consistently showed higher oil content, with Burqa exhibiting superior performance. These varieties also displayed relative stability across locations in terms of oil yield, with Burqa consistently outperforming the others.

Taking into account the overall effect, variety Burqa exhibited the highest oil content at 7.40% in Sodo Zuria, followed by the same variety in Damot Gale with a mean oil content of 6.30%. On the other hand, variety Bishofitu had the lowest oil content at 3.70% in Damot Gale (Table 4).

Table 4. Mean performance of fenugreek varieties for yield components and oil content

Location	Varieties	Pod length (cm)	Pod number	Seeds per pod	Seed yield (kg/ha)	Oil content (%)
Sodo Zuria	Bishofitu	9.13	12.87[b-d]	11.57[ab]	2.27[fg]	4.00[de]
	Burqa	10.33	12.57[b-d]	11.73[ab]	6.53[bc]	7.40[a]
	Chala	10.27	11.33[c-d]	11.17[ab]	3.91[d-f]	5.00[c]
	Ebbisa	12.40	24.13[a]	12.03[a]	8.83[a]	5.80[b]
	FG 10	10.10	16.20[bc]	11.90[a]	5.50[cd]	5.10[c]
	Hunda	11.30	17.23[b]	11.13[a-c]	7.46[ab]	5.80[b]
Damot Gale	Bishofitu	9.80	4.07[g]	7.67[d]	1.87[g]	3.70[e]
	Burqa	10.53	9.30[d-f]	9.33[b-d]	3.63[ef]	6.30[b]
	Challa	9.93	4.50[fg]	8.17[d]	2.53[fg]	4.20[de]
	Ebbisa	12.80	16.40[b]	11.43[ab]	8.36[a]	4.50[cd]
	FG 10	10.20	8.73[d-g]	10.07[a-d]	5.14[c-e]	4.40[c-e]
	Hunda	11.23	7.33[e-g]	8.67[cd]	5.83[bc]	5.00[c]
	LSD	NS	5.06	2.49	1.65	0.70
Varieties mean	Bishofitu	9.47[d]	8.47[c]	9.67[b]	2.07[d]	3.90[e]
	Burqa	10.43[c]	10.93[bc]	10.53[ab]	5.08[c]	6.80[a]
	Chala	10.10[cd]	7.92[c]	9.62[b]	3.22[d]	4.60[d]
	Ebbisa	12.60[a]	20.27[a]	11.73[a]	8.60[a]	5.20[bc]
	FG 10	10.15[b]	12.47[b]	10.98[ab]	5.32[c]	4.90[cd]
	Hunda	11.27[b]	12.28[b]	9.90[b]	6.65[b]	5.40[b]
	LSD	0.78	3.57	1.76	1.17	0.50
Location means	S/Zuria	10.75	15.72[a]	11.59[a]	5.69[a]	5.50[a]
	D/Gale	1059	8.39[b]	9.22[b]	4.62[b]	4.70[b]
	LSD	NS	2.06	1.07	0.67	0.20
	CV (%)	6.37	24.45	14.14	18.98	8.39

Mean within a column followed by the same letters are not significantly different from each other according to LSD at a 5% probability level. LSD = Least Significant Difference, CV = Coefficient of Variation, and NS= not significant.

Variance Components:
Phenotypic and genotypic variations

Phenotypic and genotypic coefficients of variations are used to estimate the variability that exists in a given population under consideration (BURTON & DEVANE 1953, ZEVEN *et al.* 1999). In this study, the phenotypic variance of fenugreek varieties ranged from 0.03 for oil content to 65.36 for number of pods per plant. Higher phenotypic variance (≥ 100) was not observed for all traits considered. Relatively medium phenotypic variance (50-100) was observed for traits plant height and number of pods per plant. Lower phenotypic variance (< 50) was recorded for days to maturity, primary branches, secondary branches, total branches, pod length, seeds per pod, seed yield, and oil content. On the other hand, genotypic variance ranged from 0.02 to 56.67 with the higher genotypic variance for several pods per plant. Moderate genotypic ($\sigma 2g$) variance was observed for the number of pods per plant only. Lower genotypic variance ($\sigma 2g$) was observed for days to maturity, primary branches, secondary branches, total branches, pod length, seeds per pod, seed yield, and oil content.

In general, the phenotypic coefficient of variation (PCV) varied from 3.92 for days to maturity to 65.97% for seed (Table 5). DESHMUKH *et al.* (1999) classified phenotypic coefficient variation (PCV) and genotypic coefficient of variation (GCV) values as high (>20%), medium (10-20%), and low (<10%). Based on this grouping, the traits primary branches, secondary branches, total branches, pods per plant, seed yield, and oil content had higher PCV. Conversely, the traits plant height, pod length, and seeds per pod exhibited moderate PCV, whereas only days to maturity showed lower PCV, with a PCV value below 10%. This could be evidenced by the pronounced impact of the environment on the expression of these traits. In line with this, genotypic coefficient variance (GCV) varied from 3.59 to 63.19%, where the traits secondary branches, total branches, pods per plant, and seed yield had high GCV and plant height, pod length, and oil content showed moderate PCV value. In contrast, the traits days to maturity, primary branches, and seeds per pod had low GCV values below 10% (Table 5). It indicated that selection may be effective based on these traits which showed medium and high phenotypic coefficient of variation (PCV) and genotypic coefficient of variation (GCV) values.

Broad sense heritability and genetic advance

In general, the heritability in a broad sense (H^2) varied from 13.33% for primary branches per plant, which represented the lowest value, to 91.72% for seed yield, which was the highest value observed. According to JOHNSON *et al.* (1955), heritability estimates are categorized as low if they are less than 30%, moderate if they fall between 30 and 60%, and high if they surpass 60%. Based on this classification, traits such as days to maturity, total branches per plant, plant height, pod length, pods per plant, seed yield, and oil content demonstrated high H^2 estimates.

Relatively moderate H^2 estimates were noted for the trait of secondary branches per plant, possibly due to the influence of the environment on the polygenic nature of these traits. It was also evident that traits such as primary branches per plant and seeds per pod exhibited low heritability (H^2). The low heritability observed for these traits restricts their inclusion in the selection of desirable genotypes in breeding programs. This limitation may be attributed to the greater influence of the environment on the expression of phenotypic variation compared to genotypic variation.

The genetic advance as a percentage of the mean varied from 5.68% for primary branches per plant to 124.42% for seed yield (Table 5). According to FALCONER & MACKAY (1996), genetic advancement as a percentage of the mean is classified as low (0-10%), moderate (10-20%), and high (20% and above). This finding suggests that selecting the top 5% of the genotypes could potentially result in an improvement of 5.68% to 124.42% over the respective population mean. Based on this classification, traits such as secondary branches per plant, total branches per plant, plant height, pod length, pods per plant, seed yield, and oil content demonstrated high genetic advance. On the other hand, traits including days to maturity, primary branches per plant, and seeds per pod showed low genetic advance. Notably, there were no traits that displayed a moderate genetic advance (Table 5).

Furthermore, traits such as total branches per plant, plant height, pod length, pods per plant, seed yield, and oil content exhibited high heritability along with high genetic advance. In contrast, secondary branches per plant showed moderate heritability coupled with moderate genetic advancement. Therefore, these traits should be prioritized in selection breeding for fenugreek as they contribute significantly to the genetic variation through additive gene action, and selection might be effective in early generations for these traits.

Table 5. Phenotypic and genotypic coefficient of variability, heritability and genetic advance for varieties.

Trait	$\sigma 2p$	$\sigma 2g$	$\sigma 2e$	PCV (%)	GCV (%)	H^2 (%)	GA	GA (%)
Days to maturity	18.43	15.51	2.92	3.92	3.59	84.16	7.43	6.78
Primary branches	0.30	0.04	0.26	20.75	7.58	13.33	0.15	5.68
Secondary branches	0.94	0.39	0.55	36.04	23.22	41.49	0.83	30.86
Total branches	2.76	1.73	1.03	28.06	22.22	62.68	2.14	36.15
Plant height	64.89	31.12	10.77	18.49	15.94	74.29	9.89	28.27
Pod length	2.78	2.32	0.46	15.63	14,28	83.45	2.86	26.80
Pod number per plant	65.36	56.67	8.69	55.85	50.17	84.57	11.71	92.42
Seed number per pod	2.86	0.69	2.17	16.25	7.98	24.13	0.84	8.07
Seed yield	11.59	10.63	0.96	65.97	63.19	91.72	6.42	124.42
Oil content	0.03	0.02	0.01	51.88	19.61	66.67	0.24	47.06

PCV = Phenotypic coefficient of variability, GCV = Genotypic coefficient of variability, H^2 = Heritability, and GA = Genetic Advance.

Perspectives for Future Studies

Future research should prioritize developing highly resistant fenugreek varieties using both conventional breeding and genetic engineering. Understanding the disease epidemiology and pathogen variability of powdery mildew is crucial, including its life cycle, environmental influences, and genetic diversity. This knowledge can inform targeted resistance breeding and disease management strategies. Relying solely on resistant varieties is insufficient. Integrated disease management strategies should be explored, combining resistant varieties with tactics such as adjusted planting times, biological control agents, and minimal fungicide use. Quantifying the impact of powdery mildew on fenugreek yield and quality is essential for economic analysis and guiding farmers toward the most resilient and profitable varieties. Finally, research must address the looming threat of climate change. Investigating how shifting temperature and precipitation patterns influence powdery mildew incidence and severity is crucial for developing adaptation strategies and ensuring the long-term viability of fenugreek.

CONCLUSION

The study found that fenugreek varieties Ebbissa and Hunda displayed resistance to powdery mildew in field conditions, with significant yield losses observed in susceptible varieties. Understanding relevant variables was highlighted as crucial for disease management in Ethiopia, a center of diversity for fenugreek. Variability in agronomic traits and genetic parameters was observed among the varieties, with Ebbisa and Hunda showing higher seed yield in Sodo Zuria, and Ebbisa, Hunda, and FG-10 performing well in Damot Gale. These varieties demonstrated stability in seed yield in both locations, with Ebbisa showing superior performance. Therefore, Ebbisa and Hunda are recommended for production in both locations, with additional consideration given to Burqa in Sodo Zuria and FG-10 in Damot Gale. In conclusion, the research confirmed that different fenugreek varieties responded differently to powdery mildew under field conditions, suggesting the promising use of resistant varieties like Ebbissa and Hunda to mitigate the disease's impact in the Wolaita zone, Southern Ethiopia. Furthermore, the study underscores the importance of understanding the interplay between varietal performance, disease pressure, and environmental factors for optimizing fenugreek production in different agroecological zones.

NOTES

AUTHOR CONTRIBUTIONS

Dr. Alemu Nega and Mr. Daniel Munda played pivotal roles in the development of the research proposal, conducting fieldwork, data collection, analysis, and interpretation using SAS software version 9.20. They were instrumental in crafting the manuscript, involving themselves in various key aspects of the study, such as conceptualization, methodology, software validation, investigation, resource management, data curation, original draft preparation, writing, reviewing, and editing. Additionally, they contributed to visualization, supervision, project administration, and funding acquisition. Dr. Gobeze Loha provided valuable assistance in data analysis and interpretation, as well as in the writing of the manuscript. All authors have reviewed the final version of the manuscript and have provided their approval for publication.

FUNDING

This work was supported by Wolaita Sodo University, Research, and Technology Transfer Vice President's Office.

INSTITUTIONAL REVIEW BOARD STATEMENT

This study did not involve human participants or animals; therefore, an Institutional Review Board (IRB) review is not applicable.

INFORMED CONSENT STATEMENT

Not applicable because this study did not involve humans.

DATA AVAILABILITY STATEMENT

Data generated during this study can be made available upon request.

ACKNOWLEDGEMENTS

This original research article was conducted at Wolaita Sodo University, College of Agriculture, Department of Plant Sciences. The authors express their gratitude to Wolaita Sodo University, Research, and Technology Transfer Vice President for their financial and logistical support. Additionally, special thanks are extended to the Debre Zeit Agricultural Research Center, Kulumsa Agricultural Research Center, and Tepi National Spice Research Program for providing the fenugreek variety seeds used in the study.

CONFLICTS OF INTEREST

The authors declare that there are no conflicts of interest regarding the publication of this article.

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