Distribution of Fusarium Wilt of Chickpea and its Association with Biophysical Factors in East Shewa Zone, Central Ethiopia

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Abstract

Chickpea fusarium wilt (CFW) caused by Fusarium oxysporum f.sp. ciceris has become a great threat to chickpea production in Ethiopia. A field survey was conducted to determine the distribution and association of CFW with biophysical factors in the Central Rift Valley of Ethiopia in the 2019/20 main cropping season. The associations of CFW incidence with independent variables were analyzed using a logistic regression model. A total of 68 fields were assessed in four districts and results revealed that all the surveyed fields were infected with CFW. However, substantial variations were observed in CFW incidence across the surveyed districts. The mean incidence varied from 31.79% in Lume to 55.81% in the Gumbichu district. Variables like district, crop growth stage, variety, previous crop history, seed source, crop density, and weed density had a very highly significant (P<0.0001) association with disease incidence in reduced multiple variable models. Associations between disease parameters and chickpea variety were also observed to be significant in the reduced model. Results from this study showed a 100% prevalence of CFW in the study area, implying the need for proper intervention. Emphasis on proper agronomic practices such as the use of improved seeds, appropriate sowing date, cropping pattern, and weed management should be given in the integrated management of CFW in the study area and other related agroecologies.

Keywords: Biophysical factors, disease incidence, disease severity

Introduction

Chickpea (*Cicer arietinum* L) is a major grain legume crop in Africa, particularly in Ethiopia, where it is widely produced as a rotational crop as well as a source of cash for farmers and foreign currency in the highland and semi-highland regions of the country (Asfaw, 1993). In Ethiopia, it is the second most important cool-season legume crop after the faba bean (Diapari et al., 2014). According to the CSA (2019) and FAOSTAT (2019) reports, Ethiopia is the leading chickpea producer in Africa, producing more than 500,000 metric tons per year from an area of about 243,000 ha of small-holder farms, which account for over 90% of grain production in sub-Sahara Africa (Verkaart et al., 2017). Despite its huge importance and area coverage, the productivity of this crop is estimated at 2.016 tons ha^{-1} (CSA, 2020), which is far below the potential of the crop which is 5 tonnes ha^{-1} (Verkaart et al., 2017). Both abiotic

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and biotic factors contribute to the low productivity of chickpeas in Ethiopia.

Crop damage caused by disease pathogens is among the major yield-limiting factors under rainfed vertisol cropping systems (Lijalem et al., 2020). Fusarium wilt (FW) caused by *Fusarium oxysporum* and Ascochyta blight (AB) caused by *Ascochyta rabiei* are the major limiting factors in chickpea production in Ethiopia (Yimer et al., 2018). The average yield losses due to these diseases have been estimated from 10 to 90% and sometimes escalate to 100% when the relative humidity is greater than 60% and the temperature ranges between 10 and 25°C (Navas-Cortes et al., 2000). Cultural management methods such as crop rotation, and ridge and furrow planting are suggested as the best management option (Tebkew and Ojiewo, 2016) against Chickpea fusarium wilt (CFW) in Ethiopia. However, cultural management options alone are not sufficient as root-inhibiting pathogens are known to persist in the soil for several years (Sultan et al., 2018).

The use of resistant varieties is also suggested to be a feasible approach to managing the CFW disease (Bereket and Habtamu, 2021). The problem with the use of resistant varieties, however, is that the resistance mechanism is not stable, due to the introduction of new pathotypes/isolates (Choudhary AK and Kumar S, 2018). The deployment of resistant varieties for the control of plant diseases requires an understanding of environmental, cultural, and epidemiological factors (Singh et al., 2007). Thus, the available disease control options as a sole disease management practice may provide some level of control, but may not be adequate because of the nature of the pathogen as *Fusarium oxysporum* f.sp. *ciceris* is a vascular pathogen that persists in seed and soil for long period (Jiménez-Fernández et al., 2011). Several researchers have recently reported the need to rely on an integrated management approach to mitigate damage caused by fusarium wilt (Chudasama and Pithia, 2018; Dagnachew et al., 2021). This entails an understanding of the disease's epidemiology.

Many factors were reported to influence root-rot disease epidemics, among which the major ones are production system and environmental variables such as high soil moisture, low nutrient supply, wet soil physical conditions, agronomic practices, and occurrence of other diseases and pests (Fininsa and Yuen, 2001; Woldeabe et al., 2007). Monitoring the effects of diversified environmental factors and cropping practices on crop diseases and production is an important strategic approach to determining the status and dynamics of plant disease as it can influence disease occurrence, epidemic development, and damage to crops (Fininsa and Yuen 2001; Samuel et al., 2008). However, information on the occurrence of CFW and the effect of cropping systems, field management practices, and environmental variables on the disease was scanty. Therefore, the current study was initiated to assess the distribution and relative importance of CFW (*Fusarium oxysporum* f.sp. *ciceris*) in major chickpea growing areas of east Shewa zone in the CRV and to determine the association of CFW intensity with biophysical factors.

Materials and Methods

Description of surveyed areas

The survey was conducted in four major chickpea-growing districts (Adea, Lume, Bora, and Gumbichu) of the east Shewa Zone in the CRV. The study area is located between 08^{0}20'76''to 09^{0}00'29°N latitude and 038^{0}47.91° to 039.12'49''E longitude with elevation ranging from 700 to 2557 meters above sea level (m.a.s.l.) (Fig. 1).

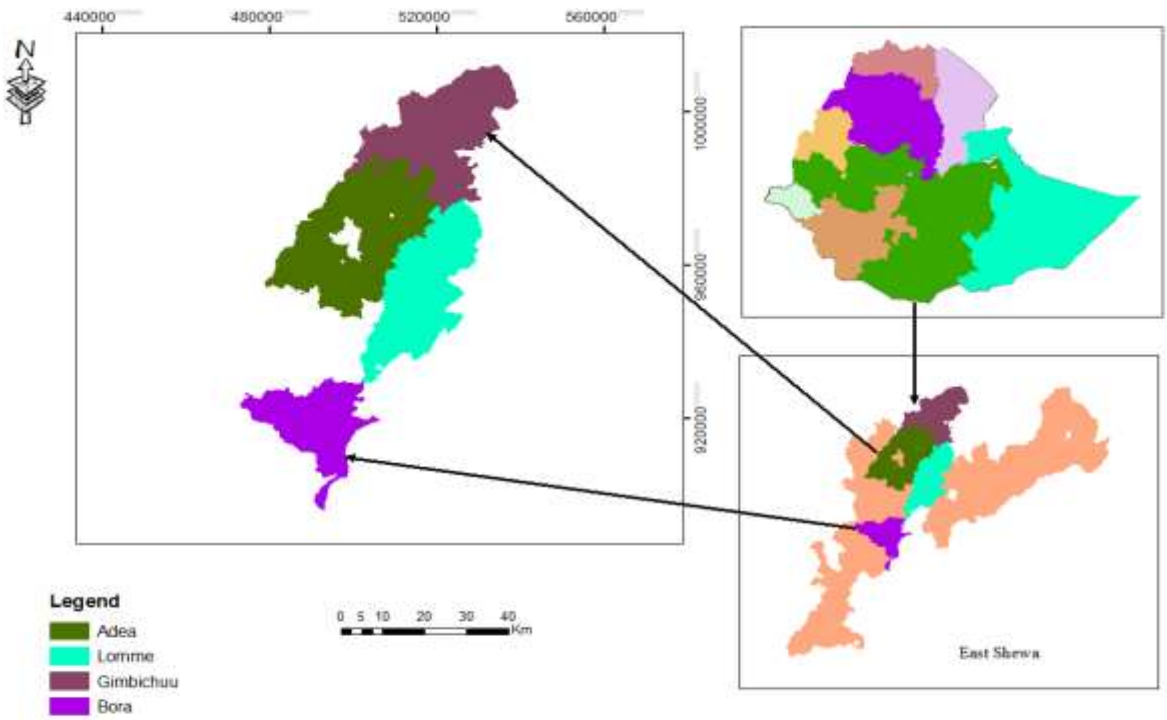

Figure 1. Map depicting areas surveyed for CFW in 2019/20 cropping season.

Sampling and disease assessments

The survey was conducted between September to November 2019 during the main chickpea-growing season across four representative chickpea-growing districts (Adea, Bora, Lume, and Gimbichu) to assess the distribution, relative importance, and intensity of CFW, and to determine the associations of the disease epidemics with biophysical factors. The survey districts were selected purposively based on the chickpea production potential and disease problems. Selection of Farmers. A total of 14 FAs' selected randomly were assessed from the entire districts. Chickpea fields in each FA along the main and accessible roads were sampled at 2 to 5 Km intervals. The disease assessment was made by randomly placing five quadrats each measuring one square meter in an 'X fashion. Chickpea plants with typical fusarium wilt symptoms were uprooted from five different spots of each field and composited as described by Vikram et al. (2017). A composite sample was formed for each assessed field by mixing diseased plant samples collected from each sampling spot. The plants within the quadrat were counted and recorded as diseased or infected, and healthy or non-infected based on visual symptoms they showed for Fusarium wilt. Furthermore, symptomatic plants from each field were collected for additional laboratory testing to confirm the pathogens identify. The mean plant and weed population densities were also estimated by averaging the number of populations in the four quadrats for analysis. Disease prevalence was determined by the ratio of the number of fields showing this disease to the total number of fields. The field incidence of each field was calculated as the proportion of plants showing wilt symptoms out of the total plants per quadrat.

$$\text{Diseases Incidence} = \frac{\text{Number of plan}}{\text{Total nu}}$$

During the survey, additional information, such as previous field history, variety, cropping systems, planting date, weeding practices, crop and weed density, fertilizer usage, and seed source was recorded to estimate their relationship with the observed disease incidence.

Data analyses

Disease incidence was classified into distinct groups of binomial qualitative data (Chemeda and Yuen, 2001: Misganaw et al., 2019). Quantitative data on incidence were categorized in qualitative data form for logistic regression analysis according to Habtu et al (1996). Accordingly, contingency tables of the disease incidence and independent variables were built to represent the bivariate distribution of the fields (Table 1). The binary outcome was the probability that fusarium wilt incidence exceeds 44% in a given chickpea field. Mean percent disease incidence was grouped into class boundaries (Fininsa and Yuen, 2001) to analyze the relationship between CFW and biophysical factors (Table 1).

If the predicted probability of the outcome is denoted as (P), the logistic regression model assumes the logarithm of the odds of P (P/ (1-P)), which equals logit (P), and is a linear function of the independent variables (Yuen et al., 1996). In this case, the importance of the risk factors under study (Table 1) was evaluated in two ways; first, the association of fusarium wilt disease incidence with independent variables was tested in a single-variable model. Second, those independent variables with a high association with fusarium wilt incidence were added to reduce multiple variable models (Yuen, 2006). A complete analysis of the deviance table was created for the final reduced multiple models, where deviance reduction was calculated for each factor as it was added to the reduced model. Exponentiation of the parameter estimates of each variable class results in the odds ratio, which is interpreted as the relative risk that the higher the odds ratio of a variable the higher the disease infestation (Yuen et al., 1996). The fitness of the models was tested based on the magnitude of deviance and Pearson the χ^2 value from the table of criteria for assessing goodness of fit (Yuen, 2006). The difference between the two models, a likelihood ratio test (LRT) was used to examine the importance of variables and was tested against a χ^2 value (McCullagh and Nelder, 1989), using logistic regression as described by McCullagh and Nelder (1989) and Chemeda and Yuen (2001) with the SAS procedure GENMOND (SAS, 2008).

Results

Overview of surveyed fields

A total of 68 chickpea fields were assessed in the surveyed districts. All the surveyed chickpea fields were infected with fusarium wilt corresponding to a 100% disease prevalence. It was observed that none of the chickpea fields were irrigated; the crop was cultivated under residual soil moisture or rainfall during the growing season. All the fields were sown by broadcasting methods. Different growth stages of chickpeas were encountered during the survey in the different fields of each district. About 65% of the farms were at the flowering and pod-filling growth stages. About half of the fields were sown in August, while the remaining farms were sown in early September. Fertilizer was applied only on 11.8% of the farms. Fields with poor weed management showed the highest incidence of CFW. Farmer-to-farmer seed exchange was the major seed source accounting for 31% followed by own saved and local market each accounting for 25 %. Seeds from the research center accounted for the rest 19 %. Twenty-two (32.33%) chickpea fields were sown to local chickpea varieties. The most common improved chickpea varieties grown in these areas were Habru, Arerti, Shasho and Dubei.

Chickpea fusarium wilt prevalence and incidence

Chickpea fusarium wilt was prevalent in all chickpea fields assessed. However, incidence of CFW varied for all the variables considered (district, altitude, variety, crop growth stage and agronomic practice) (Table 2). The highest mean disease incidence (55.81%) was recorded from Gumbichu district while the lowest (31.79%) from Lume district. Regarding the crop growth stage, the highest incidence (48.65%) was recorded at the maturity growth stage and the lowest (32.33%) at seedling. Fields above 2000 m.a.s.l. showed a high (52.37%) mean disease incidence compared to fields located between 1500-2000 m.a.s.l. with a mean disease incidence of 36.49%. August planted chickpea showed highest mean CFW (48.63%) and early September planted showed the lowest incidence (39.53%). Incidence of CFW was higher (47.53%) in weedy fields than weed-free fields (39.53%). Similarly, chickpea fields with seed source from the market, preceded by chickpea, higher plant and weed density showed a higher CFW incidence than fields with seeds from own saved, preceded by other crops, and lower plant and weed density (Table 2).

Table 1. Categorization of variables used in analysis for CFW distribution in four districts (n = 68) of east Shewa zone of CRV

Variable	Variable Class	No of field	CFW Incidence (%)	
			≤44	>44
Districts	Gumbichu	20	5	15
	Bora	8	2	6
	Adea	20	15	5
	Lume	20	11	9
Growth stage	Seedling	4	3	1
	Vegetative	2	2	0
	Flowering	10	6	4
	Flower/podding	44	20	24
	Full podding	8	2	6
Altitude	1500-2000	42	24	18
	>2000	26	9	17
Planting date	August	35	13	22
	September	33	20	13
Weeding practice	No	36	14	22
	Yes	32	19	13
Fertilizer Practice	No	60	32	28
	Yes	8	1	7
Chickpea cultivar	Local	22	6	16
	Improved	46	27	19

Variable	Variable Class	No of field	CFW Incidence (%)	
			≤44	>44
Preceding crop	Chickpea	7	4	3
	Lentil	3	2	1
	Field pea	4	2	2
	Haricot bean	2	1	1
	Fababen	4	2	2
	Wheat	15	6	9
	Maize	5	1	4
	Barley	17	6	11
	Tef	11	9	2
Seed source	Market	17	6	11
	Farmers	21	10	11
	Own saved	17	9	8
	Research center	13	8	5
Crop density	≥33 plants m^{-2}	26	12	14
	<33 plants m^{-2}	42	21	21
Weed density	<30 weeds m^{-2}	48	22	26
	≥30 weeds m^{-2}	20	11	9

Table 2. Incidence (mean ± SD) of CFW for different independent variables during the 2019/20 main growing season, central refit valley, Ethiopia

Variable	Variable Class	Incidence (%)	Variable	Variable Class	Incidence (%)
District	Gumbichu	55.81±15.98	Chickpea cultivar	Local	49.86±14.78
	Bora	44.32±6.91		Improved	40.91±18.01
	Adea	36.46±11.35	Previous crop history	Chickpea	53.74±17.85
	Lume	31.79±13.17		Lentil	49.62±21.74
Growth stage	Seedling	32.33±20.75		Field pea	49.80±18.01
	Vegetative	33.19±1.03		Haricot bean	53.17±14.25
	Flowering	38.25±14.50		Fababean	46.12±21.53
	Flower/podding	45.70±18.11		Wheat	41.61±15.68
	Full podding	48.65±18.91		Maize	37.03±11.99
Altitude	1500-2000	36.49±12.51		Barley	45.20±16.50
	>2000	52.37±19.53		*Tef*	35.06±13.41
Planting date	August	48.63±17.98	Seed source	Market	49.88±18.36
	September	39.53±16.85		Farmers	40.06±15.87
Weeding practice	No	47.53±16.77		Own saved	43.50±15.78
	Yes	39.61±17.76		Research center	42.29±19.19
Fertilizer practice	No	42.48±17.70	Crop density	≤33 /m^2	43.40±16.54
	Yes	53.72±15.32		>33 /m^2	44.45±17.81
Weed density	≤30 /m^2	43.04±18.64			
	>30 /m^2	45.83±14.81			

Association of chickpea fusarium wilt with biophysical factors

Among the biophysical factors, district (χ^2 =279.85, df=3), crop growth stage (χ^2 =41.27, df =4), fertilizer practice (χ^2 =18.79, df=1), previous crop history (χ^2 =95.26, df=8), seed source (χ^2 =21.66, df=3), crop density χ^2 =15.94, df =1), and weed density (χ^2 =20.20, df =1) showed highly significant (P<0.0001) associations with disease incidence in the logistic model as a single variable (Table 3). However, fertilizer and weeding practices lost their significance when entered last into the model (Table 3).

All significantly associated independent variables were tested in reduced multiple variable models with CFW incidence as the dependent variable. The deviation analysis of these variables in reduced multiple variable models showed different levels of importance of their association with chickpea CFW incidence (Table 4). The probability of CFW incidence of >44% was highly associated with district, altitude, growth stage, chickpea variety, preceding crop, and source of planting materials. Accordingly, the probability of occurrence of high (>44%) CFW incidence in Gumbichu district was 3.64, 3.76 and 4.51 times higher than Bora, Adea, and Lume districts, respectively (Table 4). Probability of CFW incidence was higher in local variety, full podding growth stage, and chickpeas as preceding crop, than in their references (Table 4).

Table 3. Logistic regression model for CFW incidence and likelihood ratio test on independent variables in east Shewa of CRV, 2019 main cropping season.

Independent variable	DF	CFW Incidence LRT[a]			
		Type 1 analysis		Type 3 analysis	
		DR	Pr>χ^2	DR	Pr>χ^2
District	3	279.85	<.0001	135.46	<.0001
Altitude	1	14.08	0.0002	4.3	0.0382
Planting date	1	11.92	0.0006	3.56	0.0592
Growth stage	4	41.27	<.0001	32.67	<.0001
Fertilizer practice	1	18.79	<.0001	0.03	0.8587
Weeding practice	1	7.72	0.0055	0.77	0.3817
Variety	1	11.04	0.0009	51.55	<.0001
Previous crop history	8	95.26	<.0001	105.95	<.0001
Crop density	1	15.94	<.0001	26.25	<.0001
Weed density	1	20.2	<.0001	15.77	<.0001
Seed source	3	21.66	<.0001	21.66	<.0001

[a]LRT = likelihood ratio test; CFW= chickpea fusarium wilt; DF = Degrees of freedom; DR Deviance reduction; Pr = Probability of a value χ^2 exceeding the deviance reduction; Type 1 analysis = variable entered first; Type 3 analysis = variable entered last.

Table 4. Analysis of deviance, natural logarithms of odds ratio and standard error of CFW incidence (%) and likelihood ratio test on independent variables in the reduced regression model in East Shewa Central Ethiopia, during 2019 main cropping season.

Variable	Residual deviance[a]	Df	CFW incidence LRT[b]		Variable Class	Estimate Log_e (odds ratio)	SE[c]	Odds ratio
			DR	Pr>χ2				
District	684.3275	3	129.59	<.0001	Gumbichu	1.51	0.13	4.51
			3.33	0.0682	Bora	0.21	0.12	1.24
			2.94	0.0863	Adea	0.19	0.11	1.20
					Lume	0*	0	1.00
Altitude	670.2475	1	4.28	0.0386	1500-2000	0.26	0.13	1.30
					>2000 m.a.s.l.	0*	0	1.00
Growth stage	617.0609	4	14.89	0.0001	Full podding	0.67	0.17	1.95
			0.24	0.6206	Flower+pod	0.07	0.14	1.07
			3.72	0.0537	Flowering	0.31	0.16	1.37
			0.41	0.5241	Vegetative	0.14	0.22	1.15
					Seedling	0.00	0.00	1.00
Variety	579.5117		0.60	0.08	Local	51.18	0001	1.82
					Improved	0*	0	1
Previous crop history	484.2561	8	1.23	0.13	Chickpea	90.3	<.0001	3.43
			0.19	0.16	Lentil	1.41	0.2357	1.21
			0.49	0.15	Field pea	9.92	0.0016	1.62
			0.77	0.19	Haricot bean	17.15	<.0001	2.15
			0.51	0.15	Fababean	12.15	0.0005	1.66
			0.50	0.11	Wheat	22.02	<.0001	1.65
			0.29	0.14	Maize	4.3	0.038	1.33
			0.48	0.10	Barley	24.23	<.0001	1.61
					Tef	0*	0	1
Seed source	426.448	3	-0.50	0.11	Farmer	19.37	<.0001	0.61
			-0.13	0.10	Market	1.66	0.1974	0.88
			-0.24	0.09	Own saved	6.69	0.0097	0.79
					Research center	0*	0	1
Crop density	468.3113	1	-0.35	0.07	<33/m^2	25.96	<.0001	0.70
					>33 /m^2	0*	0	1
Weed density	448.1075	1	0.29	0.07	<30/ m^2	15.66	<.0001	1.34
					>30/ m^2	0*	0	1

[a] Residual deviance = unexplained variation after fitting model; [b] Likelihood ratio test; DR = deviance reduction; df = degrees of freedom; Pr = probability of χ^2 value exceeding the deviance reduction; [c]SE = standard Error; . * = reference group

Discussion

Chickpea fusarium wilt was present in all chickpea growing fields with varying degree of incidence ranging from 31.8 to 55.8%,depening on location, altitude, sowing date, crop growth stage, variety, fertilizer use, weeding practice, type of preceding crop, seed source as well as weed, and crop density. The high incidence observed in Gimbichu might be associated with the poor cultural practices adopted by smallholder farmers in the area including poor weed management and unreliable seed source which is predominantly ‘farmer to farmer seed exchange (Njingulula et al., 2014; Kijana et al., 2017). The stage of the crop might have also contributed to the high level of CFW incidence in Gimbichu area as most of the fields (60%) were at podding stage during the survey (Zemouli-Benfreha et al., 2014). A higher CFW incidence was observed mostly on fields sown to local cultivars than on fields sown to improved varieties which is in agreement with the findings of Raju et al. (2013). Similarly, presence and density of weeds affect the level of incidence. It was observed from this study that incidence of CFW was 16.6% lower in weeded field compared to unweeded fields. This is in agreement with previous reports of Sultan et al. (2018) who reported a higher level of CFW incidence in unweeded field than in weeded in central and northern highlands of Ethiopia. A weakened plant due to weed infestation becomes less vigorous and more susceptible to plant pathogens (Sultan et al., 2018; Misganaw et al., 2019). The full podding crop growth stage exhibited higher level of CFW incidence than earlier stages such as seedling, vegetative and flowering as reported by Zemouli-Benfreha et al. (2014). This increment in incidence at the reproductive stage could be due to increased temperature (Chaudhry et al., 2007; Darvishnia et al., 2014; Ddamulira et al., 2014; Zemouli-Benfreha et al., 2014; and Asfaw, 2018; Daniel and Tilahun, 2020; Bereket and Habtamu, 2021).

The observed high level of CFW incidence in altitude above 2000 m.a, s, l. in this study is unclear and differed with reports of several researchers (Daniel and Tilahun, 2020; Bereket and Habtamu, 2021) who reported a decrease in incidence and prevalence of the disease with increasing altitude. They explained the higher incidence observed in low elevations by warmer climatic conditions and low soil moisture favoring the disease. Altitudinal based categorization of the incidence of the disease may be misleading as other agronomic and ecological factors could affect the development of the disease necessitating further investigation.

The type of preceding crop was strongly associated with the epidemics of chickpea fusarium wilt. Fields that had previously been planted with legumes had a greater CFW incidence than fields planted with non-legumes. This could be because the farmers in the surveyed area grow chickpeas in rotation with various cereal and legume crops, and the previous crop residue appears to be a source of inocula for the following cropping seasons. Previous studies also reported a lower incidence of CFW when legumes were rotated with non-legumes compared to legumes planted after legumes (Srinivas 2016; Misgana, 2017; Dagnachew et al., 2021). The presence of CFW in all the surveyed districts indicates the potential threat that this disease poses to chickpea production unless sustainable management strategies are not put in place.

Conclusion and Recommendation

This study showed a chickpea fusarium wilt was present in all farms surveyed in east Shewa zone of central Ethiopia. In general chickpea fields sown early, weeded, less dense and preceded with cereals suffered less damage from CFW.

The findings of the present study recognized the need to carry out proper weeding practices, maintaining optimum crop density, and crop rotation with non-host (especially cereal) to minimize CFW incidence and impact on chickpea. However, the relationship of seed source and altitudinal range to CFW needs further investigation. Likewise, a detailed analysis of the factors responsible for high CFW incidence especially in Gimbichu district needs further studies. The findings of the present study showed the need to carry out proper weeding practices, maintain optimum crop density, and crop rotation with non-host (especially cereal) to minimize CFW incidence and impact on chickpea. This study highlighted factors that are most frequently associated with this disease and provided a framework for integrated CFW management to improve the production and productivity of chickpea. However comprehensive field surveys are required to generate conclusive information about the association of biophysical factors with CFW disease intensity..

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