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RESEARCH PAPER

Intensity of Chickpea Dry Root Rot [*Macrophomina phaseolina* (Tassi.) Goid] and Its Association with Biophysical Factors in Chickpea-producing Regions of Central Ethiopia

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Abstract

Chickpea (Cicer arietinum L.) is an important pulse crop in Ethiopia as well as worldwide. Due to the present shift in climate patterns, dry root rot (DRR) has become a threat to chickpea production. A field survey was conducted to assess the intensity and association of biophysical factors with chickpea DRR in three zones of central Ethiopia. A logistic regression model was used to evaluate the association between disease parameters and biophysical factors. A total of 165 chickpea fields were inspected in ten districts. DRR was prevalent in all ten districts. The incidence and severity of the disease were variable among the districts and with biophysical factors. The highest incidence was recorded in Liben (10.8%) and Ada'a (9.6%) districts. The highest severity was in Ambo (42.5%), whereas the lowest incidence (2.3%) and severity (18.3%) were in Sebeta Hawas. The incidence and severity were higher in Kabuli type and areas with altitudes ≤2100 meters above sea level (m.a.s.l). High DRR incidence (≥6%) showed a high probability of association with East Shewa, early sowing, low plant density, and Kabuli type. High severity (≥30%) was highly associated with altitudes ≤2100, early sowing, and Kabuli type. This study showed that DRR is an important disease in Ethiopia, necessitating the development of effective management strategies that could avoid heat and moisture stresses in the post-flowering stages of chickpeas.

Keywords: Biophysical factors, Central Ethiopia, chickpea, intensity, dry root rot

Introduction

Chickpea (*Cicer arietinum* L.) is an ancient cultivated pulse crop in the Leguminosae family. It is the third most crucial crop worldwide after dry beans and field peas (Nene *et al.,* 2012). Chickpea seed is a good source of proteins, carbohydrates, vitamins, and minerals (Gaur *et al*., 2012; Wallace *et al*., 2016). The crop has low lipid content and is an excellent source of nutritionally essential unsaturated fatty acids like linoleic and oleic acids (Rashid *et al*., 2020). In developing countries, chickpea is valued for its cheap protein source and for improving soil fertility by nitrogen fixation (Gaur *et al*., 2010). Chickpea is widely cultivated in over 50 countries on 14.8 million hectares (Mha) of land with 18.1 Metric tons (Mt) of grain production. India is the leading producer, accounting for 72.5% of area coverage and 74.8% of world chickpea production, followed by Pakistan with area coverage of 5.8% and Australia in terms of production volume of 5.9% (FAOSTAT (The Food and Agricultural Organization of the United Nations Statistical Database), 2022). With over 0.23 Mha (1.5% of the world) under cultivation, Ethiopia is the eighth largest producer in terms of area coverage and the third largest producer with a production of 0.49 Mt (2.7% of the world) (FAOSTAT, 2022).

Despite its nutritional and economic values, Ethiopia's average national chickpea yield remains far below its potential (5 tons per hectare), which is attributed to several biotic and abiotic factors. Among biotic constraints threatening chickpea production in Ethiopia, 16 diseases were reported of which Fusarium wilt (*Fusarium oxysporum f.sp. ciceris*), dry root rot (*Macrophomina phaseolina*), Ascochyta blight (*Ascochyta rabiei*) and Chlorotic Stunt virus diseases (Abraham *et al*., 2006; Tadesse *et al*., 2017; Mengist *et al*., 2018; Ayana *et al*., 2019) are economically important. However, due to the present shift in climate patterns, chickpea DRR has emerged as the most serious constraint in Ethiopia. The disease is widely distributed in semi-arid chickpea growing areas with high temperatures and water-stressed conditions, causing substantial yield losses to the crop worldwide (Sharma and Pande, 2013; Rai *et al*., 2022). The average yield loss ranged from 5-50% and up to 100% losses in susceptible cultivars under favorable conditions (Pande *et al.,* 2012). In chickpeas, DRR causes significant yield loss by reducing plant population; that is, when roots of chickpea plants contract dry root rot, petioles, and leaflets droop and results in sudden complete drying during the flowering to maturity growth stage (Sharma *et al*., 2016).

In Ethiopia, chickpeas could be vulnerable to DRR disease because the crop is grown on residual moisture largely on vertisols which are characterized by fast cracking nature causing rapid moisture loss from the crop's root zone (Korbu *et al*., 2021). This farming system makes the crop face progressive depletion of reserve moisture at the critical chickpea growth stages, leading the system to experience terminal drought and heat stress (Mohammed *et al*., 2017). The dry and warm conditions would create a more favorable environment and further intensify the incidence and subsequent damage to the chickpea fields by soil-borne diseases including DRR, and such problems were common in the highland and semi-arid chickpea growing areas like our study areas, including Southwest, West, and East Shewa zones (Damte and Ojiewo, 2016; Mohammed *et al*., 2017; Yimer *et al.,* 2018).

Several attempts were made to design control strategies against chickpea DRR disease in many countries across the globe. Plant host resistance is the most economically and environmentally feasible approach, but its utilization has been restricted due to the absence of chickpea lines with high levels of resistance and genetically diverse pathogen populations (Pande *et al*., 2004; Sharma *et al*., 2012). Seed treatment and soil inoculation with strains of bio-agents are recommended as an alternative option for managing soil-borne pathogens including *M. phaseolina* (Rangeshwaran and Prasad, 2000; Patel *et al*., 2011). Systemic fungicide applications through seed dressing and soil application were also found effective for the control of DRR of chickpeas (Khan and Gangopadhyay, 2008; Manjunatha and Saifulla, 2021). However, the fungicide treatment may not provide the desired control due to the soil-borne nature and ability of the pathogen to persist in the soil in the form of sclerotia (Baird *et al.,* 2003). Moreover, the continuous evolution of the pathogen races and unpredictable features of environmental factors require frequent evaluation of cultural control strategies at each locality (Mengistu *et al*., 2009). Unfortunately, limited attempts were made to control chickpea DRR disease in Ethiopia, as the disease has been gaining importance recently due to climate change.

Thus, as the occurrence and extent of damage caused by the chickpea DRR disease are interlinked with additional heat and water stress abiotic factors (Sharma and Pande, 2013; Sinha *et al*., 2021), control strategies alone could not provide complete protection. That is, because of the continuous cultivation of chickpeas in major chickpea-growing areas of central Ethiopia and in connection with the current climate change scenario, DRR is a constant threat every year in the region. Therefore, designing a sustainable chickpea DRR management approach requires a primary understanding of the intensity and associated biophysical factors influencing epidemics of the disease.

So far, several disease survey studies on the distribution and biophysical factors influencing epidemics of chickpea soil-borne fungal diseases (wilt and root rot complex) have been carried out and reported together in different chickpea-growing areas of Ethiopia (Damte and Ojiewo, 2016; Bekele *et al*., 2018; Yimer *et al*., 2018). However, no separate attempts were made to understand the status of chickpea DRR and its influencing biophysical factors in central chickpea-producing areas of Ethiopia. In addition, quantitative information on the current status of chickpea DRR disease is lacking. Therefore, this survey study was conducted to determine the importance, intensity of chickpea DRR and its association with biophysical factors in major chickpea-producing regions of the central highlands of Ethiopia.

Materials and methods

Description of Survey Areas

A field survey for chickpea DRR was carried out in ten primary chickpea-producing districts within three administrative zones (East, West, and Southwest Shewa) of central Ethiopia (Figure 1). The agroecological features of the surveyed districts viz., Ada'a, Lume, and Liben are found in East Shewa; Becho, Illu, Kersana Malima, and Sebeta Hawas are found in Southwest Shewa; while Ejersa Lafo, Dendi, and Ambo districts are found in West Shewa zone, central Ethiopia. Geographically, the districts are located between 08°26' to 09°59' N and 037°47' to 039°10' E, and their elevations range from 1590 to 2445 meters above sea level (m.a.s.l). Southwest and West Shewa are found in Ethiopia's highlands and have relatively colder weather. In contrast, East Shewa is located on the Eastern escarpment of the country's central rift valley with a semi-arid climate. Based on meteorological data records in the last six years (2016-2021), each study district in the East, Southwest, and West Shewa zones received an average of 872.6, 1018.3, and 1053.8 mm annual rainfall, respectively.

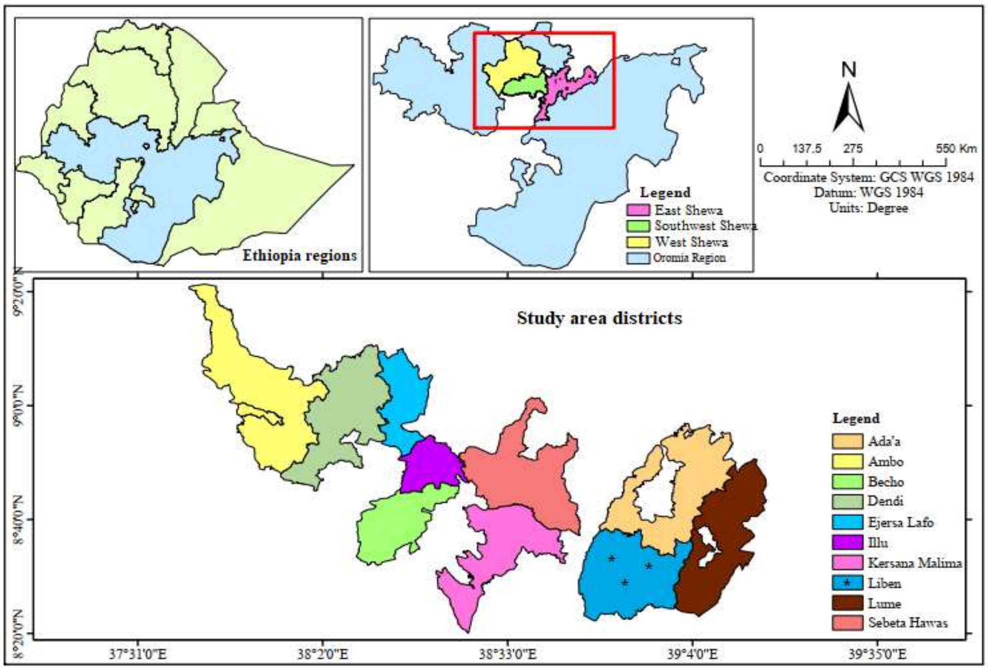

Figure 1. The geographical location of major chickpea-producing districts in central Ethiopia.

Survey procedures and sampling unit

The field survey was undertaken from the flowering to the physiological maturity growth stage of chickpeas from November to February for two years (2020-2021). In this study, a total of 165 chickpea fields (64 in 2020 and 101 in 2021) were assessed for the disease. Based on accessibility, 8-25 chickpea fields were randomly sampled in each district at 3-5 km intervals along the main and feeder roads. Three spots in each field (15-20 m apart) were inspected by making diagonal moves in a 'Z' pattern and a 1 m^2 quadrant and the mean disease incidence of the three samples was calculated and utilized as one field.

Disease assessment

Based on the number of DRR infected and the total number of chickpea plants in each quadrant, the percent disease incidence was calculated using the following formula:

$$\text{Disease incidence (\%)} = \frac{\text{Number of infected plants}}{\text{Total no. of plants observed}} \times 100$$

In each sample quadrant, three infected chickpea plants with visible above-ground symptoms were randomly considered for assessing severity. Thus, the disease severity was estimated by up-rooting and evaluating the proportion of root volume infection on three chickpea plants in each sampled field. It was assessed using a 1-9 disease rating scale suggested by Nene *et al.,* (1981) and Sharma and Pande (2013). Where; 1 = No infection on roots; >1 and <3 = Very few small lesions (black discoloration) on roots; >3 and <5 = Lesions (black discoloration) on roots clear but less; new roots free from infection; >5 and <7 = Lesions (black discoloration) on roots more; many new roots generally free from lesions and >7 = Roots infected and completely discolored (black). Severity scores were converted to the Percent Severity Index (PSI) (Wheeler, 1969).

$$\text{PSI} = \frac{\text{Sum of numerical ratings}}{\text{No. of plants scored x maximum score on the scale}} \times 100$$

Similarly, the same quadrant was used to assess the incidence of chickpea Fusarium wilt disease. The disease was distinguished by its symptoms like wilting and the death of the seedlings exhibiting dull green leaves and shrunken stems, usually visible in the pre-flowering stages of the crop (at seedling and vegetative) (Sharma *et al.*, 2016). In addition, data on biophysical factors, including chickpea types, plant density, weeding practices, previous crops, altitude range, sowing dates, soil types, and crop growth stages were recorded to investigate the association of these factors with DRR disease parameters. Visual observation of the fields was made to classify the soil types into heavy black, intermediate, and light soils. Likewise, the collection of data on previous crops and sowing dates was carried out by questioning the growers. Moreover, root samples of diseased chickpea plants showing characteristics of DRR symptoms were collected from surveyed fields to isolate and identify the pathogen.

Data analysis

Survey data were summarized and analyzed using descriptive statistics to describe the spatiotemporal distribution and relative importance of chickpea DRR across the districts. Disease incidence and severity were classified into distinct class boundaries (Fininsa and Yuen, 2001; Yuen, 2006) to analyze the relationship between DRR and biophysical factors (Table 1). Based on the approximate similarity of the variables to the total assessed fields in each zone, class boundaries were chosen for disease incidence and severity data separately. Accordingly, class boundaries of ≥6 and <6% and ≥30 and <30% were selected for DRR incidence and severity, respectively. A contingency table of dependent (incidence and severity) and independent variables were constructed to represent the bivariate distribution of the fields (Table 1). The association of DRR with various biophysical factors was analyzed by the logistic regression model (Yuen, 2006) using the SAS procedure of GENMOD version 9.4 (SAS Institute Inc, 2017).

Table 1. Class boundaries used in the analysis of the association of biophysical factors with DRR incidence and severity in central Ethiopia (n=165)

Variable	Variable class	No. of fields	DRR incidence		DRR severity	
			≥6	<6	≥30	<30
Zones	East Shewa	54	37	17	39	15
	Southwest Shewa	56	27	29	20	36
	West Shewa	55	21	34	24	31
Year	2020	64	36	28	23	41
	2021	101	49	52	60	41
Altitudes	≤2100	74	44	30	47	27
(m.a.s.l)	>2100	91	41	50	36	55
Soil type[a]	Heavy black	107	59	48	58	49
	Intermediate	49	23	26	21	28
	Light soil	9	3	6	4	5
Sowing dates	Late Aug to early Sept	22	14	8	16	6
	Mid-to-late Sept	78	49	29	43	35
	October	65	22	43	24	41
Density[b]	Low (<20 plants m^{-2})	30	21	9	19	11
	Normal (20-30 plants m^{-2})	79	39	40	37	42
	High (>30 plants m^{-2})	56	25	31	27	29
Growth stage[c]	Flowering	15	6	9	8	7
	Podding	90	48	42	41	49
	Maturity	60	31	29	34	26
Weed management[d]	Weeded	44	27	17	23	21
	Unweeded	121	58	63	60	61
Chickpea types	Kabuli	98	61	37	59	39
	Desi	67	24	43	24	43
Previous crop[e]	Teff	119	61	58	60	59
	Wheat/barley	33	17	16	16	17
	Legumes	5	2	3	1	4
	Other crops[f]	8	5	3	6	2

[a]The soil type is classified based on visual observation as heavy black when it is deep black clay or vertisols; light soil: soil with light red or brown color, and intermediate between the black and light soil.

[b]Crop density was determined from $1m^2$ as low (<20 plants m^{-2}), normal (20-30 plants m^{-2}) and high (>30 plants m^{-2})

[c]Growth stage refers to flowering when 50% of the plants in the quadrant show flowers, podding when 50% of the plants in the quadrant start pod formation; and maturity when the plants reach the physiological maturity stage.

[d]Weed management practices were recorded as weeded (fields free of any weed infestation) and non-weeded (presence of few to high weed infestation).

[e]Previous crop refers to a crop that grew before chickpea in the same field.

[f]Onion, tomato and cabbage.

The importance of the independent variables was evaluated twice in terms of their effect on disease incidence and severity. Firstly, the degrees of association of all the independent variables with the two disease parameters (incidence and PSI) were tested using a single-variable model. Secondly, the association of the independent variable with percent disease incidence and PSI was tested, when entered first and last with all the other variables in the model. Selected independent variables that have a significant association with disease parameters were sequentially added to a reduced multiple-variable model (Yuen, 2006). Deviance reduction and odds ratios were calculated for each independent variable as it was added to the reduced model. The deviance, the logarithm of the ratio of two likelihoods was used to compare the single- and multiple-variable models. The difference between the likelihood ratio statistics (LRTs) was then used to examine the importance of the variable and tested against chi-square ($\chi 2$) values (McCullagh and Nelder, 1989).

Results

Characteristics of surveyed fields

Among the assessed farmers' chickpea fields, most were planted to the Kabuli type (59.4%), while 40.6% of the fields were planted to the Desi type. During the survey, five improved chickpeas, namely Arerti, Habru, Natoli, DZ 10-4, and Dubie were grown. Nearly 49.9% of the surveyed chickpea fields were sown at a recommended plant density (20-30 plants m^{-2}), but 18.2% and 33.9% of the fields had low and high plant densities, respectively. The altitude of the surveyed chickpea fields was in a range of 1590 (Liben) to 2445 (Dendi) m.a.s.l.

Figure 2. Chickpea types, and above-and below-ground DRR symptoms: DRR-infected fields planted to Kabuli type in East Shewa (a and b); fields planted to Desi type in Southwest Shewa (c); Dry, straw-colored foliage and fallen leaves symptoms of DRR (d); and black discolored tap root devoid of lateral roots (e).

Chickpea sowing dates were variable across the surveyed districts and zones, starting from the end of August and extending up to mid-October. The survey was carried out throughout the three crop growth stages of chickpeas. Of which 9.1%, 54.5%, and 36.4% of the chickpea fields were found at flowering, podding and physiological maturity stages, respectively. Most surveyed fields had heavy black soil (64.8%), whereas 29.7% and 5.5% of the fields had intermediate and light soil types, respectively. About 26.7% of chickpea fields were weed-free, while the majority (73.3%) were infested with different levels of weeds. Burclover (*Medicago polymorpha*), Adeyabeba (*Bidens macroptera*), and Nutgrass (*Cyperus rotundus*) were the major weeds encountered during the survey. Farmers use hand weeding to control weeds.

In all districts surveyed, farmers plant chickpeas as the main crop (98.2%) and double-crop (1.8%) after-harvesting cereals. Moreover, most percentages of the surveyed chickpea fields (92.1%) were sown in fields where cereal crops were previously grown, primarily teff followed by wheat and barley. Farmers exhaustively practice insecticides against stem borer (*Helicoverpa armiger*) in all fields assessed. Though almost all the chickpea fields visited were affected by DRR, farmers in the study areas were not using any management practices against this disease (Figures 2 a-e).

Dry root rot incidence and severity

DRR of chickpea was prevalent in all the surveyed districts of central Ethiopia. However, the incidence and severity recorded were variable across the districts (Table 2). The highest (10.8%) average incidence was recorded in Liben district, followed by Ada'a (9.6%), Ambo (8.9%), and Lume (8.2%). Contrarily, the lowest incidence was recorded in Sebeta Hawas (2.3%), followed by Ejersa Lafo (3.3%), Dendi (4.8%), and Becho (5.2%). Regarding DRR severity, the highest average severity (46.2%) was recorded in Ambo, followed by Kersena Malima (42.5%), Lume (42.2%), Ada'a (39.1%), and Liben (37.7%). In contrast, the lowest average DRR severity was recorded at Sebeta Hawas (18.3%), followed by Ejersa Lafo (23.3%) and Becho (24.2%).

Similarly, the incidence and severity of DRR varied among chickpea types and over the two cropping seasons when compared at the zonal level. East Shewa had the highest DRR incidence for the year 2020 (11.6%) followed by Southwest Shewa (5.7%) (Figure 3 a). Despite a slight decline in incidence, East Shewa (7.7%) recorded a higher incidence in 2021 than the West and Southwest Shewa. The disease severity recorded in 2021 exceeded the severity in the year 2020 in all three zones of central Ethiopia. In both years, the severity was higher in East Shewa than in West and Southwest Shewa zones (Figure 3 c). Concerning the disease status on chickpea types, higher incidence, and severity were recorded in Kabuli than on Desi type except for a slightly higher severity in West Shewa on Desi type (Figure 3 b and d).

Table 2. Prevalence, mean incidence and percent severity index of DRR and Fusarium wilt (FW) incidence in three major chickpea growing zones of central highlands of Ethiopia

Zones	Districts	DRR Preva	DRR incidence		DRR PSI		FW incidence	
			Range	Mean±SEM	Range	Mean±SEM	Range	Mean±SEM
East Shewa	Ada'a	96	0-40.4	9.6±1.8	11.1-71.6	39.1±2.7	0-35.3	9.9±1.8
	Lume	100	1.2-18.4	8.2±0.9	13.6-84.0	42.2±4.0	0-22.6	5.3±1.4
	Liben	100	2.9-19.2	10.8±2.4	23.5-45.7	37.7±2.6	0-15.1	7.2±2.1
Southwest Shewa	Becho	100	1-10.0	5.2±0.2	16-48.2	24.2±2.0	0-10.6	4.0±0.7
	Ilu	100	1.8-14.1	6.2±1.1	16.1-40.7	26.1±6.9	0-25.3	7.8±1.0
	Kersana Malima	93	0-13.7	6.9±1.1	11.1-74.1	42.5±5.1	0-18	4.5±1.4
	Sebeta Hawas	50	0-6.1	2.3±0.9	11.1-39.5	18.3±10.9	0-9.5	2.9±1.0
West Shewa	Ambo	100	5.1-19.4	8.9±1.4	27.2-63.0	46.2±2.6	1.5-8.6	5.1±0.8
	Dendi	96	0-10.3	4.8±0.6	11.1-55.6	29.1±4.2	0-14.4	4.8±0.7
	Ejersa Lafo	85	0-7.4	3.3±0.5	11.1-38.3	23.3±1.9	1-14.7	5.8±0.8

Preva=prevalence; Mean±SEM=Mean and standard error of means; PSI=Percent Severity Index.

Chickpea fields located at altitudes ≤2100 m.a.s.l had higher average incidence (7.9%) and severity (36.9%) than fields located at altitudes >2100 m.a.s.l (Table 3). The highest mean incidence and severity were recorded from chickpeas sown on vertisols compared to chickpea fields sown on light and intermediate soil types. The highest average incidence (8.81%) and severity (39.0%) of DRR were recorded from fields sown from late August to early September. In contrast, the lowest incidence (4.79%) and severity (26.9%) were recorded from early October sown fields (Table 3). Fields with lower plant density (less than 20 plants m^{-2}) had recorded the highest incidence and severity as compared to fields with recommended (20-30 plants m^{-2}) and high (>30 m^{-2}) plant density. Both average incidence and severity showed increasing trends through flowering to podding and physiological maturity growth stages of chickpea. Thus, DRR incidence was higher by 27% and 13.5% at physiological maturity than at flowering and podding stages, respectively. Similarly, severity was higher by 26.2% and 7.8% at the maturity stage than at the flowering and podding growth stages, respectively.

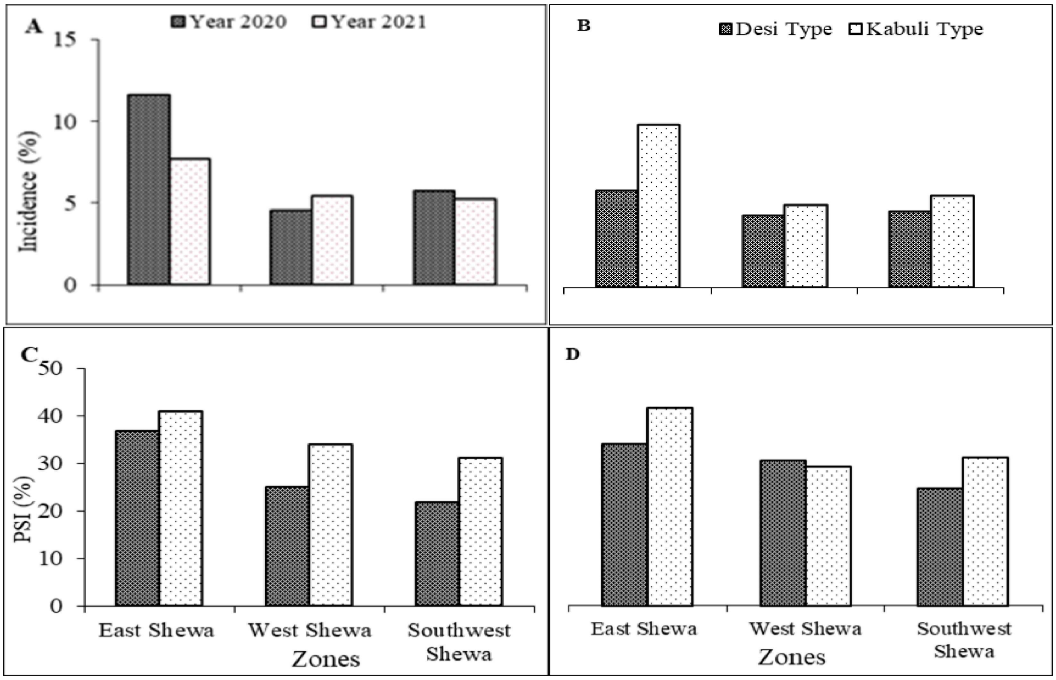

Figure 3. Incidence (a & b) and PSI (c & d) of DRR recorded on chickpea types and in the year 2020 and 2021 growing seasons from 165 fields surveyed in three zones of central Ethiopia

A higher average DRR incidence was observed in weed-free fields compared to weed-infested fields. Meanwhile, weed-free and infested fields recorded a relatively equal degree of severity. Concerning the reaction of chickpea types to DRR, the highest incidence (7.5%) and severity (35.2) were recorded when farmers sow their fields with the improved Kabuli type, while the lowest incidence (5.1%) and severity (29.1%) were exhibited from fields sown to local Desi type.

Table 3. Disease incidence and severity (Mean±SEM) of chickpea DRR for different independent variables in three zones of central Ethiopia during the 2020 and 2021 cropping season

Variables	Variable class	DRR incidence	DRR PSI
Zones	East Shewa	9.22±0.95	40.08±2.02
	Southwest Shewa	5.34±0.47	28.14±2.00
	West Shewa	5.00±0.47	30.08±1.79
Year	2020	7.38±0.82	27.86±1.37
	2021	5.94±0.42	35.76±1.66
Altitude (m.a.s.l)	≤2100	7.87±0.76	36.90±1.93
	>2100	5.38±0.38	29.27±1.37
Soil type	Heavy black	7.17±0.56	33.88±1.36
	Intermediate	5.40±0.54	30.16±2.24
	Light soil	4.45±1.48	32.37±8.00
Sowing date	Late Aug to early Sept	8.81±1.83	39.00±2.88
	Mid-to-late Sept	7.27±0.54	35.74±1.93
	October	4.79±0.46	26.90±1.35
Density	Low	9.35±1.44	33.05±2.25
	Normal	5.88±0.49	31.69±1.78
	High	5.83±0.56	33.93±2.11
Growth stage	Flowering	5.26±1.35	25.84±3.05
	Podding	6.23±0.46	32.29±1.61
	Maturity	7.20±0.83	35.01±2.00
Weed management	Weeded	8.26±1.08	32.01±1.91
	Unweeded	5.85±0.39	32.94±1.46
Chickpea types	Kabuli	7.49±0.60	35.17±1.58
	Desi	5.04±0.45	29.07±1.69
Previous crop	Teff	6.23±0.44	32.84±1.31
	Wheat/barley	7.07±1.06	32.70±3.14
	Legumes	5.46±3.78	21.98±5.56
	Other crops	8.27±2.52	31.19±6.21

Mean ± SEM=Mean±standard error of means

Isolation frequency of *Macrophomina phaseolina* (MP) and associated diseases

In addition to DRR, FW of chickpea was prevalent in all surveyed districts of central Ethiopia (Table 2). The highest average incidence of FW was recorded at Lume (9.9%), whereas the lowest was at Sebeta Hawas (2.9%). In terms of individual fields, the maximum incidence of FW was recorded in the Ada'a (35.3%) district. MP was the most frequently isolated pathogen from the root samples collected post-flowering, followed by *Fusarium oxysporium* (FOC) in East Shewa. FOC followed by MP were dominantly isolated in Southwest and West Shewa. On average, the highest percentage of FOC (49.7%) was isolated, followed by MP (35.6%), *Fusarium solani* (7.6%), *Rhizoctonia solani* (3.5%), and 3.6% unidentified (Figure 4).

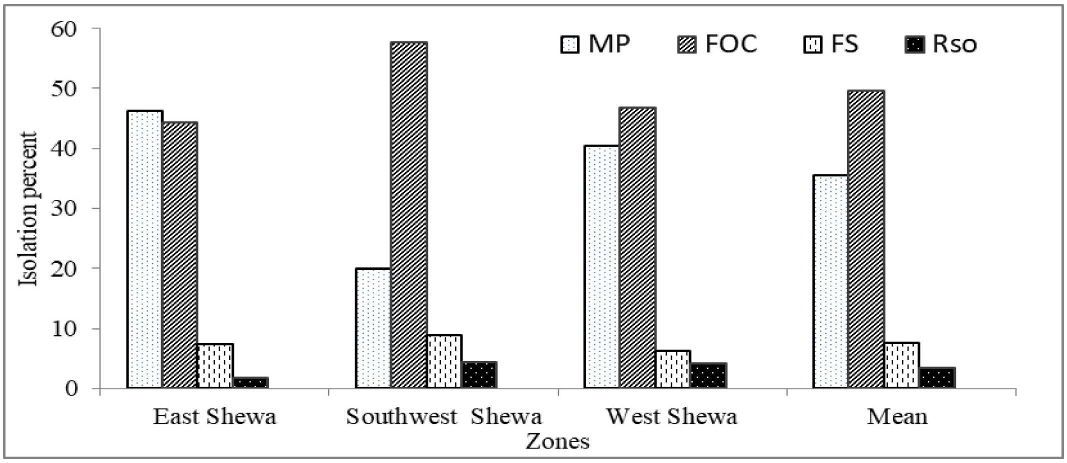

Figure 4. Percent isolation of fungi causing chickpea wilt-root rot complex from root samples collected in three zones of central Ethiopia. MP, *Macrophomina phaseolina*; FOC, *Fusarium oxysporium*; FS, *Fusarium solani* and Rso, *Rhizoctonia solani*

Association of DRR incidence and severity with biophysical factors

Associations of DRR disease parameters with biophysical factors were analyzed using a logistic regression model, and the results are shown in Table 4. The zones, sowing dates, and chickpea types were highly associated with the DRR incidence when entered first into a logistic regression model (Table 4). The zones, sowing date, and chickpea-type variables maintained their significance when entered last into the model. Meanwhile, plant density gained significance when entered into the model last by adding other variables. Zones (χ^2=10.6, 11.1), sowing date (χ^2=13.6, 9.7), and chickpea type (χ^2=11.2, 5.0) were the most significant variables associated with DRR incidence when entered first and last into the model.

Table 4. Logistic regression model of chickpea DRR incidence and percentage severity index in central Ethiopia and likelihood ratio test on independent variables in the two cropping seasons

Independent variable	DF	DRR incidence, LRT				DRR PSI, LRT			
		VEF		VEL		VEF		VEL	
		DR	Pr > χ^2	DR	Pr > χ^2	DR	Pr > χ^2	DR	Pr > χ^2
Zones	2	10.61	0.005	11.10	0.0039	16.57	0.0003	17.54	0.0002
Year	1	0.94	0.33	0.94	0.33	8.72	0.0031	5.43	0.02
Altitude	1	3.40	0.065	0.04	0.85	9.46	0.0021	2.15	0.1427
Soil type	2	2.18	0.34	2.33	0.31	1.87	0.39	1.14	0.5666
Sowing date	2	13.60	0.0011	9.70	0.0078	10.03	0.0066	3.36	0.1861
Plant density	2	5.44	0.066	13.73	0.001	2.54	0.28	0.24	0.3269
Growth stage	2	0.92	0.63	0.42	0.81	1.84	0.40	1.39	0.4988
Weed	1	2.35	0.13	0.13	0.71	0.09	0.76	0.20	0.6564
Chickpea type	1	11.25	0.0008	4.98	0.026	9.57	0.0021	4.50	0.0338
Previous crop	3	0.66	0.88	1.86	0.60	4.05	0.26	3.64	0.3033

DF=Degrees of freedom; DR=Deviance reduction; VEF=Variables entered first; VEL=Variables entered last; LRT=Likelihood ratio test; Pr=Probability of a value χ^2 exceeding the deviance reduction

A group of four independent variables: zones, sowing date, plant density, and chickpea type significance were tested in a reduced multiple-variable model. The parameter estimates resulting from a reduced regression model and their standard error are shown in Table 5. A low DRR incidence (<6%) showed a high probability of association with the Southwest Shewa zone, Desi type, October sowing, and high plant density. Whereas high DRR incidence (≥6%) had a high probability of association with East Shewa, August to September sowing, low plant density, and Kabuli type. East Shewa, August to September sowing (early sowing), low plant density and Kabuli type had about 2.05, 3.16, 3.06, and 2.4 times DRR incidence than West Shewa zone, October sowing, high plant density, and Desi type, respectively. Year, altitude, soil types, growth stage, weed management, and previous crop did not show a significant association with DRR incidence.

Table 5. Analysis of deviance, odds ratio, and standard error of explanatory variables in the reduced model on mean percent DRR incidence in central Ethiopia

Added variables	RD	DF	LRT		Variables class	Estimate	SE	Odd ratio[c]
			DR	Pr> χ^2				
Intercept	87.58[a]	1				-1.88	0.50	0.15
Zones	76.97	2	10.61	0.0050	East Shewa	0.72	0.52	2.05
					Southwest Shewa	0.09	0.45	1.09
					West Shewa	0[R]		
Sowing date	69.75	2	7.23	0.0270	Late Aug to early Sept	1.11	0.65	3.16
					Mid-to-late Sept	1.2	0.42	3.32
					October	0[R]		
Plant density	60.85	2	8.89	0.0117	Low	1.12	0.56	3.06
					Normal	0.47	0.43	1.60
					High	0[R]		
Chickpea	55.29	1	5.56	0.0184	Kabuli	0.89	0.38	2.44
					Desi	0[R]		

RD=residual deviance; DF=Degrees of freedom; DR=Deviance reduction; LRT=Likelihood ratio test; Pr=Probability of χ^2 value exceeding the deviance reduction; R=reference group; a=Variables are added into the model in order of presentation in the table; Estimates are from the model with all independent variables added; SE=Standard error; c=Exponentiating the estimates.

With regard to severity, five variables, viz. year, zone, altitude, sowing date, and chickpea types had significant association with the DRR percent severity index when entered as a single variable into the model. However, altitude and sowing date lost their significance when entered last into the model along with other variables (Table 4). Zones (χ^2=16.57, 17.54) and chickpea types (χ^2=9.57, 4.50) were the most highly associated variables with PSI when entered first and last with other variables into the model. The variables showing significant association were tested in a reduced multiples variable model. The parameter estimates resulting from a reduced regression model and their standard error are shown in Table 6. The 2020 cropping year, Southwest Shewa zone, altitudes >2100 m.a.s.l, and Desi type reduced the DRR severity. On the other hand, high severity was highly associated with altitudes ≤2100 m.a.s.l, early sowing, and Kabuli type. The probability of occurrence of high severity (≥30%) was about 2.66 times at altitudes ≤2100 than at altitudes >2100 m.a.s.l, 2.18 times in early (late August to September) than October sowing, and 2.71 times in Kabuli type than Desi type. The biophysical factors such as soil type, plant density, growth stages, weed management, and previous crops grown did not show significant associations with DRR severity. Zones, sowing dates, and chickpea types significantly influenced DRR incidence and severity.

Table 6. Analysis of deviance, odds ratio, and standard error of explanatory variables in reduced model on mean DRR Percent Severity Index in central Ethiopia

Added variables	RD	DF	LRT DR	LRT Pr> χ^2	Variables class	Estimate	SE	Odd ratio[c]
Intercept	86.30[a]					0.56	0.42	1.75
Zones	60.04	2	17.54	0.0002	East Shewa	0.012	0.65	1.01
					Southwest Shewa	-1.16	0.55	0.31
					West Shewa	0^R		
Years	77.58	1	8.72	0.0031	2020	-0.98	0.34	0.38
					2021	0^R		
Altitudes	57.89	1	2.15	0.1427	≤2100	0.77	0.52	2.66
					>2100	0^R		
Sowing date	54.92	2	2.97	0.2270	Late Aug to early Sept	0.78	0.68	2.18
					Mid-to-late Sept	0.78	0.43	2.18
					October	0^R		
Chickpea types	48.05	1	6.88	0.0087	Kabuli	0.96	0.37	2.71
					Desi	0^R		

RD=residual deviance; DF=Degrees of freedom; DR=Deviance reduction; LRT=Likelihood ratio test; Pr=Probability of χ^2 value exceeding the deviance reduction; a=Variables are added into the model in order of presentation in the table; R=reference group; Estimates are from the model with all independent variables added; SE=Standard error; c=Exponentiation of the estimates.

Discussion

The current study revealed that zones and districts had variable DRR distribution. East Shewa had higher incidence and severity than the Southwest and West Shewa zones. Moreover, higher incidence and severity were recorded at Liben, Ada'a, Lume, and Ambo than in the remaining districts. Similar wide distributions of chickpea root rot diseases were previously documented by several authors (Damte and Ojiewo, 2016; Yimer *et al.*, 2018; Bekele *et al.*, 2021). Previous studies showed that warm temperatures in a range of 30-35^{o}C and the presence of moisture-stressed conditions had a significant influence on the development of DRR disease (Sharma and Pande, 2013; Srinivas *et al.*, 2017; Chilakala *et al.*, 2022). In the surveyed areas of central Ethiopia, chickpeas were grown in the post-rainy season under progressive depleting moisture levels towards terminal growth stages with differing degrees of stress in each district (Desta *et al.*, 2015). This condition, therefore, increased the chickpea's vulnerability and enhanced the pathogen's aggressiveness, resulting in increased incidence and severity of the disease in the surveyed districts. Similar findings of variable distribution of DRR on legume crops such as chickpea, common bean, pigeon pea, and cowpea were reported by many authors in several areas with prolonged dry periods and low rainfall (Maruti *et al*., 2017; Deepa *et al*., 2018; Lamini *et al.,* 2020).

Similarly, the incidence and severity of DRR varied with biophysical factors, and a significant association was found with chickpea type grown and sowing date. Most farmers (59.4%) in central Ethiopia were found to practice the Kabuli type mono-cropping system, and chickpea production is constrained by the high distribution and intensity of DRR as well as wilt disease. The Kabuli types being grown by farmers in Ethiopia are improved cultivars. However, the improvement program did not yet target the development of DRR-resistant cultivars, although DRR is getting increasingly important in connection with the current climate change. Mono-cropping of chickpea crops was known to impose frequent disease occurrences through continuous buildup of inoculums (Deepa *et al*., 2018). According to the report by Sinha *et al.,* (2021), evaluation of the reaction of chickpea genotypes to DRR revealed that the genotypes became susceptible to the disease when tested under high temperatures and moisture stress conditions, irrespective of their levels of resistance. Meanwhile, Chiranjeevi *et al*., (2019) reported through a survey that variable DRR pressure was recorded at different locations regardless of cropping systems, chickpea types, and cultivars, corroborating this study's results. A recent evaluation of improved chickpea genotypes against moisture stress reported higher sensitivity of improved Kabuli than the Desi type (Korbu *et al*., 2021). This might have contributed to the high incidence and severity of DRR in the present study.

The comparison of chickpea sowing dates extending from the end of August to mid-October revealed a significant association with DRR. Farmers in the study area widely practice chickpea sowing dates to utilize residual moisture at the end of the main rainy season. Thus, early sowing (end of August to early September) predisposes chickpea to wet, collar, and black root rot disease complexes, which can be aggravated by wet soil conditions (Nene *et al*., 1981; Tarafdar *et al*., 2018; Yimer *et al*., 2018). In contrast, the late sowing practice made to escape the earlier biotic stress exposes chickpea to acute terminal drought consequences, which could result in substantial yield losses to the crop (Mohammed *et al*., 2017; Korbu *et al*., 2020). Conversely, early sowing followed by a sudden drop in soil moisture status could enhance DRR infection and cause immediate associated damage to the crop.

The probability of association of low and normal plant population to high (≥6%) incidence was about 3.1 and 1.6 times higher than high plant population. The high plant population in crop fields is important to maintain changes in microclimate within the crop canopy (Elad and Pertot, 2014). Conversely, open areas in fields with low crop stands are vulnerable to soil moisture loss due to evaporation from the soil surface, which would result in warm and decreased moisture levels around the crop root zone. Likewise, a low plant density may provide a space for weed growth that would impair crop vigor by competing for available resources. As a result, a weaker crop plant is likely to be more susceptible to soil-borne diseases. Furthermore, Fuhlbohm *et al*., (2012) reported that MP isolates were recovered from several symptomless weed species and verified that weeds may act as an alternate host or a source of inoculum. Similar roles of weeds in the epidemic development of chickpea Fusarium wilt were reported by Hawere and Nene, (1982). The increased incidence of DRR under low plant populations may be related to either the decrease in moisture levels via evaporation from sparse surfaces or the impact of weeds on disease development.

The probability of association of lower (≤2100 m.a.s.l.) altitudes with high DRR severity (≥30%) was 2.66 times higher than high (>2100 m.a.s.l) altitudes. The low altitude areas are characterized by relatively high temperatures and erratic rainfall patterns than the reverse class that were responsible for the occurrences of several diseases on chickpea. With regards to DRR, high altitude areas with wet soils under extended rainfall negatively impact the survival of sclerotia (Olaya and Abawi, 1996). On the other hand, low altitude semi-arid areas exhibiting frequent stresses (high temperature and moisture stress) are conducive to excessive sclerotia production that could account for increased incidence and severity of the disease (Soni *et al*., 2022). These suggest that the mid-altitude areas (1500-2100 m.a.s.l) with warm climates and erratic rainfall were more favorable for developing DRR epidemics.

High incidence and severity of DRR were obtained in chickpeas grown on vertisols than intermediate and light soil types, though a non-significant association was observed in a logistic regression model. In contrast, Mallaiah and Krishna Rao, (2016) and Partap and Godara, (2022) assessed the intensity of DRR on different soil types and obtained that increased incidence and severity of DRR in sandy loam than clay soils. The high incidence and severity of the DRR disease recorded could be explained by the fact that sandy soils have better aeration and less water-retention capacity than clay soils, which creates an environment favorable to MP activity. On the other hand, as vertisols or clay soils are well-suited to providing residual moisture following the end of the rainy season, farmers in central Ethiopia have been using them for the cultivation of chickpeas year after year (Korbu *et al.,* 2020; Allito and Geda, 2021). This continuous cultivation of chickpeas together with other environmental and management factors might have contributed to the high intensity of DRR on vertisols. Similar reports of high wilt and root rot pressure on vertisols than light soils in major chickpea-growing areas of Ethiopia were previously reported by Yimer *et al*., (2018) and Bekele *et al*., (2021).

The survey data analyzed using logistic regression revealed that biophysical factors influence the incidence and severity of DRR epidemics when evaluated singly and in combination. The results identified biophysical factors, namely, zones, plant density, sowing dates, altitude, and chickpea types as important variables influencing DRR epidemics. The regression model quantified the relative importance of biophysical factors favoring DRR epidemics. The analysis revealed that the East Shewa, early sowing, low plant density, and Kabuli type were associated with DRR incidence. In contrast, early sowing, lower altitude, and Kabuli type were associated with severity and significantly contributed to the disease epidemics. Yimer *et al*., (2018) reported that the incidence and severity of soil-borne fungal diseases of chickpea (wilt and root rots) were influenced by cultural practices and genotypes.

Conclusions

The present study revealed that DRR disease is widely distributed and a major problem in major chickpea-growing areas of the central highlands of Ethiopia. Under the threat of climate change, the distribution and intensity of DRR disease are expected to increase rapidly in many areas. The result of this study suggests the importance of utilizing appropriate cultural and climate change-resilient agronomic practices that create unfavorable conditions for disease development. Furthermore, the evaluation of chickpea genotypes and breeding for resistance to DRR should be a prior agenda for chickpea researchers to manage the disease effectively.

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Data availability

The authors confirm that the data supporting the findings of this study are available within the article and/or its supplementary material.

Conflict of interest

No potential conflict of interest was reported by the authors.

References

Abraham, A. D., Menzel, W., Lesemann, D. E., Varrelmann, M. and Vetten, H. J. 2006. Chickpea Chlorotic Stunt Virus: A new polerovirus infecting cool-season food legumes in Ethiopia. Phytopathol. 96(5), 437-446.

Allito, B. B. and Geda, G. G. 2021. Evaluation of chickpea varieties growing on residual moisture of vertisols in Southern Ethiopia. Ann. Agric. Crop. Sci. 6(6), 1096.

Ayana, A., Hailu, N. and Taye, W. 2019. Screening Desi and Kabuli chickpea varieties against Fusarium wilt resistance in West Gojam, Northwestern Ethiopia. J. Plant. Pathol Microbiol. 10(2), 474. doi: 10.4172/2157-7471.1000474.

Baird, R. E., Watson, C. E. and Scruggs, M. 2003. Relative longevity of *Macrophomina phaseolina* and associated mycobiota on residual soybean roots in soil. Plant. Dis. 87, 563-566.

Bekele, D., Tesfaye, K., Fikre, A. and Cook, D. R. 2021. The extent and association of chickpea Fusarium wilt and root rot disease pressure with major biophysical factors in Ethiopia. J. Plant. Pathol. 103(2), 409-419.

Chilakala, A. R., Mali, K. V., Irulappan, V., Patil, B. S., Pandey, P., Rangappa, K., Ramegowda, V., Kumar, M. N., Puli, C. O., Mohan-Raju, B. and Senthil-Kumar, M. 2022. Combined drought and heat stress influences the root water relation and determine the dry root rot disease development under field conditions: a study using contrasting chickpea genotypes. Front. Plant. Sci. 13, 890551. doi: 10.3389/fpls.2022.890551.

Chiranjeevi, N., Reddi Kumar, M., Padmodaya, B., Venkateswarlu, N. C. and Sudhakar, P. 2019. Occurrence and distribution of dry root rot in major chickpea growing regions of Andhra Pradesh. Inter. J. Pure. App. Biosci. 7(4), 448-456.

Damte, T. and Ojiewo, C. O. 2016. Current status of wilt/root rot diseases in major chickpea growing areas of Ethiopia. Arch. Phytopathol. Plant. Protec. 49(9-10), 222-238.

Deepa, D., Sunkad, G., Sharma, M., Mallesh, S. B., Mannur, D. M. and Sreenivas, A. G. 2018. Distribution and severity of dry root rot of chickpea caused by *Rhizoctonia bataticola* in parts of North Karnataka. Inter. J. Curr. Microbiol. App. Sci. 7(04), 194-200.

Desta, F., Bissa, M. and Korbu, L. 2015. Crop water requirement determination of chickpea in the central vertisol areas of Ethiopia using FAO CROPWAT model. Afric. J. Agric. Res. 10(7), 685-689.

Elad, Y. and Pertot, L. 2014. Climate change impacts on plant pathogens and plant diseases. J. Crop. Improv. 28, 99-139.

FAOSTAT (Food and Agriculture Organization of the United Nations Statistical Database). 2022. Production statistics of crops. http://faostat.fao.org/site/567/default.aspx#anco.

Fininsa, C. and Yuen, J. 2001. Association of maize rust and leaf blight epidemics with cropping systems in Hararghe highlands, Eastern Ethiopia. Crop. Protec. 20, 669-678.

Fuhlbohm, M. J., Ryley, M. J. and Aitken, E. A. 2012. New weed hosts of *Macrophomina phaseolina* in Australia. Australasian. Plant. Dis. Notes. 7(1), 193-195.

Gaur, P. M., Tripathi, S., Gowda, C., Ranga Rao, G., Sharma, H. and Pande, S. 2010. Chickpea Seed production Manual. Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 28 pp.

Gaur, P. M., Jukanti, A. K. and Varshney, R. K. 2012. Impact of genomic technologies on chickpea breeding strategies. Agron. 2, 199-221.

Haware, M. P. and Nene, Y. L. 1982. Symptomless carriers of chickpea wilt *Fusarium*. Plant. Dis. 66, 250-251.

Khan, M. A. and Gangopadhyay, S. 2008. Efficacy of *Pseudomonas fluorescens* in controlling root rot of chickpea caused by *Macrophomina phaseolina.* J. Mycol. Plant. Pathol. 38, 581-587.

Korbu, L., Tafes, B., Kassa, G., Mola, T. and Fikre, A. 2020. Unlocking the genetic potential of chickpea through improved crop management practices in Ethiopia. A review. Agron. Sustain. Dev. 40(2). doi.org/10.1007/s13593-020-00618-3.

Korbu, L., Fikre, A., Tesfaye, K., Funga, A., Bekele, D. and Ojiewo, C. O. 2021. Response of chickpea to varying moisture stress conditions in Ethiopia. Agrosyst. Geosci. Envir. 5(1), 1-18.

Lamini, S., Cornelius, E. W., Kusi, F., Danquah, A., Attamah, P., Mukhtaru, Z., Awuku, J. F. and Mensah, G. 2020. Prevalence, incidence and severity of a new root rot disease of cowpea caused by *Macrophomina phaseolina* (Tassi) Goid in Northern Ghana. West. Afric. J. App. Ecol. 28(2), 140-154.

Mallaiah, B. and Krishna-Rao, V. 2016. Survey and virulence studies on dry root rot of Greengram [*Vigna Radiate (L.)* Wilczek] incited by *Macrophomina Phaseolina* (Tassi.) Goid. Inter. J. Tropic. Agric. 34(3), 521-527.

Manjunatha, H. and Saifulla, M. 2021. Management of dry root rot in chickpea (*Cicer arietinum L.*) caused by *Macrophomina phaseolina* by utilizing host plant resistance, fungicides and bioagents. Legume. Res. 44(1), 115-119.

Maruti, M., Savitha, A. S., Sunkad, G., Mahalinga, D. and Patil, M. G. 2017. Incidence of dry root rot of pigeonpea in North Eastern Karnataka, India. Int. J. Curr. Microbiol. Appl. Sci. 6(11), 1071-1078.

McCullagh, P. and Nelder, J. A. 1989. Generalized linear models. 2nd editions. Chapman and Hall. London, New York. pp.511.

Mengistu, A., Reddy, K. N., Zablotowicz, R. M. and Wrather A. J. 2009. Propagule densities of *Macrophomina phaseolina* in soybean tissue and soil as affected by tillage, cover crop, and herbicide. Plant. Health. Progress. 10(1). doi:10.1094/PHP-2009-0130-01-
RS.

Mengist, Y., Sahile, S., Sintayehu, A. and Singh, S. 2018. Evaluation of chickpea varieties and fungicides for the management of chickpea Fusarium wilt disease (*Fusarium oxysporum f.sp. ciceris*) at Adet sick plot in Northwest Ethiopia. Inter. J. Agron. doi.org/10.1155/2018/6015205.

Mohammed, A., Tana, T., Singh, P., Korecha, D. and Molla, A. 2017. Management options for rainfed chickpea (*Cicer arietinum L.*) in Northeast Ethiopia under climate change condition. Climate. Risk. Manag. 16(1), 222-233.

Nene, Y. L., Haware, M. P. and Reddy, M. V. 1981. Chickpea diseases: resistance-screening techniques. Information Bulletin No. 10. Patancheru, AP, India: International CroDS Research Institute for the Semi-Arid Tropics. 1-16pp

Nene, Y. L., Reddy, M. V., Haware, M. P., Ghanekar, A. M., Amin, K. S., Pande, S. and Sharma, M. 2012. Field diagnosis of chickpea diseases and their control. Information Bulletin No. 28 (revised). Patancheru, A.P. 502 324, India: International Crops Research Institute for the Semi-Arid Tropics. 1-60 pp.

Olaya, G. and Abawi, G. S. (1996). Effect of water potential on mycelial growth and on production and germination of sclerotia of *Macrophomina phaseolina.* In Plant. Dis. 80(12), 1347-1350.

Patel, D., Singh, H. B., Shroff, S. and Sahu, J. 2011. Antagonistic efficiency of *Trichoderma* strains against soilborne disease of chickpea crop under *in vitro* and *in vivo*. Life Science Bulletin. 8(1), 49-52.

Pande, S., Kishore, G. K. and Rao J. N. 2004. Evaluation of chickpea lines for resistance to dry root rot caused by *Rhizoctonia bataticola*. Inter. Chickpea and Pigeonpea Newsletter. 11, 37-38.

Pande S., Sharma, M., Nagavardhini, A. and Rameshwar T. 2012. High throughput phenotyping of chickpea diseases: Stepwise identification of host plant resistance. Information Bulletin No. 92 Patancheru 502 324, Andhra Pradesh, India: International Crops Research Institute for the Semi-Arid Tropics. 1-56 pp.

Partap, M, and Godara, S. L. 2022. Occurrence and distribution of dry root rot of chickpea caused by *Macrophomina phaseolina* (Tassi) Goid. in arid region of Rajasthan. Legume. Res. 45(5), 639-645.

Rai, A., Irulappan, V., and Senthil-Kumar, M. 2022. Dry root rot of chickpea: A disease favored by drought. Plant. Dis. 106, 346-356.

Rangeshwaran, R. and Prasad, R. D. 2000. Isolation and evaluation of rhizospheric bacteria for biological control of chickpea wilt pathogens. J. Biolog. Contr. 14(1), 9-15.

Rashid, H., Taj, M. K., Rafiq, M., Shahzad, F., Jogezai, S., Taj, I., Khan, S., Azam, S., Sazain, L. B., Ali, S. A., Hussain, A. and Samreen, Z. 2020. Nutritional importance of chickpea. J. Bio. Env. Sci. 16(3), 111-117.

SAS (Statistical Analysis Software). 2017. Users' Guide Statistics Version 9.4. SAS Institute Inc., Cary.

Sharma, M., Ghosh, R., Sharma. T. R. and Pande S. 2012. Intra population diversity in *Rhizocotonia bataticola* causing dry root rot of chickpea (*Cicer arietinum* L.) in India. Afric. J. Microbiol. Res. 6(37), 6653-6660.

Sharma, M., Ghosh, R. and Pande, S. 2016. Dry root rot (*Rhizoctonia bataticola* (Taub.) Butler): an emerging disease of chickpea-where do we stand? Arch. Phytopathol. Plant. Protec. 48(13-16), 797-812.

Sharma, M. and Pande, S. 2013. Unravelling effects of temperature and soil moisture stress response on development of dry root rot [*Rhizoctonia bataticola* (Taub.)] Butler in Chickpea. Amer. J. Plant. Sci. 04(03), 584-589.

Sinha, R., Irulappan, V., Patil, B. S., Reddy, P. C., Ramegowda, V., Mohan-Raju, B., Rangappa, K., Singh, H. K., Bhartiya, S. and Senthil-Kumar, M. 2021. Low soil moisture predisposes field-grown chickpea plants to dry root rot disease: evidence from simulation modeling and correlation analysis. Scientific Reports. 11(1), 1-12.

Soni, N., S. Raghuwanshi, K., and L. Kulwal, P. 2022. Effect of abiotic factors on the incidence of dry root rot in chickpea (*Cicer arietinum L.*). J. Agric. Res. Technol. 47(02), 205-211.

Srinivas, P., Ramesh-Babu, P. S., Narayan-Reddy, M. S. and Pushpavathi, B. 2017. Effect of temperature on *Rhizoctonia bataticola* and dry root rot in chickpea. Inter. J. Curr. Microbiol. App. Sci. 6(6), 3349-3355.

Tadesse, M., Turoop, J. and Ojiewo, C. O. 2017. Survey of chickpea (*Cicer arietinum* L.) Ascochyta Blight (*Ascochyta rabiei* Pass.) disease status in production regions of Ethiopia. Plant. 5(1), 23-30.

Tarafdar, A., Rani, T. S., Chandran, U. S., Ghosh, R., Chobe, D. R. and Sharma, M. 2018. Exploring combined effect of abiotic (soil moisture) and biotic (*Sclerotium rolfsii* Sacc.) stress on collar rot development in chickpea. Front. Plant. Sci. 9, 1154.

Wallace, T. C., Murray, R. and Zelman, K. M. 2016. The nutritional value and health benefits of chickpeas and hummus. Nutrients. 8(12), 1-10.

Wheeler, B. E. 1969. An introduction to plant disease. Wiley, London, 347p.

Yimer, S. M., Ahmed, S., Fininsa, C., Tadesse, N., Hamwieh, A. and Cook, D. R. 2018. Distribution and factors influencing chickpea wilt and root rot epidemics in Ethiopia. Crop. Prot. 106, 150-155.

Yuen, J. 2006. Deriving Decision Rules. Department of Forest Mycology and Pathology. Swedish University of Agricultural Sciences.