Journal of Agrometeorology

ISSN : 0972-1665 (print), 2583-2980 (online)
Vol. No. 25 (2) : 312 - 319 (June- 2023)
DOI : https://doi.org/10.54386/jam.v25i1.2017
https://journal.agrimetassociation.org/index.php/jam

Research Paper

Impact of temperature, moisture and CO_2 on growth of pathogen and severity of emerging dry root rot disease of chickpea in Karnataka

GURURAJ SUNKAD[1*], DEEPA DORE[1], MEGHANA PATIL[1], RANJANA JOSHI[1] and MANOJ KUMAR[2]

[1]*Department of Plant Pathology, University of Agricultural Sciences, Raichur-584104, Karnataka, India*
[2]*Department Agricultural Statistics, University of Agricultural Sciences, Raichur-584104, Karnataka, India*
[*]*Corresponding author* e-mail: sunkadgururaj@gmail.com

ABSTRACT

Chickpea is one of the most important food legumes being cultivated in many countries in the world. Dry root rot caused by *Rhizoctonia bataticola* is becoming an emerging disease and considered as potential threat to chickpea productivity and production under changing climatic scenario. The pathogenecity of *R. bataticola* was proved and the identity of pathogen was confirmed molecularly using ITS-1 and ITS-4 primers which produced amplified product size of 500-650 bp in three studied isolates indicating that all the isolates belonged to genus *R. bataticola.* The maximum colony growth of pathogen and the dry root rot disease severity was recorded at 30-35ºC which is considered as optimum temperature range for growth of pathogen and development of disease. Highest severity of dry root rot and lesser plant growth parameters such as root length, shoot length and total biomass were observed at 40-60% soil moisture regimes, irrespective of type of soil. The elevated CO_2 @ 550 ± 25 ppm with 2ºC rise in temperature recorded higher dry root rot well as reduced growth parameters of chickpea. The increase in the temperature lead to decreased radial growth of pathogen and dry root rot incidence and increase in the soil moisture led to increase in growth parameters in both black as well as red soils.

Key words: Dry root rot, *R. bataticola*, climate change, temperature, soil moisture

Chickpea (*Cicer arietinum* L.) is one of the most important food legumes and the crop faces various problems throughout the growing areas, some related to specific regions and some under wider range of climatic conditions. Chickpea cultivation is often subjected to significant yield losses due to insects and diseases ranging from 5-10 per cent in temperate and 50-100% in tropical regions (Van Emden *et al.,* 1988). Recent reports indicated that dry root rot is an emerging as a potential threat to chickpea productivity and production (Ghosh *et al*., 2013). The disease is more prevalent during hot temperature 30 to 35 °C and low soil moisture conditions (Pande *et al*., 2010). Dry root rot caused by *R. bataticola* (Taub.) Butler [Pycnidial stage: *Macrophomina phaseolina* (Tassi) Goid] is a soil and seed borne necrotrophic fungal pathogen that has a global distribution, which can infect more than 284 plant species throughout the world including monocot and dicots (Farr *et al*., 1995). *R. batticola* do not produce spores, but are composed of hyphae and sclerotia (hyphal propagules) acing as facultative plant pathogen causing complete loss in grain yield if chickpea crop is infected.

Environmental factors like temperature, soil moisture and carbon dioxide play an important role in the viability and growth of *R. bataticola* (Khan, 2007). *R. bataticola* is able to produce microsclerotia under relatively low water conditions while viability of microsclerotia drastically reduced at high water potentials (Olaya and Abawi, 1996). In the changing climatic scenario, studies on impact of climatic factors on pathogen and disease are scanty. Moreover, the crop is largely grown in rainfed environments and change in climatic factors within the rainfed ecologies may lead to varying degrees of growth of pathogen and intensities of dry root rot. Keeping this in view, studies on impact of climatic variables such as temperature, moisture and carbon dioxide on growth of pathogen and disease incidence was felt necessary under changing climatic scenario.

Article info - DOI: *https://doi.org/10.54386/jam.v25i1.2017*
Received: 10 February 2022; Accepted: 21 April 2023; Published online : 25 May 2023

MATERIALS AND METHODS

The laboratory and glass house studies were conducted at Department of Plant Pathology, University of Agricultural Sciences, Raichur, Karnataka during 2020-2021.

Isolation, purification and detection of R. bataticola isolates

Chickpea plants showing typical dry root rot symptoms were collected from three different geographic regions and isolation of three *R. bataticlola* isolates was done using standard isolation method. The cultures isolates were purified by placing single sclerotial body transferred to PDA slants and Koch postulates were carried out. For molecular detection, the extraction of total DNA of three isolates was carried out as per Murray and Thompson (1980) and the ITS region three isolates of was sequenced to confirm the identity of isolates by PCR amplifications of the Internal Transcribed Spacers (ITS) of rDNA was performed by using universal primers ITS-1 (5′CCTGTGCACCTGTGAGACAG-3′) as forward primer and ITS-4 (5′-TGTCCAAGTCAATGGACTAT-3′) as reverse primer and PCR product was sequenced at Medauxin Biotech. Ltd., Bengaloru. Homology search was done using BLAST algorithm available at the http://www.ncbi.nlm.nih.gov.

The effect of three climatic change variables viz., temperature, moisture and carbon dioxide was studied on growth of pathogen and development of disease during present investigation.

Effect of temperature on R. bataticola and on dry root rot

Three isolatesof pathogen namely, Rb1, Rb2 and Rb3 were used to study the effect of temperature on pathogen virulence. The isolates were inoculated on PDA medium and kept forincubation at different temperature regimes, 15 °C, 20 °C, 25 °C, 30 °C, 35 °C, 40 °C and 45 °C. Later, the radial growth of mycelium of pathogen was recorded.

Chickpea seedlings were raised in small plastic containers filled with pre-autoclaved sand by sowing chickpea seeds. To study the effect of temperature on dry root rot, each isolate of pathogen was inoculated to ten days old seedlings separately, grown under *in vitro* conditions using paper towel technique. The inoculated seedlings were incubated at different temperature regimes 15°C, 20°C, 25°C, 30°C, 35°C, 40°C, 45°C and 50°C with a 12 h photoperiod. Total 15 plants per treatment (Each temperature regime) with four replications were scored for severity of dry root rot using 1-9 rating scale (Sharma and Pande, 2013).

Rating	Observation
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
>7 and 9	Roots infected and completely discoloured (black)

Effect of soil moisture on dry root rot

In the pot experiment in glasshouse, the mass multiplication of fungus was done on sorghum grain medium and sufficient inoculum was applied to pots. The sick pots were incubated for 4 days to and the effect of seven soil moisture regimes, i.e. 40, 50, 60, 70, 80, 90 and 100 per cent was studied with black and red soils separately. Each treatment was replicated four times and each replication consisted of three pots (five plants/pot). The soil moisture content (SMC) in each treatment was maintained by deionized water and the SMC was determined using the gravimetric method on an oven-dry basis. The method includes saturation of soil sample followed by removal of availablesoil moisture by oven drying (100 °C–110 °C) until the weight remains constant. After removing from oven, samples were cooled slowly to room temperature and weighed again. The difference in weight was amount of moisture in the soil. The available SMC inthe soil was calculated by the following formula.

$$\text{SMC (\%)} = \frac{\text{Saturated soil weight - Oven dry soil weight}}{\text{Oven dry soil weight}} \times 100$$

Effect of carbon dioxide (CO_2) on dry root rot

The study was conducted in the open top chambers maintained by Centre for Climatic Studies, UAS, Raichur with five sets of treatments

T_1: Elevated CO_2 @ 550 ± 25 ppm alone

T_2: Elevated CO_2 @ 550 ± 25 ppm with 2 ºC rise in temperature

T_3: Ambient CO_2 @ 390 ± 25 ppm with 2 ºC rise in temperature

T_4: Reference Open Top Chamber

T_5: Open plot

Under the open top chamber, susceptible chickpea variety (Annigeri-1) was sown in the sick pots and each sick pot was sown with five seeds with five replications. Observations on growth parameters and disease severity of dry root rot was recorded at 75 DAS.

Statistical analysis

The data obtained in the laboratory as well as open top chamber experiments through Factorial Completely Randomized Design were analyzed by Statistical Package for Social Sciences (SPSS V.20). Further, correlation analysis was carried out to understand the relationship between the parameters.

RESULTS AND DISCUSSION

Isolation, purification and detection of R. bataticola isolates

The results indicated that *R. bataticola* pathogen isolates produced black, brown to grey coloured mycelium that become darker with age (Fig. 1). The young hyphae were thin, hyaline, septate and dichotomously branched and later produce typical

Table 1: Effects of temperature regimes on radial growth of *R. bataticola* at 48 and 96 hours after inoculation

*Radial growth of *R. bataticola* at 48 and 96 HAI (mm)

Temperatureregimes (˚C)	Rb1		Rb2		Rb3		Mean	
	48 HAI	96 HAI	48 HAI	96 HAI	48 HAI	96 HAI	48 HAI	96 HAI
15	2.50	12.55	1.40	10.20	4.50	18.15	2.80	13.66
20	30.00	50.00	29.00	34.20	31.00	61.00	30.00	48.40
25	43.00	64.00	32.00	37.00	47.00	75.50	40.66	58.80
30	50.00	85.00	40.00	47.70	52.00	86.50	47.33	73.06
35	65.00	90.00	50.00	80.00	68.00	90.00	61.00	86.66
40	12.00	17.00	10.00	15.00	15.00	18.00	12.33	16.66
45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mean	25.31	39.81	20.31	28.01	27.18	43.64	24.26	37.15

***Mean of three replications HAI- Hours after inoculation**

Factors	S.Em±	CD @ 1%
Temperature (T)	0.30	0.95
Isolate (I)	0.32	0.98
T x I	0.34	1.11

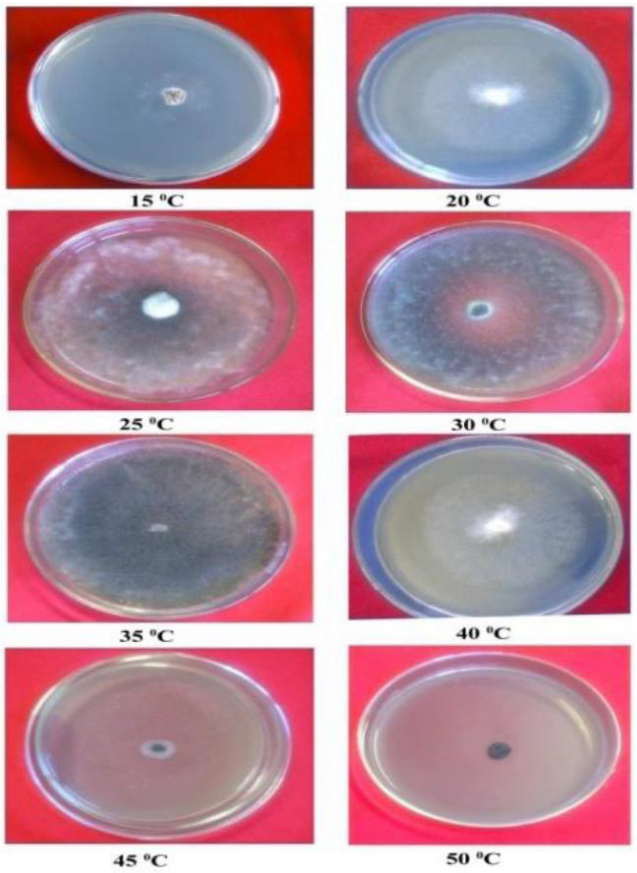

Fig. 1: Effect of temperature on radial growth of *R. bataticola*

black sclerotia. The pathogenecity was proved successfully using Koch postulates and both ITS-1 and ITS-4 primers produced amplified product size of 500-650 bp in all the three isolates indicating that all the isolates belonged to genus *R. bataticola.* Further, nucleotide sequencing for ITS region of 18S rRNA and the BLAST data results revealed that the *R. bataticola* species matched with the reference strains of NCBI and molecularly confirmed as *R. bataticola.* The sequences are deposited in NCBI GeneBank, Maryland, USA along with location of the isolates and accession number Rb1 (KX270355.1), Rb2 (MG001962.1) and Rb3 (HQ392772.1) were obtained.

Effect of temperature on pathogen

The results indicated that the maximum colony growth was observed in Rb3 at 48 h after inoculation, while Rb1 recorded least growth of pathogen. The results also indicated that the temperature levels such as 45 ºC and 50 ºC recorded lesser growth in all the three isolates (Table 1 and Fig. 2). Similarly, at 96 h after inoculation Similarly, the maximum colony growth was of pathogen observed in Rb3 (18.15, 61.00, 75.50, 86.50, 90.00 and 18.00 mm at 15, 20, 25, 30, 35, 40 ºC, respectively) and this was followed by isolate Rb1 (12.55, 50.00, 64.00, 85.00, 90.00 and 17.00 mm) and least growth was observed in Rb2 (10.20, 34.20, 37.00, 47.70, 80.00and 15.00 mm at 15, 20, 25, 30, 35 and 40 ºC, respectively). However, all three pathogen isolates did not grow at 45 and 50 ºC as observed at 48 h after inoculation (Table 1). The present investigations are in line with Srinivas (2016) who reported that significant difference in the radial growth among the isolates of ***R. bataticola*** ranging from 17.7 mm to 80.0 mm at 72 h after incubation. Isolate Rb 14, Rb 17, Rb 22, Rb 26, Rb 49 and Rb 54 showed significantly highest colony growth (80 mm).

Effect of temperature on dry root rot

The maximum disease severity was recorded in Rb3 with 1.7, 3.1, 7.4, 8.2, 9.0 and 3 grade on 1-9 scale followed by Rb1 (1.3, 3.0, 7.2, 8.0, 9.0 and 3.0) at 15, 20, 25, 30, 35 and 40 ºC, respectively. Whereas the least disease severity rating was recorded in Rb2 (1.0, 2.9, 6.7, 7.2, 8.5 and 2.5 at 15, 20, 25, 30, 35 and 40 ºC, respectively (Table 2 and Fig. 2). The correlation results indicated that the negative correlation coefficients (-0.29

Table 2: Effects of temperature regimes on dry root rot disease caused by *R. bataticola* isolates on Annigeri-1 variety

Temperature(˚C)	*Disease severity (1-9 scale)		
	Rb1	Rb2	Rb3
15	1.3	1.0	1.7
20	3.0	2.9	3.1
25	7.2	6.7	7.4
30	8.0	7.2	8.2
35	9.0	8.5	9.0
40	3.00	2.5	3.0
45	0.00	0.00	0.00
50	0.00	0.00	0.00
Mean	3.93	3.60	4.05

*Mean of three replications

Factors	S.Em±	CD @ 1%
Temperature (T)	0.20	0.65
Isolate (I)	0.22	0.72
T x I	0.16	0.69

Table 3: Correlation analysis of temperature regimes on radial growth of *R. bataticola and* disease severity *R. bataticola* isolates on Annigeri-1 variety

Parameters		Correlation coefficient
Radial growth	48 HAI(mm)	-0.29*
	96 HAI(mm)	-0.38*
Disease severity	Rb1	-0.28*
	Rb2	-0.28*
	Rb3	-0.31*

** *Significant at 5% LOS*

and -0.38 for 48 and 96 hours, respectively) between temperature regimes and radial growth of ***R. bataticola*** suggest a weak negative relationship between the two variables (Table 3). This means that as the temperature regime increases, the radial growth of ***R. bataticola*** is likely to decrease. However, the same pattern was observed with disease severity in *R. bataticola* isolates that is as the temperature regime increases, the disease severity by ***R. bataticola*** isolates is likely to decrease (Table 3). Sharma and Pande (2013) reported that the disease incidence of dry root rot was significantly affected by high temperature. Out of five temperature levels *viz.,* 15 °C, 20 °C, 25 °C, 30 °C and 35 °C tested, chickpea predisposed to dry root rot early and severity was more at 35 °C.

Effect of soil moisture on dry root rot

Root length **:** The highest mean root length of three isolates (Rb1, Rb2 and Rb3) was observed in red soil (3.67 cm) compared to the black soil (3.60 cm), but there was no significant difference (Table 4 and 5). Among the three isolates, maximum mean root length of 3.74 cm and 3.90 cm was recorded in both the soils by Rb2 followed by Rb1 (3.59 cm and 3.60 cm). Whereas Rb3 recorded least root

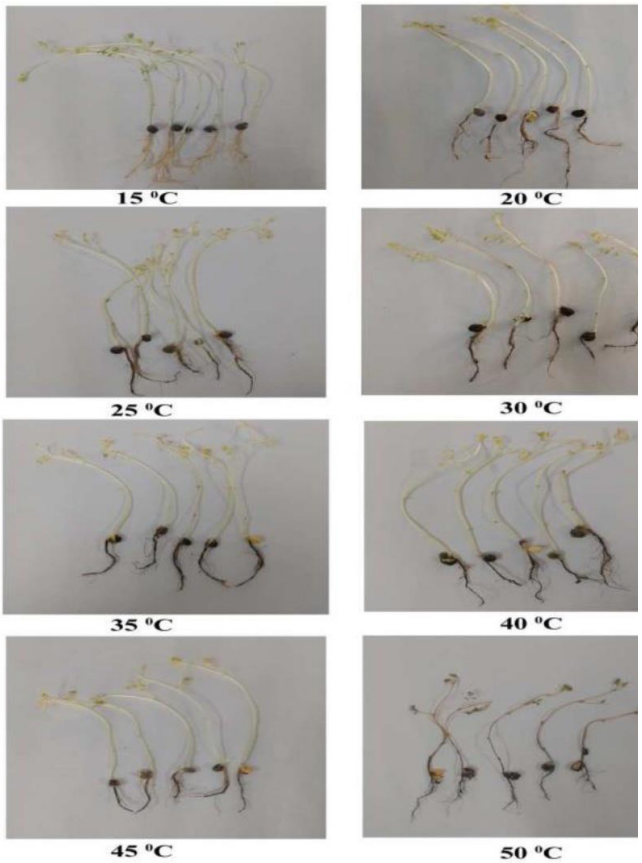

Fig. 2: Effect of temperature regimes on dry root rot disease in chickpea

length in two types of soils (3.43 cm and 3.54 cm).

Among the seven soil moisture regimes tested against the dry root rot and its effect on plant root length, the maximum mean root length was recorded inboth black and red soil at 100% moisture level (4.97 cm and 5.29 cm) followed by 90% (4.45 cm and 4.80 cm) and 80% (4.16 cm and 4.60 cm). The least root length was observed at 40% (2.14 cm and 1.98 cm) soil moisture regime.

Shoot length: The highest mean shoot length of three isolates (Rb1, Rb2 and Rb3) was observed in red soil (19.38 cm) when compared to the black soil (19.29 cm). Among the three isolates, maximum mean shoot length was recorded Rb2 (19.96 cm and 20.26 cm in black and red soil, respectively) followed by Rb1 (19.13 cm and 19.26 cm) and least was observed in Rb3 (18.79 cm and 18.63 cm) (Table 4 and 5).

With respect to seven soil moisture regimes tested against the dry root rot,the maximum mean shoot length was recorded in both black and red soil at 100% (29.56 cm and 29.13 cm, respectively) followed by 90% (29.48 cm and 28.85 cm) and 80% (25.21 cm and 27.14 cm) when compared to least shoot length of 8.45 cm and 7.30 cm at 40% in both soils (Table 4 and 5).

Total biomass**:** The highest mean total biomass of three isolates (Rb1, Rb2 and Rb3) was observed in red soil (1.59 g) compared to the black soil (1.42 g). Among the threeisolates, maximum mean total biomass was in Rb2 (1.89 g and 1.68 g in black and

Table 4 : Effect of soil moisture levels on growth parameters of chickpea in black soil inoculated with *R. bataticola*

Moisture(%)	Growth parameters											
	Root length (cm)				Shoot length (cm)				Total biomass (g)			
	Rb1	Rb2	Rb3	Mean	Rb1	Rb2	Rb3	Mean	Rb1	Rb2	Rb3	Mean
40	2.05	2.10	2.00	2.14	8.20	8.67	8.50	8.45	0.37	0.40	0.38	0.38
50	2.76	2.80	2.70	2.75	10.00	11.00	10.07	10.35	0.45	0.55	0.37	0.45
60	3.10	3.45	3.00	3.18	11.23	11.50	11.00	11.24	0.48	0.65	0.35	0.49
70	3.57	3.55	3.38	3.50	20.10	23.00	19.19	20.76	0.67	0.70	0.61	0.66
80	4.56	4.80	4.00	4.16	25.04	26.00	24.59	25.21	1.10	1.54	1.33	1.32
90	4.16	4.20	4.15	4.45	29.54	29.70	29.20	29.48	3.40	3. 27	3.51	3.45
100	4.88	5.23	4.80	4.97	29.81	29.88	29.00	29.56	3.77	3. 90	3.80	3.82
Mean	3.59	3.74	3.43	3.60	19.13	19.96	18.79	19.29	1.36	1.89	1.35	1.42

*** Mean of three replications**

Factors	S.Em±	CD @ 1%
Moisture (M)	0.29	0.93
Isolates (I)	0.32	1.01
M x I	0.41	1.31

Table 5: Effect of soil moisture levels on growth parameters of chickpea in red soil inoculated with *R. bataticola*

Moisture(%)	Growth parameters											
	Root length (cm)				Shoot length (cm)				Total biomass (g)			
	Rb1	Rb2	Rb3	Mean	Rb1	Rb2	Rb3	Mean	Rb1	Rb2	Rb3	Mean
40	1.84	2.00	2.1	1.98	7.50	7.65	7.00	7.30	0.35	0.50	0.25	0.36
50	2.64	2.67	2.63	2.60	9.53	10.89	9.55	10.00	0.66	0.85	0.70	0.73
60	2.60	3.40	3.00	3.00	11.46	11.66	11.38	11.54	0.60	0.64	0.57	0.60
70	3.33	3.60	3.30	3.46	20.76	26.23	18.00	21.66	0.98	1.00	0.83	0.93
80	4.50	4.75	4.56	4.60	27.20	27.24	27.00	27.14	1.39	1.43	1.35	1.39
90	5.00	5.06	4.35	4.80	29.07	29.00	28.50	28.85	3.54	3.45	3.10	3.35
100	5.24	5.85	4.8	5.29	29.33	29.20	29.00	29.13	3.88	3.90	3.90	3.81
Mean	3.60	3.90	3.54	3.67	19.26	20.26	18.63	19.38	1.61	1.68	1.52	1.59

Factors	S.Em±	CD @1%
Moisture (M)	0.21	0.70
Isolates (I)	0.26	0.82
M x I	0.32	1.06

Table 6: Effect of soil moisture levels on disease severity of dry root rot caused by *R. bataticola* isolates in black soil and red soil

Moisture (%)	Disease severity (1-9 scale)							
	Black soil				Red soil			
	Rb1	Rb2	Rb3	Highestscale	Rb1	Rb2	Rb3	Highestscale
40	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
50	9.0	9.0	9.0	9.0	9.0	9.0	9.0	9.0
60	8.90	8.35	8.91	8.91	9.0	8.45	8.95	8.95
70	7.80	6.60	8.03	8.03	8.00	7.82	8.33	8.33
80	5.00	4.87	5.62	5.62	5.25	5.22	5.73	5.73
90	4. 55	4.32	4. 86	4.86	5.08	4.25	5.40	5.40
100	3.10	2.80	3.30	3.30	3. 16	3.00	3. 56	3.56

***Mean of three replications**

Factors	S.Em±	CD @ 1%
Soil type (S)	0.20	0.81
Isolate (I)	0.23	0.93
Moisture (M)	0.20	0.42
S x I x M	0.35	1.17

red soils, respectively) followed by Rb1 (1.36 g and 1.61 g) and Rb3 (1.35 g and 1.52 g) (Table 4 and 5). Among the seven soil moisture regimes, the maximum mean total biomass was recorded at 100% soil moisture (3.82 g and 3.81 g in black and red soils, respectively) followed by 90% (3.45 g and 3.35 g) and 80% (1.32 g and 1.39 g) in comparison to least moisture level of 40% (0.38 g and 0.36 g) (Table 4 and 5).

Mayek *et al.,* (2002) reported that the stress prone and infected plants had poor growth compared to healthy and irrigated plants. Drought stress showed higher negative effects coupled with *R. bataticola* which attack in vegetative growth of the plant which decreased leaf area and dry weight of all vegetative structures significantly. Srinivas (2016) studied different soil moisture levels on growth of chickpea and reported that 100% and 90% soil moisture levels recorded the highest root length, shoot length and total dry weight of chickpea plants in as observed in present investigation.

Effect of soil moisture on dry root rot incidence

The results indicated that there was significant difference between moisture levels but not with respect to soil types. In black soil the highest disease severity rating was 9.0 grade, 9.0, 8.91, 8.03, 5.62, 4.86 and 3.30 while in red soil, it was 9.0, 9.0, 8.95, 8.33, 5.73, 5.40 and 3.56 at 40, 50, 60, 70, 80, 90 and 100 per cent soil moisture, respectively. The disease severity decreased as the soil moisture increased in both the types of soils (Table 6).

Among the seven levels of moisture content, the disease severity decreased slowlywith respect to the increase in soil moisture. At 40% and 50% soil moisture, there was early development of disease symptoms. Yellowing of leaves was started at ten days after sowing and at twenty days after sowing the plants completely dried and root system was completely black. The plants recorded the highest disease severity grade of 9 in both the soils at 40% and 50% soil moisture. While in 60% (8.91 and 8.95) and 70% (8.03 and 8.33) soil moisture, the dry root symptoms such as yellowing and upward turning of leaflets was started after 20 days after sowing and recorded the moderate disease severity in both black and red soils. The lesser disease severities were recorded at 100% (3.30 and 3.56) followed by 90% (4.86 and 5.40) and 80% (5.62 and 5.73) soil moisture levels in black soil and red soil, respectively.

The results (Table 7) on correlation analysis of moisture levels percentage and growth parameters indicated that, the high correlation coefficients of 0.98, 0.95, and 0.88 in black soil and 0.98, 0.98, and 0.90 in red soil suggest a strong positive relationship between the two variables. This means that as the moisture level increases, the growth parameters such as root length, shoot length and total biomass are also likely to increase. The high negative correlation is observed with -0.94 and -0.93 coefficients values for black and red soil between moisture levels percentage and disease severity. This means that as the moisture level increases, the severity of disease in plants is likely to decrease. The present investigations are in line with Srinivas (2016) who also observed difference in the dry root rot incidence with change in soil moisture content. The plants grown in 50%, 60% soil moisture recorded highest disease severity grade compared to the 80%, 90% and 100% soil moisture. Further, Sharma and Pande (2013) reported that plants exposed to 40% and 60% soil moisture, dry root rot severity was maximum, showed higher mortality as compared to 80% and 100%.

Table 7: Correlation analysis of soil moisture levels on growth parameters of chickpea in black and red soil inoculated with *R. bataticola and* disease severity

Type of soil	Parameters	Correlation coefficient
Black	Root length	0.97**
	Shoot length	0.96**
	Total biomass	0.88**
	Disease severity	-0.94**
Red	Root length	0.98**
	Shoot length	0.95**
	Total biomass	0.90**
	Disease severity	-0.93**

*** Significant at 1% LOS*

Effect of carbon dioxide combined with temperature on growth parameters

Shoot length: Elevated carbon dioxide combined with temperature on phenology of chickpea crop revealed that the highest shoot length of 31.66 cm was observed in open plot followed by 27.66 cm in ambient CO_2 @ 390 ± 25 ppm. These two treatments significantly differed with respect of shoot length in elevated CO_2 @ 550 ± 25 ppm with 2 ºC rise in temperature (12.91 cm) followed by elevated CO_2 @ 550 ± 25 ppm alone (20.33 cm) and 24.58 cm in ambient CO_2 @ 390 ± 25 ppm with 2 ºC rise in temperature. The results indicated that the carbon dioxide alone and coupled with increased temperature has detrimental impact on shoot length of chickpea plants (Fig. 3).

Root length: There was a significant difference between root length of plants in the different carbon dioxide levels tested. Highest root length of 10.41 cm was observed in open plot followed by 7.45 cm in ambient CO_2 @ 390 ± 25 ppm while the least growth of 3.66 cm was observed in elevated CO_2 @ 550 ± 25 ppm with 2 ºC rise in temperature. Further, the treatment that is elevated CO_2 @ 550 ± 25 ppm alone recorded root length of 5.30 cmand it was 6.61cm in ambient CO_2 @ 390 ± 25 ppm with 2ºC rise in temperature. Finally, it is inferred that the elevated carbon dioxide combined with increased temperature of 2 ºC resulted in increased the severity of disease and reduced the root length of plants (Fig. 3).

Number of branches: There was a significant difference between number of branches of plants in the different sets of treatments. The maximum number of branches (17.26) was observed in open plot followed by in ambient CO_2 @ 390 ± 25 ppm (13.33) and ambient CO_2 @ 390 ± 25 ppm with 2 ºC rise in temperature (12.55). In contrast to this, there was a reduction in the number of branches in elevated CO_2 @ 550 ± 25 ppm with 2ºC rise in temperature (8.30) followed by elevated CO_2 @ 550 ± ٢٥ ppmalone (0.29) (Fig. 3).

Total biomass: Maximum total biomass (1.43 g) was recorded in open plot followed by 1.07 g in ambient CO_2 @ 390 ± 25 ppm and 0.85 in ambient CO_2 @ 390 ± 25 ppm with 2ºC rise in temperature (Fig. 3), while least biomass of 0.54 g was recorded in elevated CO_2

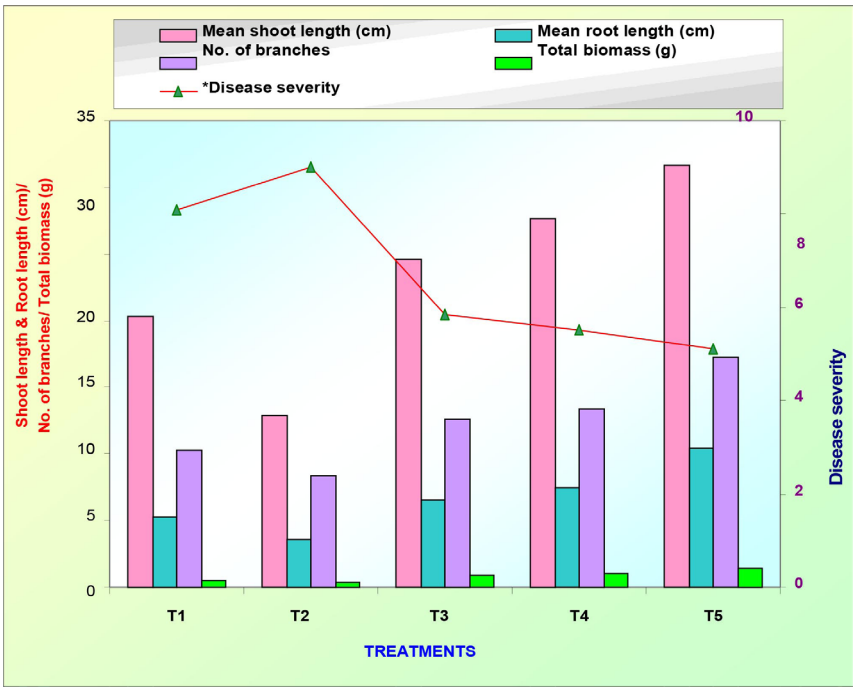

Fig. 3: Effect of elevated carbon dioxide and temperature on growth parameters and disease severity of dry root rot of chickpea

@ 550 ± 25 ppm with 2 ºC rise in temperature (0.36 g) followed by elevated CO_2 @ 550 ± 25 ppm alone. Jagadish *et al*., (2007) who reported that reduction in the weight of grains of pigeon pea under increased temperature with high levels of CO_2. Further, Baker (2004) also studied the effect of elevated CO_2 (700 ppm) under different temperature regimes (24 °C, 28 °C, 32 °C, 36 °C and 40 °C) and reported that there was no increase in grains weight of chickpea under enriched CO_2 combined with high temperature.

Severity of dry root rot

Higher concentration of carbon dioxide alone and in combination with increased temperature of 2 ºC has aggravated the disease. Elevated CO_2 @ 550 ± 25 ppm with 2 ºC rise in temperature showed higher disease severity (9 grade) with early infection showing drying of leaves and wilting of entire plant and roots were completely rotten while open plot recorded least disease severity (5.1 grade). Apart from this, the treatment that is Ambient CO_2 @ 390 ± 25 ppm showed moderate disease severity of 5.50 grade and ambient CO_2 @ 390 ± 25 ppm with 2ºC rise in temperature recorded 5.83 grade (Fig. 3). Similarly, Jagadish *etal*., (2007) studied effect of carbon dioxide on root rot of pigeon pea grown in elevatedCO_2 condition of 550 ± 25 ppm with raised temperature which increased disease incidence in pigeon pea.

ACKNOWLEDGEMENT

Authors are grateful to University of Agricultural Sciences, Raichur for providing facilities to conduct the research work.

Funding: This research received no external funding.

Conflicts of Interest**:** The authors declare no conflicts of interest.

Author Contributions**: G. Sunkad:** Conceptualization, investigation, prepared daft and revise, **D. Dore:** Conceptualization, investigation, prepared daft and revise, statistical analysis of data, **M. Patil:** Daft preparation and reviewing, **R.Joshi:** Daft preparation and reviewing **M. Kumar** statistical analysis of data. All authors have read and agreed to the published version of the manuscript.

Disclaimer: The contents, opinions, and views expressed in the research article published in the Journal of Agrometeorology are the views of the authors and do not necessarily reflect the views of the organizations they belong to.

Publisher's Note: The periodical remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

REFERENCES

Baker, M.A. (2004). Additional sources of resistance of wilt and root rot of chickpea in Bangladesh. *Int. Chickpea News lett.,* 25: 28-29.

Farr, D.F., Bills, G.F., Chamuris, G.P. and Rossman, A.Y. (1995). Fungi on plants and plant products in the United States. 2nd ed. St Paul, MN: APS Press, pp. 1252.

Ghosh, R., Sharma, M., Telangre, R. and Pande, S. (2013). Occurrence and distribution of chickpea diseases in central and southern parts of India. *American J. Plant Sci*., 4: 940-944.

Jagadish, S.V.K., Craufurd, P.Q. and Wheeler, T.R. (2007). High temperature stress and spikelet fertility in rice (*Oryza sativa* L.). *J. Experimental Bot*., 58: 1627-1635.

Khan, S.N. (2007). *Macrophomina phaseolina* as causal agent for

charcoal rot of sunflower. *Mycopathol.,* 5(2): 111-118.

Mayek, N.C., Lopez-Castaneda, J.A. and Acosta-Gallegos (2002). Reaction of Phaseolus germaplasm to *Macrophomina phaseolina. Rev. Fitotec. Mex.,* 25 (1): 35-42.

Murray, M.G. and Thompson, W.F. (1980). Rapid isolation of high molecular weight plant DNA. *Nucleic Acid Res*., 8: 4321.

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

Pande, S., Sharma, M., and Ghosh, R. (2010). Climate Change: Potential Impact on Chickpea and Pigeonpea Diseases in the Rainfed Semi-Arid Tropics (SAT). *In*: 5th International Food Legumes Research Conference (IFLRC V) and 7th European Conference on Grain Legumes, Antalya, Turkey.

Sharma, M. and Pande, S. (2013). Unraveling effects of temperature and soil moisture stress response on development of dry root rot [*Rhizoctonia bataticola* (Taub.)] Butler in chickpea. *American J. Plant Sci.,* 4: 584-589.

Srinivas, P. (2016). Studies on dry root rot [*Rhizoctonia bataticola* (taub.) butler] ofchickpea (*Cicer arietinum*). (Doctoral Dissertation, Professor Jayashankar Telangana State Agricultural University, India).

Van Emden, H.F., Ball, S.L. and Rao, M.R. (1988). Pest diseases and weed problems in pea, lentil and faba bean and chickpea. *Food leg.es,* 519-534.