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Spatio-temporal dynamics of chilli fruit rot incidence in Telangana, India

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Abstract
Chilli (*Capsicum annuum* L.) is one of the most important spice crops in India, but its production is severely constrained by fruit rot caused by *Colletotrichum* spp. To assess the spatial and temporal distribution of the disease, systematic roving surveys were conducted during kharif 2023-24 and 2024-25 across five major chilli-growing districts of Telangana. A total of 20 representative villages were surveyed each year, and mean fruit rot severity was recorded using the Percent Disease Index (PDI). Results revealed that fruit rot was widespread, with severity ranging from 28.88 to 83.33% in 2023-24 and from 24.44 to 84.44% in 2024-25. Warangal and Khammam districts consistently emerged as hotspots with higher PDI values, while Peddapalli and Wanaparthy recorded comparatively lower levels of infection. Varietal response indicated that Teja (S17) was highly susceptible, whereas Super 10 showed moderate tolerance. A year-to-year comparison suggested a slight reduction in disease severity during 2024-25, which may be attributed to seasonal variation and management practices. GIS-based mapping provided clear visualization of spatial distribution and hotspot areas. The findings highlight the urgent need for integrated disease management strategies, deployment of tolerant varieties, and use of spatial epidemiology tools for targeted disease forecasting and mitigation in chilli production systems.

Keywords: Chilli, fruit rot, *Colletotrichum*, disease survey, GIS mapping, Telangana

Introduction

Chilli (*Capsicum annuum* L.) is one of the most economically important spice crops grown worldwide, occupying a unique position as both a vegetable and a spice. India is the leading producer, consumer, and exporter of chilli, accounting for nearly 36% of the global production and more than 25% of international trade in dried chilli (FAOSTAT, 2022) [5]. In India, Telangana, Andhra Pradesh, Karnataka, and Madhya Pradesh are major chilli-producing states, together contributing more than 70% of the total area and production. Among these, Telangana has emerged as a key chilli hub due to its favourable agro-climatic conditions, availability of commercial hybrids, and strong market infrastructure. However, chilli cultivation in the state is challenged by several biotic stresses, of which fruit rot caused by *Colletotrichum* spp. are the most devastating.

Fruit rot disease affects both fresh green and dried red chilli fruits, resulting in pre-and post-harvest losses ranging from 30-50% under endemic conditions and up to 80-100% during epiphytotics (Than *et al.*, 2008; Pakdeevaraporn *et al.*, 2005) [21, 12]. The disease manifests as small, sunken, water-soaked lesions on fruits, which later enlarge and coalesce, leading to complete rotting of fruits and making them unmarketable. Besides yield reduction, the pathogen also affects seed quality, germination, and export potential due to stringent phytosanitary restrictions (Saxena *et al.*, 2016) [16].

The disease is primarily associated with *Colletotrichum truncatum*, *C. scovillei*, and *C. acutatum* in India, with *C. truncatum* reported as the predominant species in South India (Than *et al.*, 2008; Sharma *et al.*, 2019) [21, 18, 19]. The pathogen survives in infected crop residues, alternate weed hosts, and seed, contributing to its persistence across cropping seasons (Manandhar *et al.*, 1995) [7]. The warm and humid climate of Telangana, especially during the kharif season (July-October), provides a congenial environment for disease outbreaks. High rainfall, relative humidity (>80%), and temperatures between 25-30 °C have been identified as critical epidemiological factors for fruit rot development (Pakdeevaraporn *et al.*, 2005) [12].

Varietal susceptibility plays a key role in disease severity. Teja (S17), a widely cultivated variety in Telangana due to its high pungency and export demand, has been consistently reported as highly susceptible to fruit rot (Saxena *et al.*, 2016; Rani *et al.*, 2020) [16, 14]. In contrast, hybrids like Super 10 have shown relatively better tolerance. Continuous cultivation of susceptible varieties, coupled with monocropping and inadequate disease management, aggravates the disease burden.

Management of chilli fruit rot relies heavily on fungicides, particularly triazoles and strobilurins. While chemical control provides temporary relief, frequent applications increase production costs and raise concerns about fungicide resistance (Sharma *et al.*, 2019) [18, 19]. Biological control using antagonists like *Trichoderma* spp. and *Bacillus* spp., and cultural practices such as field sanitation and crop rotation, have shown promise but are often adopted at low levels by farmers (Sharma *et al.*, 2019) [18, 19]. Development and deployment of resistant varieties remain the most sustainable strategy, but progress has been hampered by limited sources of durable resistance (Pakdeevaraporn *et al.*, 2005; Montri *et al.*, 2009) [12, 9].

Disease surveys are critical for understanding the spatial distribution, temporal dynamics, and varietal susceptibility to fruit rot. Such surveys provide baseline epidemiological information, help identify hotspot locations for screening resistant genotypes, and support the development of forecasting models (Than *et al.*, 2008; Saxena *et al.*, 2016) [21, 16]. Although chilli fruit rot has been extensively reported in Andhra Pradesh and Karnataka, systematic documentation from Telangana is scarce. Given the state's prominence in chilli production, updated surveys are essential for guiding breeding and integrated management strategies.

Therefore, the present study was undertaken to assess the incidence and severity of fruit rot disease of chilli in major growing districts of Telangana during kharif 2023-24 and 2024-25. The objectives were to (i) document the district-wise distribution of chilli fruit rot, (ii) identify hotspot regions and susceptible varieties, and (iii) compare year-to-year variations in disease severity. The findings will provide crucial baseline information for breeding programs, disease forecasting, and integrated disease management in Telangana.

Materials and Methods

Survey locations and cropping season

Disease surveys were conducted during kharif 2023-24 and 2024-25 in major chilli-growing districts of Telangana, namely Khammam, Peddapalli, Suryapet, Wanaparthy, and Warangal. These districts were selected based on their high acreage under chilli. Surveys were carried out during kharif, coinciding with the peak fruiting stage when fruit rot symptoms are most evident.

Field survey procedure

A roving survey method (Singh *et al.*, 2009) [20] was adopted to cover representative farmer fields in each district. In each district, 4 villages were selected and from each village at least 2-3 fields were surveyed. A diagonal walking pattern was followed in each field, and ten plants per field were randomly selected for disease scoring. Observations were recorded on different chilli varieties/hybrids cultivated by farmers.

Recording of disease severity

Disease severity (Percent Disease Index, PDI) was estimated using the 0-9 scale proposed by Mayee and Datar (1986) [8], where:

Scale	Symptoms description
0	No symptoms
1	<1% fruit area infected (tiny pinhead lesions)
3	1-10% fruit area infected (few small sunken spots)
5	11-25% fruit area infected (moderate lesions on fruits)
7	26-50% fruit area infected (large coalescing lesions, fruit partially rotted)
9	>50% fruit area infected (severe rotting, unmarketable fruit)

The PDI was calculated as:

PDI = ∑ (Numerical rating)/Total fruits observed x maximum rating X 100

For each field, a minimum of 50 fruits per variety were examined across randomly selected plants to calculate the mean PDI.

Data analysis

The data collected from all districts were pooled separately for 2023-24 and 2024-25 cropping seasons. District-wise mean disease severity was calculated using Microsoft Excel and SPSS (v.26) statistical software. Analysis included: Mean and range of PDI across districts, Comparative analysis of year-to-year variation in disease severity and Graphical representation using bar charts to visualize distribution trends.

Results

Disease prevalence across surveyed districts

The survey conducted during kharif 2023-24 and 2024-25 revealed that fruit rot of chilli was prevalent in all the major chilli-growing districts of Telangana, albeit with varying intensities. Disease severity, expressed as Percent Disease Index (PDI), ranged from 28.88 to 83.33% in 2023-24 and from 24.44 to 84.44% in 2024-25 (Tables 1 and 2).

District-wise mean disease severity

The mean PDI values indicated clear district-level differences (Fig. 1). Warangal consistently recorded the highest disease severity with mean PDI of 79.16% (2023-24) and 76.38% (2024-25). Among villages, Singaram (83.33-84.44%) and Bollikunta (78.88-80.00%) were identified as hotspot locations. Khammam also exhibited high incidence with mean PDI of 69.44% (2023-24) and 64.44% (2024-25), indicating that the region is highly vulnerable to fruit rot. Suryapet recorded moderate levels of disease with mean PDI values of 62.77% (2023-24) and 54.72% (2024-25). Wanaparthy showed comparatively lower severity (41.66% in 2023-24 and 42.27% in 2024-25). Peddapalli had the least severity, with mean PDI of 32.22% (2023-24) and 26.66% (2024-25). Overall, the disease severity was relatively higher in 2023-24 compared to 2024-25 in most districts (Table 1 and 2), suggesting possible influence of seasonal variations in rainfall and humidity on pathogen spread.

Varietal susceptibility

The variety-wise survey revealed differential susceptibility: Teja (S17), Cultivated predominantly in Khammam, Peddapalli, and Warangal, this variety exhibited high to very high susceptibility, with PDI values ranging from 28.88-83.33% in 2023-24 and 24.44-84.44% in 2024-25. In hotspot villages such as Singaram and Mamnoor (Warangal), disease severity exceeded 80%, classifying Teja as highly susceptible (HS). Whereas Super 10, Grown mostly in Suryapet and Wanaparthy, this hybrid showed moderate susceptibility, with PDI values ranging from 37.77-66.66% in 2023-24 and 35.55-60.00% in 2024-25. The lowest disease severity was recorded in Kanimetta (35.55% in 2024-25) and the highest in Jeellacheruvu (66.66% in 2023-24). Thus, while both varieties were susceptible, Super 10 performed relatively better compared to Teja, especially in less favourable environments like Wanaparthy.

Year-to-year variation in disease intensity

A comparison of the two consecutive years indicated that disease severity declined slightly in 2024-25 across most districts (Fig. 1). The reduction was more prominent in Peddapalli (-5.56% mean PDI) and Khammam (-5.00%), while in Wanaparthy, the disease severity remained almost constant across years. Interestingly, Warangal showed only a marginal decline (-2.78%), with Singaram village continuing to be a persistent hotspot.

Identification of hotspot areas

Based on pooled analysis across two years, Warangal (Singaram, Mamnoor, Bollikunta, Gavicherla) and Khammam (Konijarla, Venkatayapalem) were identified as hotspot locations for chilli fruit rot, where disease severity consistently exceeded 70% PDI (Table 3 and Fig.2). These areas represent ideal sites for screening breeding material and fungicidal efficacy trials.

In Fig. 3 Panel A shows a PDI-weighted heat map for 2023-24, with high-intensity hotspots concentrated in Warangal (Singaram, Bollikunta, Mamnoor) and Khammam (Konijarla, Venkatayapalem). Panel B illustrates the corresponding heat map for 2024-25, where hotspots remained in Warangal and Khammam but with comparatively lower intensity in Khammam villages. Panel C presents village-level severity for 2023-24 using a bubble map, where larger bubble sizes denote higher mean percent disease index (PDI). The most severe incidence (PDI $\geq$ 80) was recorded in Singaram (83.33%) and Bollikunta (80.00%) villages. Panel D shows village-level incidence for 2024-25, with Singaram again exhibiting the highest severity (84.44%), followed by Bollikunta (78.88%). Overall, both heat maps and bubble plots demonstrate consistent hotspot regions across years, with slightly reduced disease intensity in Khammam and Peddapalli districts in 2024-25 compared with 2023-24.

Table 1: Survey on chilli fruit rot disease severity in Telangana during *kharif* 2023-24

Sl. No	Villages	District	Latitude	Longitude	Variety	*Mean fruit rot severity (PDI)
1	Konijarla	Khammam	17.2227	80.2940	Teja (S17)	71.11
2	Tanikella	Khammam	17.2407	80.2603	Teja (S17)	68.88
3	Venkatayapalem	Khammam	17.2491	80.1400	Teja (S17)	73.33
4	Wyra	Khammam	17.1921	80.3600	Teja (S17)	64.44
5	Brahamanapalli	Peddapalli	18.6170	79.3831	Teja (S17)	33.33
6	Gundaram	Peddapalli	18.6383	79.4889	Teja (S17)	28.88
7	Hanumanthunipet	Peddapalli	18.61702	79.38317	Teja (S17)	31.11
8	Penchikalpet	Peddapalli	18.6170	79.3831	Teja (S17)	35.55
9	Gopalraopeta	Suryapet	17.23034	80.02342	Super 10	62.22
10	Jeellacheruvu	Suryapet	17.23199	80.01611	Super 10	66.66
11	Keshavapuram	Suryapet	17.23469	79.99602	Super 10	64.44
12	Gaddipally	Suryapet	16.9642	79.7120	Super 10	57.77
13	Gummadam	Wanaparthy	16.0926	78.0592	Super 10	40.00
14	Kanimetta	Wanaparthy	16.4350	77.9383	Super 10	42.22
15	Palem	Wanaparthy	16.4044	77.9408	Super 10	46.66
16	Rayanipet	Wanaparthy	16.3147	77.9646	Super 10	37.77
17	Bollikunta	Warangal	17.8914	79.6157	Teja (S17)	80.00
18	Gavicherla	Warangal	17.8726	79.6663	Teja (S17)	75.55
19	Mamnoor	Warangal	17.90827	79.57855	Teja (S17)	77.77
20	Singaram	Warangal	17.90832	79.57848	Teja (S17)	83.33

Table 2: Survey on chilli fruit rot disease severity in Telangana during *kharif* 2024-25

Sl. No	Villages	District	Latitude	Longitude	Variety	*Mean fruit rot severity (PDI)
1	Konijarla	Khammam	17.2227	80.2940	Teja (S17)	66.66
2	Tanikella	Khammam	17.2407	80.2603	Teja (S17)	63.33
3	Venkatayapalem	Khammam	17.2491	80.1400	Teja (S17)	67.77
4	Wyra	Khammam	17.1921	80.3600	Teja (S17)	60.00
5	Brahamanapalli	Peddapalli	18.6170	79.3831	Teja (S17)	30.00
6	Gundaram	Peddapalli	18.6383	79.4889	Teja (S17)	24.44
7	Hanumanthunipet	Peddapalli	18.61702	79.38317	Teja (S17)	26.66
8	Penchikalpet	Peddapalli	18.6170	79.3831	Teja (S17)	25.55
9	Gopalraopeta	Suryapet	17.23034	80.02342	Super 10	55.55
10	Jeellacheruvu	Suryapet	17.23199	80.01611	Super 10	60.00
11	Keshavapuram	Suryapet	17.23469	79.99602	Super 10	53.33
12	Gaddipally	Suryapet	16.9642	79.7120	Super 10	50.00
13	Gummadam	Wanaparthy	16.0926	78.0592	Super 10	44.44
14	Kanimetta	Wanaparthy	16.4350	77.9383	Super 10	35.55
15	Palem	Wanaparthy	16.4044	77.9408	Super 10	42.22
16	Rayanipet	Wanaparthy	16.3147	77.9646	Super 10	48.88
17	Bollikunta	Warangal	17.8914	79.6157	Teja (S17)	78.88
18	Gavicherla	Warangal	17.8726	79.6663	Teja (S17)	70.00
19	Mamnoor	Warangal	17.90827	79.57855	Teja (S17)	72.22
20	Singaram	Warangal	17.90832	79.57848	Teja (S17)	84.44

Table 3: Pooled chilli fruit rot disease severity in Telangana during *kharif* 2023-24 and 2024-25

Sl. No	Villages	District	Latitude	Longitude	Mean fruit rot severity (PDI)-pooled data		Mean fruit rot severity (PDI%)
					2023-24	2024-25	
1	Konijarla	Khammam	17.2227	80.2940	71.11	66.66	68.89
2	Tanikella	Khammam	17.2407	80.2603	68.88	63.33	66.11
3	Venkatayapalem	Khammam	17.2491	80.1400	73.33	67.77	70.55
4	Wyra	Khammam	17.1921	80.3600	64.44	60.00	62.22
5	Brahamanapalli	Peddapalli	18.6170	79.3831	33.33	30.00	31.67
6	Gundaram	Peddapalli	18.6383	79.4889	28.88	24.44	26.66
7	Hanumanthunipet	Peddapalli	18.61702	79.38317	31.11	26.66	28.89
8	Penchikalpet	Peddapalli	18.6170	79.3831	35.55	25.55	30.55
9	Gopalraopeta	Suryapet	17.23034	80.02342	62.22	55.55	58.89
10	Jeellacheruvu	Suryapet	17.23199	80.01611	66.66	60.00	63.33
11	Keshavapuram	Suryapet	17.23469	79.99602	64.44	53.33	58.89
12	Gaddipally	Suryapet	16.9642	79.7120	57.77	50.00	53.89
13	Gummadam	Wanaparthy	16.0926	78.0592	40.00	44.44	42.22
14	Kanimetta	Wanaparthy	16.4350	77.9383	42.22	35.55	38.89
15	Palem	Wanaparthy	16.4044	77.9408	46.66	42.22	44.44
16	Rayanipet	Wanaparthy	16.3147	77.9646	37.77	48.88	43.33
17	Bollikunta	Warangal	17.8914	79.6157	80.00	78.88	79.44
18	Gavicherla	Warangal	17.8726	79.6663	75.55	70.00	72.78
19	Mamnoor	Warangal	17.90827	79.57855	77.77	72.22	75.00
20	Singaram	Warangal	17.90832	79.57848	83.33	84.44	83.89

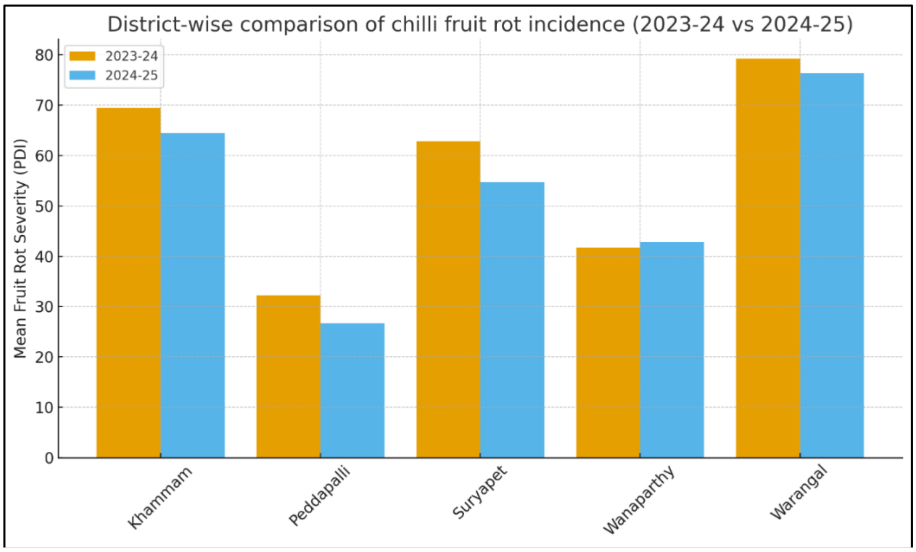

Fig 1: Graph shows the district-wise mean fruit rot severity (PDI) comparison for 2023-24 and 2024-25

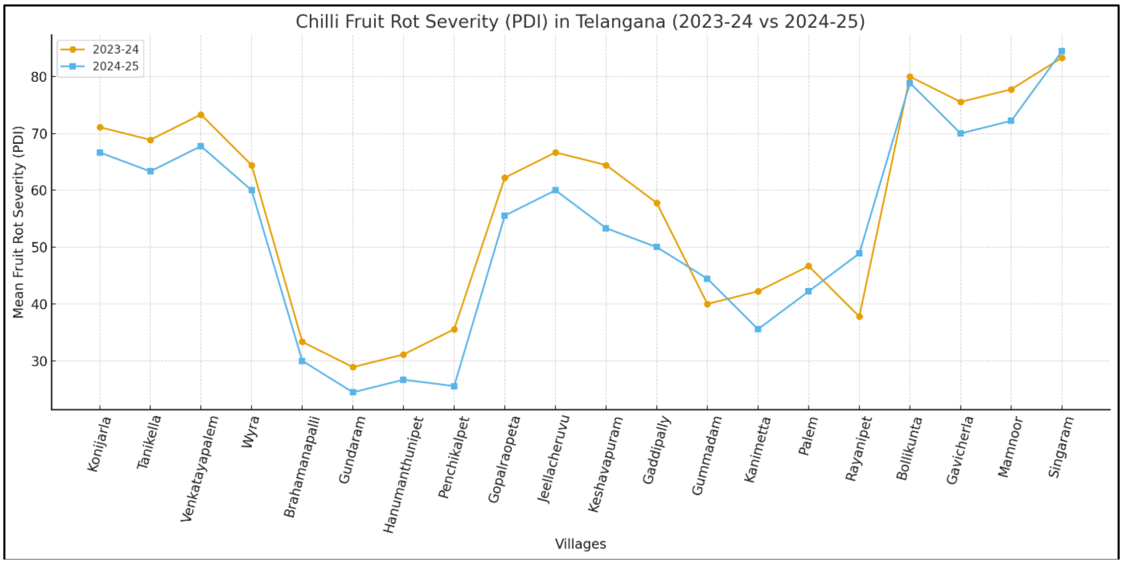

Fig 2: Comparative line graph of chilli fruit rot severity (PDI) across Telangana villages for 2023-24 vs 2024-25.

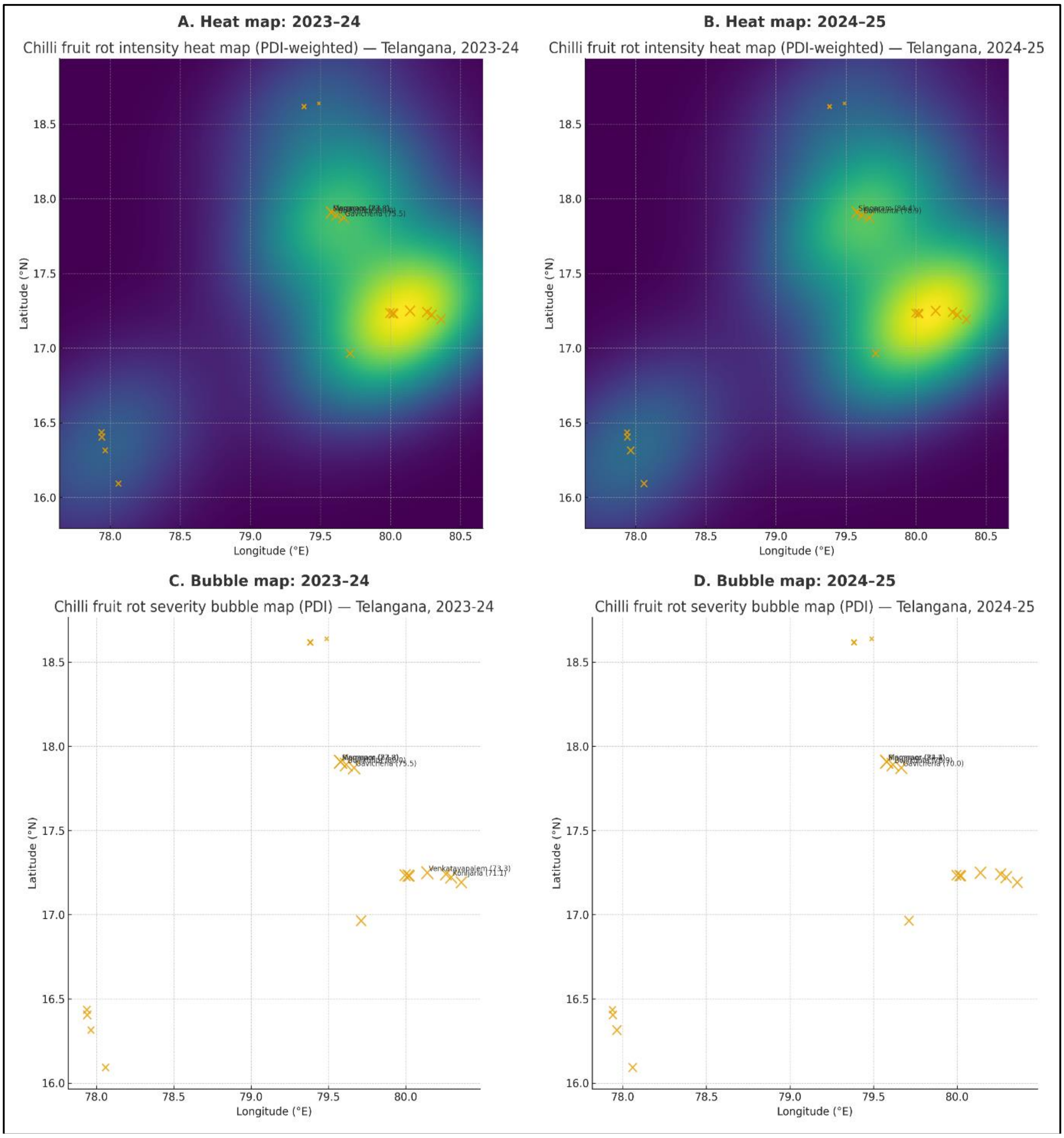

Fig 3: Spatial patterns of chilli fruit rot disease severity in Telangana during kharif 2023-24 and 2024-25.

Discussion
Chilli (*Capsicum annuum* L.) is one of the most important spice crops cultivated in India, valued for its pungency, flavour, nutritional significance, and export potential (Bosland and Votava, 2012) [1]. Telangana is a major chilli-producing state, contributing significantly to national production and international trade (DPPQS, 2022) [4]. However, the crop is highly vulnerable to several diseases, among which fruit rot, predominantly caused by *Colletotrichum* spp., is considered one of the most destructive (Than *et al.*, 2008; Saxena *et al.*, 2016) [21, 16]. The disease is favoured by warm and humid weather during the kharif season and may cause yield losses ranging from 50% to 80% under severe epidemics (Rao *et al.*, 2014; Chowdappa *et al.*, 2015) [15, 3]. Regular monitoring of the disease and mapping its distribution are essential to understand its epidemiology and design targeted management strategies. Geographic Information System (GIS)-based surveys have proven to be powerful tools in visualizing disease hotspots and aiding forecasting efforts (Nelson *et al.*, 1999; Chakraborty and Newton, 2011) [10, 2]. In this context, the present study was undertaken to assess the spatial and temporal variability of chilli fruit rot incidence in Telangana during 2023-24 and 2024-25 and to identify varietal susceptibility under natural field conditions.
The present survey revealed substantial spatio-temporal variation in chilli fruit rot incidence across major chilli-growing districts of Telangana during two consecutive kharif seasons (2023-24 and 2024-25). Mean fruit rot severity, expressed as percent disease index (PDI), ranged from 28.88-83.33% in 2023-24 and 24.44-84.44% in 2024-25, indicating that the disease continues to pose a serious threat to chilli production in the region. The study revealed that chilli fruit rot is widely prevalent in Telangana, with Warangal and Khammam consistently identified as hotspots. These results align with earlier studies reporting high fruit rot incidence in central India under humid conditions (Pakdeevaraporn *et al.*, 2005) [12]. These results also align with earlier studies reporting high fruit rot incidence in Telangana (Kavya *et al.*, 2024) [6].

Spatial patterns and hotspots
The GIS-based maps and PDI-weighted heat surfaces clearly identified Warangal and Khammam districts as consistent hotspots, with several villages (e.g., Singaram, Bollikunta, Mamnoor, Konijarla, and Venkatayapalem) recording PDI values above 75% in both years. This persistence suggests a favourable microclimate for pathogen survival and epidemic development in these districts. In contrast, Peddapalli and Wanaparthy districts exhibited comparatively lower mean severity (< 40% in most surveyed villages), suggesting either reduced pathogen pressure or varietal and agronomic differences. The slightly reduced intensity in Khammam during 2024-25 compared to 2023-24 may be attributed to seasonal rainfall variation, altered crop management, or increased farmer awareness of fungicide applications.

Varietal susceptibility
Two major commercial varieties were surveyed: Teja (S17) and Super 10. Results suggest that Teja (S17) exhibited consistently higher severity (up to 83.33% in 2023-24 and 84.44% in 2024-25), particularly in Warangal and Khammam. In contrast, Super 10 recorded moderate disease severity, generally ranging from 35-66% across surveyed districts. This aligns with previous reports that varietal differences significantly influence fruit rot severity (Sharma *et al.*, 2019; Priya *et al.*, 2021) [18, 19, 13]. The relatively lower disease severity on Super 10 suggests a degree of tolerance, though not complete resistance, highlighting the importance of breeding for durable resistance to *Colletotrichum* spp.

Temporal differences
Although overall disease patterns were similar across the two seasons, the second year (2024-25) showed a slight reduction in mean severity in most districts (Khammam, Peddapalli, and Suryapet). This may be due to lower rainfall distribution during the critical fruiting stage, adoption of improved crop protection practices, or changes in sowing windows. However, the persistence of severe epidemics in Warangal indicates that environmental conduciveness and inoculum buildup can override seasonal fluctuations. Such year-to-year variability has been widely reported in chilli pathosystems (Oh *et al.*, 2017; Sharma *et al.*, 2019) [11, 18, 19].

Epidemiological implications
The clustering of hotspots suggests localized inoculum reservoirs, possibly from crop residues, volunteer plants, or continuous chilli cultivation. In Warangal, where chilli is cultivated intensively, pathogen carryover may sustain high inoculum loads. Similarly, microclimatic factors such as prolonged leaf wetness, high humidity, and moderate temperatures during kharif Favor rapid fruit infection and disease spread. GIS mapping in this study demonstrates its utility in delineating high-risk zones, enabling targeted disease forecasting and management interventions.

Conclusion
The two-year survey confirmed chilli fruit rot as an endemic and severe problem in Telangana. Warangal and Khammam districts were identified as major hotspots, with Teja (S17) highly susceptible. Super 10 showed relatively better tolerance. These findings provide critical baseline information for designing integrated management strategies and guiding resistance breeding programs.

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