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Status of Grain Discoloration Disease in Paddy Growing Ecosystems of Karnataka, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Among different diseases that affect rice crops, grain discoloration disease (GD) is one of the emerging diseases in all rice cultivating areas around the world. Though the disease has recently emerged, it is catching the attention of the scientific and farming community due to its qualitative and quantitative loss. Since the disease is a highly complex disease caused by multiple pathogens,

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thus its management is challenging. As the disease is still in the emerging stage, its incidence and severity in different rice ecosystems are still not available. Assessment of disease incidence, severity, and yield loss is very crucial for disease management. We carried out an intensive roving survey to assess the incidence of GD across Karnataka. An intensive roving survey was conducted across 130 villages, covering 192 paddy-growing locations and 14 districts of six major rice-growing ecosystems in Karnataka state, India. The highest disease incidence (98) was recorded in Sutturu village of Nanjanagud Taluk of Mysuru District of Kaveri ecosystem. In contrast, the lowest disease incidence (3) was recorded in the Kadakal village of Shahpur taluk of Yadgir District of Upper Krisha Project (UKP) of Karnataka state. Among six distinct ecosystems, the highest mean disease incidence was recorded in the coastal ecosystem (85.11), followed by the Kaveri ecosystem (74.34), which is considered a hot spot for GD incidence. Upper Krishna Project (UKP) and Thunga Bhadra Project (TBP) are considered less risky regions for GD. Analyzing hotspots for GD in Karnataka aids in formulating ecosystems and ecologically specific disease management practices. This study also helps to identify rice cultivars distributed and the disease incidence observed. The highest disease incidence was recorded in bold-seeded cultivars such as Jyothi, KCP-1, Sahyadri Panchamukhi, MO-4, MTU-1001, Kempu Jyothi, Kaje 25-9, Kaje Jaya, Godavari, IR-64, Meenakshi, Sahyadri Kempumukthi, Abhilash, Guttasale, Gandhasale, Uma with more than 90 disease incidence. Whereas the lowest disease incidence was recorded in small and slender seeded cultivars such as Cross Sona, Sona and Gandu Sona, RNR-15048, Nellore Sona, MTU-1010, BPT-5204 recording < 10 disease incidence. This is the first intensive study to document the status of GD in the distinct rice ecosystems of Karnataka.

Keywords: Grain discoloration; rice; disease incidence; hot spots; ecosystems; cultivars; disease management.

1. INTRODUCTION

Rice (*Oryza sativa* L.) is the most important staple food crop that suffers from various biotic and abiotic agents, resulting in huge losses to the farming community. India is one of ajor country that contribute to rice production. ; India alone accounted for 47.8 million acres of area, producing 135.7 million tons. In Karnataka, rice cultivation accounts for 13.28 lakh ha, with a production of 42.80 lakh tons and a productivity of 3223 kg ha^{-1} (Indiastat, 2023). In Karnataka, rice is being cultivated in six major ecosystems covering various districts such as Koppal, Raichur, Yadgir, Ballari, Vijayanagara, Shivamogga, Davanagere, Udupi, Dharwad, Haveri, Uttara Kannada, Mysuru, Mandya, and Chamarajanagara covering various paddy growing ecosystems of Karnataka (Muniraju et al., 2017a; Pramesh et al., 2020a; Pramesh et al., 2020b, Amoghavarsha et al., 2022a; Amoghavarsha et al., 2022b; Amoghavarsha et al., 2022c; Amoghavarsha et al., 2021; Huded et al., 2022; Raghunandana et al., 2023a; Raghunandana et al., 2023b; Sharanabasav et al., 2021). Rice production in Karnataka state was limited due to various pests and diseases. Rice crop is attacked by more than 76 pathogens, including fungi, bacteria, viruses, and mycoplasma-like organisms, causing various diseases in the field and storage (Mustafa and Mohsan, 2017; Pampana et al., 2019). Among the several biotic constraints, diseases caused by fungi, bacteria, viruses, and nematodes cause major economic losses. Among the biotic stresses, diseases are continuously causing much more damage than ever before under the influence of changing environmental conditions. Apart from the major diseases such as leaf blast, neck Blast, sheath blight, brown leaf spot, bacterial leaf blight, false smut and tungro disease, various minor diseases significantly affect paddy production (Sharanabasav et al., 2021; Sharanabasav et al., 2020; Huded et al., 2022; Raghunandana et al., 2023b, Amoghavarsha et al., 2022a, Amoghavarsha et al., 2022c; Muniraju et al., 2017b). Among minor diseases, rice grain discoloration (GD) has recently emerged with high incidence and severity, posing a major threat to rice cultivation (Ramesh and Lokesh., 1996; Sharanabsav et al., 2023; Sharanabasav et al., 2022b, Sharanabasav et al., 2023a, Sharanabasav et al., 2023b, Sharanabasav et al., 2023c). Grain discoloration was also recorded as Dirty panicle, Grain rot, Glume blight, Panicle blight, etc., in the previous reports (Zeigler and Alvarez. 1989; Raghu et al., 2018; Sharanabasav et al., 2023b).

GD is a serious problem in rice, which affects the grain quality and quantity, decreases the value of rice crop, and causes a great loss in grain and seed production (Sharanabasav et al., 2023b, Raghu et al., 2020; Prathuangwong et al. 2013). Brown patches on rice hulls and discolored rice grains were signs of infection that began in the early boot stage, however symptoms will express only after the panicle emergence. Infected rice seeds will have minimum germination, and when seedlings eventually emerge, they are malformed or abnormal in size, shape, color, and weight. Infected rice seeds carrying pathogenic fungi also act as a source of inoculum for new season. Caused by a number of fungal pathogens, including pathogenic and saprophytic pathogens from field and storage, the predominant fungi being *Fusarium* spp., *Curvularia lunata, Pyricularia oryzae*, *Helminthosporium oryzae* and some other weak saprophytic fungi like *Alternaria* species, *Cercospora* spp. *Saracladium oryzae* and *Rhizoctonia solani* which depends on the existing environmental conditions and also depends on cultivars distributed (Abdelmonem, 2000). Causal agents of GD and their effect on the seed quality were previously described (Kumar et al., 2021). Multiple fungal species *viz*., *Bipolaris* (=*Drechslera*) *oryzae*, *Alternaria padwickii, Alternaria alternata, Pyricularia oryzae, Fusarium moniliformae, Fusarium graminaerum, Nigrospora oryzae, Epicoccum nigrum, Curvularia lunata, Phoma sorghina, Aspergillus niger* and *Aspergillus flavus* (Teja et al., 2018)., bacterial pathogens such as *Burkholderia gladeoli*, *B. glumae*, *P. ananitis*, *P. agglomerans, Pseudomonas oryzhihabitans* also said to be associated with GD (Nandakumar et al., 2009; Hou et al., 2020; Kim et al., 2021). These pathogens were reported to cause seed discoloration, seed rot, reduced seed germination, and reduced seedling vigor, making the plants more susceptible and weaker during their early growth period. Fungal pathogens which are reported to be seed-borne are majorly challenging to manage because of their firm establishment as dormant deep seated fungal hyphae in different seed compartments such as embryo, glume, and endosperm (Butt et al., 2011).

Grain discoloration incidence and distribution previously been reported from various states of India. However, studies on the evaluation of disease incidence from all traditional rice-growing ecosystems of Karnataka were still unclear. Some studies reported 2 to 19 per cent of GD incidence was from Kymore Plateau and Satpura Zone of Madhya Pradesh (Teja et al., 2018). In 2017, Yadahalli and Konnur surveyed for grain discoloration disease in northern Karnataka. However, the assessment of disease incidence across the different paddy-growing ecosystems was not clearly mentioned. Thus, in this study, formulated objectives for conducting an intensive survey for GD disease assessment in the entire Karnataka covering six major paddy-cultivating ecosystems of Karnataka, wherever the paddy is being cultivated. In India, no varieties have been found to be completely resistant to grain discoloration disease. However, some tolerant entries were recently nominated for release against GD (Anon., 2019). Still, QTL’s associated with GD resistance identification from these local landraces and popular cultivars lacking in India. Thus, during the survey aimed to identify and search for some resistant/tolerant cultivars.

Since GD is one of the minor but emerging diseases across paddy-growing countries of the world, clear data on disease incidence across the traditional paddy-growing ecosystems of Karnataka is still lacking. Karnataka state is known for diverse agro-ecological zones cultivating very wide variety of cultivars including landraces, unexplored farmer-saved rice seeds, and elite varieties with superior agronomical traits. Thus, it’s essential to conduct a survey to assess GD across the various locations of Karnataka. This study highlights the complete GD status across Karnataka state, covering all soil types, Irrigation methods, and cultivars.

2. MATERIALS AND METHODS

Survey area: A random roving survey was conducted across six traditional paddy-growing ecosystems of Karnataka, such as, the Upper Krishna Project (UKP), Thunga Bhadra Project (TBP), Kavery ecosystem, Hilly ecosystem, Irrigated Bhardra ecosystem, and Coastal ecosystem covering various districts covering different agro-ecological zones along with geographical coordinates were being noted during survey. Districts included were Ballari, Chamarajanagara, Davanagere, Dharwad, Haveri, Koppal, Mandya, Mysuru, Raichur, Shivamogga, Udupi, Uttara Kannada, Vijayanagara, Yadgir representing a range of diverse ecologies such as Irrigated, Rainfed, lowland, upland and direct sown conditions with the aim of covering the data on all paddy cultivating conditions across Karnataka (Table 1).

Sampling site and fields: A total of 192 sampling sites covering fourteen districts were surveyed, including thirty-seven Taluks’, covering 130 villages. Geographical coordinates were noted along with the cultivar name. A total radius of approximately 1347 km of paddy cultivating areas of Karnataka were surveyed, representing different sampling sites (Fig. 1). The survey was conducted in *Kharif*-2021, from the grain filling stage to the harvesting stage, since the grain discoloration symptoms appear only upon panicle emergence.

Observations recorded: Initially, a 1 m^2 area was marked and selected randomly across the various locations of the field by using a sq. measuring steel tool. The total number of hills, the total number of productive panicles per hill, and the total number of infected panicles in each hill were noted. The number of discolored panicles was noted.

$$\text{Disease Incidence (\%)} = \frac{\text{Number of discolored panicles}}{\text{Total number of panicles sampled}} \times 100$$

Disease incidence i.e., per cent infected tillers, was calculated based on the formula mentioned above. Ecosystem mean disease incidence was noted (Table 2). Based on recorded observations, we identified cold spots and hot spots for the GD.

Data collection and statistical analysis: Data on the disease incidence was taken for all surveyed locations, and additional information on the cultivars grown was noted. Other relevant data on field cultivation history and varieties being cultivated was noted (Data not shown). Collected data were analyzed using appropriate statistical methods such as ANOVA to compare the disease incidence across the ecosystem. Maps were created using Google Maps- a web-based, free user interface (https://www.google.com/maps/d/u/0/edit?mid=1uRisKQ_asTeUtGB8_3qdeeg0ZOFnPhk&ll=14.549266600246993%2C73.71871723541598&z=8) . Maps showed sampling sites, cultivars identified, and disease incidence (Fig. 2). A disease distribution map was created using R studio software.

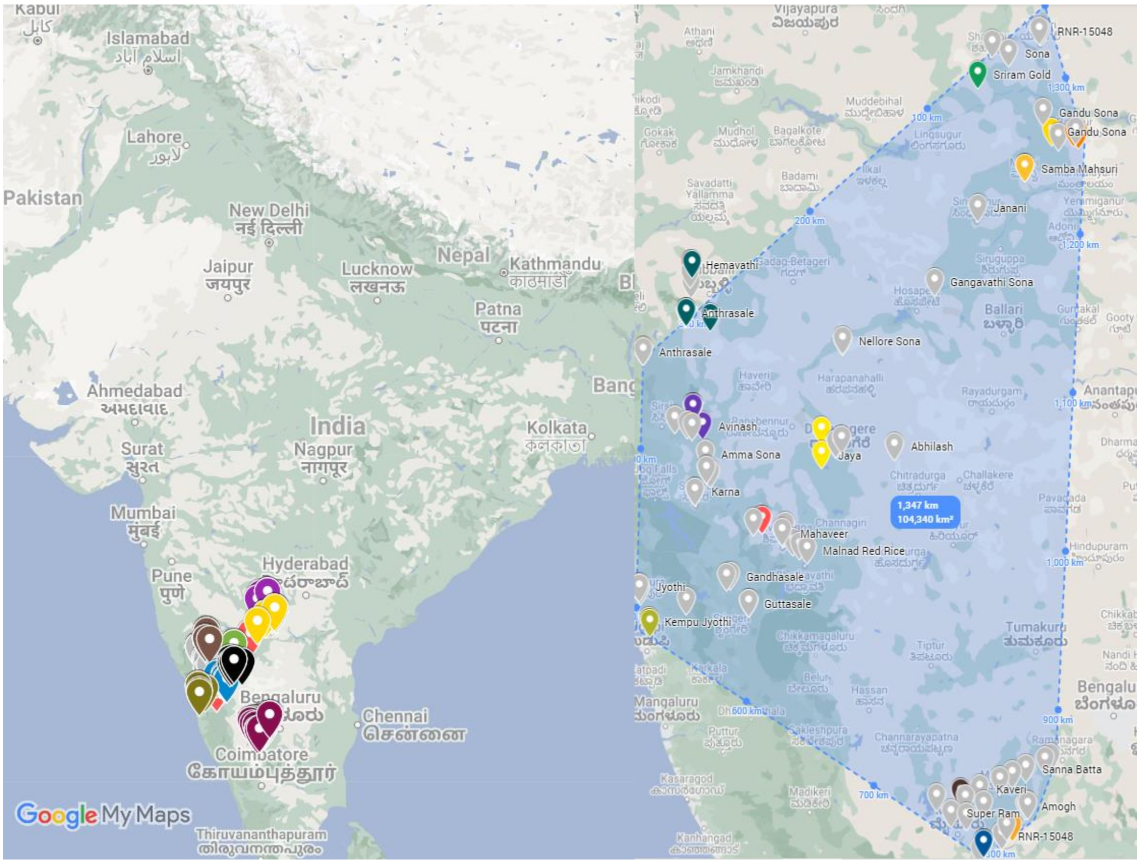

Fig. 1. Google base map showing sampling sites and distance covered during the survey for GD. A. India map showing the sampling sites. B. Distance covered during the survey

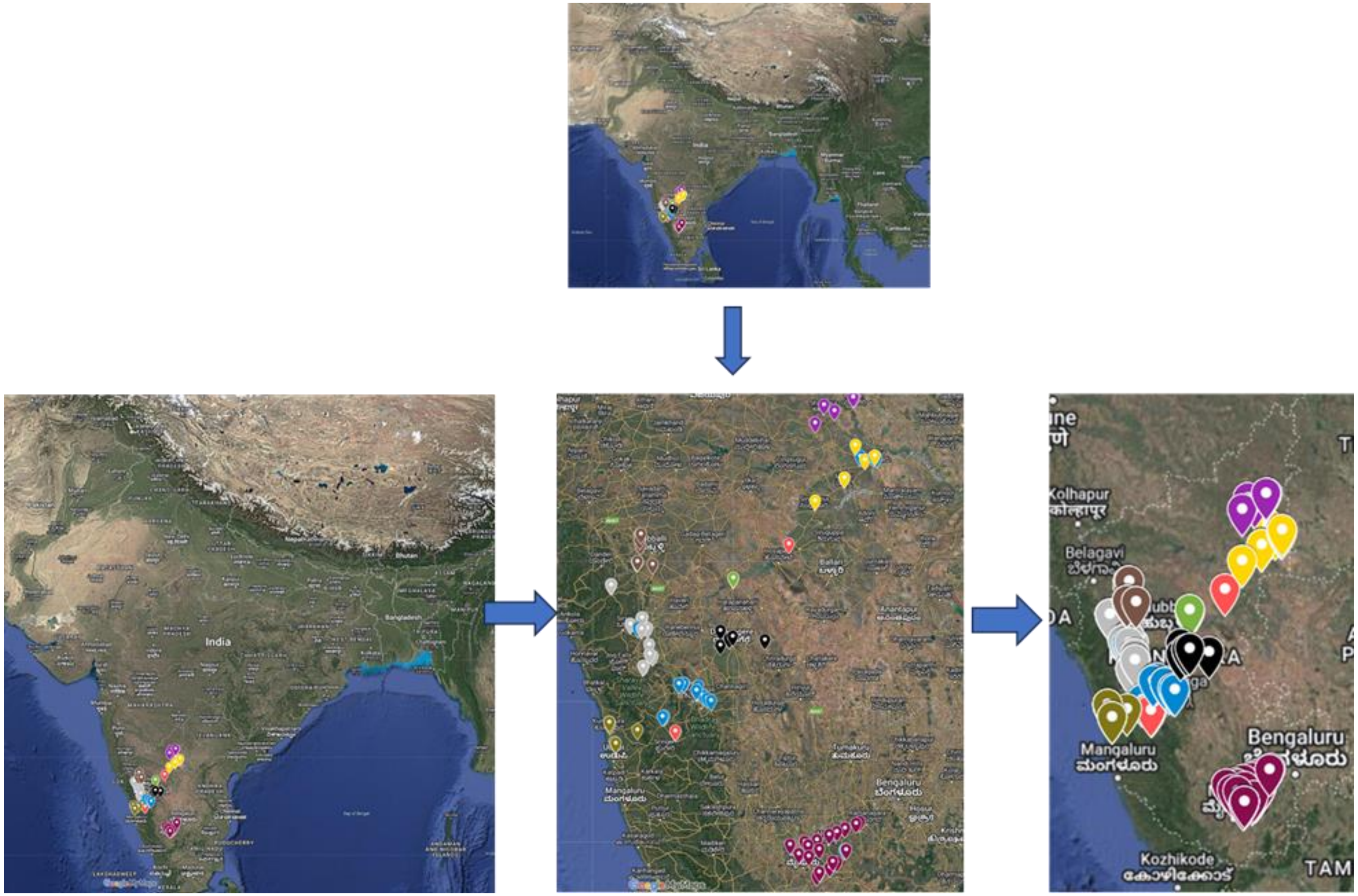

Fig. 2. Map showing the surveyed locations across the rice growing ecosystems of Karnataka state (Coastal, Kaveri, Irrigated Bhadra, Hilly,TBP, and UKP covering different Districts (individually colour marked)

3. RESULTS

An intensive roving survey was conducted for assessment of grain discoloration disease during *Kharif*-2021 in different rice-growing ecosystems of Karnataka state, namely TBP, UKP, Hilly, Coastal, and Irrigated Bhadra ecosystem covering various rice-growing districts of Karnataka. Disease incidence observation was recorded in all the surveyed sites, along with the cultivar name (Table 1).

Disease intensity was recorded in all the villages surveyed with varied extents. The disease incidence recorded across the surveyed samples was in the range of 3 to 98 (%). The highest disease incidence (98%) was recorded in Sutturu village of Nanjanagud Taluk of Mysuru District of Kaveri ecosystem. In contrast, the lowest disease incidence (3%) was recorded in the Kadakal camp village of Shahpur taluk of Yadgir District of UKP of Karnataka state.

Among all five ecosystems surveyed, the highest mean disease incidence (85.11%) was noticed from the Coastal ecosystem, followed by the Kaveri ecosystem (74.34%), and the Hilly ecosystem recorded 57.73 per cent. Meanwhile, the Irrigated Bhadra ecosystem recorded 55.81 disease incidence. In contrast, lowest disease incidence was observed from the UKP ecosystem, with a mean disease incidence of 33.64 per cent, followed by the TBP ecosystem (51.61%) (Table 1 and Fig. 3).

UKP ecosystem: Two Districts under the UKP ecosystem were surveyed, including the Raichur and Yadgir Districts. Five Taluk's have been covered for disease assessment. A total of seventeen villages were surveyed for the assessment of GD disease incidence. Among them, the highest disease incidence (80 %) was observed in Manchagundala village of Shorapur Taluka of Yadgir District. Followed by Khanapur village of Shahpur Taluka of Yadgir (78 %) and Neelahalli village of Yadgir (76). Thus, these villages were considered as GD hot spots in the UKP ecosystem. At the same time, the lowest disease incidence was recorded in Kadakal camp (3 %) of Shahpur Taluk of Yadgir, followed by Siddapur (5 %), Tadibidi village (8 %) of Shahpur taluks. Meanwhile, in the Raichur District, the lowest disease incidence (8 %) was observed in the Gabburu village of Devadurga taluk. The mean disease incidence of the UKP ecosystem was found to be 33.64 per cent (Table 1 and Fig. 3).

TBP ecosystem: A total of 23 villages were surveyed in the TBP ecosystem, covering six Taluks of three Districts. The highest disease incidence was recorded in Jawalagera village (90 %) of Sindhanur taluk of Raichur District. Followed by Pothnal village (83 %) of Manvi taluk of Raichur District, Jangamara Kalgudi village (80 %), and Gangavathi rural (75 %) of Gangavathi taluk of Koppal District. The lowest disease incidence (5 %) was observed in Hampasagara village of Hagari Bommanalli taluk of Bellary District, Neer Manvi (5 %), and Maremma Bagudi (5 %) village of Manvi taluk. The mean disease incidence of the TBP ecosystem was 51.61 per cent(Table 1 and Fig. 3).

Hilly ecosystem: The mean disease incidence observed across surveyed sites of hilly ecosystem of the Karnataka state was found to be 57.73 per cent. A total of 26 sites were surveyed to assess the GD incidence , covering seven taluk's in four districts. Among the villages surveyed, highest disease incidence was observed in Ammadi village (95 %) of Koppa Taluk of Chilkkamagaluru District, followed by Koppa rural (90 %), Jodalli village (90 %) Kalghatagi taluk of Dharwad, Chikkabengale village (85 %) of Sirsi taluk, Kirwatti village (80 %) of Sirsi taluk, Karehalli village (80 %) of Sagar Taluk of Shivamogga district. The lowest disease incidence was observed in Tavanandi village (6 %) of Sorab Taluk of Shivamogga district, followed by Malalagadde village (18 %) of Sorab Taluk of Shivamogga district (Table 1 and Fig. 3).

Irrigated Bhadra ecosystem: The mean disease incidence observed from this ecosystem was 55.81 per cent. A total of 23 villages were surveyed for disease assessment, covering six taluks of two districts, namely Davanagere and Shivamogga. The highest disease incidence was observed in the UAHS campus (92 %), Chinnamane village (90 %) of Shivamogga, followed by Savalanga village (91 %), Machena Halli (87 %) of Shivamogga. The lowest disease incidence (6) was found in Shamanur village of Davanagere district, followed by Gajanuru village of Shivamogga taluk with 10 per cent disease incidence (Table 1 and Fig. 3).

Kaveri ecosystem: The mean disease incidence observed was 74.34 per cent across the surveyed locations. Totally 29 villages were surveyed, covering 10 Taluks of 3 Districts. Among the villages surveyed, the highest disease incidence was found in the Sutturu village of Nanjangud

Table 1. Survey for assessment of grain discoloration disease incidence across traditional rice growing ecosystems of Karnataka

Sl. No.	Ecosystem	Geographical co-ordinates		Village	Taluk	District	Cultivar	Disease incidence (%)
1	**Upper Krishna Project (UKP)**	16.1157	77.1242	Kalmala	Raichur	Raichur	MTU-1010	26
2		16.1158	77.1240				Gandu Sona	44
3		16.1004	77.1510	Kasbe Camp			BPT-5204	45
4		16.393853	77.350209	Krishna Mandal			BPT-2595	55
5		16.1753	77.0936	Gabburu	Devadurga	Raichur	Gandu Sona	8
6		16.3844	76.5643	Gundagurthi		Yadgir	Sona	12
7		16.4231	77.0109	Khanapur	Shahpur		RNR-15048	78
8		16.4225	77.0105				BPT-5204	78
9		16.4105	76.5836	Tadibidi			Sona	8
10		16.3935	76.5824	Hundekal			BPT-5204	8
11		16.2137	76.2527	Kadakal camp			Cross Sona	3
12		16.3253	76.4428	Siddapur			Sona	5
13		16.4331	77.0713	Khanapur			BPT-5204	30
14		17.0606	76.1028	Vibhoothi Halli			BPT-5204	7
15		16.3546	76.4201	Manchagundala	Shorapur	Yadgir	BPT-5204	80
16		16.3530	76.4235				Sriram Gold	18
17		16.4653	77.0856	Yadgir	Yadgir	Yadgir	RNR-15048	18
18		16.3700	77.1735	Neelahalli			RNR-15048	76
19		16.283612	77.17196	Sulthanpur			Pure Sona	48
20		16.3700	77.1735	Neelahalli			BPT-5204	37
21		16.3264	76.4435	Siddapura			RNR-15048	14
22		16.2649	76.3726				BPT-5204	44
23	**Thungabhadra Project ecosystem (TBP ecosytem)**	15.4681	76.5762	Marali	Gangavathi	Koppal	Nellore Sona	30
24		15.2708	76.3133	Gangavathi Rural			GGV-05-01	75
25		15.2729	76.3333	Jangamara Kalgudi			GNV-10-89	80
26		15.2741	76.4445	Sugur			GGV-05-01	70
27		15.2758	76.4301	Manur			GGV-05-01	65
28		15.3118	76.I2911	Arlahalli			BPT-5204	75
29		15.354693	76.491759	Anegundi			Gangavathi Sona	60
30		15.3006	76.3000	Kesarahatti			BPT-5204	65
31		15.2411	76.3554	Kampli	Kampli	Ballary	BPT-5204	70
32		14.2635	75.0453	Hampasagara	Hagari Bommanalli	Ballary	RNR-15048	5
33		14.985259	75.930358	Nagati Basapur	Huvina Hadagali	Vijayanagara	Sona Mahsoori	40
34		14.985275	75.930413				Nellore Sona	28
35		15.121142	76.040149	Huvina Hadagali			BPT-5204	22
36		15.0030	75.5510	Kanakana Halli			BPT-5204	30
37		16.0235	77.0608	Neer manvi	Manvi	Raichur	RNR-15048	75
38		15.901885	76.867025	Pothnal			RNR-15048	83
39		15.90195	76.86699				Samba Mahsuri	75

Sl. No.	Ecosystem	Geographical co-ordinates		Village	Taluk	District	Cultivar	Disease incidence (%)
40		15.90978	76.867046				Samba Mahsuri	80
41		15.900585	76.864709				Samba Mahsuri	78
42		16.157448	77.238134	Maremma Bagudi			Nellore Sona	5
43		16.049688	77.115102	Neer manvi			BPT-5204	5
44		15.855923	76.840057	Jawalgera	Sindhanur	Raichur	Uma	90
45		15.5153	76.4918				BPT-5204	25
46		15.855769	76.839952	Turikatte, Jawalagera			Janani	40
47		15.3944	76.4155	Hanchinal Camp			BPT-5204	14
48		15.5648	76.5534	Amareshwara camp			BPT-5204	70
49		15.4633	76.4619	Sindhanuru			RNR-15048	18
50		15.796416	76.77816	Konganahatti			Janani	72
51	**Hilly ecosystem**	14.975522	74.760899	Bavigadde		Uttara Kannada	Anthrasale	60
52		14.97561	74.760587		Yallapura		Sannavallya	58
53		15.07119	74.872985	Kiravatti			Anthrasale	49
54		15.0310	74.5113				MO-4	30
55		15.071134	74.873039		Sirsi	Uttara Kannada	MTU-1001	45
56		15.07119	74.872985				Avinash	78
57		15.07119	74.872988				Intan	60
58		15.07119	74.872992				Abhilash	80
59		15.071148	74.873008				Hemavathi	45
60		15.07112	74.873036				Abilash	35
61		15.071118	74.873029				Abilash	45
62		15.071118	74.873031				MTU-1001	25
63		15.071118	74.873029				Amruth	65
64		15.053923	74.843233				MTU-1010	50
65		14.58318	74.893661	Unchalli			Jigguvaltiga	37
66		14.3356	74.5705	Navanagere			Jiggavaltiga	50
67		14.551279	74.968708	Chikkabengale			MTU-1001	85
68		14.559569	74.983713	Gudnapur			Abhilash	30
69		14.548687	74.998977	Banavasi			Speaker	65
70		14.18369	75.046618	Bheemaneri	Sagara	Shivamogga	BPT-5204	72
71		14.1454	75.0554	Kambalikoppa			IR-20	60
72		14.0404	75.0905	Karehalli			Karna	80
73		14.25853	75.101615	Duguru	Soraba	Shivamogga	Amruth	68
74		14.472926	75.048646	Thekkuru			Amma Sona	50
75		14.418552	75.078285	Karekoppa			Mahaveer	62
76		14.305098	75.106107	Hosa Malalagadde			Intan	64
77		14.305051	75.106154				MTU-1001	25
78		14.2635	75.0453	Tavanandi			Speaker	6
79		14.25853	75.101615	Ulavi			Govardhana	65
80		14.1718	75.0618	Malalagadde			Pragathi	18

Sl. No.	Ecosystem		Geographical co-ordinates		Village	Taluk	District	Cultivar	Disease incidence (%)
81			13.606828	75.143598	Kaimara	Tirthahalli	Shivamogga	MR-272	68
82			13.902321	75.561366	Harakere			Gandhasale	82
83			13.682513	75.221454	Shivarajapura			IT	72
84			15.4146	74.976505	Dharwad	Dharwad	Dharwad	Hemavathi	87
85			15.41461	74.976487				Doddasali	75
86			15.2046	74.5959	Jodalli	Kalghatgi	Dharwad	Gandhasale	90
87			15.247766	75.005671	Hirehonnalli			Anthrasale	50
88			15.414587	74.976511	Yarikoppa			IR-64	54
89			15.414589	74.976507				Intan	70
90			15.355093	75.007522	Dhummawada			Ankursale	72
91			15.355008	75.007579				Jiggavaltiga	20
92			15.355011	75.007574				Amruth	65
93			15.355027	75.007552				Rasi	78
94			15.355051	75.007546				Vijetha	80
95			15.355008	75.007579				Abilash	32
96			15.357076	75.012972				Phalguni	29
97			13.5247	75.3352	Koppa rural	Koppa	Chikkamagaluru	Guttasale	90
98			13.5420	75.3331	Ammadi			Abhilash	95
99	**Irrigated**	**Bhadra**	13.4329	75.1713	Nellasara	Shivamogga	Shivamogga	RNR-15048	20
100	**ecosystem**		13.5821	75.3438	UAHS			Sahyadri siri	50
101			14.002604	75.451715	Ayanuru			Sannabatta	85
102			14.002576	75.451701				Jyothi	78
103			14.002604	75.451715				Karibhatta	84
104			13.996838	75.377073	Chinnamane			Meenakshi	90
105			13.847416	75.526271	Gajanuru			Jyothi	10
106			13.755831	75.466968	Mandagadde			MTU-1001	28
107			13.5829	75.3440	UAHS, Shivamogga			Red rice	87
108			13.5311	75.3802	Nidige, Shivamogga			Jaya	80
109			13.972455	75.577863	UAHS, Shivamogga			Sahyadri Kempumukthi	92
110			13.892929	75.630293	Machena Halli			Jyothi	87
111			13.855569	75.675644	Ujjanipura, Bullapura			Kempu Jyothi	86
112			13.862637	75.677044	Jannapura, Kadadakatte	Bhadravati	Shivamogga	Hemavathi	85
113			14.076517	75.157488	Yedehalli			Prasanna	60
114			14.068259	75.189608				Malnad Red Rice	55
115			13.5112	75.3907	Siriyuru Thanda			MO-4	84
116			14.0615	75.3153	Savalanga	Honnalli	Davanagere	RNR-15048	25
117			14.1347	75.3811	Honnalli			RNR-15048	25
118			14.1255	75.3642	Chaudihalli			Vijetha	25
119			14.105759	75.529932	Savalanga/Sovalanga			MTU-1001	91
120			14.240751	75.663451	Gollarahalli			Abhilash	75

Sl. No.	Ecosystem	Geographical co-ordinates		Village	Taluk	District	Cultivar	Disease incidence (%)
121		14.3538	75.5045	Kurubara halli	Harihar	Davanagere	RNR-15048	38
122		14.3439	75.4919	Deeturu			Sriram Gold	35
123		14.393306	75.822434	Budihala			Samba Mahsoori	32
124		14.393139	75.822482				Jaya	27
125		14.562909	75.828248	Karalahalli			IR-20	48
126		14.602851	75.84673	Kurubarahalli			RNR-15048	62
127		14.3609	75.4908	Sarathi			RNR-15048	76
128		14.2614	75.5425	Shamanur	Davanagere	Davanagere	RNR-15048	6
129		14.433271	75.881072				RNR-15048	35
130		14.3730	76.0623	Budihal	Harapanahalli	Davanagere	Sriram Gold	25
131	**Kaveri ecosystem**	12.3546	77.0333	Madduru	Madduru	Mandya	Sanna Batta	78
132		12.345777	76.895886	Chamanahalli			Super Ammam	80
133		12.316827	77.034074	Kyathnaalli	Malvalli	Mandya	Amogh	88
134		12.262917	76.980728	Chikka Abbagilu			Kavery	90
135		12.1510	76.5815				Swetha 45	70
136		12.1532	76.5937	Hullamaballi			Omkar	75
137		12.2034	77.0042	Hangarapura			Minilong	77
138		12.3344	76.5814	Mallaiahnadoddi	Mandya	Mandya	Super Ammam	64
139		12.3215	76.5518	Mandya			Meenakshi	80
140		12.480172	76.768086	Kodishettipura			Kaveri	45
141		12.347429	77.010507	Angarapura			IR-64	90
142		12.1239	76.2749	Kyathanahalli	Pandavapura	Mandya	Omkar	69
143		12.2745	76.3929				Minilong 11	76
144		12.412226	76.669475	Karimanti	Shrirangapattana	Mandya	Mahaveer	70
145		12.41808	76.724646	Srinivasapura Agrahara			MTU-1001 13	60
146		12.2605	76.4215	Shanti koppalu			Super Ammam	86
147		12.2311	76.4824	Gende Hosalli			Amrutha	75
148		12.234726	76.912141	Sosale	T. Narsipur	Mysuru	RNR-15048 15	17
149		12.1706	76.5221	Kohalli			MTU-1010	7
150		12.228255	76.913129	Benakanahalli			RNR-15048	92
151		12.228255	76.913137	Benakanahalli-2			RNR-15048	89
152		12.345777	76.895886	Basavanahalli			Meenakshi	90
153		12.2123	76.5746	Hoovinakoppala			Jyothi	69
154		12.0909	76.5256	Vatalu			KMP-225	70
155		12.262917	76.98701	Neragyatanahalli			Dodda Batta 19	89
156		12.262936	76.9807098				RNR-15048	96
157		12.3343	76.5810	Hutagalli	Mysuru	Mysuru	Super Ram	74
158		12.366044	76.663359	Siddalingapura			Jyothi	84
159		12.366064	76.663334				KMP-220 20	86
160		12.167773	76.793803	Suttur	Nanjangudu	Mysuru	IR-64	77
161		12.158876	76.792296	Biligere			RNR-15048	58

Sl. No.	Ecosystem	Geographical co-ordinates		Village	Taluk	District	Cultivar	Disease incidence (%)
162		12.167773	76.793807	Sutturu			Jayakrishna	65
163		12.167768	76.793807				Amogh	75
164		12.163208	76.787849				Amogh	85
165		12.167766	76.7938				Jyothi	98
166		12.163192	76.787859				IR-64	94
167		12.0853	76.4714	Kupparavalli			IR-64	40
168		12.0855	76.4715				Penna Super	76
169		12.0651	76.4452	Gonahalli			Jyothi	75
170		12.167769	76.793796	Sutturu			Amogh	82
171		11.5952	76.2216	Magudilu	H. D. Kote	Mysuru	KMP-220	60
172		12.554293	76.972849	Mallur	Channapatna	Ramanagara	Sanna Batta 25	78
173		12.647003	77.175695				MTU-1001	80
174		12.554369	76.97288	Byrapatna			Godavari	92
175	**Coastal ecosystem**	13.535745	75.005555	Mandi Moorkai	Hebri	Udupi	Kajejaya	84
176		13.535768	75.005542				Mo-4	73
177		13.535772	75.005549				Jaya	82
178		13.555604	74.969163	Shedimane	Kundapura	Udupi	Kamadhare	88
179		13.555411	74.969072				Jyothi	78
180		13.585699	74.957469	Nilachagallu			Shakthi	56
181		13.585726	74.957597				Nagabhatha	68
182		13.578155	74.858998	Haladi			Kanwa	83
183		13.430967	74.736197	ZARS, Brahmavara	Brahmavara	Udupi	MO-4	94
184		13.430942	74.736197				MTU-1001	91
185		13.430932	74.736209				Kempu Jyothi	92
186		13.43093	74.736212				Kaje 25-9	93
187		13.430992	74.735979				MO-4	90
188		13.430923	74.735945				MO-4	89
189		13.430794	74.735882				Narunga	87
190		13.432726	74.735903				KCP-1	96
191		13.432859	74.735693				Kaje Jaya	93
192		13.432723	74.735923				Sahyadri Panchamukhi	95

Table 2. Grain discoloration disease incidence across traditional rice growing ecosystems of Karnataka

Sl. No.	Ecosystem	Average disease incidence (%)
1	Upper Krishna Project (UKP)	33.64
2	Thungabhadra Project ecosystem (TBP)	51.61
3	Hilly ecosystem	57.73
4	Irrigated Bhadra ecosystem	55.81
5	Kaveri ecosystem	74.34
6	Coastal ecosystem	85.11

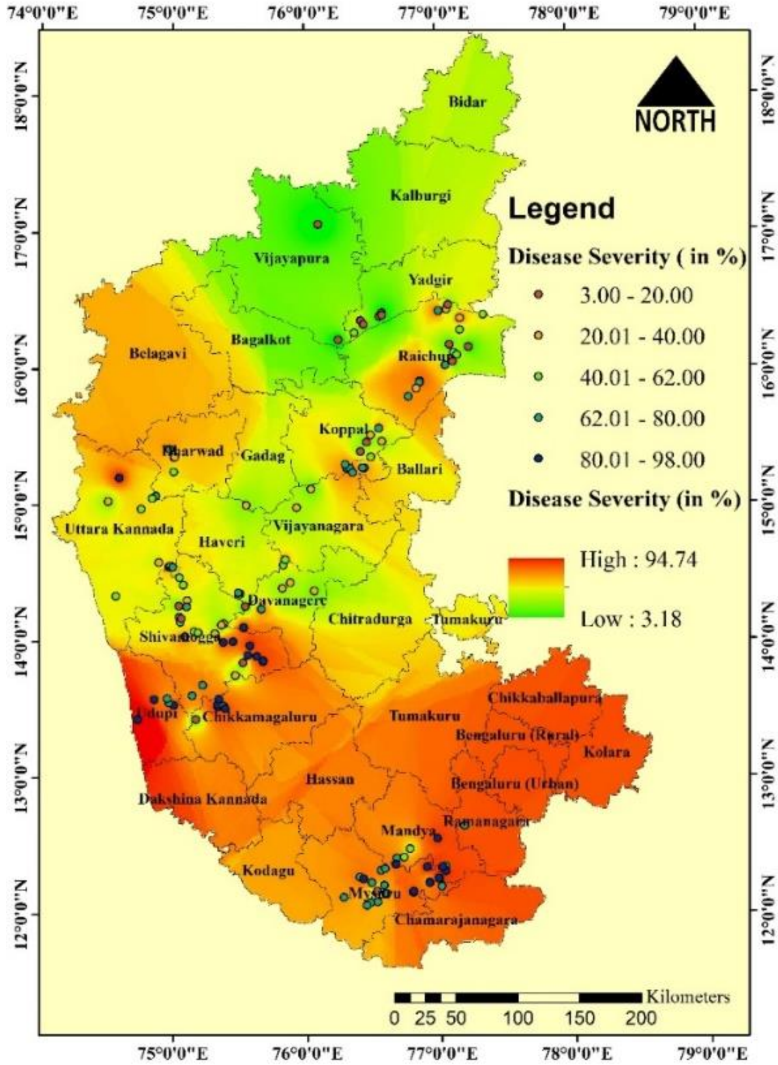

Fig. 3. Spatial distribution map of rice grain discoloration disease severity across paddy-growing Districts of Karnataka. The map shows disease severity (%) ranging from 3.00% to 98.00%, with higher severity observed in southern Districts like Udupi, Shivamogga, and Mysuru, indicated by red and orange areas covering Coastal, Irrigated Bhadra and Kavery ecosystem. Northern Districts such as Yadgir and Raichur representing Krishna River ecosystems show relatively lower severity, marked in green and yellow. The circles represent survey locations, color-coded based on the disease severity observed in each region. The heat map was generated using kernel density estimation in R, highlighting hotspots of disease incidence, with severity levels represented by the color gradient (high in red to low in green)

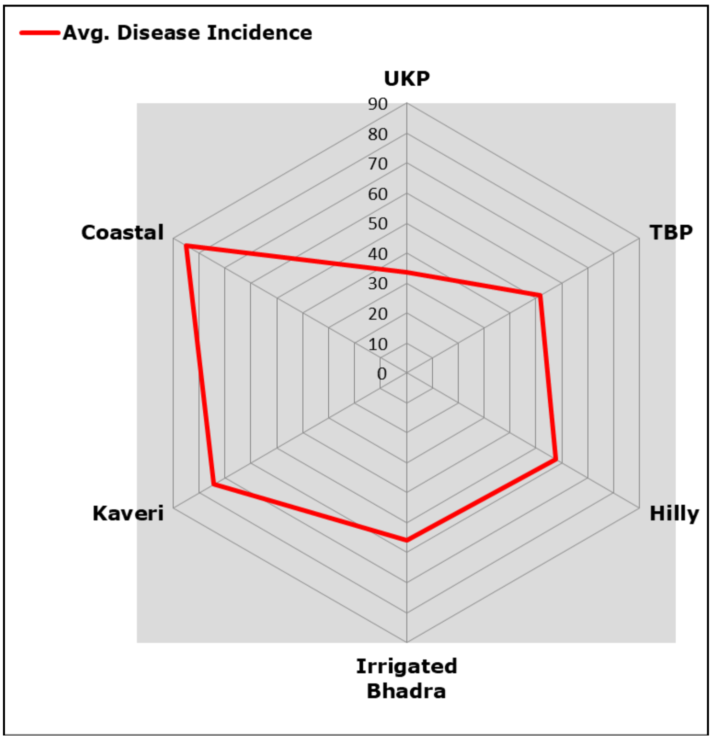

Fig. 4. Image representing the Radar graph displaying the disease incidence of rice grain discoloration across different rice growing ecosystems of Karnataka state. The ecosystems are Coastal, Kaveri, Irrigated Bhadra, Hilly, Thunga Bhadra project (TBP), and Upper Krishna Project (UKP)

Where, red lines highlight the average disease incidence across the surveyed ecosystems

Fig. 5. Heat maps highlight the disease intensity across the surveyed locations from all ecosystems. A. Scale of disease severity observed across the surveyed locations, B. Disease incidence recorded in UKP ecosystem followed by C. TBP, D. Irrigated Bhadra E. Kavery ecosystem, F. Hily ecosystem and G. Coastal ecosystem

Taluk (98 %) of Mysuru District, followed by Neragyatanahalli village (96 %), Benakanahalli village (92 %) of T. Narsipur Taluka of Mysuru District, Byrapatna village (92 %) of Channapatna Taluka of Ramanagara District and Chikka Abbagilu, Angarapura villages of Mandya districts with 90 per cent disease incidence respectively. Whereas the lowest disease incidence was recorded in Kohalli village (7 %) and Sosale village (17 %) of T. Narsipur Taluka of Mysuru District (Table 1 and Fig. 3).

Coastal ecosystem: The mean disease incidence recorded was 85.11 per cent. Five villages, covering three taluka's of Udupi District, were surveyed. Among the sites surveyed, ZARS, Brahmavara recorded the highest disease incidence (96 %), followed by Shedimane village of Kundapura Taluk of Udupi District (Table 1 and Fig. 3).

Among all six ecosystems surveyed, the highest mean disease incidence (85.11 %) was noticed in the coastal ecosystem, followed by the Kaveri ecosystem (74.34 %) and the hilly ecosystem (57.73 %). Meanwhile, the Irrigated Bhadra ecosystem recorded 55.81 per cent disease incidence. The lowest disease incidence was observed from the UKP ecosystem, with a mean disease incidence of 33.64 per cent, followed by the TBP ecosystem (51.61 %) (Table 2 and Fig. 4).

Disease incidence on different rice cultivars: In this study, all the rice cultivars under cultivation in surveyed locations showed the disease symptoms. however, incidence of the disease but with varying levels of severity. We hypothesized that cultivars are one of the factors for the varied level of disease incidence. Severity in diverse ecological conditions due to their inherent genetic variability. Eighty-nine cultivars are being cultivated across surveyed locations (Table 1). Among all the cultivars surveyed, the highest disease incidence was recorded in bold-seeded rice varieties with more glume area and higher surface area for water retention and fungal colonization. The highest disease was recorded in Cv. Jyothi (98), followed by RNR-15048 (96), KCP-1 (96), Sahyadri Panchamukhi (95), MO-4 (94), MTU-1001 (91), Kempu Jyothi (92), Kaje 25-9 (93), Kaje Jaya (93), Godavari (92), IR-64 (IR-64), Meenakshi (90), MTU-1001 (91), Sahyadri Kempumukthi (92), Abhilash (95), Guttasale (90), Gandhasale (90), Uma (90) (Table 1). At the same time, the lowest disease incidence was recorded in cultivars such as Cross Sona (3), Sona (5) and Gandu Sona (8), RNR-15048 (5), Nellore Sona (%), MTU-1010 (7), BPT-5204 (8). However, few of these cultivars show higher disease incidence in other ecosystems, depending on the prevalent climatic conditions in the existing localities and ecological features of specific ecosystems (Table 1). Generally, cultivars being grown in the TBP and UKP ecosystems recorded lesser disease incidence compared to coastal and Kavery ecosystems (Table 1). Cultivar diversity was different in different ecosystems. significant diversity was recorded across ecosystems, i.e., UKP ecosystem (No=8), TBP ecosystem (No=9), Hilly ecosystem (No=29), Irrigated Bhadra (No=21), Kavery ecosystem (No=26), and Coastal ecosystem (No=15). Comparatively high cultivar diversity was seen in coastal and Kavery ecosystems, i.e. (Southern part of Karnataka), than the UKP, TBP ecosystem (Northern part of Karnataka). Our study reported low to high Incidence of GD on cultivar BPT-5204 *i.e* 5 in Neer Manvi village of Raichur district belongs to the TBP ecosystem 80 in Manchagundala village of Shorapur taluk of Yadgir district (Table 1).

4. DISCUSSION

Rice GD is an emerging threat to rice cultivation as it reduces grain yield and quality. In India, in recent years, several diseases of rice, such as false smut (Ladhalakshmi et al., 2012; Muniraju et al., 2017a; Pramesh et al., 2020a; Pramesh et al., 2020b, Huded et al., 2022), sheath blight (Nagaraj et al., 2017; Nagaraj et al., 2019a; Nagaraj et al., 2019b) and brown spot (Pramesh et al., 2024), have become more severe (due to impact on yield) and complex (due to multiple pathogens). Similarly, GD is of rice is emerging in almost all rice rice-growing regions of India; however, its status and impact on yield have not been reported clearly. Our survey in the six ecosystems of the state indicated the wider occurrence of this disease where the cultivar density and distribution played a major role in degree of disease incidence recorded. -Where, Coastal and Kaveri ecosystems were reported as hotspots for the diseases. Surprisingly, UKP and TBP, where rice is being cultivated extensively with high chemical inputs, recorded less disease incidence. This could be due to the fact that the farmers at UKP and TBP have taken 1-2 sprays of fungicides to protect the crop from neck blast and false smut, and this would have protected the crop from GD.

Similar results were identified by previous workers across the different ecosystems of Karnataka (Pampana Gouda et al., 2020). They reported that during 2017-2018 the mean PDI of 14.95 and 15 per cent was recorded across the surveyed locations. At the same time, *Kharif*-2018 reported a disease incidence of 13.64 and 13.94 per cent from the Hilly upland and Coastal ecosystems, respectively. Our study recorded less disease incidence from TBP compared to Kaveri and coastal ecosystems. However, data from Shivakumar and Patil (2013) showed contrasting results where they recorded higher disease incidence in TBP and moderate disease incidence in Kavery and Hilly ecosystems. This contrasting result may be due to the changing climate and the replacement of cultivars. Raghu et al. (2020) also carried out a survey across the paddy fields of Odisha state of India and found heavy incidences of GD across cultivated rice genotypes; recorded incidence ranged from 25 to 92 per cent in different rice genotypes. Rao et al. (2000) surveyed 25 villages in the West and East Godavari districts of Andhra Pradesh state and recorded the GD incidence in several popular rice cultivars such as MTU-1001, MTU-2067, MTU-2077, MTU-7029, BPT-5204, and PLA-1100. The similar cultivars were recorded from our study also, where moderate to severe disease incidence was recorded. Our results were also supported by Yuvarani et al. (2021), who recorded disease incidence ranging from 22 to 37.5 per cent across the villages surveyed, which supports our results for having moderate disease incidence across the cultivars selected from northern India.

The severity of the disease across the ecosystem and cultivars may be attributed to the lack of inherent resistance and the coincidence of high rainfall, humidity with monocropping, and poor crop management. The non-availability of the GD-resistant varieties in the surveyed cropping area was the main possible reason for higher GD incidence. However, surveyed locations from the northern part of Karnataka showed less disease intensity, thus considered cold spots for GD. In this part of the state, rice is cultivated as a commercial, where intensive monitoring and frequent fungicidal application were being followed after flowering stage to till the harvesting stage to protect the crop from neck-blast and false smut diseases, thus indirectly managing the GD.

A production-oriented survey (POS) conducted by IIRR in 2023 recorded the low intensities of GD disease in Andhra Pradesh, whereas in Kerala, it is shown moderate to high incidences. GD was found widespread with low to moderate intensity from Uttarakhand, Maharashtra, Tamil Nadu, Uttarakhand, Haryana, and Andhra Pradesh, which were recorded as having low disease intensity (Anon, 2023b).

Presently, rice cultivation in India is affected by several diseases, such as blast, brown spot, sheath blight, false smut, sheath rot, foot rot, stem rot, and bacterial leaf blight. However, most of these are being managed by the use of resistant cultivars, fungicides, bactericides, and bioagents (Pramesh et al, 2016a; Pramesh et al., 2016b; Pramesh et al., 2016c; Pramesh et al., 2017a; Pramesh et al., 2017b; Pramesh et al., 2017c; Pramesh et al., 2017d; Pramesh et al., 2017e; Muniraju et al., 2017b; Prasannakumar et al., 2018; Amruta et al., 2019; Yadav et al., 2019a; Yadav et al., 2019b; Raghu et al., 2020; Sharanabasav et al., 2020; Pramesh et al., 2020; Amoghavarsha et al., 2021; Sharma et al., 2021; Annegowda et al., 2021; Prasanna et al., 2021; Pramesh et al., 2023c; Jeevan et al., 2023; Usha et al., 2024; Devanna et al., 2024; Pramesh et al., 2024b; Alase et al., 2024). As the GD is becoming widespread across all rice ecosystems of the country and showing all potential to cause yield and quality losses, systematic research efforts are required to identify the chemical, biological, and resistance-based strategies for managing GD in India.

5. CONCLUSION

Grain discoloration is one of the emerging, complex disease of rice, causing the quantitative yield loss and qualitative loss in terms of discolored grains. Although sporadic in nature, disease could be found in all rice growing areas of the world including India in varied extent. Thus, roving survey was conducted to assess the GD disease incidence across different paddy growing ecosystems of the Karnataka. Totally six ecosystems covering fourteen districts of Karnataka state of India were surveyed for assessment of GD disease distribution. Among them, highest disease mean incidence was recorded in Coastal ecosystem followed by Kaveri ecosystem. Thus, considered as hotspots for GD disease of rice. However, UKP ecosystem recorded least mean disease incidence followed by Thunga Bhadra Project, considered as cold spot for GD disease. Additionally, study also highlights the status of GD on cultivars distributed and varietal profile among the surveyed locations, which has impact on identification of novel source of disease resistance. Our results highlighted, small seeded cultivars such as, Cross Sona, Sona Mahsuri, RNR-15048, Nellore Sona, BPT-5204, and Gangavathi emergence recorded lesser disease incidence. However, bold seeded cultivars such as, MO-4, MTU-1001, Kempu Jyothi and IR-64 recorded the higher disease incidence. Conclusively, southern part of Karnataka considered as hotspots and northern part of the Karnataka considered as cold spots for GD disease. Aftermath, this intensive survey study is useful in understanding the status and distrubution of GD in Karnataka state of India and could contribute effectively in disease management in specific paddy ecosystems.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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