Journal of Applied and Natural Science
14(3), 938 - 945 (2022)
ISSN : 0974-9411 (Print), 2231-5209 (Online)
journals.ansfoundation.org

Research Article

Survey and surveillance on rice false smut disease severity in Tamil Nadu and the influence of wind velocity on disease progression under field conditions

P. Anbazhagan
Department of Plant Pathology, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai-625104 (Tamil Nadu), India
M. Theradimani*
Department of Plant Pathology, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai-625104 (Tamil Nadu), India
V. Ramamoorthy
Department of Plant Pathology, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai-625104 (Tamil Nadu), India
P. Vellaikumar
Department of Biotechnology, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai-625104 (Tamil Nadu), India
S. Juliet hepziba
Department of Plant Breeding and Genetics, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai-625104 (Tamil Nadu), India
R. Oviya
Department of Plant Pathology, Agricultural College and Research Institute, Tamil Nadu Agricultural University, Madurai-625104 (Tamil Nadu), India

*Corresponding author. E mail: anbupatho17@gmail.com

Article Info
https://doi.org/10.31018/jans.v14i3.3706
Received: July 2, 2022
Revised: August 8, 2022
Accepted: August 17, 2022

How to Cite
Anbazhagan, P. *et al.* (2022). Survey and surveillance on rice false smut disease severity in Tamil Nadu and the influence of wind velocity on disease progression under field conditions. *Journal of Applied and Natural Science*, 14(3), 938 - 945. https://doi.org/10.31018/jans.v14i3.3706

Abstract
The false smut disease of rice incited by *Ustilaginoidea virens* is a major constraint on rice production. The main aim of the present study was to ascertain the false smut disease severity in both delta and non-delta districts of Tamil Nadu through survey and surveillance and assess the correlation between the disease severity and wind velocity for the past three years, 2019, 2020 and 2021. Moreover, the present study addressed the disease distribution pattern of false smut diseases under field conditions. The results obtained from survey results revealed that the maximum disease severity was recorded in Nagapattinam district (Nagapattinam block) with 27.45% and the minimum disease severity was recorded in the district Theni (Bodinayakanur block) with 8% in 2021. Similarly in 2019 and 2020 maximum disease severity was recorded in the following districts Thanjavur district (Orathanadu block) with 19.91% and Thanjavur district (Peravurani block) with 18.54% and the minimum disease severity was recorded in the following districts Madurai district (Madurai north block) with 4.78% and Madurai district (Usilampatti block) with 4.78% respectively. The obtained R2 values through regression analysis were 0.70, 0.79 and 0.76 in the following years, 2019, 2020 and 2021, respectively. Besides the relationship between the false smut disease development, the pattern wind direction was also assessed. By assessing the false smut disease distribution pattern under field conditions, more disease distribution was observed around the surrounding area of the paddy field as well as the diagonal path of the field which clearly revealed that wind direction influences the disease development.

Keywords: Correlation, Regression, Surveillance, Wind velocity, Wind direction

INTRODUCTION

False smut of rice incited by *Ustilaginoidea virens* (Teleomorph- *Villosiclava virens* (Nakata) Tanaka & Tanaka) is a major fungal disease in most rice-growing tracts of Tamil Nadu. The typical symptom is usually incurred during the reproductive stage, and most infection occurs at the panicle's top one-third region. The

severity of this disease will be increased tremendously if the flowering phase of the susceptible cultivar of paddy coincided with favorable environmental conditions. Two decades back the emphasis was not given to the management of the disease since the disease occurrence appeared in a sporadic manner. In fact, the outcome of this disease was recognized as a symbol of a bumper harvest and regarded as "Laxmi" (goddess of wealth and prosperity) in southern parts of India. Currently, this disease has gained importance because it causes a loss of 2% to 75% of rice yield depending upon weather conditions prevailing during the flowering stage of the crop (Ladhalakshmi *et al.,* 2012).The rate of disease development is high during conducive environmental conditions such as high humidity (>80%), intermittent rainfall during the flowering stage, and temperature ranges from 25°C to 30°C (Yashoda *et al.,* 2000; Ping *et al.,* 2009; Fan *et al.,* 2014; Tanaka *et al.,* 2017. In India, the false smut disease incidence has been recorded in most of the rice-growing provinces (Ladhalakshmi *et al.,* 2012). A severe outbreak of the disease was reported in delta districts of Tamil Nadu during 2009–10 and the severity of the disease was also recorded as so high; it can be viewed from the distance that the air above the infected field gave a black smoky appearance as a result of the discharge of chlamydospore mass in the atmosphere (Ladhalakshmi *et al.,* 2012). In susceptible varieties, the severe infection leads to more than 50 smut balls per panicle (Ladhalakshmi *et al.,* 2012).

Nowadays, the adoption of hybrid rice cultivation is more common among farmers as this cultivation lead to yield advantage, but the continuous cultivation of hybrid rice led to an increase in false smut prevalence and severity. The absence of resistance sources among rice cultivars paves the way for chemical management. Thus, the application of new generation fungicides at the proper growth stages of the crop is the key approach to minimize the losses caused by false smut. Tsuda *et al.* (2006) stated that Ergosterol Biosynthesis Inhibitor (EBI) fungicides showed better control efficacy in controlling rice false smut, as this group of fungicides not only act as prophylactic agents but also revert the diseased panicle into a healthy panicle. However, the indiscriminate usage of this fungicide lead to the formation of resistance gene development in the pathogen over a period of time. This is the first-time experiment was carried out to understand the impact of wind velocity on the false smut disease development.

The objectives of this study were to (I) Survey and surveillance of false smut-affected areas in selected districts of Tamil Nadu, (II) To understand the disease distribution of false smut disease development under field conditions and (III) To assess the relationship between the wind velocity and false smut disease severity in the selected surveyed areas of Tamil Nadu

MATERIALS AND METHODS

Survey and surveillance of false smut disease-affected areas

A survey was conducted for the past three years, *viz.,* 2019, 2020 and 2021, in the major rice-growing tracts of selected districts (Madurai, Theni and Delta Districts) of Tamil Nādu (Table 1) The survey provides information on the disease severity of the *U.virens* in those selected districts. Using the survey data from 2019 to 2021, a district-wise database was developed as 5% (low), 6-15% (low to medium), 16-25% (medium) and >25% (medium to severe) as cited in Duraisamy *et al.* (2019). The database was then joined to the digital map of Tamil Nadu at the district level. The disease distribution map was generated by using QGIS software (version 3.24). In Tamil Nadu maximum rice cultivation intensity was observed in the delta district *viz.,* Thanjavur. The average disease severity of a particular block is obtained from the mean value of disease severity of five villages surveyed. The average disease severity of a particular district is derived based on the average disease severity data obtained from all the blocks surveyed in the following years 2019, 2020 and 2021. In Tamil Nadu, maximum rice cultivation intensity was observed in delta districts, which comprised the following districts: Thanjavur, Thiruvarur, Trichy, Perambalur, Pudukottai, Cuddalore and Ariyalur.

Layout of disease distribution at the field level

The entire field exploration is highly necessary to find out the focal point of infection. Once the focal point is identified, the disease spread can be prevented by giving the management strategies only to the focal point of infection. Since the false smut disease intensity is high in delta districts, the agricultural farmland was selected at Kaatuthottam, Thanjavur block, Thanjavur district. Besides, the weeds grown in the bunds were also explored during the survey on the selected farmland. The wind direction was also assessed to understand the developmental disease pattern in the selected farmland in Kaatuthottam, Thanjavur block, and Thanjavur district.

Data analysis

The wind velocity data were obtained from the NASA data access viewer website for the following years 2018, 2019 and 2021 (www.power.larc.nasa.gov) and the corresponding disease severity was recorded, which were then correlated with the disease severity to understand the relationship between wind velocity and disease severity. The strength of the relationship between wind velocity and disease severity was obtained through a simple linear regression analysis. The correlation and regression analysis were carried out through R-studio statistical software.

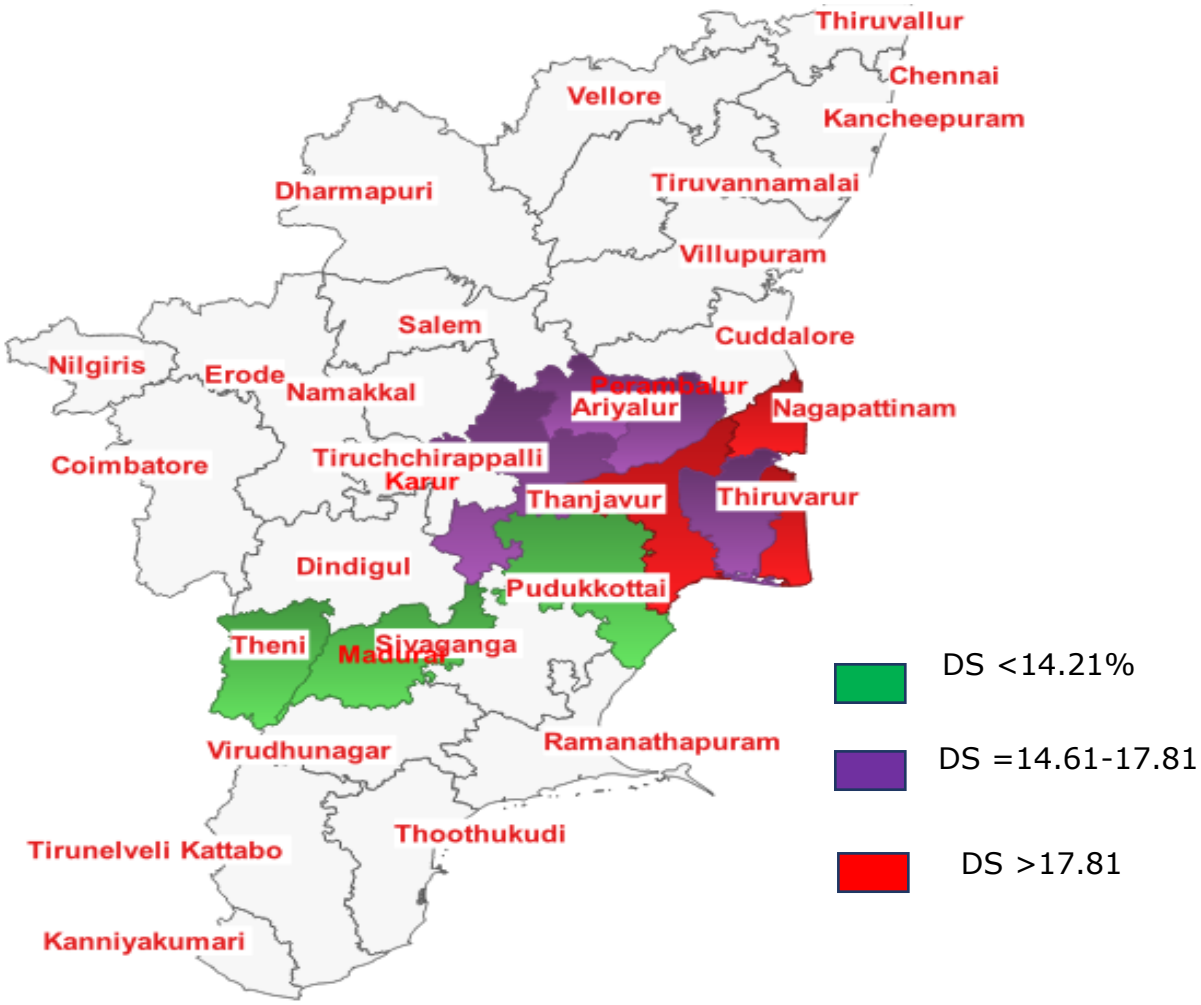

Fig. 1. *Showing the surveyed districts (color-filled areas) in the years 2019, 2020 and 2021(Green color filled districts denotes the less incidence of diseases severity (DS) (less than 14.21%), Violet color filled districts disease severity ranged from 14.61% to 17.81% and the red color filled districts having more than 17.81% disease severity.*

RESULTS AND DISCUSSION

Among the selected districts surveyed, the delta districts *viz.,* Thanjavur and Nagapattinam recorded the maximum disease severity of false smut disease. In 2019 the maximum disease severity of false smut was recorded in Orathanadu block, Thanjavur district, with 19.91%. Orathanadu block was followed by Pattukottai, Peruvurani and Kumbakonam with 18.78%, 18.76% and 15.89%, respectively. After Thanjavur, Nagapattinam was the second most disease severity district, where the Kilvelur block recorded 16.92%. Kilvelur block was followed by Vedaranyam and Nagapattinam with 14.89% and 13.76% disease severity, respectively. The least disease severity was recorded in the Madurai district ranging between 4.78% and 8.89%. In the Madurai district, among the blocks surveyed during 2019, the maximum disease severity was recorded in Madurai west with 8.89% and the minimum in Madurai north with 4.78%.

Similarly, in 2020 the maximum disease severity was recorded in Peravurani block, Thanjavur district, with 18.54%. In the Thanjavur district, the disease severity ranged between 12.87% to 18.54%. The Peravurani block was followed by Papanasam and Pattukottai with 17.68% and 17.45%, respectively. Thanjavur district was followed by Nagapattinam district and the disease severity ranged between 9.34% and 17.89%. The maximum and the minimum disease severity were recorded in Nagapattinam and Mayiladuthurai blocks with 17.89% and 9.34%, respectively. The least disease severity was recorded in two districts viz., Madurai and Theni. In Madurai, the minimum disease severity was recorded in the block Usilampatti with 4.82% and the maximum in the block Kaligudi with 10.43%. In the Theni district, the disease severity ranged from 4.86% to 10.67%.

In 2021 maximum disease severity was recorded in

Table.1. Survey data of disease severity and wind velocity at selected districts of Tamil Nadu in 2019, 2020 and 2021

S. No.	Districts	Blocks	Wind velocity (m/s)			Disease severity (%)		
			2019	2020	2021	2019	2020	2021
1	Thanjavur	Buddalur	8.09	9.26	8.77	5.78±2.3	13.98±3.90	15.87±5.67
2		Kumbakonam	9.87	11.13	11.07	15.89±1.9	12.87±2.90	22.65±3.89
3		Orathanadu	10.23	10.79	11.42	19.91±3.1	15.32±2.42	18.59±4.13
4		Papanasam	9.87	11.13	11.04	14.61±2.3	17.68±3.60	19.57±2.98
5		Pattukottai	10.23	10.79	11.41	18.78±3.2	17.45±4.30	20.01±3.09
6		Peravurani	10.23	10.79	11.41	18.76±4.9	18.54±3.50	22.23±4.00
7		Thanjavur	9.87	11.13	11.05	12.95±2.5	15.28±7.50	24.90±2.75
8		Thiruvidaimaruthur	7.65	10.03	9.13	6.07±3.5	16.76±3.50	15.54±3.56
9	Madurai	Kalligudi	8.33	8.66	8.98	7.13±3.5	10.43±4.80	14.21±2.93
10		Madurai East	7.93	7.94	7.57	5.46±4.3	8.97±3.90	10.89±4.98
11		Madurai North	7.93	7.94	7.57	4.78±3.2	9.83±2.90	11.12±3.78
12		Madurai South	7.93	7.94	7.57	6.32±2.7	7.82±5.80	10.67±2.59
13		Madurai West	7.93	7.94	7.57	8.89±5.3	6.90±3.90	13.43±7.09
14		Mellur	7.92	7.93	7.94	7.63±3.9	6.80±4.50	10.59±4.23
15		Thirumangalam	7.93	7.94	7.57	7.89±2.4	7.31±3.90	12.30±5.50
16		Usilampatti	5.93	5.71	6.78	6.75±3.3	4.82±1.50	9.78±6.10
17		Vaadipatti	7.93	7.94	7.57	8.12±1.3	6.91±4.50	9.45±1.89
18	Theni	Andipatti	5.93	5.71	6.78	7.32±2.9	4.86±3.50	8.34±2.50
19		Bodinayakanur	5.93	5.71	6.78	5.89±1.2	4.94±1.90	8.00±3.50
20		Periyakulam	5.93	7.71	6.78	6.83±1.7	10.67±2.50	9.34±3.00
21	Pudukottai	Alankudi	8.07	9.09	8.43	10.78±2.5	12.43±3.20	10.52±1.50
22		Viralimalai	8.07	9.09	8.43	11.61±3.2	12.67±1.30	9.19±2.20
23	Ariyalur	Ariyalur	7.65	10.03	9.13	7.19±1.3	13.87±2.50	10.71±1.60
24		Udayarpalayam	9.71	10.65	10.03	14.78±2.5	15.56±3.90	17.81±4.50
25	Nagapattinam	Nagappatinam	9.13	11.02	11.56	13.76±3.1	17.89±8.90	27.45±5.10
26		Vedaranyam	9.55	11.30	12.57	14.89±1.9	13.45±5.80	21.59±3.90
27		Mayiladuthurai	9.71	7.65	10.03	12.54±2.8	9.34±4.50	15.32±2.50
28		Kilvelur	9.55	11.30	12.57	16.92±2.5	17.89±4.50	20.63±2.00
29		Sirkali	9.13	11.02	11.56	11.76±3.5	13.76±2.30	16.92±5.50
30	Trichy	Manapparai	8.39	8.72	8.41	9.43±2.3	11.89±2.10	10.93±3.30
31		Musiri	7.66	9.73	8.79	8.91±2.1	10.00±3.20	11.56±1.10
32		Thottiyam	7.48	9.96	8.93	8.12±3.2	10.61±2.30	9.34±5.20
33		Trichy East	7.66	9.73	8.79	7.59±2.3	12.7±4.00	10.99±3.30
34		Trichy West	7.66	9.73	8.79	5.50±4.0	11.56±3.80	13.79±4.90
35		Lalgudi	7.65	9.72	8.79	7.74±3.80	13.65±2.90	14.61±3.10
36		Manachanallur	7.65	9.72	8.79	8.83±2.90	11.1±3.75	13.71±2.90
37	Thiruvarur	Mannargudi	9.83	8.13	9.76	12.78±6.75	10.56±5.98	16.97±6.20
38		Needamangalam	7.66	10.03	9.13	5.51±3.98	14.78±7.63	17.13±3.02
39		Nannilam	7.66	10.03	9.13	7.92±2.63	13.89±5.56	13.51±4.63
40	Perambalur	Alathur	7.66	9.73	8.79	6.74±3.56	13.87±6.78	10.62±2.56
41		Kunnam	7.66	9.73	8.79	7.67±2.79	12.68±3.76	14.6±4.80

Nagapattinam block at 27.45%. In Nagapattinam district, Nagapattinam block was followed by Vedaranyam and Kilvelur with 21.59 & 20.63% disease severity, respectively. The Nagapattinam district was followed by the Thanjavur district, where the disease severity ranged between 15.54% and 24.90%. The maximum disease severity was recorded in the Thanjavur block at 24.90% and the minimum disease severity was recorded in the Buddalur block at 15.87%. Kumbakonam, Peruvurani and Pattukottai followed Thanjavur block with 22.65%, 22.23% and 20.01% disease severity, respectively. The least disease severity was recorded in the Theni district Bodinayakanur block with 8.00 % disease severity, followed by Andipatti and Periyakulam blocks

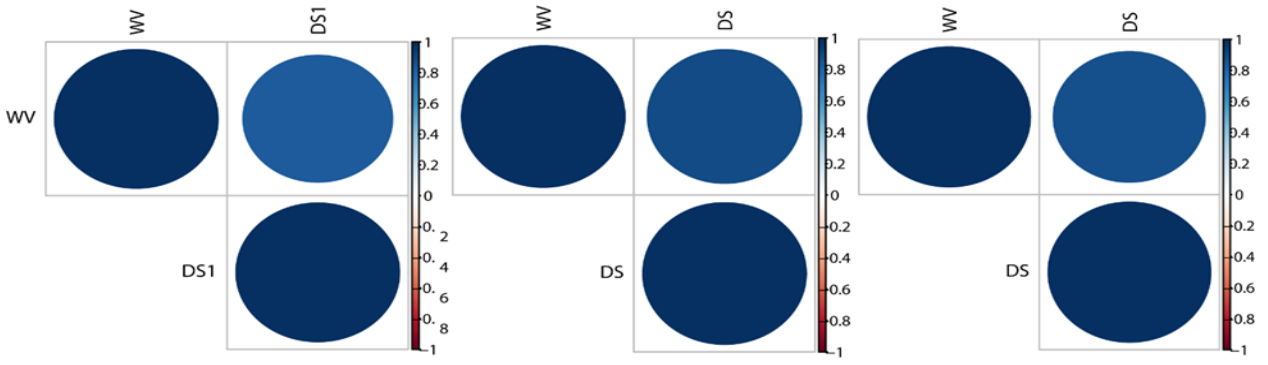

Fig. 2a Fig. 2b Fig. 2c

Fig. 2. *Showing the relationship between the wind velocity (wv) and disease severity (DS) through corrplot illustration.* **a.** *Corrplot illustration between wind velocity and disease severity in years 2019 with 0.83,* **2b.** *Corrplot illustration between wind velocity and disease severity in years 2020 with 0.89,* **2c.** *Corrplot illustration between wind velocity and disease severity in years 2021 with 0.87.*

with 8.34% and 9.34%, respectively.

Survey results revealed that the intensity of false smut disease ascendingly increased from 2019 to 2021 (Fig.1). The disease severity was highly observed in delta districts viz., Thanjavur, Nagapattinam than rest of the non-delta rice-growing districts. Correspondingly, the wind velocity was also quite higher in these two districts (7.65 to 12.57 m/s) than in other districts (5.71 to 10.03 m/s). The present results denoted that increased disease severity was positively proportional to the increase in wind speed and vice versa.

The disease severity was distributed in two parts in all the years during the survey. The disease severity was recorded between 5.78% and 15.87% when the wind velocity was between 5.93 and 8.98 m/s. At the same time, when the wind velocity was recorded beyond 8.98m/s, the disease severity also increased up to 27.45% at 12.57m/s. In 2019 when the wind velocity was in the range of 5.93 to 8.09 m/s the disease severity increased from 5.78% to 8.91%. In the same year, the disease severity increased from 9.43% to 19.91% during the wind velocity from 8.39 to 10.43 m/s. In 2020, the disease severity ranged between 4.94% and 11.89% during the wind velocity from 5.71 to 8.72 m/s and the disease severity increased from 12.43% to 17.89% during the wind velocity from 9.26 to 11.13 m/s. In 2021, also the disease severity gradually increased from 8.00 to 15.87% during the wind velocity from 6.78 to 8.98 m/s and also the disease severity increased tremendously from 16.92 to 27.45% when the wind velocity ranged between 9.13 to 12.57 m/s (Table 1).

Correlation analysis, calibration, and validation of regression model

Correlation matrix values were 0.83, 0.89 and 0.87 for the following years 2019, 2020 and 2021, respectively. They indicated that a strong association existed between wind velocity and disease severity (Fig. 2a, Fig. 2b and Fig. 2c). In the case of regression analysis, the R^2 values were 0.70, 0.79 and 0.76, which explained that the 70%, 79% and 76% variability in disease severity is contributed by the variation in the wind velocity (Fig. 3a, Fig. 3b and Fig. 3c). The regression equation was derived from the pooled mean values of the past three years (2019, 2020 and 2021) data between wind velocity and disease severity. When the mean wind velocity values were fed into the validated equation, it showed 5.21%, 8.30% and 13.24% variability for the three years *viz.,* 2019, 2020 and 2021, respectively (Table 2). The chi-square test also revealed that there

Table 2. Correlation and regression analysis between wind velocity and disease severity in the following years, 2019, 2020 and 2021, respectively

S.No.	Year	Correlation matrix value	Regression R^2 value	Regression equation	Pooled validated equation	(%) variability from the validated equation	Chi-square value	Critical value (5%)
1	2019	0.83	0.70	Y=2.8925x-13.98	Y=2.6121x-11.10	5.21	0.03	5.99
2	2020	0.89	0.79	Y=2.1736x-		8.30	0.09	5.99
3	2021	0.87	0.76	Y=2.1617x-9.47		13.24	0.22	5.99

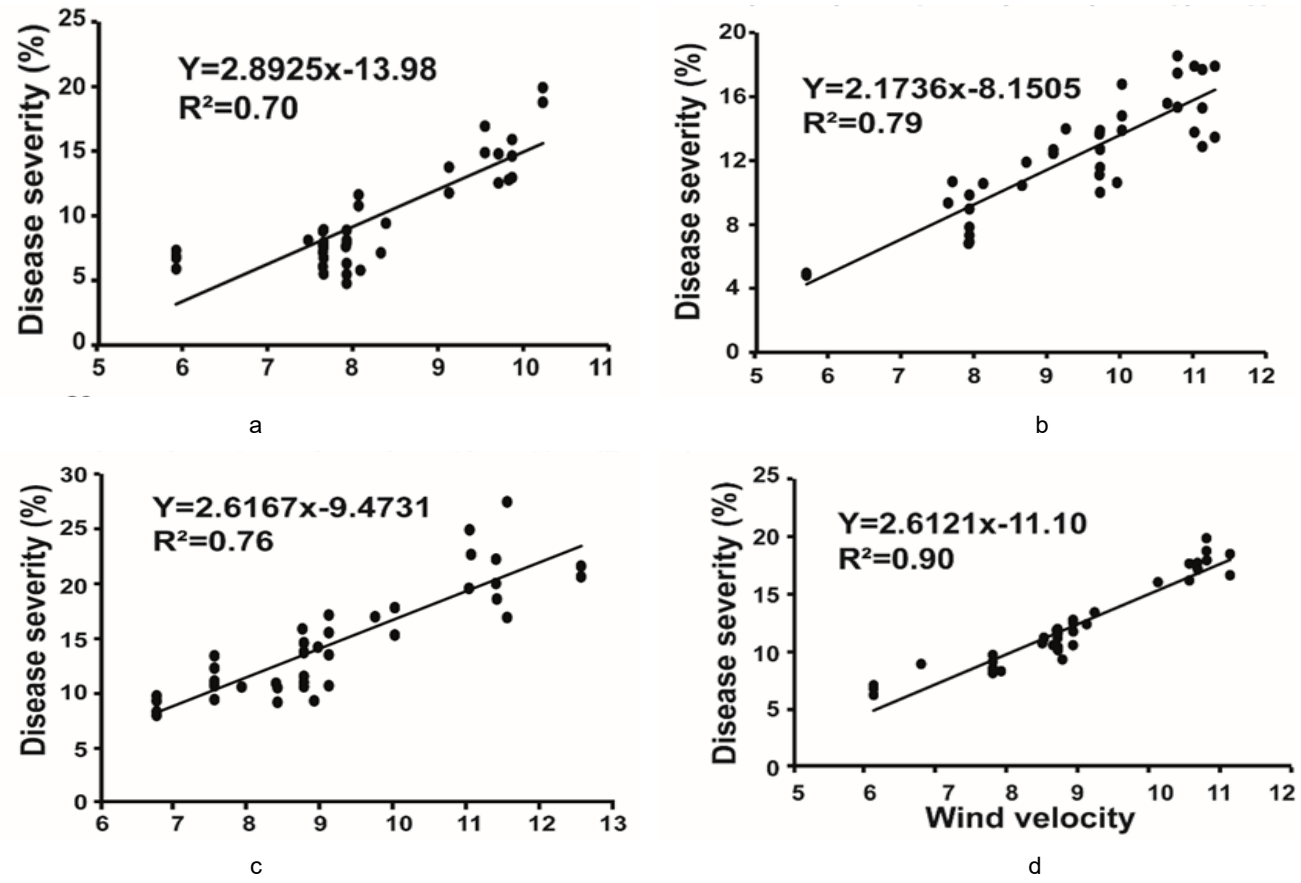

Fig. 3. *Indicated the magnitudinal relationship between the wind velocity and the diseases severity of Ustilaginoidea virens.* Fig. 3a*. Simple linear regression between wind velocity and disease severity in the year 2019.* Fig. 3b. *Simple linear regression between wind velocity and disease severity in the year 2020.*Fig. 3c*. Simple linear regression between wind velocity and disease severity in the year 2021.* Fig. 3d. *Simple linear regression between wind velocity and disease severity in the pooled years of 2019, 2020 and 2021.*

were no significant differences between the predicted and observed disease severity values since the chi-square value was less than the table value (Table. 2). Similar reports were obtained by Wang *et al*. (2016) and correlated the rice false smut infected distribution with the wind direction at Liaoning province of china and concluded that false smut disease incidence was positively correlated with the wind speed. Chen *et al.* (2020) also found that a positive correlation existed between the diversity of microbiota and wind velocity in Guiyang province of china. The present results were also supported by the findings of (Chaudhari *et al.,* 2019), who obtained negative correlation matrix values of -0.55 and -0.51 during the years 2017 and 2018, mainly due to low wind speed prevailing during disease development at Navsari, Gujarat.

Dissipation of disease development at the field level

The more disease intensity observed in the peripheral region of the farmland (Kaatuthottam village, Thanjavur block, Thanjavur district) was mainly due to the early infestation of paddy inflorescence by spore landing of chlamydospores. The disease dissipation was highly influenced by wind velocity and wind direction (Fig. 4). Wind velocity helps in spore dispersal and wind direction helps in directing the spore dispersal in the field. Fig. 4. revealed that disease distribution was mainly dissipated in the northeastern diagonal manner since the wind flow was detected in northeastern direction. 50% PE is the ideal cropping stage for spraying strobilurin-grouped fungicides to control false smut disease development (Ladhalakshmi *et al*., 2012). By knowing the wind direction and wind velocity (using pooled year regression equation), one can easily predict the disease development and distribution pattern of false smut disease. Hence spraying the fungicides in the peripheral region of the farmland is cost-effective and judicious way of managing this effectively without any resistance gene development in the pathogen. Continuous increase in the disease pressure in all the surveyed areas from 2019 to 2021 denoted the perpetuation of primary inoculum *viz.,* chlamydospore and sclerotia. Nguyen *et al*., (2012) stated that wind velocity/currents play a vital role in the disease development at the time of flowering. Besides, they reported that wind flow helps in

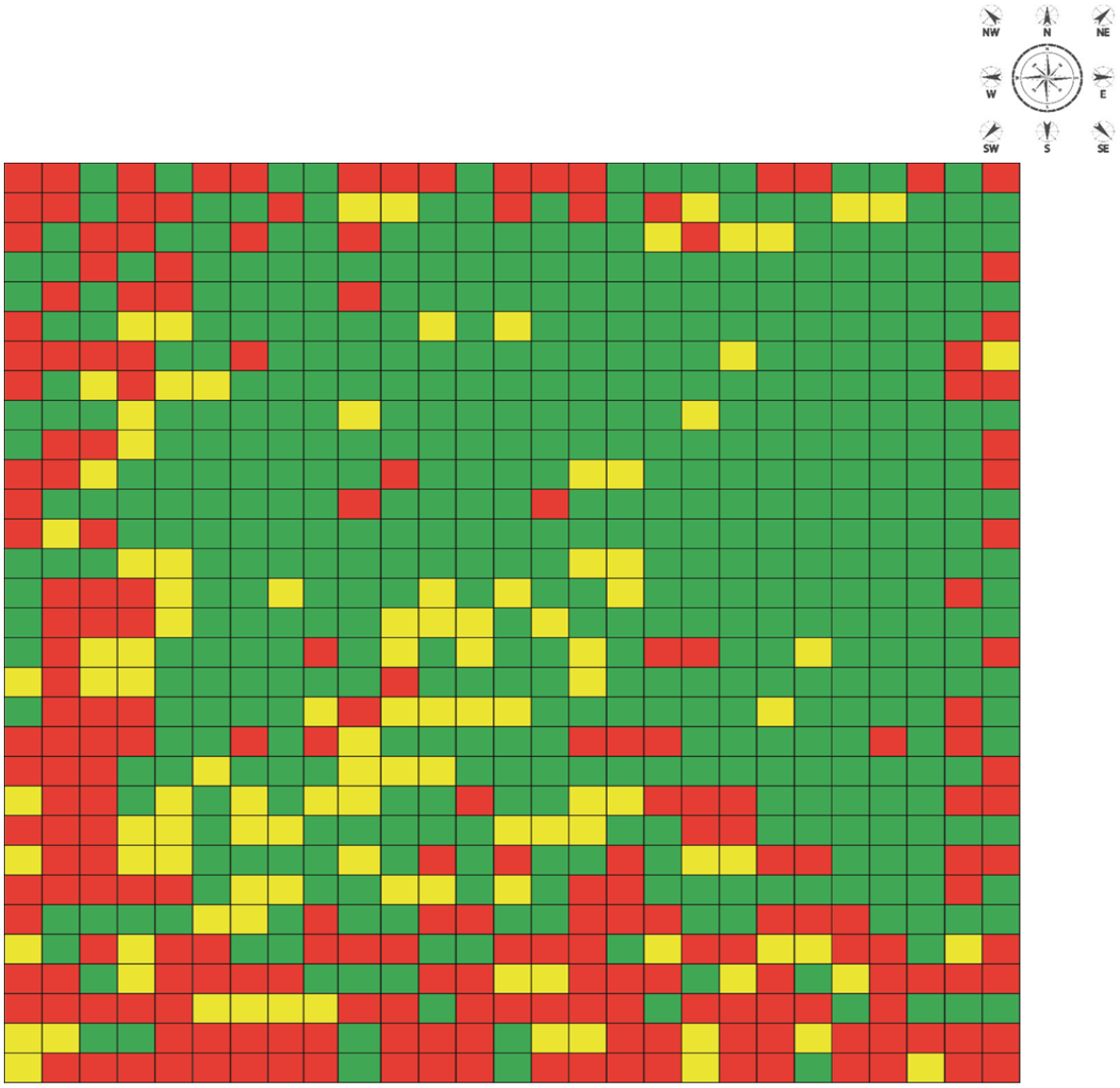

Fig. 4. *Disease development pattern of false smut disease in a paddy field at Kaatuthottam village, Thanjavur district (Red color indicating ≥ 5 panicles infected in a hill: yellow color indicating 3-5 panicles infection in a hill and green color indicating the healthy plant without any infection*

chlamydospores dispersal and tends to stick on honey dew which attracts and subsequently serves as vectors of spore dissemination. Urmila *et al.* (2015) also reported that high wind velocity and heavy rainfall aggravate the false smut disease development, especially in long duration rice varieties. Ladhalakshmi *et al.* (2012) also observed the heavy incidence of this disease recorded on the rice varieties CR1009 and BPT5204 in Kunnakudi village of Ramanathapuram district and Maharajapuram village of Thanjavur districts respectively. The heavy incidence of this disease was mainly due to the discharge of chlamydospores in the wind which helps the pathogen dispersal and is responsible for disease aggravation. Dhua and Dhua (1999) also reported that false smut severity was so high and it is positively proportional to the increase in wind speed with heavy rain. The peripheral paddy growing region of the farm land is the foci of infection for *U. virens* mainly due to the presence of collateral hosts including *Oryza officinalis*, *Digitaria marginata*, *Panicum trypheron*, *Echinochloa crusgalli*, *Imperata cylindrical* etc. (Rao and Reddy, (1955), Shetty and Shetty (1985) and Atia (2004)). These collateral hosts not only act as foci of infection but also harbors the overwintering structures *Viz.,* Sclerotia, Chlamydospores of *U. virens* during off-season.

Conclusion

The present study concluded that the foci of infection of false smut disease were distributed around the peripheral region of paddy field. False smut of rice has reached the epidemic in most delta districts (Thanjavur, Nagapattinam, Trichy, Ariyalur, Thiruvarur) and non-delta rice (Madurai, Theni, Perambalur) growing dis-

tricts of Tamil Nadu. Wind velocity and wind direction were the deciding factors of false chlamydospores dispersal and disease development during the flowering stage. Wind velocity dissipated the chlamydospores dispersal and wind direction involved in the orientation of disease development. Minimum fungicidal usage and site-specific fungicidal sprays are the key approaches to preventing the resistance gene development in U. virens. This study would be more informative and help farmers identify the correct site foci of infection for fungicide application.

ACKNOWLEDGEMENTS

We thank the Department of Plant Pathology, AC and RI, Madurai, for providing financial support during the survey for all the years to carry out this research. We also thank Tamil Nadu Agricultural University for providing a research facility.

Conflict of interest

The authors declare that they have no conflict of interest.

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