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Leveraging Extended Range Weather Forecast for Groundnut Bud Necrosis Disease Forewarning: A Data-driven Approach

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ABSTRACT

Background: Groundnut (*Arachis hypogaea* L.), a globally prominent oilseed crop, is experiencing significant losses due to the Groundnut Bud Necrosis Virus (GBNV). The extended range weather forecast (ERWF) provides timely weather information and protects crops from weather-induced biotic and abiotic risks.

Methods: An ERWF-based GBNV disease forewarning study was conducted at Coimbatore, Tamil Nadu in 2023 and 2024. The ERWF output from Weather Research and Forecasting (WRFv4.4) with two microphysics (WSM3 and Kessler) were leveraged to forewarn the GBNV disease, using the thumb rule as adapted in Tamil Nadu Agricultural University-Agro Advisory Service (TNAU - AAS): Web cum Mobile App, which is maximum temperature (>33°C), relative humidity (40-70%), wind speed (>5 kmph) and rainfall (0 mm).

Result: Among the two microphysics options, the WSM3 performed better and provided more usable ERWF than the Kessler scheme. The WSM3 based ERWF usability percentage was 50 to 100 for rainfall and 80-100 for all other weather variables. The higher performance of ERWF resulted in a more precise forewarning of thrips and GBNV. The first and peak activity of thrips and GBNV incidence was well correlated (70-80%) with the ERWF based forewarning.

Key words: Epidemiology, Extended range weather forecast (ERWF), Thrips, WRF, Forewarning, Groundnut bud necrosis virus (GBNV),

INTRODUCTION

Weather significantly impacts crop production, both directly (accounting for 50%) and indirectly (30%) by influencing pest and disease dynamics. Various pest and diseases respond differently to environmental conditions, particularly at the microclimate level. For a plant disease to develop, three factors *viz.*, a virulent pathogen, a susceptible host and a suitable environment must coincide (Mead *et al.,* 2022). Climate change has the potential to alter the prevalence of existing diseases and their economic significance and may introduce new diseases in specific areas (Zayan, 2019).

Recent advancements in meteorological forecasting methods offer new prospects for predicting disease outbreaks in crops including groundnut. In this study, the interplay between weather variables, the groundnut host, thrips and tospovirus spread are explored. The insights gained will contribute to the development of a robust tospovirus outbreak prediction model, enhancing disease management strategies.

Groundnut (*Arachis hypogaea* L.), commonly known as the "poor man's nut," globally ranked 13th among the plant foods consumed in tropical, subtropical and temperate zones (Anonymous, 2023[a]). It is a principal oilseed crop (Kandakoor *et al.,* 2012), ranking first in India's oilseed acreage and second in production. Among the Indian states, Karnataka has the highest acreage (1.65 lakh ha) followed by Andhra Pradesh (0.81 lakh ha), Tamil Nadu (0.94 lakh ha), Telangana (0.93 lakh ha) and Odisha (1.10 lakh ha) (Anonymous, 2023[b]). Groundnut is vulnerable to the negative effects of climate change, including increased CO_2 levels, unpredictable rainfall patterns, high temperatures and moisture stress, which have a negative impact on physiology, disease resistance, fertility and productivity (Sudhalakshmi *et al.,* 2022).

Groundnut bud necrosis virus (GBNV), also known as Peanut Bud Necrosis Virus is foliar disease which is significantly affecting groundnut productivity in India. Interestingly, GBNV also impacts tomato crop. Singh and

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Srivastava (1995) reported that GBNV infection accounts for 70-90% of groundnut losses in India, with an average incidence of 0 to 98%. Thrips, tiny insects belonging to the order Thysanoptera, are economically harmful pests affecting various crops used for food, feed and fibre (Riley *et al.,* 2011). Thrips serve as circulative and propagative hosts for tospoviruses (Mandal *et al.,* 2012). Managing thrips-tospovirus remains challenging due to its presence in both thrips and host plants. Despite efforts, insecticides and host plant resistance have proven ineffective (Mahanta *et al.,* 2022). Since 2015, a variety of insect pests, particularly sucking pests, have significantly lowered groundnut productivity (Reddy *et al.,* 2024).

Environmental factors determine the disease's breakout and can be employed to predict the severity of the disease (Vijaykumar *et al.,* 2024). Developing an effective plant disease forecasting system necessitates an understanding of host factors, pathogen dynamics and environmental influences. An attempt was made to use Principal Component Analysis (PCA) to establish a relationship between weather variables and thrips occurrences. PCA is a multivariate statistical technique that reduces related p-variables to new, smaller dimensions while minimizing information loss. In agricultural ecosystems, weather significantly influences crop disease incidence and severity. This study explores the synergy between epidemiological research and weather forecasts as a powerful tool for predicting groundnut bud necrosis disease and empowering farmers with preventive measures to protect crops.

MATERIALS AND METHODS

Study location and period

The study was conducted successively for two years during the summer (January-May) of 2023 and 2024 in groundnut crops to understand the incidence of thrips and GBNV. The groundnut fields in four different villages (L1: Viraliyur, L2: Narasipuram, L3: Thondamuthur and L4: Devarayapuram) of Thondamuthur block (Table 1) at Coimbatore district, Tamil Nadu, India (Fig 1) were taken for the study, which is in the Western Agro Climatic Zone of Tamil Nadu.

Coimbatore receives an annual rainfall of 728 mm from 47 rainy days and benefits mostly from the North East Monsoon (NEM, 358 mm). The study location is within a 10 km perimeter of Western Ghat, a rain shadow area to South West Monsoon (SWM, 198 mm) rains. The summer and winter contribute 152 and 20 mm, respectively. The elevation of WZ varies from mean sea level to 427 m. The mean monthly maximum and minimum temperature of the study location were 31.9°C and 21.9°C, RH morning and evening was 85 and 50% and the average wind speed was 7.7kmph (TNAU Observatory, Coimbatore, 2024).

Table 1: Coordinates of study locations.

Village	Latitude	Longitude
Viraliyur (L1)	10.9978°N	76.7843°E
Narasipuram (L2)	10.9880°N	76.7740°E
Thondamuthur (L3)	10.9899°N	76.8409°E
Devarayapuram (L4)	10.9961°N	76.8030°E

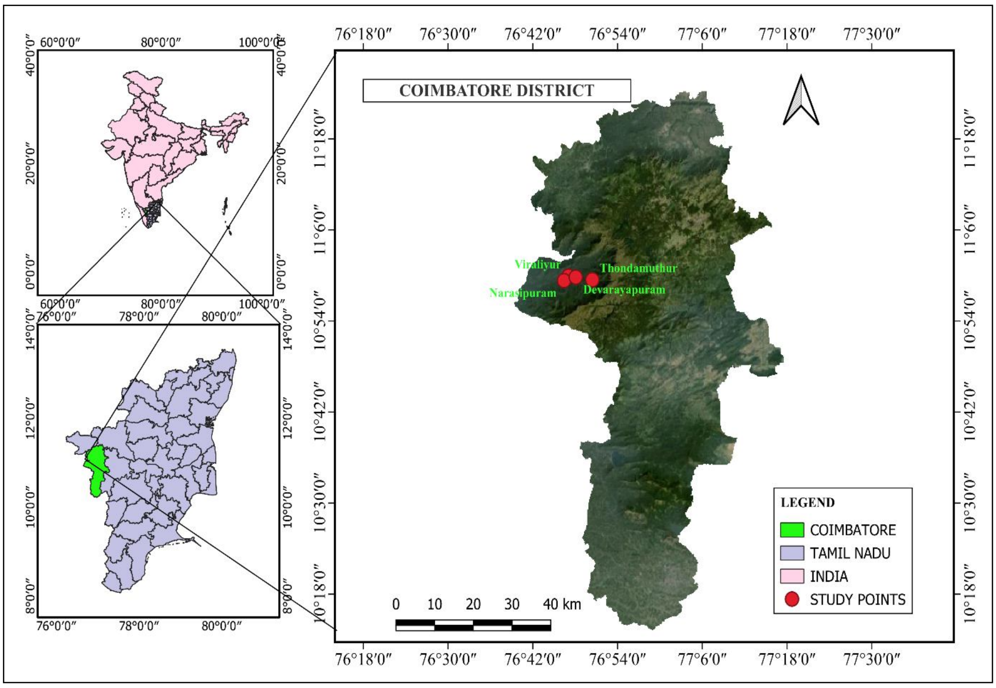

Fig 1: Study area of ERWF based forewarning of GBNV in groundnut.

ERWF development

ERWF for the experimental location was developed during the study period by using the high-resolution mesoscale numerical weather prediction model "Weather Research and Forecasting (WRF) Model" version 4.4. The Linux-based open-source WRF model developed at the National Center for Atmospheric Research (NCAR) was downloaded from "GitHub" (https://github.com/wrf-model/WRF) and installed in a physical server with 32 processors and 128 GB RAM. The name list of the WPS (WRF Preprocessing System) and WRF model was altered for two nested domains (9 km and 3 km). The six hourly Global Forecasting System (GFS) data for the next 16 days (GRIB2 format, 0.25 resolution, 12-hour cycle, gfs.t12z.pgrb2.0p25.f000 to 384) was downloaded at weekly intervals and employed as input for the Weather Research and Forecasting - Advanced Research WRF (WRF - ARW) v4.4 model. The WRF model endures several kinds of processes in its workflow as depicted in Fig 2.

The parent and nested domain centroid in namelist were fixed as 11°N and 78.5°E. The parent domain was spaced @ 9 km, consisting of 200 grids on both NS and EW directions, covering an area of 1800×1800 km. The nested domain with a finer resolution had 225 grids in the NS direction and 165 grids in EW directions, spaced at 3 km intervals and covering an area of 645×498 km. In this study, two microphysics options that are widely used for tropical conditions *viz.*, Kessler scheme (warm rain scheme-mp1) (Kessler, 1969) and WRF single moment 3 class schemes (suitable for mesoscale grid sizes-mp3) (Hong *et al.,* 2004), were tested for their performance in ERWF usability.

Final output from the WRF model for each microphysics was generated for 35640 grids @ 3 km resolution. The geographical centre point of all four study location was 10.98895°N and 76.80745°E. The ERWF output (15 days, 18 hours) of nine nearby grids that surround the four experimental fields was extracted separately, averaged and used for the study.

The forecast output included the weather variables such as maximum temperature (Tmax,°C), minimum temperature (Tmin, °C), relative humidity morning (RHm, %), relative humidity evening (RHe, %), windspeed morning (WSm, kmph), windspeed evening (WSe, kmph) and daily rainfall (RF, mm). The standard weekly temperature (maximum and minimum), relative humidity (morning and evening.), wind speed (morning and evening) and cumulative rainfall were calculated for the Standard Meteorological Week (SMW) which fall in the study period. The observed weather variables during the study period of 2023 and 2024 are depicted in Fig 3a and 3b.

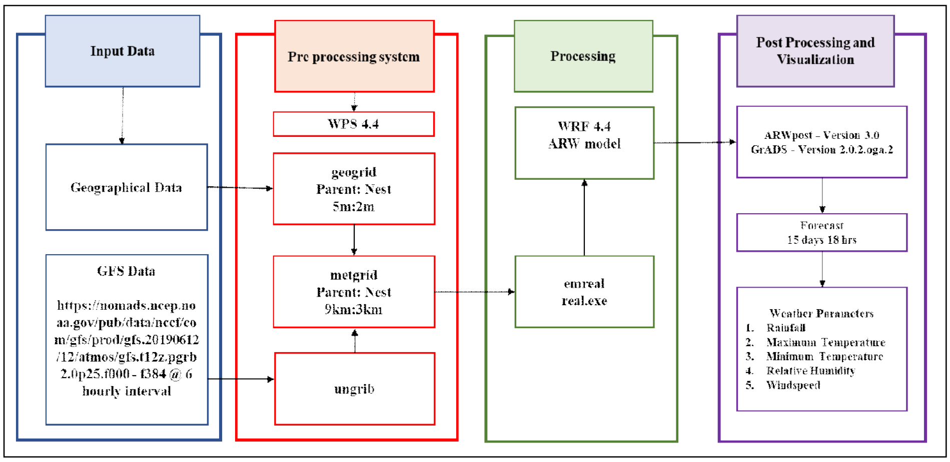

Fig 2: WRF ARW modelling system workflow diagram.

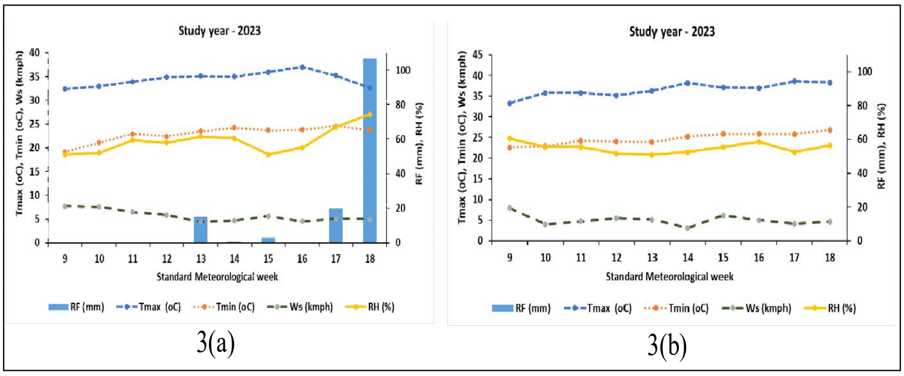

Fig 3: Observed weather during the study period Jan-May 2023(a) and 2024(b).

Epidemiology

The epidemiology of thrips and GBNV disease in groundnut was studied in four experimental locations by observing thrips population dynamics and GBNV disease by roving survey at weekly intervals for the entire cropping season. Thrips population was recorded in the top three leaves of randomly selected 20 plants and repeated in three points (40 sqm) for each location.

Mean Thrips population =

$$\frac{\text{Total number of thrips counted from all the 60 plants of a location}}{\text{Total number of plants (60 nos.)}} \times 100$$

The percentage of disease incidence (PDI) was calculated by recording the number of plants showing GBNV disease symptoms such as chlorotic and necrotic spots, chlorotic and necrotic ring spots on leaves, chlorosis of plant, axillary shoot formation, malformation of bud, drooping of leaf, bud chlorosis, terminal bud necrosis and stunted growth of the plant. The percentage of GBNV incidence was estimated by using the formula (Suganyadevi *et al.,* 2018).

Per cent disease incidence % =

$$\frac{\text{The total number of diseased plants observed}}{\text{Total number of plants (60 nos.)}} \times 100$$

Correlation between weather parameters, thrips population and GBNV disease incidence was carried out using the "R" programme to assess the pest-disease and weather relationship.

Principal component analysis

$$PC1 = \sum_{j=1}^{k} a_{1j}X_{1j} = a_{11}X_1 + a_{12}X_2 + \cdots + a_{1k}X_k$$

$$PC2 = \sum_{j=1}^{k} a_{2j}X_j = a_{21}X_1 + a_{22}X_2 + \cdots + a_{2k}X_k$$

Where:

Eigen vectors- a_{ij} and $x_1, x_2 \ldots x_k$ - Original variables in data matrix.

A versatile statistical technique known as Principal Component Analysis (PCA) can be used to distil a cases-by-variables data table down to its principal components, or key elements. A small number of linear combinations of the original variables, known as principal components, can account for the majority of the variance in all the variables. Using just these few key elements, the method approximates the original data table in the process (Greenacre *et al.,* 2022). PCA was performed using the R statistical package (version R-4.4.0).

Forewarning of thrips and disease incidence

The daily values of 15 days of weather forecast values from the WRF v4.4 model were converted into week 1 (1-7 days) and week 2 (8-14 days) by averaging (temperature, wind speed and relative humidity) and cumulated rainfall. The 2nd week values were then utilized to develop ERWF-based forewarning of thrips infestation. The thumb rule for thrips infestation, as adopted in TNAU - AAS: web cum Mobile App (Geethalakshmi *et al.,* 2019) was referred for this purpose. Thumb rule suggests that the thrips infestation may occur when the air temperature exceeds 33°C, the wind speed of above 5 km and the average relative humidity falls between 40 and 70 per cent. Additionally, this risk will be heightened when there is zero mm rainfall.

Verification of ERWF-based forewarning

The usability of ERWF-based forewarning was assessed by monitoring the thrips population count and GBNV incidence at weekly intervals in groundnut (Fig 4).

In this study, forewarning efficiency was assessed by comparing the ERWF (both WSM3 and Kessler) based forewarning and observed weather-based hindcast forewarning. If the values were aligned with the thump rule, scored as "Y"; otherwise received an "N" score. Based on the real observation in the field, if thrips infestation is observed, increasing trend, decreasing trend and not observed were scored as "Y", "Y+", "Y-" and "N", respectively. All the scores were tabulated and calculated for match cases between forewarning based on ERWF (both WSM3 and Kessler) and actual observation, hindcast forewarning based on observed weather and actual observation.

RESULTS AND DISCUSSION

Verification of ERWF with different microphysics

Understanding the performance differences between WRF microphysics schemes is crucial for improving weather forecasts and enhancing our ability to provide accurate advisories. The forecast usability percentage (FUP) of ERWF generated with two different microphysics options *viz.*, WSM3 and Kessler schemes for the period from February to May 2023 and 2024 were presented in Fig 5.

The ERWF generated with the WSM-3 scheme consistently outperformed the Kessler scheme in terms of FUP (Correct+Usable) during both 2023 and 2024 (Fig 5).

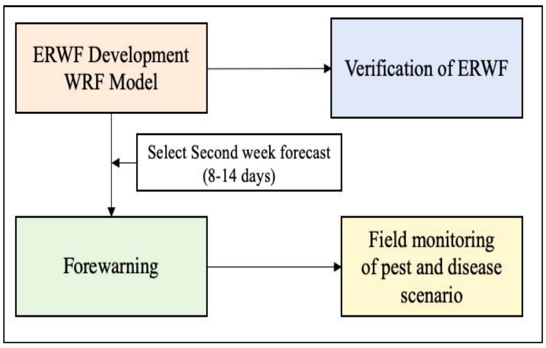

Fig 4: An illustration showing ERWF-based GBNV forewarning in groundnut.

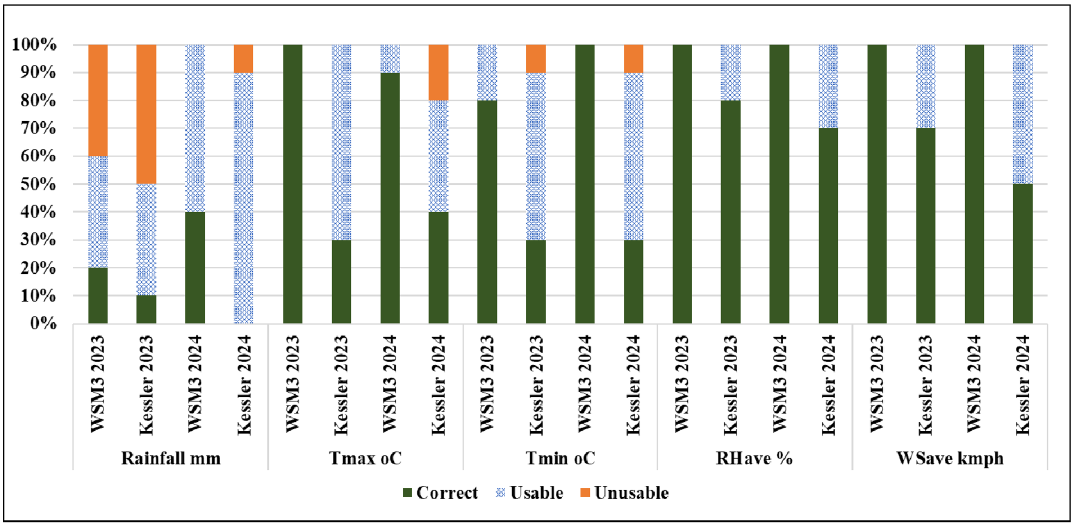

Fig 5: Forecast usability percentage of ERWF during two years study period.

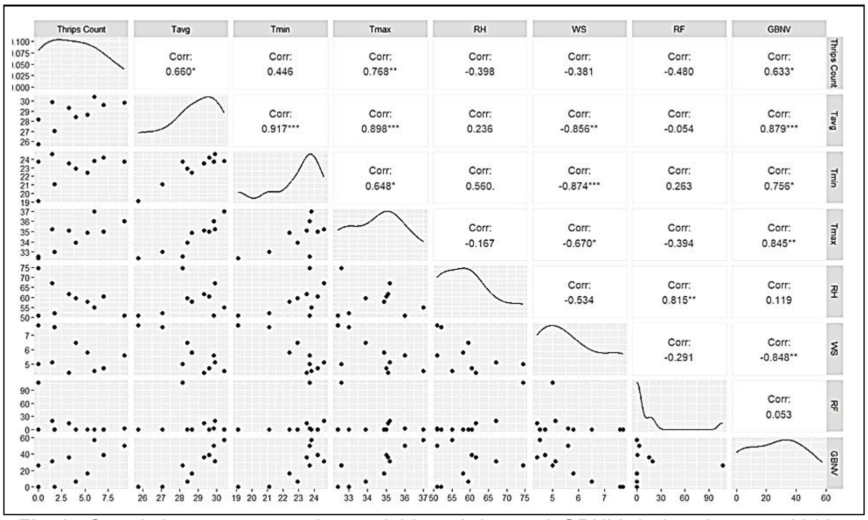

Fig 6: Correlation among weather variables, thrips and GBNV during the year 2023.

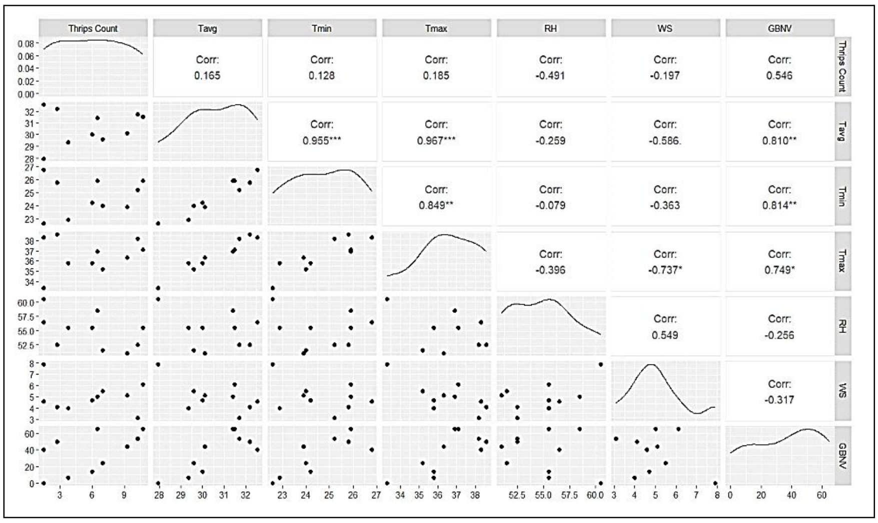

Fig 7: Correlation among weather variables, thrips and GBNV during the year 2024.

Similar results were reported by Dheebakaran *et al.* (2022) when examining the effects of WRF's microphysics options on the village level medium range rainfall forecast in Tamil Nadu. In their study, WSM3 produced better forecast with higher FUP compared to Kessler, WSM5 and WSM6. Interestingly, Zaidi and Gisen (2018) found contrasting results that WSM6 outperformed WSM3 in rainfall forecast, which might be attributed to spatial variability across different regions of study. Among the weather parameters considered, the FUP was ranked in the order of Tmax, Tmin, RH, wind speed and rainfall. Both the schemes tended to overestimate the rainfall and RH, while underestimating Tmax and Tmin. Additionally, the wind speed forecast lacked consistency. The WSM3-based ERWF usability (correct+usable) percentage was 60-100 per cent for rainfall, 80-100 per cent for Tmax, 90-100 per cent for Tmin and 100 for wind speed and RH. Comparing this study with the earlier study of Dheebakaran *et al.* (2022) in Tamil Nadu with Medium Range Weather Forecast (MRWF), the accuracy of ERWF was higher. The MRWF usability was assessed for daily rainfall, while the ERWF usability calculations were made for weekly cumulative rainfall.

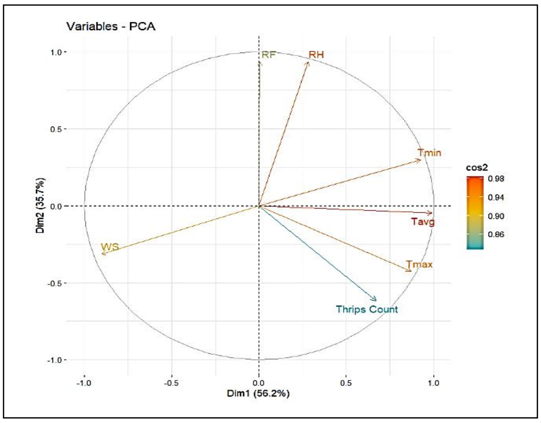

Fig 8: Weather variables contribution to PDI (%) during 2023.

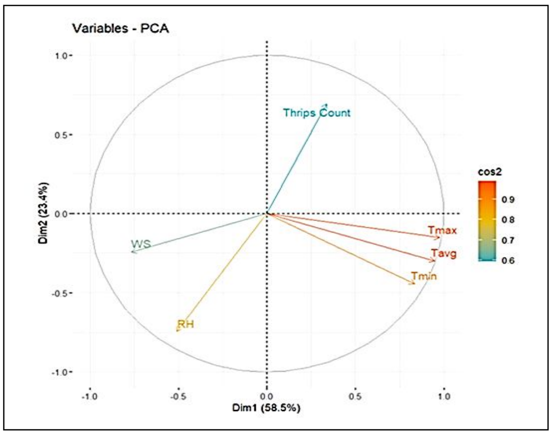

Fig 9: Variables contribution to PDI (%) during 2024.

Table 2: Verification of forewarning given by microphysics options.

SMW	2023				2024			
	Forewarning using ERWF Forecast		Hindcast incidence using observed weather	Actual Incidence observed in the field	Forewarning using ERWF Forecast		Hindcast incidence using observed weather	Actual Incidence observed in the field
	WRF-WSM3	WRF-Kessler			WRF-WSM3	WRF-Kessler		
9	N	N	N	N	N	N	Y	Y
10	N	N	Y	Y+	Y	N	Y	Y+
11	Y	N	Y	Y+	Y	N	Y	Y+
12	Y	N	Y	Y+	Y	Y	Y	Y+
13	N	N	N	Y-	Y	Y	Y	Y+
14	Y	N	Y	Y+	Y	Y	Y	Y+
15	Y	Y	Y	Y+	Y	Y	Y	Y-
16	Y	Y	Y	Y-	Y	N	Y	Y-
17	N	N	N	Y-	Y	N	Y	Y-
18	N	N	N	Y-	Y	Y	Y	Y-
Match cases								
N : N	1	1	1		0	0	0	
Y : Y+	4	1	5		4	2	4	
N : Y-	3	3	3		1	3	1	
Total	8	5	9		5	5	5	

Relationship between weather variables, thrips and GBNV incidence

The groundnut crop was observed with silvery appearance due to thrips feeding on the epidermal cells content and symptoms observed such as necrosis, bud necrosis, chlorosis and stunted growth due to GBNV infection. Basavaraj *et al.* (2017) also noted comparable symptoms.

Selected weather variables were examined for correlation between thrips, GBNV and weather parameters. The rainfall was excluded from correlation and PCA during 2024, since rain didn't occur during that specific time frame. During 2023 (Fig 6), the thrips population showed the highest positive correlation with Tmax (0.768, significant at 0.1% (p-value<0.01)) and the GBNV incidence had the highest negative correlation with Tavg (0.879, significant at 0.1% (p-value<0.01)). Between Thrips and GBNV, there was a correlation of 0.633 (significant at 5%).

Thrips occurrences showed both positive and negative association with weather variables. Heavy downpours resulted in mechanical washing-off thrips, while light rainfall alternated with dry days supported the thrips multiplication. Vijayalakshmi *et al.* (2017) also noted that the rainfall has a beneficial impact on the number of thrips at Coimbatore on groundnut.

During the year 2024 (Fig 7), the thrips population showed the highest positive correlation with Tmax (0.185, Non-significant) while the GBNV incidence had the maximum positive correlation with Tmin [(0.814, significant at 1% (p-value<0.01)]. But non-significance was observed between Thrips and GBNV (0.546). According to Vijayalakshmi *et al.* (2017) the thrips population exhibited a negative association with morning and evening RH. A positive correlation with sunshine hours, rainfall, Tmax and Tmin respectively, in the *kharif* and *rabi* seasons. There was a positive correlation for GBNV incidence with morning RH, rainfall, SSH and evening RH, but a negative correlation with Tmin and evening RH.

The PCA diagram (Fig 8 and 9) showed that the Tmax, Tmin, Tave, RH, WS, Rainfall and Thrips count were in the order of significant influence on the GBNV, which showed the importance of weather variables on the GBNV forewarning.

Forewarning of thrips and GBNV

Population of thrips was counted individually from the four study locations and the first incidence of thrips was observed in the 10th and 9th SMW during the years 2023 and 2024. The population of thrips reached above ETL (<=5 nos. / plant) during 12 to 16th SMW in 2023 (5-10 nos. in top 3 leaves), while it was 5-12 in top 3 leaves during 10 to 16th SMW in 2024. Percent disease incidence (PDI) was calculated from four locations based on the GBNV symptoms. In 2023, the GBNV incidence was observed during the 11th SMW, while it was a week earlier (10th SMW) during 2024. The PDI reached its highest during the 16th SMW during the year 2023 (60%), whereas it was 15-16th SMW during the year 2024 (70%) (Fig 10 and 11).

The favourable weather particularly, higher temperatures without rainy days might be the reason for early thrips infestation, long peak periods and higher number of thrips count during the year 2024, compared to 2023. Early incidence of GBNV was also observed in the study year 2024 as a result of the early occurrence of thrips. The incidence of GBNV was notably higher in 2024 than in 2023 possibly as an effect of the increased virus inoculum.

The fluctuations in the thrips population and PDI percentage were observed due to observation in random sampling and the exclusion of completely withered plants (Fig 10 and 11). According to Vijayalakshmi *et al.* (2017), the incidence of GBNV observed with a mean thrips population at top bud leaves was 3.4 - 6.4 numbers per plant during *kharif* and 3.2 - 7.1 numbers per plant during in *rabi*. Sunkad *et al.* (2012) noted that the disease incidence vacillated from 1 to 44 per cent during *kharif* 2007 and it was between 1 and 84 per cent during rabi 2007. The substantial variation in thrips populations was evident because of the increased influence of biotic and abiotic factors such as weather on these two characteristics.

Verification of forewarning

Comparison results of thrips forewarning verification (Table 2) revealed that the WRF-WSM3 scheme based forewarning performed equally well as that of observed weather-based forewarning. There were 8 matches during 2023 and 5

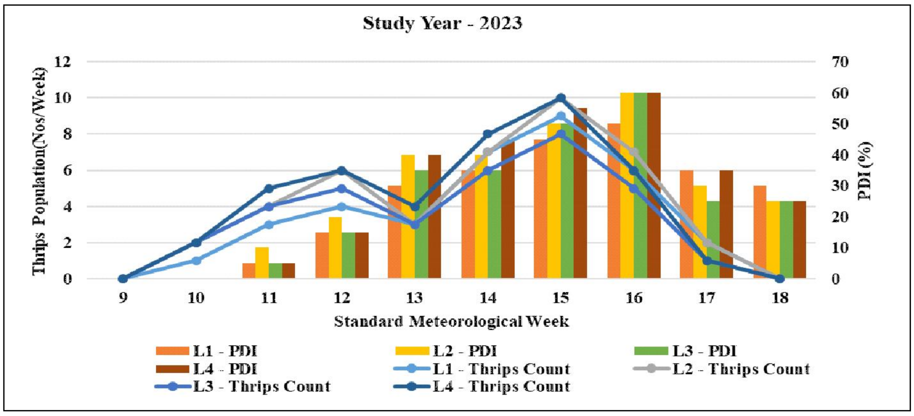

Fig 10: Thrips population and GBNV incidence observed in the study year 2023.

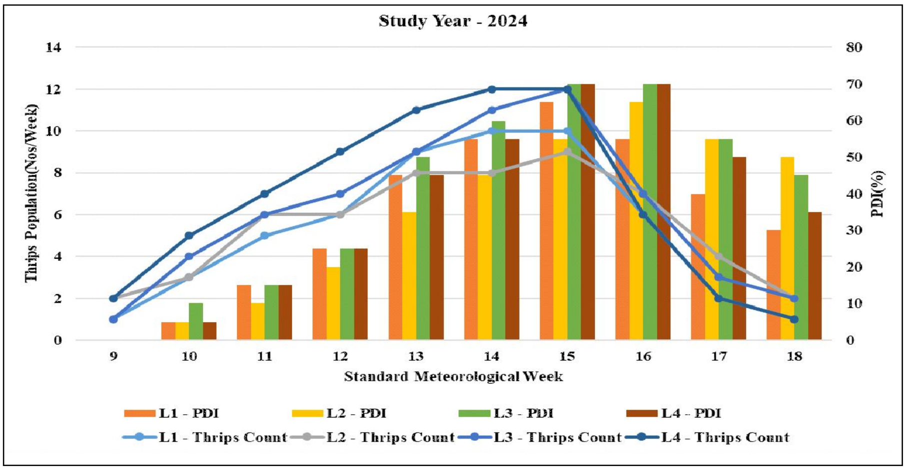

Fig 11: Thrips population and GBNV incidence observed in the study year 2024.

matches during 2024 in WRF-WSM3-based forewarning against 9 and 5 matches in observed weather-based hindcast forewarning. The WRF-Kessler scheme-based forewarning resulted with 5 match cases during both the 2023 and 2024 experiments. Similar study was done by Olatinwo *et al.* (2012) employed the high-resolution WRF model to forecast favourable infection circumstances to control early leaf spots in peanuts.

CONCLUSION

Thrips, along with the tospovirus transmit, pose a significant threat to groundnut production in India. Understanding meteorological variables like maximum temperature is essential to forecast thrips, which has a strong correlation with thrips incidence. Warmer climates accelerate thrips development, while drier environments enhance their fecundity. As thrips population grow, their impact becomes more pronounced. Moderate to heavy rains can wash away vectors, reducing thrips populations. The Extended Range Weather Forecast (ERWF) provides valuable insights by predicting the start and peak periods of thrips incidence and Groundnut Bud Necrosis Virus (GBNV) incidence two weeks in advance, with a 50-80% confidence level. Armed with this information, timely control measures can be scheduled to mitigate the impact on groundnut productivity. Spatial and temporal variation significantly impact forecast accuracy. To develop robust forewarning models and applications, integrating the ERWF with epidemiological studies across diverse climate, crops, pests and diseases would facilitate the farmers to gain the ability to anticipate and mitigate the consequences of pests and diseases in crop production.

Future research could explore ERWF applications for other pest and diseases of multiple crops with a focus on diverse agro-climatic regions in Tamil Nadu and developing algorithm for pest and disease forewarning of GBNV with management strategies.

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Disclaimers

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Conflict of interest

The authors declare that there are no conflicts of interest.

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