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Temperature influence on leafhopper population and its potential distribution in predicting spread of chickpea stunt disease in India

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Abstract

Aim: To study the influence of temperature on leafhopper population for predicting potential distribution of chickpea stunt disease.

Methodology: Leaf hopper population was sampled at weekly intervals from chickpea experimental plots at Indian Agricultural Research Institute, New Delhi, during Dec-May 2018-2019 and 2019-2020 by using yellow sticky trap. Effect of temperature on leafhopper population was fitted to a non-linear beta model and Briere model by utilizing cardinal temperature for leafhopper growth and reproduction. Daily minimum and maximum temperature data were collected from 146 geo referenced meteorological stations of important chickpea growing states of India. The cumulative temperature indices (MTI) as a measure of monthly leafhopper population was plotted using ArcGis10.0 software.

Results: Temperature index estimated as a measure of leafhopper population based on the beta model potential leafhopper population distribution was predicted. Spatio-temporal pattern of vector population indicated that the entire country is favourable for leafhopper growth round the year, except the Northern parts of India during December to February.

Interpretation: Since leafhoppers are the natural vectors of virus and phytoplasma pathogens associated with chickpea stunt disease, beta model based prediction of environmental suitability indicates leafhopper as the causative agent for the natural spread of disease in larger geographical area. Spatio-temporal distribution pattern would be useful in predicting the disease spread in different chickpea growing areas for evolving efficient management strategies.

Key words: Leafhopper population, Epidemiological model, Chickpea chlorotic dwarf virus, Phytoplasma

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Introduction

Chickpea is a cool-season crop mainly grown in arid and semi-arid areas of the world under rain-fed conditions (Millan *et al.*, 2006). India ranks first in chickpea production in the world accounting for 9.075 million tonnes production (69%) of the total global production, followed by Australia, Pakistan, Myanmar, Ethiopia, Turkey and Iran (Merga and Haji, 2019). The highest productivity of 4,770.82 kg ha⁻¹ is recorded in Israel followed by China, Egypt, Uzbekistan and Yemen whereas India's average productivity is only 935.34 kg ha⁻¹ (Merga and Haji, 2019).

Chickpea is affected by many biotic stresses like blight, grey mold, dry rot, phyllody, stunt, wilt etc., that are responsible for an estimated average yield loss of 25-30%. Among major biotic stresses, chickpea stunt is the major disease caused by different groups of viruses, e.g. cucumovirus, mastrevirus and polerovirus, reported in many chickpea growing countries worldwide (Akram *et al.*, 2016; Abraham *et al.*, 2006; Chalam *et al.*, 1986; Kanakala *et al.*, 2013; Kanakala and Kuria, 2019; Shreenath *et al.*, 2020; Reddy *et al.*, 2021). The chickpea chlorotic dwarf virus (CpCDV) is widespread in all chickpea growing states of India (Horn *et al.*, 1993; Kanakala *et al.*, 2013; Shreenath *et al.*, 2020). Chickpea phyllody associated with the presence of phytoplasma once considered as minor disease, has recently become more prominent and causes huge losses in some major chickpea growing areas of the world (Shreenath *et al.*, 2020). CpCDV and phytoplasma are reported to be transmitted by the leafhopper *Orosius albicinctus* in a persistent manner (Horn *et al.*, 1993; Akhtar *et al.*, 2011). In a recent study, CpCDV was identified in two species of leafhoppers, *Amarasca (Sundapteryx) biguttula* and *O. albicinctus* feeding in chickpea fields, suggesting that these leafhopper species may be potential source of natural vectors of CpCDV infection (Reddy *et al.*, 2021).

Phytoplasmas are mostly transmitted by sap sucking leafhoppers, planthoppers and psyllids (Weintraub and Beanland, 2006). Earlier, *O. orientalis* was identified as the main leafhopper vector for natural transmission of chickpea phyllody phytoplasma in India and Pakistan (Pallavi *et al.*, 2012). Reddy *et al.* (2021) identified two leafhopper species (*Exiantus indicus*, *Empasca motti*) feeding on symptomatic chickpea plants from Andhra Pradesh and New Delhi as putative vectors for the presence of 16SrII-D subgroup of phytoplasma. Distribution of leafhopper population in terms of its abundance, particularly in chickpea growing regions is an important feature and has direct connection with epidemics. Therefore, spatio-temporal distribution of leafhopper abundance as an important information is expected to serve as a clue to evolve management strategies. Environmental factors particularly temperature plays an important role in transmission as well as replication of virus inside the host and vector (Chellappan *et al.*, 2005; Anhalt and Almeida, 2008). Assessment of possible temperature influence on

leafhopper population and its potential impact on epidemic on a large spatial scale is necessary and is expected to provide insights for developing a rational management policy. Vector-pathogen-host interaction is a complex process for most of the vector-borne disease systems and temperature influence further adds to complicacy (Daugherty *et al.*, 2009).

Precise assessment of temperature effect and probable spatio-temporal distribution of vector population may help track down the time and locations for no or low disease incidence. Therefore, understanding the influence of temperature on leafhopper population development and prediction of its potential distribution may be an important component for predicting the chickpea stunt disease (CpSD) and developing strategic management options. Therefore, the present study was conducted to assess the effect of temperature on development of leafhopper population and its potential distribution to predict the CpS disease.

Materials and Methods

Field observation on leaf hopper population at New Delhi:

Leaf hoppers were collected at weekly intervals from chickpea experimental plots at ICAR-IARI, New Delhi during December to May 2018-2019 and 2019-2020 with a yellow sticky trap (20 × 10 cm) tied to the plants at a height of approximately one feet above the ground level (Miranda *et al.*, 2009). The number of leafhoppers trapped were counted on weekly basis from December to May and the monthly mean population count was recorded as normalized population by the formula:

$$\text{Normalized population count} = (\text{Mean count} - \text{Min}_{\text{mean count}}) / (\text{Max}_{\text{mean count}} - \text{Min}_{\text{mean count}})$$

Assessment of temperature influence on leafhopper population growth development:

Non-linear beta function which utilizes cardinal temperatures of leafhopper growth and development (Tokuda and Matsumura, 2005; Van Nieuwenhove *et al.*, 2016) was used to assess the effect of temperature variation on vector population growth (Yan and Hunt, 1999; Briere *et al.*, 1999)

$$r(T) = 0 \text{ when } T \leq T_l$$

$$r(T) = aT(T - T_0)(T_l - T)^{1/2} \text{ when } T_0 \leq T \leq T_l$$

$$r(T) = 0 \text{ when } T \geq T_l$$

where, r is the rate of development and is a positive function of temperature T (°C). T_l (40°C) is the lethal temperature (upper threshold); T_0 (10°C) is the low temperature developmental threshold (lower threshold), and a is an empirical constant. The parameter a was estimated as per given formula above for the leafhopper population (Van Nieuwenhove *et al.*, 2016; Tokuda and Matsumura, 2005).

Daily temperatures for the year 2018-20 were collected from the meteorological observatory of IARI New Delhi (28.7041° N, 77.1025° E). Daily minimum (T_{min}) and maximum (T_{max}) temperatures were converted into hourly temperatures (T_{air-h}) based on the standard formula (Bregaglio *et al.*, 2010) which provides smooth transformation from minimum to maximum air daily temperature:

$$T_{air-h} = (T_{max} + T_{min}) / 2 + (T_{max} - T_{min}) / 2 * \cos(0.2618 * (h - \text{TimeVar}))$$

where, TimeVar is the hour of the day corresponding to time of occurrence of T_{max} .

For estimation of temperature influence, hourly temperature (T_{air-h}) was corrected for upper and lower threshold limits for leaf hopper growth and development. The temperature of 10° and 40°C was considered as lower and upper threshold temperature, respectively, for the growth and development of leafhoppers (Takuda and Matsumura, 2005; Van Nieuwenhove *et al.*, 2016). First, hourly estimates of $r(T)$ were calculated and then daily $r(T)$ were obtained by summing hourly values for the day. Monthly temperature index (MTI) was calculated by summing up daily $r(T)$ values for a month by equation given below:

$$MTI = \sum_{t_1}^{t_2} r(T)$$

Where, t_1 and t_2 are the $r(T)$ for the first and last day of the week

Monthly temperature index (MTI) as compared with normalized population count: Briere's model was compared with temperature-dependent beta function which predicted population abundance based on three parameters (Yan and Hunt, 1999). Non-linear beta function which utilizes cardinal temperatures of leaf hopper growth and development was used (Yan and Hunt, 1999; Magarey *et al.*, 2005) by formula:

$$r(T) = [(T_{upper} - T_{air-h}) / (T_{upper} - T_{opt})] * [(T_{air-h} - T_{lower}) / (T_{opt} - T_{lower})]^{\lambda} (T_{opt} - T_{lower}) / (T_{upper} - T_{opt}) \text{ if } T_{lower} \leq T \leq T_{upper} \text{ and } 0 \text{ otherwise}$$

where, T_{upper} (40°C), T_{lower} (10°C) and T_{opt} (35°C) are the upper, lower and optimum threshold temperatures, respectively, for adult development. T_{air-h} is the hourly air temperature (°C).

Geographical distribution of vector abundance based on temperature index : For prediction of spatio-temporal distribution of vector abundance, data on daily minimum and maximum temperature were collected from 146 geo referenced meteorological stations of important chickpea growing states of India viz., Tamil Nadu, Andhra Pradesh, Chhattisgarh, Telangana, Karnataka, Uttar Pradesh, West Bengal, Maharashtra, Punjab, Bihar, Jharkhand, Odisha, Rajasthan Gujarat, Assam and Madhya Pradesh. Meteorological data for the year 2014-19 was downloaded from the IMD (mausam.imd.gov.in). For probable distribution of vector population round the year, monthly

cumulative temperature indices (MTI) for hopper development were estimated.

$$MTI = \sum_{t_1}^{t_2} r(T)$$

Where, t_1 and t_2 are the $r(T)$ for the first and last day of the month.

The cumulative temperature indices (MTI) were plotted using ArcGis10.0 software. For continuous surface, inverse distance weightage (IDW) interpolation technique was applied and spatial maps were generated. Sequential colour scheme was used where dense colour depicts higher values with respect to vector abundance and lighter color as lower.

Approximation of model for leaf hopper distribution: For prediction of leaf hopper population, cumulative count of hopper population was compared with cumulative MTI values with field observations made from December to January months (Pearson's correlation).

Results and Discussion

Under field conditions at experimental site of IARI-New Delhi, leafhopper population (per 10 sq m) for both the years was recorded as low during December- January- February period as indicated by low cumulative population count. From March onwards, the population count increased at exponential rate as the curve took upward turn during April- May (Fig. 1).

At experimental site, the mean leafhopper population count was compared with the outputs of two models. Briere's model predicted higher values of developmental rate $r(T)$ between the lower to optimum threshold as compared to beta-model (Fig. 2). Based on Briere's model, pattern of accumulated MTI for the period of hopper observation (December-May) did not correspond well ($r^2 = 0.80$) with the observed accumulated population count (Fig. 3). Over-estimation of developmental rate between lower and optimum threshold indicated unsuitability of the model for population prediction. However, accumulated MTI from the beta-model was in good agreement with the observed population abundance ($r^2 = 0.99$). Therefore, monthly temperature index based on beta-model represented as better indicator of leafhopper population abundance.

It became evident that the sum of developmental rate based on temperature profile reflected the pattern of leafhopper population abundance. Therefore, based on temperature index, leafhopper population can be predicted for large area as the geo-spatial temperature data is available.

Geographical distribution of monthly temperature index as an indicator of leafhopper population abundance showed variation in intensity in time and space. Monthly temperature index (MTI) estimated using beta-model indicated that the whole country was favourable for leafhopper growth round the year, except for the Northern hill zones and Indo-Gangetic plains which

Fig. 1 : Leafhopper mean population in the experimental plots at IARI, New Delhi during 2018-20.

Fig. 2 : Comparison of Briere's model with beta model for leafhoppers using reported cardinal temperature.

Fig. 3 : Comparison of Briere's model and beta model with observed population count of leaf hoppers using reported cardinal temperature.

were not congenial for hopper growth and development particularly during December, January, February and March (Fig. 4). A part of Western, Central and Southern zone as well as major part of Indo-Gangetic plains appeared to be moderately suitable for vector growth during the period. Major period of chickpea growing season in most part of the country appeared to be highly favourable for the vector population growth. Seasonal variation in

disease incidence between different regions in the major chickpea growing areas was confirmed based on preliminary survey and established leaf curl incidence pattern already reported. Disease incidence recorded through survey in the present study indicated that the southern part had relatively more disease incidence as compared to the north and western part of the country. It is evident that the period of high vector population under favourable temperature also supports higher CpSD transmission ability and also indicator of epidemic period.

Potential distribution of chickpea stunt disease was predicted based on the environmental suitability for its vector population growth. Temperature influence on leafhopper growth and development explained based on a mechanistic model is approximately able to predict the probable distribution of the disease. Disease incidence pattern in space and time as indicated by simple survey is in good agreement with the predicted pattern. Apparently, although the distribution range of *Dalbulus maidis* could be predicted by the beta function but may be more restricted due to availability of host plant than by temperature. Therefore, crop distribution is also important for prediction of disease risk from leafhopper. Nevertheless, potential distribution information can be a base for confirming the potential viruses and phytoplasma associated with the disease as several causal agents are thought to be involved. In addition, spatio-temporal pattern associated can be useful for evolving management strategy *hitherto* not available.

Epidemiological modeling provides a valuable method for prediction of interactions between plant diseases their insect vectors, natural hosts and weather parameters. The accuracy of any predictions of an epidemiological model, however, depends largely on various factors and quality of weather data that validate and improve the model (Jeger *et al.*, 2018). Such an approach is becoming applied and urgent because the world is undergoing a period of climate change accompanied by rapid expansion in human activity. Both have an impact on crop plants, vectors, pathogens, causing increasing instability within virus-and phytoplasma-crop pathosystems, including changes in their geographical distributions. This, in turn, has major implications regarding man's ability to achieve effective control of virus/phytoplasma epidemics (Jones, 2009; Jones *et al.*, 2010).

Population abundance model for leaf hopper growth and development is for predicting vectors associated with CpSD. Based on temperature, the model can predict population abundance in time and space. In the present study, accumulated temperature index pattern from both the models (beta model and Briere's model) was compared with the experimental data and beta-model was found better fit for prediction of wide spread of CpSD. The relationship between temperature variation and developmental rates of a target insect is important in predicting the seasonal occurrence of species and to establish a suitable epidemiological model and environment-friendly pest

Fig. 4 : Population distribution of leafhopper abundance month wise (July to June) in terms of predicted temperature index based on prevalent mean temperature during 2014-19.

management strategies (Notter-Hausmann and Dorn, 2010; Thompson and Brooks-Pollock, 2019). The effects of different temperature regimes on bean yellow mosaic virus infection in potato mop top virus was recorded maximum on plants grown at 12 °C and minimum at 24 °C (Carnegie et al., 2010). Weather factors associated with the distribution of disease incidence of tomato spotted wilt virus on tobacco transmitted by thrips were modeled successfully by considering different weather factors affecting thrips and plant biology (Chappell et al., 2013). Dubey et al. (2019) also suggested the impact of temperature influence through non-linear beta epidemiological model on incidence of leaf crinkle disease in urdbean and proved its potentiality in successfully predicting the natural distribution of urdbean leaf crinkle disease in India.

The epidemiology of diseases associated with phytoplasma is also related with the insect vectors' population, their dispersal and survival in host/vector. The choice of a specific epidemiological strategy would depend on the biology of vectors and the host plants. The pathogen-vector-plant-habitat is considered to be very important epidemiological components in describing epidemics of phytoplasma diseases (Alma et al., 2019). Galetto et al. (2011) studied the multiplication patterns of 'flavescence dorée' and chrysanthemum yellows in grapevine and broad bean leafhopper vectors (*Scaphoideus titanus*, *Euscelidius variegatus*) under different climatic (temperature and CO₂) conditions. The results suggested that the phytoplasma multiplication was faster in insects under cooler conditions (18-22°C; CO₂ 400 ppm) and under warmer conditions in plants (22-26°C; CO₂ 800 ppm).

The challenge of modelling epidemics of phytoplasma diseases and their insect vectors has been influenced by various factors including temperature as a major component in order to control the incidence of phytoplasma more efficiently during different seasons (Rigamonti et al., 2011; Falzoi et al., 2014). Similar model has been used to predict population of *Cacopsylla pyri*, a potential vector for fruit phytoplasma strains (Schaub et al., 2005; Maggi et al., 2014) and grapevine phytoplasmas (Lessio et al., 2015). Maggi et al. (2014) suggested another stochastic epidemiological model which was validated with populations of leafhoppers within the vineyard in different years and spreading of aster yellows phytoplasma strain of carrot with vector, *Macrostelus quadrilineatus* (Frost et al., 2013). So far, no epidemiological forecasting model for any phytoplasma borne diseases has been suggested and developed in India (Rao et al., 2017).

In the present study, two models were used to predict the leaf hopper population based on the temperature variation in the year 2019-20. Beta-model provided better fit to variation in leaf hopper population growth in different parts of India, because of the optimum threshold parameter in the model which explained the shape of the curve near the optimum range as compared to

Briere's model which has only lower and lethal thresholds. Between the two models, beta model was found effective and matching with increase in vector population in the present study, and thus can be used in predicting a forecast for the CpSD development in chickpea growing fields in India. Since leafhoppers are the source for natural spread reservoirs and sources of both the CpCDV and phytoplasma, beta model enables better prediction of stunt disease in larger geographical area and may be useful for timely management of the disease. This model can also be efficiently applied in prediction of distribution of other important leafhopper borne associated virus/phytoplasma diseases of important crops in India.

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Add-on Information

Author's contribution : **M. G. Reddy:** Investigation, Data Collection, Lab analysis, Writing- original draft; **G.P.Rao:** Editing, Revising the Draft, Visualization, Formal analysis, Technical guidance; **P. Sinha:** Methodology, Technical guidance; Analysis of epidemiological models; **S.M. Shukla:** Software analysis, Construction of GIS Map; **D. Sagar:** Methodology, Technical guidance.

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