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Short Communication

Weather based prediction model for yellow mosaic disease of soybean (*Glycine max* (L.) Merrill)

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Soybean (*Glycine max* (L.) Merrill) [2n = 40] is popularly known as "Miracle Crop or Golden Bean" owing to its multifaceted uses and nutraceutical properties. Among the important diseases adversely affecting the soybean cultivation, the crop is very much susceptible to whitefly (*Bemisia tabaci Gen.*) transmitted yellow mosaic disease (YMD). It is more serious and widespread disease of soybean in the Northern and Central India and Pantnagar is considered as a hotspot for YMD. Understanding of weather factors and their role in disease incidence is a prerequisite for developing disease forewarning system (Amrate *et al.,* 2021). Hence, a detailed investigation was undertaken to study the influence of weather parameters on the incidence of YMD and differential response of the soybean genotypes varying in YMD resistance under varying agro-climatic conditions.

The epidemiology and role of weather factors on YMD was studied on six soybean varieties varying in disease reaction *viz.,* PK-327 (Highly resistant), Shilajeet (Resistant), JS-20-27 (Moderately resistant), Alankar (Moderately susceptible), JS-335 (Susceptible) and AMS-59 (Highly susceptible) under natural epiphytotic conditions for three consecutive years *viz.,* 2018 to 2020 in the experimental field of Department of Plant Pathology, G. B. Pant University of Agriculture and Technology, Pantnagar. The disease reaction of different cultivars was recorded in the form of disease incidence and percent disease index (Wheeler, 1969) using the standard key described by Singh and Singh (2000). The Karl Pearson's correlation coefficient was used to estimate the correlation between the weather parameter and the disease severity. Multiple regression equation was in the form of $Y=b_0+ b_1X_1+ b_2X_2+\ldots b_nX_n$; where, Y is per cent disease severity (dependent variable), b_0 refers to constant (intercept), b_1, b_2, … b_n are the partial regression coefficients and X_1, X_2, ….. X_n are the different weather parameters. All statistical analyses were performed using SPSS 16.0 for Windows. Significance was considered to be $p <0.05$ for all tests.

Correlation between whitefly populations with PDI

In pooled analysis, the highest disease index was observed in highly susceptible variety AMS-59 (80.86%), followed by JS-335 (66.11%). The AUDPC and infection rate varied from 21.88 to 221.86 units and 0.031 to 0.095 units per day in PK-327 and AMS-59, respectively (Table 1). The correlation analysis has revealed that there is non-significant positive correlation between the final PDI and the mean whitefly population in all the varieties (r = 0.349). This shows that there is no any significant relationship between the resistance to YMD and whitefly population in the soybean cultivars. However, when the data on the susceptible cultivars (AMS-59, JS-335 and Alankar) were pooled alone, there was a significant positive correlation (r = 0.677*). The same was not true for the resistant cultivars (JS-20-27, Shilajeet and PK-327). The non significant correlation may be due to the fact that 5-10 whiteflies are sufficient for efficient transmission of the disease. Moreover, the resistance to YMD does not purely be attributed to the resistance to the vector as there are other mechanisms of resistance against the pathogen. This non significant correlation between the YMD and its vector are evident from the reports of Srivastava and Prajapati (2012) and Patel *et al.* (2021). The r value between the two has been reported to range from 0.59 to 0.79 (Meti and Kenganal, 2017).

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Table 1: Response of different soybean varieties to yellow mosaic disease and its vector during 2018-2020 (Pooled)

Variety	Percent disease index (%)	AUDPC (Units)	Infection rate (Units/day)	Mean whitefly population/ plant	Correlation coefficient
AMS-59	80.86	221.86	0.095	2.89	0.960
JS-335	66.11	174.13	0.069	2.35	0.837
Alankar	44.33	129.79	0.061	2.34	0.824
JS-20-27	27.19	78.07	0.046	2.39	0.963
Shilajeet	21.24	66.31	0.043	2.16	0.464
PK-327	8.81	21.88	0.031	2.80	0.879

* Correlation is significant at 0.05 level

Table 2: Correlation coefficient matrix of YMD in soybean with weather parameters (Pooled)

Variety	Maximum temperature (X_1)	Minimum temperature (X_2)	Morning RH (X_3)	Evening RH (X_4)	Rainfall (X_5)	Sunshine hours (X_6)	Wind velocity (X_7)
AMS-59	0.40	-0.808**	0.202	-0.946**	-0.832**	0.916**	0.226
JS-335	0.424	-0.786**	0.213	-0.939**	-0.833**	0.922**	0.210
Alankar	0.421	-0.765**	0.217	-0.945**	-0.846**	0.928**	0.206
JS-20-27	0.417	-0.785**	0.196	-0.938**	-0.831**	0.930**	0.189
Shilajeet	0.437	-0.758**	0.227	-0.928**	-0.842**	0.934**	0.164
PK-327	0.394	-0.806**	0.186	-0.947**	0.828**	0.922**	0.207
Pooled Mean	0.260	-0.758**	0.136	-0.642**	-0.496**	0.771**	0.199

**Correlation is significant at 0.01 level

Table 3: Forecasting model for predicting YMD in different soybean varieties during *Kharif* 2018-2019

Cultivar	Multiple regression equation (Pooled)	R^2	Stepwise regression (Pooled)	R^2
AMS-59	Y = -406.66 +36.145 X1- 30.80X_2 + 0.42X_3 +1.53X_4 -0.26X_5 -6.84X_6 -8.44X_7	0.80 (0.69)	Y = 222.305 – 9.83X_2 + 13.98X_6	0.69 (0.65)
JS-335	Y= -375.00 + 26.34X_1 - 22.55X_2 + 0.90X_3 + 1.52X_4 - 0.23X_5 - 4.17 X_6 - 6.07X_7	0.80 (0.68)	Y = 186.824 – 7.94X_2 + 9.880 X_6	0.67 (0.63)
Alankar	Y= -76.68 +14.68X1 – 12.78X2 -0.05X_3 -0.10X_4 -0.13X_5 -1.036X_6 – 5.61X_7	0.74 (0.60)	Y = 70.771 – 3.73X_2 + 9.97X_6	0.60 (0.56)
JS-20-27	Y= -35.68 + 8.68X_1 -7.59X_2 - 0.26X_3 + 0.05X_4 -0.06X_5 -0.11X_6 -3.44X_7	0.73 (0.58)	Y = 37.30 – 2.031X_2 + 5.90X_6	0.60 (0.55)
Shilajeet	Y= -43.99 + 4.10X_1 -3.78X_2 + 0.29X_3 - 0.04X_4 -0.4X_5 + 0.52X_6 -1.32X_7	0.73 (0.58)	Y = 31.57 – 1.536 X_2 + 3.493X_6	0.65 (0.61)
PK-327	Y= -11. 34 + 4.42X_1 - 3.70X_2 – 0.275X_3 + 0.10X_4 - 0.4X_5 -1.21X_6 - 1.78X_7	0.69 (0.50)	Y = 14.775 – 0.782X_2 + 1.917X_6	0.45 (0.39)

Correlation analysis

The results of the correlation studies between the PDI and the weather parameters are presented in Table 2. The disease transmission was highest during 33rd to 35th SMW when the maximum temperature (X_1), minimum temperature (X_2), morning relative humidity (X_3) and evening relative humidity (X_4) varied from 30.7-33.8 ºC, 24.7-26.2 ºC, 85-95.1% and 65.6-83.0%, respectively. In pooled data, T_{min}, RH_E and rainfall (X_5) had highly significant negative correlation while Sunshine Hours (X_6) had highly significant positive correlation with PDI irrespective of the varieties. The other 3 parameters *viz.,* T_{max}, RH_M and wind velocity (X_7) had non-significant positive correlation with PDI. The relationship between the weather variables and the PDI is highly variable from location to location and during the different years of study. Hence, the available reports on the relationship among the weather parameters and YMD severity are highly variable and in many cases contradictory to each other. Our findings are in partial agreement with the findings of Gupta and Varma (2015), Marabi *et al.* (2017) and Srivastava and Prajapati (2012). The negative correlation between minimum temperature and rainfall could be attributed to the fact that lower temperature and higher rainfall hamper the growth and multiplication of the vector which restricts the transmission of the disease. Our findings on the significant correlation of PDI with sunshine hours are in corroboration with the findings of Gupta and Varma (2015) and Chahal *et al.* (2009). The increase in sunshine hours reduces the humidity and helps in maintaining dry conditions that are conducive for the whiteflies.

Multiple regression analysis

Multiple regression analysis revealed that the R^2 value varied from 0.69 to 0.80 whereas the adjusted R^2 value varied from 0.50- 0.69 (Table 3). The pooled data of the two years have been used for the final regression analysis and conclusion was drawn based on the pooled data analysis. The stepwise regression analysis was performed for recognizing the significant and best subset of weather factors that play pivotal part in development of YMD in soybean. It can be concluded from Table 3 that minimum temperature and sunshine hours explained more than 60 percent variability in all the susceptible varieties tested. The final regression equation developed for AMS 59 was $Y_{AMS59} = 222.305 – 9.83X_2 + 13.98X_6$ with adjusted R^2 value of 0.65. The association between the weather parameters and individual varieties vary from year to year and from season to season and hence, it requires validation based on more than 6 year data. Based on a disease index data and weather data for 23 years, Kaur *et al.* (2014) observed a significant correlation between disease incidence and weather parameters of 29^{th} to 33^{rd} SMW. The linear model developed had R^2 value of 0.47 and predicted estimates were in full agreement with the observed estimates. The usefulness of the weather based multiple regression in YMD prediction is also evident from the studies of Marabi *et al.* (2017) and Chahal *et al.* (2009).

The findings of the present study revealed that the minimum temperature, evening relative humidity, rainfall and sunshine hours play a crucial role in the development of YMD in soybean in the Tarai region of Uttarakhand. The disease prediction model developed can be used to devise integrated and efficient management strategies against the disease which will help in reducing the losses incurred by the farmers.

Conflict of Interest Statement: The author (s) declares (s) that there is no conflict of interest.

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