Indian Journal of Biochemistry & Biophysics
Vol. 58, October 2021, pp. 486-497

Weather based rules for yellow mosaic disease prediction on soybean in Madhya Pradesh

AK Srivastava*, RS Marabi, Lalit M Bal & Yogranjan

College of Agriculture, Jawaharlal Nehru Krishi Vishwavidyalaya, Tikamgarh-472 001, Madhya Pradesh, India

Received 24 January 2021; *revised 17 July 2021*

The yellow mosaic disease (YMD) found to be one of the major constraints in soybean production in Madhya Pradesh. For timely management of this disease and for reducing the calendar based prophylactic pesticides spray, this study was conducted to screen out critical weather limits for peak YMD incidence. Field experiments as well as farmers field survey were conducted during *kharif* seasons of 2015 to 2019 in four districts *viz*. Tikamgarh, Chhatarpur, Datia and Jabalpur of Madhya Pradesh to record spacio-temporal variability of whitefly and YMD on soybean. Isolation of DNA from the infected soybean leaf samples was executed as per the standardized protocol of DNA isolation and molecular level identification of mungbean yellow mosaic India virus (MYMIV) was carried out as well. It was noted that the preceding week's weather conditions significantly influenced the peak YMD incidence during the study periods. It was observed that maximum temperature, sunshine hours, number of whitefly population were positively related with YMD at the significant level; while the rainfall, evening relative humidity were negatively related. A weather based rule was worked out for peak prediction of YMD in soybean during the previous two weeks period when the following conditions were satisfied: Whitefly population per plant was above 12, maximum temperature was above 33°C and passive phase of monsoon was for more than a week. The transmission rate was found to be higher when dry period coincide with maximum temperature above 33°C for greater than or equal to 5days. This weather based rule for peak YMD prediction was also validated.

Keywords: DNA, Monsoon, Mungbean yellow mosaic India virus (MYMIV), Rainfall, Temperature, Whitefly

Madhya Pradesh is occupied with 33 percent area (55.54 lakh ha) of soybean in India and also known as soya state[1]. Soybean is one of the important cash oil seed crop and a good source of protein for vegetarian diet in India as well as in Madhya Pradesh. Soybean being luxuriant crop, having lush green, soft, succulent and nutritive dense foliage is infected by a number of fungal, bacterial and viral diseases from sowing to harvesting stage. More than 50 virus pathogens have been reported causing various diseases in soybean crop[2,3]. Among them mungbean yellow mosaic India virus (MYMIV) is the most prevalent in the Central India[4,5]. In central India, MYMIV has been reported to be a serious disease of blackgram, mungbean and soybean[4,6].

Under sever attack of insect pest-disease, around 50% loss is resulted in soybean production, while in case of their outbreaks, losses are much higher resulting in to complete damage[7]. The minimization of such losses and to reduce environment pollution, in parallel, substantial consideration of forewarning of pests and diseases is essential for taking timely control measures. The soybean area has witnessed a sharp decrease during current decade from 62.6 lakh ha (2013) to 50.13 lakh ha in 2017. The development of the proper and simple methods for identification of virus species and strains is fundamental to conduct the extensive field survey as it will help in forecasting of virus diseases and determination of resistant varieties at field level.

In India, YMD cause yield losses varied from 10 to 88% in soybean annually[8] and the monetary losses in legumes (soybean, blackgram and mungbean) caused by yellow mosaic disease (YMD) have been estimated to be approximately US $300 million per year[9]. In India, two species of Begomovirus causing YMD in soybean[4] are more prevalent *i.e.*: Mungbean Yellow Mosaic India Virus (MYMIV) in Northern and Central India, while Mungbean Yellow Mosaic Virus (MYMV) in Southern and Western India. The MYMIV is the most prevalent in soybean[5] in central India particularly in Madhya Pradesh (MP) and farmers face significant production loss. So the management of YMV is of immense important to reduce the crop loss and also to minimize the

*Correspondence:
E-mail: ajay_weather@yahoo.com

deterioration quality of the crop produce. Control of YMD in a particular region depends largely on the management of vector (*Bemisiatabaci*) population. So, it necessitates in-depth investigation on the relationship of whitefly population and prevalence of the virus on different soybean varieties.

Weather-based location-specific forewarning models have been developed for major diseases (*Alternaria* blight, white rust, powdery mildew) of oilseed *Brassica* in India[10,11]. Kaundal *et al.*[12] used six significant weather variables and developed two series of models (cross-location and cross-year) for rice blast prediction in India. Mungbean Yellow Mosaic India Virus has been reported by several workers[13,14]. The prediction of peak YMD incidence on soybean prediction was not yet been attempted in Madhya Pradesh. Therefore, it is necessary to find the degree of relationship, that exists between YMD and weather factors, with ultimate aim to develop the weather based prediction rule for its peak incidence. The present study was carried out to identify the disease species prevalent in soybean and screen out critical weather limits for peak YMD incidence as well as its weather based prediction tool. It was also analyzed the temporal and spatial scale variability. A weather based rule for peak YMD incidence and its characterization was worked out and presented in this paper.

Materials and Methods

Madhya Pradesh lies in the central India, and is located in the geographic heart of India in between the latitude of 21.6°N and 26.30°N and longitude of 74°9'E and 82°48'E. Agro-climatic diversity and topographical variations enable the state to grow a wide range of cereals, pulses, oilseeds and cash crops. The state comprises with hill, valley, plateau and plain regions. The whole state is divided into 11 Agro Climatic Zones (ACZ) shown in (Fig. 1). In this study two ACZ number IV and VIII was selected. From the zone VIII, the districts Tikamgarh, Chhatarpur, Datia and from zone IV, Jabalpur district were taken. Field experiments (Fig. 2A) and farmers field surveys (Fig. 2B) were conducted during *kharif* season on soybean cultivars under unprotected conditions during 2015 to 2019. The YMD incidence was recorded at weekly interval at Jabalpur, Tikamgarh, Chattarpur and Datia districts of Madhya Pradesh.

Field experiments

The field experiments were conducted in a randomized block design with three replications in a plot size of 450 m^2 with spacing of 30 cm (plant to plant) and 40 cm (row to row). The major cultivars of soybean (JS 95-60, JS 93-05, JS 335, JS 20-29) were sown at two dates D1 (between 7thand 10thJuly), and D2 (between 18th and 20th July) during 2015, 2016, 2017 and 2018 at College of Agriculture, Tikamgarh (24° 40′ N lat., 77° 80′ E long. and 324 meter above m.s.l.), and Jabalpur (23° 13′ N lat., 79° 57′ E long. and 387 meter above m.s.l.) with recommended dose of fertilizers N:P:K=40:60:40 kg/ha. The field experiments during 2019 were conducted at Tikamgarh with one date of sowing i.e. on 7th July with recommended dose of fertilizers.

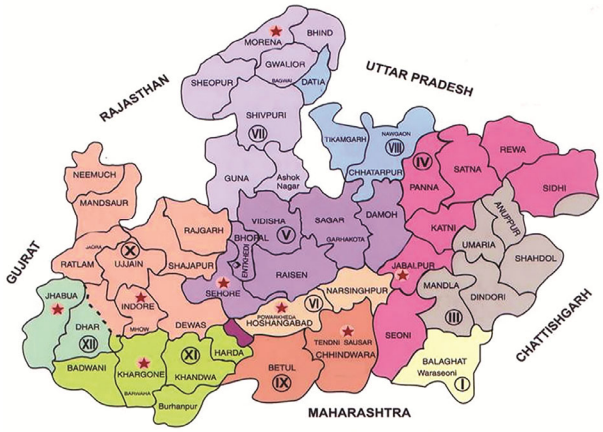

Fig. 1 — Agro climatic zones of Madhya Pradesh

Fig. 2 — (A) Field experiment at Tikamgarh; and (B) Farmers' field survey at Chhatarpur

Farmers' field survey

Farmers' field surveys were conducted in 24 villages of three districts i.e.Tikamgarh (24° 38′ N lat., 77° 75′ E long. and 345 meter above m.s.l.), Chhatarpur (24° 53′ N lat., 79° 37′ E long. and 412 meter above m.s.l.) and Datia (25° 31′ N lat., 78° 26′ E long. and 302 meter above m.s.l.) to collect weekly data on YMD incidence during 2015, 2016, 2017and 2018. Three blocks of each district were selected for this study and from each village one farmers' soybean field was selected (Table 1). Fixed plot survey was conducted at every village in an area of 5 × 5 m^2,

Table 1 — Multi location farmers fix field plot survey to record spatial variability

District	Tikamgarh	Chhatarpur	Datia
No. of Blocks	03	03	02
No. of villages	03	03	03

where no plant protection measures were taken. Observations were recorded at weekly intervals.

Weather data

The daily weather data of temperature (Maximum, Minimum), relative humidity (morning, evening), rainfall and sunshine hours from 2015 to 2019 was collected from meteorological observatory of Tikamgarh, Jabalpur, Chhatarpur and Datia districts. The daily weather data were converted to weekly mean and total for correlation and critical weather parameters analysis.

Disease incidence

Observations on YMD incidence was recorded on 10 tagged plants and were identified visually by observing bright yellow specks on soybean leaves, which later coalesced to form a larger yellow patch and eventually the entire leaf turned yellow (Fig. 3). The incidence of yellow mosaic virus disease was determined by calculating the percent disease incidence by using the following formula:

$$\text{Disease Incidence (\%)} = (x_1/x)*100$$

where, x= Total number of plants x_1= Number of infected plants.

The plants were inspected during the morning period of the day to monitor the population dynamics of whitefly and to note the appearance and development of the symptoms of yellow mosaic disease (YMD). The population count of whitefly was taken at seven days intervals in ten randomly selected plants in each replicated plot. The incidence of the disease was recorded at weekly intervals started from two to three weeks after sowing to maturity stage.

Detection of MYMIV through PCR

The leaf samples of soybean with yellow mosaic disease were collected during field survey from the fields of four districts of the *kharif* season of 2015 for molecular level identification of mungbean yellow mosaic India virus (MYMIV). Genomic plant DNA was isolated using Plant Dneasy Mini Kit (Quiagen) at Tikamgarh. The polymerase Chain Reaction (PCR) study was done in small PCR tubes having capacity of 0.2 mL with genomic DNA as template and the

Fig. 3 — MYMIV infected healthy soybean plants under field conditions at Tikamgarh

primer(s) that amplified DNA sequence. The coat protein PCR primer (DNA-A) was employed to confirm the virus was forward and reverse as follow:

Forward primer

5′ACACGGATCCGTTGCATACACAGGATTTG3′

Reverse primer

5′ACACGAGCTCCTCTACCCCGATATCGAATG3′.

The PCR was programmed with initial denaturation at 94°C for 1 min, followed by 30 cycles at the same 94°C for 20 Sec, 56°C for 20 Sec and 72°C for 1 min. Final extension was carried out at 72°C for 3 min and stored at 15°C for further use. Amplified products were verified by electrophoresis using a 1.0% agarose gel and positive amplified products were visualized under gel documentation system to ascertain the virus

Statistical analysis

The association of YMD incidence and weather parameters were statistically analyzed with weekly values. The correlation and regression studies were carried out with the help of SPSS software (version 27) to find out relationship. The significance of correlation and regression was determined based on t test. The significant level was set at P <0.05 and P <0.01.

Weather rule for peak YMD incidence

The highly correlated weather parameters during peak YMD incidence that is one and two weeks previous weather parameters were segregated based on their significance. These critical weather parameters during *kharif* seasons of 2015 to 2018 were analyzed and their threshold values were fixed. Based on the critical weather parameters and their threshold values, a weather rule for peak YMD incidence was formulated

and validated with independent data set of 2019 at Tikamgarh.

Results and discussion

Characterization of YMD

It is difficult to identify the virus species and strains from soybean individual plants in Madhya Pradesh, because their symptoms may be changed or masked depending on soybean varieties or the crop growing conditions. Furthermore, sometimes symptoms induced by Mungbean Yellow Mosaic India Virus (MYMIV) are similar to those caused by excess moisture and nutritional deficiency. To ascertain this, molecular diagnosis through DNA extraction was carried out from infected plants followed by agarose gel electrophoresis.

Isolation of DNA from all the infected samples was executed as per the standardized protocol of DNA isolation (CTAB Method). Quality and quantity of the isolated DNA was checked on 0.1% agarose gel. After quantification of DNA on agarose gel, PCR amplification was carried out followed by their visualization in gel doc system.

Primer designing and selection

To identify MYMIV, specific DNA sequences, online BLAST X analysis at the National Center for Biotechnology Information (NCBI) were used. The coat protein (CP) of Begomovirus sequence has high degree of conserve region, which have been approved by the International Committee on Taxonomy of Viruses to ascertain the molecular identification of a Begomovirus[15]. It was used to amplify isolated DNA template from the leaf of soybean plants. The programmed polymerase chain reaction test resulted in to amplified DNA fragments having size about 750 bp of MYMIV in YMD infected soybean leaf samples collected from the fields during *kharif* season of 2015. PCR products were electrophoresed using 1.0% agarose gel and amplified products confirmed as MYMIV[16-19].

The above characterization of MYMIV in soybean shown in (Fig. 4) was confirmed by the Usharan *et al*.[4] in soybean at Delhi. The molecular identification of MYMIV infection was also reported in Tomato, Cotton crops in India by Agnihotri *et al*.[20] and Singh *et al*[21]. Similarly, Chen *et al*.[22] identified the incidence of apple chlorotic leaf spot virus (ACLSV) which is great threat in China through RT-PCR and they reported that this diseased was ranged between 43.6 and 68.2 percent in different provinces.

MYMIV incidence on cultivars and places

The weekly YMD incidence on different cultivars at two dates of sowing (D1, D2) were recorded at Tikamgarh (TKG) and Jabalpur (JBP) during 2015 to 2018 and their mean values are presented in (Table 2).The highest (86 to 90%) YMD incidence was observed during 2015 at both the places. The maximum YMD incidence (90%) was observed on cultivar JS 335.The lowest (2-3%) or almost negligible incidence (0%) was noted for cultivar JS 20-29. The soybean cultivar JS 335 is highly susceptible and JS 20-29 is resistance cultivars for YMD. The YMD incidence was high for cultivar JS 93-05 at Tikamgarh and for JS 335 at Jabalpur. Silodia[23] observed from the eight places (Patan, Katangi, Panagar, Maharajpur, Jabalpur, Bhedaghat, Tilwara and Barela Road) near Jabalpur and reported the cultivar wise YMD incidence ranged from 65 to 75 for JS-335, 54 to 59

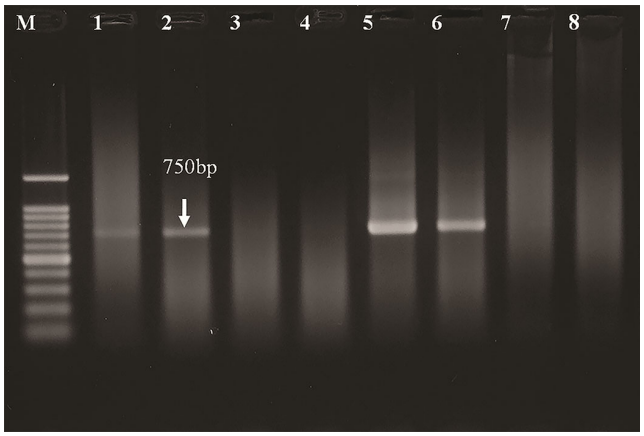

Fig. 4 — PCR amplifications results of soybean leaf DNA using coat protein (CP) primer. Lane 1-2 MYMIV infected leaves (positive), 3-4 healthy leaves (negative), 5-6 MYMIV infected leaves (positive) and 7-8 healthy leaves of soybean (negative), M (Marker)=100 bp DNA ladder

Table 2 — YMV incidence in different varieties of soybean at Tikamgarh (TKG) and Jabalpur (JBP)

Varieties	2015		2016		2017		2018	
	TKG	JBP	TKG	JBP	TKG	JBP	TKG	JBP
JS 93-05	84.5	71.6	30.0	32.3	20.0	11.5	25.0	20.5
JS 335	85.2	89.5	35.0	59.3	25.0	28.3	35.0	23.0
JS 95-60	78.1	73.5	29.2	21.0	18.0	17.4	18.1	14.8
JS 20-29	-	-	-	-	3.3	3.4	2.9	2.2
Mean	82.6	78.2	31.4	37.5	16.6	15.2	20.3	15.1

for JS 93-05 and 60 to 69% for JS 95-60 and 0.0% for JS 20-29 during *kharif* 2015. This reported YMD incidence percentage was a mixture of field experiment and farmers' fields and therefore slightly less percentage of YMD incidences was observed. Other researchers[24-26] reported YMD outbreak in Madhya Pradesh during *kharif* season of 2015 in soybean.

The standard meteorological week (SMW) number for initiation of YMD incidence and its peak incidence during the study period were analyzed and presented in (Table 3). The mean week (SMW) for incidence of YMD varied from 31 to 32 SMW, while the peak incidence ranged between 38 and 40. The analysis indicates that peak YMD incidence on an average started at 7 to 8 SWM after initiation of YMD on soybean. Silodia *et al*.[25] reported the maximum YMD incidence at Jabalpur during 2nd to 3rdweek of September (36-38 SMW).

Temporal variability

Temporal variability of YMD incidence was analyzed from the field`s experimental data of the year 2015, 2016, 2017 and 2018. YMD incidences on weekly interval for two dates of sowing were shown in (Figs. 5 & 6) for Tikamgarh and Jabalpur. It was observed that YMD incidences varied from 29 to 40th SMW at Tikamgarh and from 30 to 40th SMW at Jabalpur. The perusal of the data indicates that the date of sowing influenced the peak incidence number as well as its duration. The lowest peak was recorded during *kharif* 2018 and the highest peak was observed during *kharif* 2015. The peak YMD incidence was observed for second date of sowing. The maximum YMD incidence was noted during 37 to 38th SMW at Tikamgarh and 37 to 39th SMW at Jabalpur. Delay in sowing does not only advance the peak incidence period but also influences the YMD incidence percentage. Srivastava and Prajapati[27] reported that the temporal variability of

Table 3 — YMD incidence weeks in soybean at different districts of Madhya Pradesh

Year	Tikamgarh		Chhatarpur		Datia		Jabalpur	
	Initiation	Peak	Initiation	Peak	Initiation	Peak	Initiation	Peak
2015	30	37	32	38	32	39	31	36
2016	30	38	31	39	30	40	30	39
2017	32	39	33	40	33	40	32	38
2018	31	38	32	39	33	39	31	37
Mean	31	38	32	39	32	40	31	38

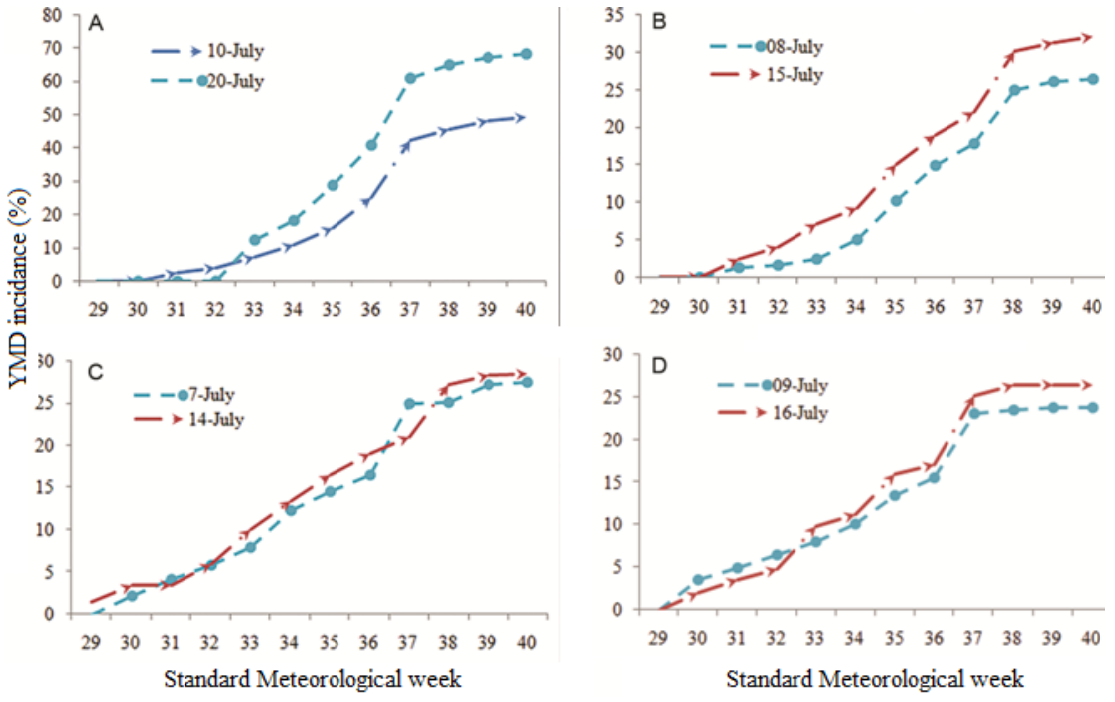

Fig. 5 — Weekly distribution of YMD incidence at (A) TKG in 2015; (B) TKG in 2016; (C) TKG in 2017; and (D) TKG in 2018

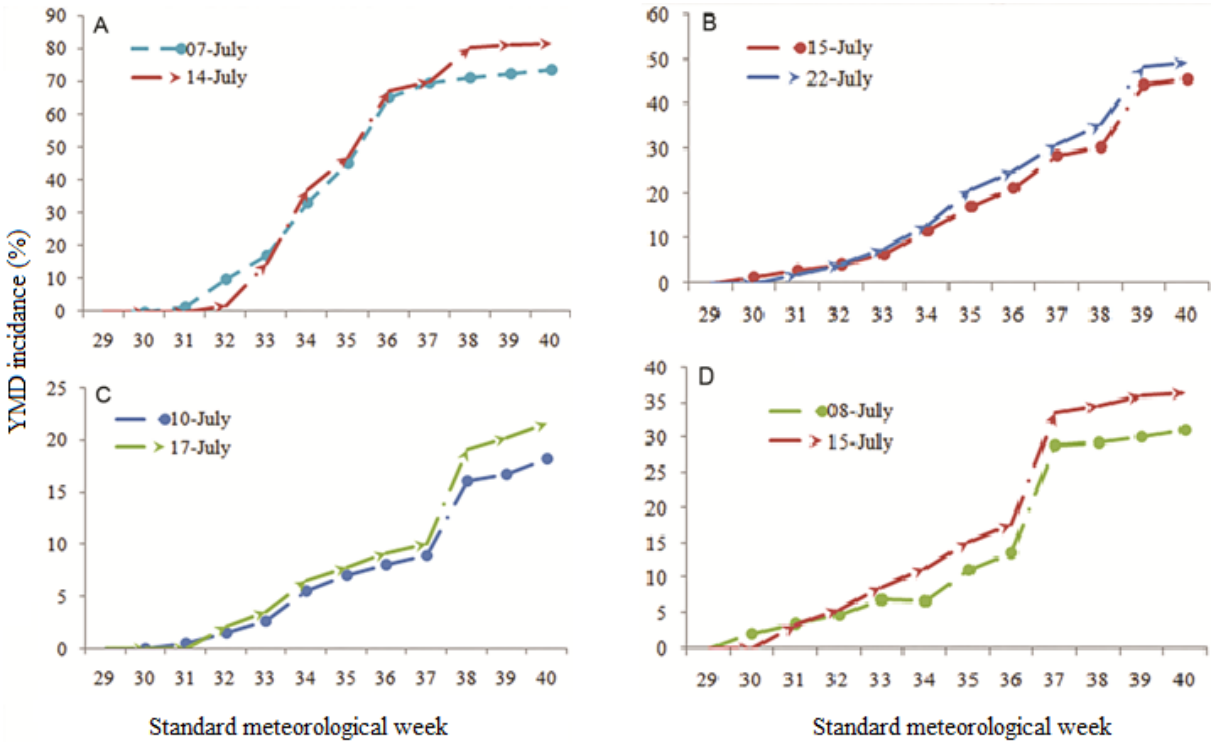

Fig. 6 — Weekly distribution of YMD incidence at (A) JBP in 2015; JBP in 2016; (C) JBP in 2017; and (D) JBP in 2018

whitefly population per plant and percentage YMD incidence was associated in Blackgram. The duration for peak adult whitefly occurrence was varied from 33 to 39th standard meteorological weeks (SMW) in agroclimatic zoneVIII[28].

The perusal of the above analyzed data of different places and date of sowing indicates that the peak YMD incidence over the years generally follow almost similar trends though its YMD incidence percentage has much more variables. During the period of maximum YMD incidence, the maximum temperature, evening relative humidity, sunshine hours, rainfall and vector population were found 32.0±2°C, 65±10%, 5.5±1.0 h, 31±10.0 mM and 10±5 adult whiteflies/plant, respectively. The present findings confirms the findings of Gupta and Keshwal[29], Biswas *et al.*[30] and Singh *et al.*[31], as they also reported that during the peak incidence of YMD maximum temperature, evening relative humidity, sunshine hours and rainfall were 31.0±4.0°C, and 79.0±7%, 5.0 h and 14.0 mm, respectively.

Spatial variability

Field experiments as well the farmers' field survey were carried out to observe the special variability of YMD incidence in soybean during 2015 to 2018 at Tikamgarh, Chhatarpur, Datia and Jabalpur and shown in (Fig. 7). The seasonal change has influenced the spatial change of YMD incidence. The YMD incidence at Tikamgarh was lower than Jabalpur during 2016 to 2018. This may be because of the variability in summer mungbean cultivation nearby area of these districts. The first incidence of YMD recorded when the soybean crop age was 3 weeks and the disease intensity was low and varied from 0.0 to 2.5±2%. Present findings are partially in agreement with the findings of Salam *et al.*[32], Silodia[23] and Srinivasaraghavan *et al.*[33], as they also reported that during the first incidence of YMD, the disease intensity ranged from 0.4 to 3.0% on urdbean, mungbean and soybean.

It was observed that the disease infection increased gradually and attained peak after 9 weeks of sowing. The maximum YMD incidence varied from 21 to 81% during 2017 and 2015. Similar findings have been reported by several workers[23,31-34] that the maximum YMD disease intensity ranged from 0.2-47.1 in mungbean, 33-100 in urdbean, 30.9-60% in soybean and more than 80% in Indian bean.

In the present investigation, the maximum disease incidence was observed when the crop age was 9 weeks after sowing and it contradicts the findings of Gupta and Keshwal[29,35] as they observed that the peak disease incidence on soybean was recorded on 45th days after sowing. The difference in the vulnerable

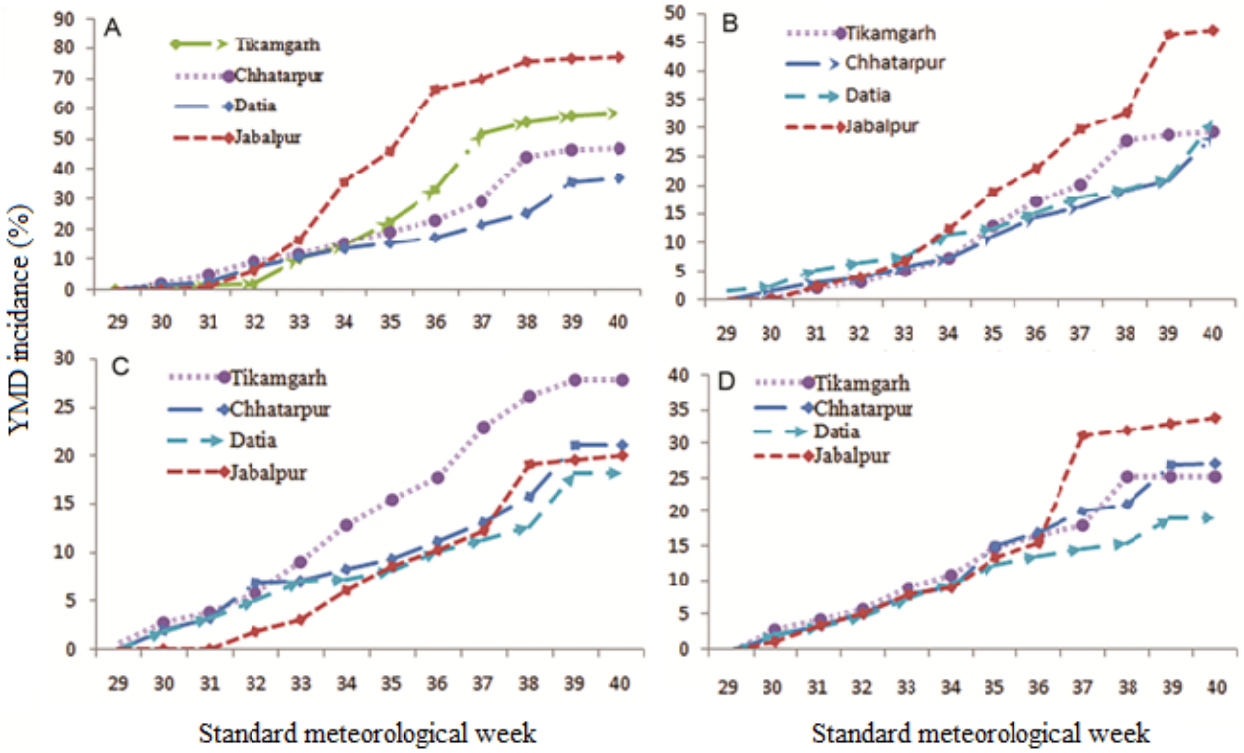

Fig. 7 — Spatial distribution of YMD incidence in (A) 2015; (B) 2016; (C) 2017; and (D) 2018

age of the crop may be attributed due to the change in date of sowing, YMD susceptible/resistant variety included in the study coupled with the availability of the viruliferous vectors.

The above analysis indicates that the status of peak disease incidence may be categorized into low (4-30%), moderate (31-59%) and high (60-100%). Lu *et al*.[36] has reported the low, moderate and high incidences of soybean mosaic virus in soybean and the above low, moderate and high category was in accordance to reported category.

Association of weather parameters with YMD incidence

To quantify the association between weather parameters and YMD incidence, correlation analysis was carried out for same week, previous one week and previous two week's weather parameters separately and for pooled data also and presented in (Table 4), respectively. The same week weather and YMD incidence correlation coefficients values are presented in (Table 4). Maximum temperature has consistent positive correlation with YMD incidence across the all four stations. There was a negative correlation between minimum temperature, relative humidity of morning and evening with YMD incidence. Though the correlation coefficients are changing over the places but the significant correlation was observed between maximum temperature, sunshine hours, evening relative humidity, rainfall and YMD incidence. However, the correlation coefficients values were higher for maximum temperature, rainfall and sunshine hours with YMD incidence of same week.

The preceding one week weather and YMD incidence were worked out and presented in (Table 4). From the table, it was noted that the maximum temperature, sunshine hours and rainfall were also significantly related with YMD incidence. This association was also observed with same week's weather parameters and YMD association, though the correlation coefficient values were lower for previous one week's weather.

The correlation coefficient with previous two week's weather data and YMD incidence were worked out and presented in (Table 4). It was noted that only maximum temperature and rainfall were significantly related with YMD incidence.

The above results were supported by other workers[25] that maximum temperature and rainfall significant impacted on YMD incidence. Khan *et al*.[37] and Srivastava and Prajapati[27] reported that rainfall was negatively associated on YMD in mungbean and urdbean, respectively.

Table 4 — Correlation coefficient between same week weather parameters and YMD incidence

Weather parameter	Places				
	Tikamgarh	Chhatarpur	Datia	Jabalpur	Pooled
Maximum Temperature	0.78**	0.82**	0.72**	0.58*	0.68*
Minimum Temperature	−0.48	−0.60*	−0.28	-0.70**	0.35
Relative Humidity Morning	−0.38	−0.41	0.40	−0.39	0.30
Relative Humidity Evening	−0.53	−0.49	−0.59*	−0.68*	−0.58*
Sunshine hours	0.61*	0.57	0.68*	0.70**	0.60*
Rainfall	0.47	−0.71*	−0.58	−0.61*	−0.63*
Previous one week and YMD incidence					
Maximum Temperature	0.67*	0.65*	0.56	0.48	0.59*
Minimum Temperature	−0.34	−0.33	−0.36	−0.63*	−0.37
Relative Humidity Morning	−0.44	−0.40	−0.51	−0.40	−0.41
Relative Humidity Evening	−0.53	0.59*	0.48	−0.55	−0.52
Sunshine hours	0.68*	0.56	0.58*	0.56	0.57*
Rainfall	−0.58*	−0.63*	−0.57*	−0.50	−0.58*
Previous two week and YMD incidence					
Maximum Temperature	0.60*	0.57	0.56	0.51	0.58*
Minimum Temperature	−0.44	−0.33	0.16	−0.59*	−0.35
Relative Humidity Morning	−0.39	−0.48	−0.40	−0.43	−0.30
Relative Humidity Evening	−0.63*	−0.29	−0.51	−0.52	−0.42
Sunshine hours	0.56	0.62*	0.50	0.45	−0.40
Rainfall	−0.61*	0.52	−0.59*	−0.55	−0.57*

(*Significant at 5% level,** Significant at 1% level)

To have the threshold values of these weather parameters, the weekly weather conditions during the peak YMD incidences and one, two week previous weather conditions of Tikamgarh during the year 2015, 2016, 2017 and 2018 were presented in (Table 5). It was observed that the date of sowing, crop cultivar and weather conditions are playing the major role in YMD incidence at a place.

Though the sunshine hours is also positively related to a highly significant level with YMD incidence but the availability of sunshine hours data at many stations are generally not available in Madhya Pradesh, hence this weather factor was excluded for formulation of weather rule. Upon perusal of the year wise weather factors and their association with YMD incidence, it was found that the maximum temperature was highly, significantly and invariably correlated weather parameter. Hence, this weather factor is selected for formulation of weather rules. The rainfall has shown highest significant correlation with YMD incidence. Both relative humidity (morning and evening) have weak and changing association (negative and positive) with YMD incidence (Table 4), the evening relative humidity has influenced the YMD incidence. Similarly, rainfall has also changing correlation but association was significant and its amount and numbers of events have also influenced the YMD incidence[38], therefore these weather parameters were selected for formulation of disease prediction rule. The above reported results showed that these weather factors, maximum temperature, rainy days, evening relative humidity, and rainfall amount were suitable for formulation of peak YMD incidence.

Gupta and Keshwal[29] reported that YMV development in soybean during 50 days after sowing (DAS) was significantly correlated with maximum temperature (0.71) and sunshine duration (0.67). After inoculation of virus strain, it normally takes 17-28 day to develop the YMV symptoms on Soybean[4,39]. Therefore, the weather condition during 2 to 3 weeks prior to highest YMV infection was important factors and screened and shown in (Table 5). It was found that maximum temperature above 33°C greater than or equal to 5 days may be critical for its higher rate of virus transmission in soybean. Our result was similar to the finding of Gupta and Keshwal[35]. They have reported that YMV disease development on soybean in Jabalpur of Madhya Pradesh was high when maximum temperature and relative humidity ranged between 31.0°C-36.2°C and 62–75%, respectively.

Maximum temperature above 33°C for greater than or equal to two week period and occurrence of light rain/drizzling, crop age and whitefly population of the

Table 5 — Critical weather parameter during peak YMD incidence and previous one, two week at Tikamgarh

Weather parameters	Maximum temperature(°C) & number of day above			Relative humidity (%)		Rainy days	White fly/plant
			2015				
SMW	33°C	34°C	35°C	Morning	Evening	Number	
35	3 days	3 days	0 days	88	68	3	3.5
36	4 days	4 days	1 days	89	54	0	12.2
37	7 days	1 days	5 days	92	49	1	17.3
			2016				
SMW	33°C	34°C	35°C	Morning	Evening	Number	
35	2 days	1 days	1 days	95	72	1	7.2
36	0 days	0 days	0 days	92	64	0	10.4
37	6 days	2 days	0 days	89	49	1	12.0
			2017				
SMW	33°C	34°C	35°C	Morning	Evening	Number	
35	3 days	0 days	0 days	92	70	3	2.0
36	6 days	5 days	2 days	88	56	1	5.9
37	7 days	5 days	2 days	92	60	3	10.2
			2018				
SMW	33°C	34°C	35°C	Morning	Evening	Number	
35	0 days	0 days	0 days	99	88	6	1.6
36	0 days	0 days	0 days	97	89	3	3.7
37	0 days	0 days	0 days	92	63	1	9.2
			2019				
SMW	33°C	34°C	35°C	Morning	Evening	Number	
35	3 days	0 days	0 days	92	85	2	1.2
36	3 days	1 days	0 days	87	76	2	5.7
37	1 days	1 days	0 days	92	82	5	8.8

previous two weeks period of the peak YMD incidence are the factors congenial for high incidence. Srivastava and Prajapati[27] also reported that weekly rainfall above 50 mM is detrimental for whitefly population in balckgram. Kaur *et al*.[40] observed that the peak YMD incidence was found in Mungbean at Ludhiana, when the maximum temperature varied between 33 and 35°C. They also reported that morning relative humidity ranged between 85 and 90% and evening relative humidity varied from 50 to 60% was most favourable for disease development.

Critical weather parameters for peak YMD incidence prediction rule

Weather parameters, vector population and crop age of preceding two week of MYMIV incidence revealed that vector population and weather parameters exhibited significant association with disease incidence.

It was reported that the whitefly population of preceding two weeks of YMD incidence had significant positive impact on YMD incidence[28]. Previous weeks' weather conditions were utilized by other worker to formulate weather based prediction rule for insect-disease in India. Srivastava *et al*.[41] reported that rainfall of January and February significantly influenced the incidence of the chickpea pod borer peak population. Srivastava and Prajapati[27] reported weather based forewarning of Mungbean yellow mosaic virus (MMV) on Black gram and concluded that the previous weeks play an important role for its peak prediction. Srivastava and Yadav[28] also reported that preceding week weather conditions are influencing the whitefly peak population in Bundelkhand Agroclimatic Zone. The two preceding weather conditions of peak YMD incidence play an important role to reach the highest incidence.

Higher YMD incidence was observed in years following warm and humid weather conditions. The temperature of the previous week's weather explained the variability of high YMD incidence. Thus the temperature, humidity and rainfall of previous week's explained the seasonal variability of the disease at a place. These results highlight the importance of multi-seasonal monitoring activity in understanding the dynamics of YMD incidence at a regional scale.

It was observed and reported that there was an outbreak of YMD in Madhya Pradesh and also at Tikamgarh during 2015. The data presented in (Table 5) is utilized to frame the threshold values of

the each parameter. The peak YMD incidence was 37 SMW at Tikamgarh during 2015. The previous two weeks (35, 36 SMW) critical weather parameters and their specified values were examined and reported here. The number of days of weekly maximum temperature of 34°C was 7 in 2015 and 1, 5 and 0, respectively, during 2016, 2017 and 2018. The number of week having less than 70% evening humidity was 2, 1, 1 and 0 during 2015, 2016, 2017 and 2018, respectively. The number of rainy days was 3, 1, 4 and 9 during 2015, 2016, 2017 and 2018, respectively. The mean number of whiteflies during 35 and 36 SMW in 2015, 2016, 2017 and 2018 was below 12 in 2016 and 2017 and above 12 in 2015 and 2018.

Many workers[27,42] had reported the association of whiteflies with weather parameters for black gram. Tiwari *et al*.[43] reported that the peak infestation of YMV was at the stage of 25-50 days after sowing (DAS) in western Madhya Pradesh. They reported that hot and humid weather coupled with excess growth of crops and as well as weeds provided a congenial environment for faster multiplication of whiteflies and other insects and pests in soybean. It was also pointed out that summer moong which was generally sown prior to soybean also contributed towards increased infestation of whiteflies. In another study, Silodia *et al*.[24] recorded the whitefly population from 29th to 41st SMW and noticed least whitefly population during 29th SMW and maximum population during 37th SMW at Jabalpur. They observed that spread of YMV increased with increased number of whitefly population. When the number of whitefly population reaches its peak up to 39 and then the number of virus infected plant was the highest.

Threshold values for prediction of peak YMD incidence

It was observed that the upsurge of whitefly population and incidence of YMV in Madhya Pradesh caused soybean yield losses ranged from 10 to 90%[29,44]. To reduce the yield loss, farmers needs a prior knowledge of the YMV incidence for its efficient management. To have a prior peak status of YMV incidence in soybean, a thumb rule is proposed if it satisfy the following conditions: Whitefly population per plant is above 12, maximum temperature is above 33°C and passive phase of monsoon for more than a week is congenial for moderate YMV infection. The passive phase of monsoon is a shifting behavior of monsoon rainfall from above normal to below normal during July to September and during this phase, a place received slightly low rainfall compared to its normal vale or it may be a dry period also[45]. The transmission rate was found to be higher when dry period coincide with maximum temperature above and equal to 34°C for more than 5 days. If the above conditions prevails than possibility of YMD outbreak in soybean may be possible. To know the status of peak YMV incidence, the soybean crop from 33 to 34th SMW (normal sowing window) needs to be monitored for next two weeks and if the following conditions are found that there may be moderate to high YMD incidence at a place.

If the number white fly per plant ≥12

If crop age is more than ≥06 weeks

If the number of rainy days ≤ 2days .

If the number of day of maximum temperature ≥ 34°C is more than 3-5 days.

If the afternoon relative humidity is less than 70 % ≤ 2 weeks and monsoon is in passive phase

If the above rules occurred than there will be a change of peak incidence of YMD could moderate (>30%) to high (>60%) in soybean.

The above weather congenial conditions (rule) may be used to predict the peak YMD incidence in Madhya Pradesh.

Validation of YMD incidence rule

The above disease predictive rule was validated during *kharif* 2019 at Tikamgarh. The weather and whitefly conditions during 35, 36 and 37 SMW were screened out and are presented in (Table 5). Upon perusal of the above reported disease predictive rule, it was noted that the number of whitefly is 6 which was only the 50% number of threshold value. The maximum temperature above 34°C and number of rainy days were 1 and 0 day, respectively. The number of week below 70% evening humidity was 0. Thus through this disease prediction rule; the peak YMD incidence may not be moderate or high. The weekly YMD incidence at Tikamgarh during 2019 is shown in (Fig. 8).

It was observed that peak YMD incidence occurred during 37th SMW (10-16th September 2019) and the YMD incidence in soybean was<30%. The observed data reveals that the YMD incidence was low on soybean because the previous two week's selected parameters for disease prediction were not be matched with their critical limits.

Medium range weather forecast coupled with extended range weather forecast could be used for forecasting of YMD peak incidence in Madhya Pradesh. The bi-weekly weather parameters are

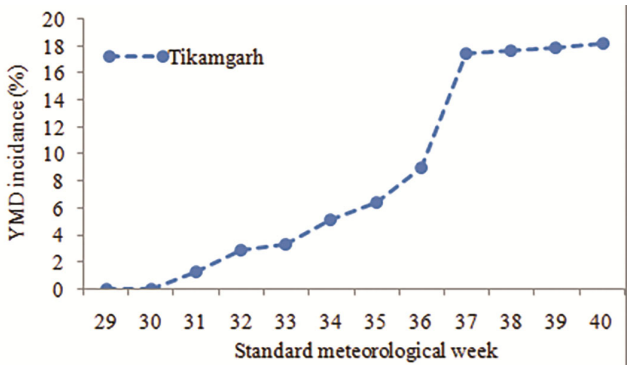

Fig. 8 — YMD incidence in Tikamgarh during 2019

forecasted at medium range scale for almost every district of India under the umbrella of Gramin Krishi Mausam Sewa (GKMS) of Indian Meteorological Department (IMD), which may be utilized for estimation of YMD incidence on soybean for its timely and judicious management. Besides, the extended range weather forecast information on weekly basis about active and passive phase on monsoon and temperature above normal may also be used for prediction of outbreak of YMD in soybean.

Conclusion

The YMD incidence initiation varied from 30 to 32 SMW and peak incidence between 37 and 40 SMW in Madhya Pradesh. Preceding week temperature, rainfall and humidity are the most dominating weather factors affecting peak YMD incidence. Whitefly population, maximum temperature, evening relative humidity and rainy days significantly influence peak YMD incidence in soybean in all over Madhya Pradesh. A rule for peak status of YMD incidence was developed taking the preceding week's weather and vector conditions. Maximum temperature above 34°C, mean relative humidity below 70% and passive phase of monsoon for more than a week is congenial to know the peak status of YMD incidence. This disease predictive rule has ability to predict the peak YMD incidence. Thus it may be utilized in formulation of weekly district level agromet advisory bulletins, which may also be used by extension workers to make tactical decisions for YMD control measures in minimizing soybean yield loss.

Acknowledgement

The author is thankful to the NRDMS, DST, Govt. of India, New Delhi for funding the project "weather based forewarning and management of major pest-disease of Soybean - Chickpea in Bundelkhand Agroclimatic zone of Madhya Pradesh".

Conflict of interest

The authors declare no conflict of interest

References

1 Jha DK, Mosaic virus pest attacks in three states to hit soybean output this year, Business standard, Mumbai, July 23, (2020).
2 Gupta, GK & Chouhan, GS, Symptoms Identification and Management of Soybean Diseases. Technical Bulletin no. 10, (*National Research Centre for Soybean. Indore*). (2005) 92.
3 Mandhare, VK & Gawade SB, Effect of seed borne soybean mosaic virus infection on quality and yield parameters in soybean. *Legu Res*, 33 (2010) 43.
4 Usharani KS, Surendranath B, Haq QMR & Malathi VG, Yellow mosaic virus infecting soybean in northern India is distinct from the species infecting soybean in southern and western India. *Cur Sci*, 86 (2004) 845.
5 Ramesh SV, Bhaskale R, Admane N, Gupta GK & Husain SM, Multiply Primed Rolling Circle Amplification (MPRCA) of Yellow mosaic virus genome from infected soybean in central Indian region divulges it as Mungbean yellow mosaic Indian virus -[sb] and its implications for RNAi mediated virus resistance. In: Proceeding "World Soybean Research Conference-IX (WSRC-IX)" held at Durban, South Africa from 17-22 February, 2013 Abstract No. 116.
6 Marabi RS, Das SB, Bhowmick AK, Pachori R, Vibha, Sharma HL, Seasonal population dynamics of whitefly (Bemisia tabaci Gennadius) in soybean. *J Ent Zool Stud*, 5 (2017) 169.
7 Singh OP & Singh KJ, Yield response to girdling by the girdle beetle, Obereopsis brevis (Swed.) on different plant parts of soybean. *Trop Agri*, 73 (1996) 77.
8 Singh VB, Haq QMR & Malathi VG, Antisense RNA approach targeting Rep gene of mungbean yellow mosaic India virus to develop resistance in soybean. *Arch Phytopatho Plant Protect*, 46 (2013) 1.
9 Varma A & Malathi VG, Emerging geminivirus problems: a serious threat to crop production. *Ann Appl Bio*, 142 (2013) 145.
10 Chattopadhyay C, Agrawal R, Kumar A, Bhar LM, Meena PD, Meena RL, Khan SA, Chattopadhyay AK, Awasthi RP, Singh SN, Chakravarthy NVK, Kumar A, Singh RB &Bhunia CK, Epidemiology and forecasting of Alternaria blight of oilseed Brassica in India – a case study. *J Plant Dis Prot*, 112 (2005) 351.
11 Laxmi RR & Kumar A, Forecasting of powdery mildew in mustard (Brassica juncea) crop using artificial neural networks approach. *Ind J Agric Sci*, 81 (2011) 855.
12 Kaundal R, Kapoor AS & Raghava GP, Machine learning techniques in disease forecasting: a case study on rice blast prediction. *BMC Bioinfor*, 7 (2006) 485.
13 Salam SA, Patil MS & Salimath PM, Evaluation of Mungbean cultures against MYMV in Karnataka under natural conditions. *Legume Res*, 324 (2009) 286.
14 Karthikeyan A, Shobhana VG, Sudha M, Raveendran M, Senthil N, Pandiyan M & Nagarajan P, Mungbean Yellow Mosaic Virus (MYMV): A threat to green gram (*Vigna radiata*) production in Asia. *Int J Pest Manag*, 60 (2014) 314.
15 Mayo MA & Pringle CR, Virus taxonomy. *J Gen Virol*, 79 (1998) 649.

16 Accotto GP & Sardo L, Transovarial transmission of begomoviruses in Bemisiatabaci. In: Stansly P.A., Naranjo SE, editors. Bemisia: Bionomics and Management of a Global Pest. Springer; New York: (2010) 339.

17 Naimuddin, Akram M & Pratap A, First report of natural infection of *Mungbean Yellow Mosaic India Virus* in two wild species of *Vigna*. *New Dis Rep*, 23 (2011) 21.

18 Ramesh SV, Chouhan BS, Gupta, GK, Ramteke R, Chand S & Husain S, Molecular diversity analysis of coat protein gene encoded by Begomoviruses and PCR assay to detect Yellow Mosaic Viruses infecting Soybean in India. *Br Biotechnol J*, 12 (2016) 1.

19 Mishra GP, Dikshit HK, Ramesh SV, Tripathi K, Kumar RR, Aski M, Singh A, Roy A, Priti, Kumari N, Dasgupta U, Kumar A, Praveen S & Nair RM, Yellow Mosaic Disease (YMD) of Mungbean (*Vigna radiata* (L.) Wilczek): Current Status and Management Opportunities. *Front Plant Sci*, 11 (2020) 1.

20 Agnihotri AK, Mishra SP, Ansar M, Tripathi RC, Singh R & Mohammad A, Molecular characterization of Mungbean yellow mosaic India virus infecting tomato (*Solanum lycopersicum* L.). *Australas Plant Pathol*, 48 (2019) 159.

21 Singh CM, Singh P, Pratap A, Pandey R, Purwar S, Vibha, Douglas CA, Baek KH & Mishra AK, Breeding for enhancing Legumovirus resistance in Mungbean: Current understanding and future directions. *J Agron*, 9 (2019) 622.

22 Wei C, Jing X, Sun L, Cai HC & Wang Y, Genome cloning and genetic diversity of Apple chlorotic leaf spot virus. *Indian J Biochem Biophys*, 56 (2019) 514.

23 Silodia K, Investigations on epidemiology of Soybean diseases with special reference to Mungbean Yellow Mosaic and its impact on sowing seed quality. M.Sc. (Ag) thesis, (*Jawaharlal Nehru Krishi Vishwa Vidyalaya*, *Jabalpur* (*M.P.*) (2016), 1.

24 Silodia K, Bhale U & Bhale MS, Epidemic of Mungbean Yellow Mosaic Virus (MYMV) Disease of Soybean: A Potential Threat in Changing Weather under Agro-climatic Conditions of Jabalpur, Madhya Pradesh. *Int J Bio-resour Stress Manag*, 8 (2017) 827.

25 Silodia K, Bhale U & Bhale MS, Indian Status and evaluation of soybean varieties against Mungbean Yellow Mosaic (MYMV) disease under changing climatic conditions of Kaymore plateau zone, Madhya Pradesh, India. *J Agric Res*, 52 (2018) 686.

26 Marabi, RS, Das SB, Tripathi N, Wada T & Noda H, Identification of begomoviruses from legume crop and weed plants and viruliferous status of the whitefly *Bemisiatabaci* in Central India. *Curr Sci*, 120, 7(2021) 1240.

27 Srivastava AK & Prajapati RK, Influence of weather parameters on outbreak of mungbean yellow mosaic virus in blackgram (*Vignamungo* L.) of Bundelkhand Zone of Central India. *J Agril Phys*, 12 (2012) 143.

28 Srivastava AK & Yadav SS, Temporal scale variability of whitefly population and weather rules for peak adult population prediction in soybean at Bundelkhand Agroclimatic zone. *J Agromet*, 20 (2018) 110.

29 Gupta KN & Keshwal RL, Epidemiological studies on yellow mosaic disease of soybean. *Ann Plant Prot Sci*, 11 (2003) 324.

30 Biswas KK, Malathi VG & Varma A, Diagnosis of symptomless yellow mosaic begomovirus infection in pigeonpea by using cloned mungbean yellow mosaic India virus as probe. *J Plant Biochem Biot*, 17 (2008) 9.

31 Singh PK, Rai N, Verma A & Singh DV, Dolichos yellow mosaic virus influenced by environmental conditions. *Ann Plant Prot Sci*, 17 (2009) 164.

32 Salam SA, Patil MS & Byadagi AS, Status of mungbean yellow mosaic virus disease incidence on green gram. *Kar J Agril Sci*, 24 (2011) 247.

33 Srinivasaraghavan A, Lingwal S & Kushwaha KPS, Field evaluation of urdbeangermplasm against mungbean yellow mosaic India virus in North western tarai region of India. *Int J Basic App Agril Res*, 14 (2016) 203.

34 Khan MH, Tyagi SD & Dar ZA, Screening of soybean (*Glycine max* (L.) Merrill) genotypes for resistance to rust, yellow mosaic and pod shattering. In: Soybean-Pest Resistance (Eds. Hany El-Shemy). (*Intech Open Limited, London*) (2013), 173.

35 Gupta KN & Keshwal RL, Studies on the events prior to the development of epidemic in mungbean yellow mosaic virus on soybean. *Ann Plant Prot Sci*, 10 (2002) 118.

36 Lu X, Robertson AE, Byamukama E & Nutter FW, Prevalence, Incidence, and Spatial Dependence of Soybean mosaic virus in Iowa. *Phytopath*, 100 (2010) 931.

37 Khan MA, Rashid A, Mateen A, Sajid M, Rasheed F, Anjum MA, Anjum A, Fayyaz M & Farooq M, Incidence of mungbean yellow mosaic virus (MBYMV), its epidemiology and management through Mycotal, Imidacloprid and Tracer. *Agril Bio J North Am*, 3 (2012) 476.

38 Srivastava AK & Marabi RS, Evaluation of critical weather rule for prediction of yellow mosaic disease on soybean in Central India (Theme 7: Crop-weather-pest-disease relationship and forewarning under changing climate). In Abstract Compendium of National Seminar on "Agrometeorological Interventions for Enhancing Farmers Income (AGMET-2020)" organized by Association of Agrometeorologist, Anand and Kerala Agricultural University, Thrissur, India held from 20th to 22nd January, (2020) 240.

39 Raj SK, Khan, MS, Snehi SK, Srivastava S & Singh HB, A Yellow Mosaic Disease of Soybean in Northern India is caused by Cotton leaf curl Kokhran virus. *Plant Dis*, 90 (2006) 975.

40 Kaur Sarabjot, Sandhu & Dhaliwal, LK, Epidemiology of mungbean yellow mosaic virusunder Ludhiana conditions. *J Agromet*, 21 (2019) 27.

41 Srivastava AK, Nayak MK, Yogranjan, Tomar DS & Gurjar K, Weather based prediction of Chickpea *Helicoverpaarmigera* population in Bundelkhand agroclimatic zone of Madhya Pradesh. *Mausam*, 67 (2016) 377.

42 Kooner BS & Cheema HK, Screening of mungbeangermplasm against whitefly *(Bemisia Tabaci Genn.)* and mungbean yellow mosaic virus. *J Food Legu*, 20 (2007) 100.

43 Tiwari AK, Shivhare, AK, Kumar V & Singh JP, Study on assessment of causes of outbreak of YMV and estimation of yield losses in soybean during Kharif – 2015 in Madhya Pradesh. *Proceeding of Workshop* on "Selection of resistant varieties of soybean for YMV and other biotic and a-biotic stresses" held at ICAR-IISR, Indore on 15th February (2016) 1.

44 Dasgupta I, Malathi VG & Mukherjee SK, Genetic engineering for virus resistance. *Cur Sci*, 84 (2003) 341.

45 Tyagi Ajit, Asnani GC, De US, Hatwar HR & Mazumdar AB, Monsoon Monographs, Government of India, Ministry of Earth Sciences, India Meteorological Department, 2 (2012) 97.