J. Hortic. Sci.
Vol. 21(1), 2026

https://doi.org/10.24154/jhs.v21i1.4025

Original Research Paper

Field screening for identification of sources of resistance in okra (*Abelmoschus* spp) germplasm against Okra yellow vein mosaic virus

Anitha K.[1*], Holajjer P.[1], Ajay B.C.[2], Sairam Reddy P.[3], John J.[4], Parameswari B.[1] and Celia Chalam V.[5]

[1]ICAR-National Bureau of Plant Genetic Resources, Regional Station, Rajendranagar, Hyderabad - 500 030, Telangana, India
[2]ICAR-Directorate of Groundnut Research, Regional Station, Anantapur - 515 701, Andhra Pradesh, India
[3]Urban Kisaan Farms Pvt Ltd, Vattinagulapally, Hyderabad - 500 075, Telangana, India
[4]ICAR-National Bureau of Plant Genetic Resources Regional Station, Thrissur - 680 656, Kerala, India
[5]ICAR-National Bureau of Plant Genetic Resources, Pusa Campus, New Delhi - 110 012, India
[*]Corresponding author Email: aniyagnya1964@gmail.com

ABSTRACT

The present study was conducted to screen 158 okra germplasm including parental lines, wild *Abelmoschus* species, wild *Abelmoschus* derived materials and cultivated *A. esculentus*, against yellow vein mosaic virus (YVMV) under natural field conditions at two different dates of sowing during Summer 2018. YVMV disease incidence was initiated within 28 days after sowing and reached its peak in 20 days time in March sown plot as compared to 35 and 30 days, respectively in the February sown plot. Some of the wild *Abelmoschus* derivatives and okra accessions, *viz*., $C_3$50mizo-2(5), $C_3$50mizo-3(3), $C_3$50mizo-34, $C_3$50mizo-40, IC090379 (*A. tetraphyllus*), $C_2$106mizo-8, $C_2$106mizo-20, $C_3$50mizo-30(1), $C_2$106mizo-33, $C_3$50mizo-5(8), $C_3$50mizo-17(3), $C_2$741mizo-8 and RJR 124 recorded either resistant or tolerant reactions in both experiments. These accessions could be utilized in future okra crop improvement programmes for developing cultivars resistant to yellow vein mosaic disease.

Keywords: Sowing time, wild *Abelmoschus* derivatives, yellow vein mosaic disease

INTRODUCTION

Okra (*Abelmoschus esculentus*), popularly known as lady's finger or bhendi (Family: Malvaceae), is an important vegetable crop of tropical countries. Okra is a rich source of nutrients, fibers and minerals and is mostly grown for its nutritive pods. Several *Abelmoschus* species are globally recognized including *A. callei*, *A. moschatus*, *A. crinitis*, *A. ficulneus*, *A. tuberculatus*, *A. enbeepeegearense*, *A. angulosus*, *A. palianus*, *A. rogosus*, *A. rhodopetalus*, *A. manihot* etc. and *A. esculentus* is the most common and widely cultivated species (Mkhabela et al., 2022). India ranked the highest in the world with production to the tune of 68,73,000 tonnes of okra in 2022, which is about 61.2% of the global production (Food & Agricultural Organisation, updated as on 01-12-2023). Okra has lot of potential for earning foreign exchange through fresh vegetable exports (2,442.96 million US $ fresh vegetable export during 2022-2023; https://agriexchange.apeda.gov.in/IndExp/PortNew.aspx accessed on Aug 3, 2023). Telangana and Andhra Pradesh, India are in the list of top 10 okra producing states in India.

Among the biotic stresses, yellow vein mosaic disease (YVMD) plays a crucial role in affecting crop yield besides other diseases such as okra enation leaf curl disease (OELCuD) powdery mildew, Cercospora leaf spot, damping off etc. YVMD is caused by yellow vein mosaic virus (YVMV), a monopartite Begomovirus, transmitted by whitefly, *Bemisia tabaci*. The characteristic symptom of the disease is veinal chlorosis, leading to yellowing of the entire veinal network in the leaf blade. Severe infection leads to the clearing of leaf veins and the interveinal area turns completely yellow or white. The younger leaves turn yellow, become reduced in size and the plant gets severely stunted. Flowering gets reduced and the affected plants produce smaller, yellow or white fruits, which are harder and not suitable for marketing. YVMV infection is often severe, causing yield losses ranging from 50 to 95% depending on crop growth stage and disease intensity (Sastry & Singh, 1974; Pun & Doraiswamy, 1999). The disease is characterized by characteristic symptoms of chlorosis and yellowing of leaves, malformation, and development of small sized fruits (Pun & Doraiswamy, 1999).

Table 1 : Disease reaction of okra germplasm against yellow vein mosaic virus at two different dates of sowing

Category	PDI	Accession	
		February sown plot	March sown plot
Resistant	≤10.0	*A. esculentus*: IC218886 *A. esculentus* (IC265650) × *A. manihot var. pungens*: $C_3$50mizo-2(5), $C_3$50mizo-3(3), $C_3$50mizo-34, $C_3$50mizo-40	*A. tetraphyllus:* IC090379 *A. esculentus* (IC260106) × *A. manihot var. pungens*: $C_2$106mizo-8 and $C_2$106mizo-20. *A. caillei* (IC306741) × *A. manihot var. pungens*: $C_2$741mizo-8 *A. esculentus* (IC265650) × *A. manihot var. pungens*: $C_3$50mizo-2(5), $C_3$50mizo-3(3), $C_3$50mizo-30(1), $C_3$50mizo-34
Tolerant	10.1-30.0	*A. esculentus*: IC049734 *A. tetraphyllus*: IC090379 (wild) *A. esculentus* (IC260106) × *A. manihot var. pungens*: $C_2$106mizo-8, $C_2$106mizo-20, $C_2$106mizo-33 *A. caillei* (IC306741) × *A. manihot var. pungens*: $C_2$741mizo-8 *A. esculentus* (IC265650) × *A. manihot var. pungens*: $C_3$50mizo-5(8), $C_3$50mizo-17(3), $C_3$50mizo-27, $C_3$50mizo-30(1) *A. esculentus* (IC412987) × *A. angulosus* var. *grandiflorus* : $C_3$87gr-4, Cultivars:ABBL 102-3, PSRJ 12952, RJR 124	*A. esculentus* (IC260106) × *A. manihot var. pungens*: $C_2$106mizo-33 *A. esculentus* (IC265650) × *A. manihot var. pungens*: $C_3$50mizo-5(8), $C_3$50mizo-17(3), $C_3$50mizo-40 Cultivars: ABBL 102-3, RJR 124
Susceptible	30.1-70.0	*A. esculentus*: IC032398A, IC032855,IC033122, IC033343, IC033350, IC033405, IC033804, IC033854, IC033854A, IC033854B, IC043735, IC043736, IC043745, IC043748, IC043750, IC045792, IC045802B, IC045805, IC045815,IC045823, IC045824, IC045828, IC045831, IC045838, IC052298, IC052298B, IC052299, IC052301, IC052305B, IC052310, IC052312, IC052314, IC052320, IC052322, IC058710, IC059713, IC062738, IC069113, IC069259, IC069290, IC069303, IC085536, IC085583, IC086008, IC086045, IC089712, IC089926, IC089948, IC089976, IC090044, IC090049, IC090072, IC090073, IC090074, IC090075, IC090077, IC090082, IC090096, IC090098, IC090168, IC090170, IC090171, IC090174, IC090177, IC090181, IC090184, IC090185, IC090189, IC090194, IC090195, IC090206, IC090209, IC113876, IC128890, IC128892, IC140897, IC218869, IC218871, IC218874, IC218893, IC218900, IC260106, IC265650, IC282227, IC282228, IC282229, IC282232, IC282233, IC282243, IC282246, IC282251, IC282252 *A. esculentus* (IC412987) × *A. angulosus* var. *grandiflorus* : $C_3$87gr-2 Cultivars: Pusa Sawani, Parbhani Kranthi	*A. esculentus*: IC032398, IC02398A, IC033122, IC033343, IC033350, IC033405, IC033804, IC033854, IC033854A, IC033854B, IC043736, IC043745, IC043748, IC043751, IC045792, IC045802B, IC045805, IC045815, IC045823, IC045824, IC045828, IC045831, IC045838, IC049734, IC052298, IC052299, IC052301, IC052302, IC052305B, IC052310, IC052314, IC052320, IC052322, IC058705A, IC069258, IC069290, IC069303, IC085581, IC085583, IC090049, IC090074, IC090075, IC090077, IC090082, IC090096, IC090098, IC090168, IC090170, IC090171, IC090172, IC090174, IC090177, IC090184, IC090185, IC090206, IC113904, IC218869, IC218871, IC218874, IC218886, IC218900, IC252230, IC260106, IC282229, IC282232, IC282233, IC282243, IC282245, IC282246, IC282248, IC282251, IC282252 *A. esculentus* (IC265650) × *A. manihot var. pungens*: $C_3$50mizo-27 *A. esculentus* (IC412987) × *A. angulosus* var. *grandiflorus* : $C_3$87gr-2, $C_3$87gr-4 Cultivars: PSRJ 12952, Pusa Sawani, Parbhani Kranthi
Highly Susceptible	>70.0	*A. esculentus*: IC018540, IC031855, IC032212, IC032398, IC033301, IC033302, IC033315, IC033329, IC033345, IC033823, IC042279, IC043737, IC043751, IC052302, IC058705A, IC058768, IC069211, IC069232, IC069242, IC069248, IC069254, IC069257, IC069258, IC069261, IC069263, IC069304, IC069712, IC072082, IC072093, IC085581, IC089924, IC090172, IC090196, IC090202, IC113904, IC140898, IC140927, IC218870, IC218881, IC252230, IC282226, IC282239, IC282245, IC282248, IC282256, IC282259, IC282282	*A. esculentus*: IC018540, IC031855, IC032212, IC032855,IC033301, IC033302, IC033315, IC033329, IC033345, IC033823, IC042279, IC043735, IC043737, IC043750, IC052298B, IC052312, IC058710, IC058768, IC059713, IC062738, IC069113, IC069211, IC069232, IC069242, IC069248, IC069254, IC069257, IC069259, IC069261, IC069263, IC069304, IC069712, IC072082, IC072093, IC085536, IC086008, IC086045, IC089712, IC089924, IC089926, IC089948, IC089976, IC090044, IC090072, IC090073, IC090181, IC090189, IC090194, IC090195, IC090196, IC090202, IC090209, IC113876, IC128890, IC128892, IC140897, IC140898, IC140927, IC218870, IC218881, IC218893, IC265650, IC282226, IC282227, IC282228, IC282239, IC282256, IC282259, IC282282

Use of varieties resistant to YVMV is the best alternative for the management of the disease. Earlier, many workers screened okra germplasm for YVMV resistance (Amit Kumar et al., 2015; Sanwal et al., 2016; Meenakshi Kumari et al., 2018). However, frequent breakdown of the viral disease resistance has been reported in popular cultivars of okra like Parbhani Kranti, P-7, Arka Anamika, and Arka Abhay (Sanwal et al., 2014). Emergence of new viral strains and polyphagous "B" biotype of *Bemisia tabaci*, have been considered as major factors responsible for the breakdown of tolerance, as the tolerance in most of the cases has been found to be location specific (Singh et al., 2013). Crop wild relatives (CWRs) that are undomesticated possess rich sources of genes providing resistance to various diseases, pests, and unfavorable environmental conditions (Rattan & Kumar, 2020). Thus, looking for new sources of resistance is a constant approach against such type of diseases under the changed climatic regime. The sowing dates significantly influence the YVMD incidence (Singh & Singh, 1989; Gill et al., 1991; Magar & Nirmal, 2010). Keeping the above points in view, the present study was carried out to evaluate okra germplasm to identify resistant sources against YVMD at two different dates of sowing.

MATERIALS AND METHODS

One hundred and fifty-eight okra genotypes, received from ICAR-National Bureau of Plant Genetic Resources (NBPGR), New Delhi, India Regional Station, Thrissur, India were selected as experimental material. These include okra parental lines (02), wild *Abelmoschus* species (01), wild *Abelmoschus* derived materials (14) and cultivated *A. esculentus* accessions (141). The wild *Abelmoschus* derivatives were derived by choosing cultivated *A. esculentus* (IC260106, IC265650, and IC412987) or *A. callei* (IC306741) as female parent and *A. manihot var. pungens* (Syn: *A. pungens* var. *mizoragensis*) or *A. angulosus* var. *grandiflorus* as male parent (Table 1). Local checks, *viz*., ABBL-102-3 (resistant check), Pusa Sawani and Parbhani Kranthi (susceptible checks) were used. Venkataravanappa et al. (2022) also used Pusa Sawani as susceptible check, while, screening okra germplasm against YVMD and Okra enation leaf curl virus.

Two experiments were set up by choosing two different dates of sowing (19.02.2018 and 06.03.2018, respectively) in summer season, with a gap of one fortnight between the two experiments. The pre-scarified seeds of all genotypes were sown at 60 cm ×15 cm spacing between rows and plants, accommodating 20 plants per row and two rows for each genotype following Augmented block design including the standard checks in the research plots of ICAR-NBPGR Regional Station, Hyderabad (GPS coordinates: 17.3329° N, 78.4104° E). No plant protection measures were taken against sucking pest complex to safeguard the whitefly population as it is a vector for transmitting the YVMV. All other package of practices for growing okra plants were followed for getting good crop stand. Observations on incidence of YVMV were recorded at regular intervals by scoring all the established plants of each accession.

Disease severity scale of 0-4 was used for visual evaluation of the diseases. The disease severity rating was assessed as follows: 0=no disease; 1=initiation of vein clearing and yellowing of leaf area up to 10%; 2=10-50% of leaf area affected and no symptoms on fruits; 3=50-75% of leaf area affected along with discoloured fruits; and 4=greater than 75% of leaf area affected; all leaves and fruits exhibit symptoms. YVMD was scored in a scale of per cent disease index (PDI) values (Das et al., 2013), where in a resistant (R) had a PDI$\leq$10%, tolerant (T) 10.1-30%, susceptible (S) 30.1-70% and highly susceptible (HS) >70%. The number of plants infected in each entry was recorded to calculate PDI as per the formula given below:

$$PDI = \frac{\text{Sum of all numerical ratings}}{\text{All higher grade of rating} \times \text{Total number of plants of the entry examined}} \text{ X } 100$$

Envirotyping

For each season, weather data was collected on a daily basis using the R package EnvRtype (Costa-Neto et. al. 2021a). Based on geographical coordinates (WGS84), plant date, and harvest date, the package collects and processes remote weather data from "NASA's Prediction of Worldwide Energy Resources" (NASA POWER, https://power.larc.nasa.gov/). The environmental covariables (EC) were gathered using the get weather function of EnvRtype package and are listed in Table 2. EC were used to create an envirotype-covariable matrix (W) which was further used to calculate the environmental kinships using the function W_matrix() of the EnvRtype package. We used the function W_matrix() of the EnvRtype

Table 2 : Details of climatic variables gathered

Abbreviation	Environmental factors	Units
SW	Surface shortwave downward irradiance	$MJ/m^2/day$
PAR	Surface PAR total	W/m^2
T2MDEW	Dew/frost point at 2 meters	!
T2MWET	Wet bulb temperature at 2 meters	!
T2M_MAX	Temperature at 2 meters maximum	!
T2M_MIN	Temperature at 2 meters minimum	!
RH2M	Relative humidity at 2 meters	%
PRECTOT	Precipitation corrected	mm/da
WS2M	Wind speed at 2 meters	m/s
n	Actual duration of sunshine	hour
N	Daylight hours	hour
RTA	Extraterrestrial radiation	$MJ/m^2/day$
VPD	Vapour pressure deficit	kPa
SPV	Slope of saturation vapour pressure curve	kPa.Celsius
ETP	Evapotranspiration	mm d^{-1}
PETP	Deficit by precipitation	mm d^{-1}
TA	Thermal amplitude	!

package (Costa-Neto et al., 2021a) to create a covariate matrix (W), as proposed by (Costa-Neto et al., 2021b). Using the W matrix, we calculated an enviromic kernel (Gaussian), using the function env_kernel() of the EnvRtype package (Costa-Neto et al., 2021b). Therefore, it was possible to compare how environments (and mega-environments) are similar or not related to this environmental covariable.

Partial least square regression for selecting Eco-climatic factors

Nineteen environmental covariables (EC) form Eco-climatic factors (EFs) were used for running partial linear square (PLS) regression model with YVMV disease incidence. Partial linear square (PLS) regression is a linear regression model, which uses principles similar to PCA. In PLS two datasets are used, one matrix with predictors/ independent variables (X matrix) and second matrix with responses/ dependent variables (Y matrix). Decomposition is done for both matrices, computing scores, loadings and residuals. PLS analysis generates statistical parameters that can be used to identify most important Eco-factor associated with the oil yield (Mehmood et al., 2012) such as Variable importance in projection (VIP) and selectivity ratio. Commonly used threshold VIP for selecting a set of relevant variables is 1 (Cocchi et al., 2018). For PLS analysis, the X matrix contained the 17 EFs and the Y matrix contained the YVMV disease incidence. To avoid variable dimension issues, the X matrix was centered and scaled. The number of components selected in PLS was defined based on minimising the root mean square error (RMSE) using cross-validation (Kvalheim et al., 2018). A VIP of 1.5 was used as the threshold for retaining the most relevant yield contributing EFs. Subsequently the selectivity ratio was calculated as the ratio of explained variance to total variance of the eco-factors followed by multiplication by the overall explained variance of the model (Aadland et al., 2019). This results in the predictor variables specific explained variance of the response variable with positive or negative values depending on the sign of the PLS coefficients. PLS analysis was performed under R software (version 4.4.1) using 'mdatools' (Kucheryavskiy, 2020) package.

RESULTS AND DISCUSSION

Okra germplasm was screened against Yellow vein mosaic virus (YVMV) at two different dates of sowing to make sure that the accessions get exposed to the YVMV. It was noticed that the overall plant growth

Table 3 : Eco-climatic factors with a variable importance in projection (VIP) attributed after PLS analysis with 17 ecoclimatic factors

Parameter	VIP Scores	β-Coeff	Selectivity Ratio	Loadings
SW	0.38	-0.04	0.19	-0.43
PAR	1.19	-0.13	1.86	-1.36
T2MDEW	1.47	0.16	2.83	1.68
T2MWET	0.84	0.09	0.92	0.96
T2M_MAX	0.17	-0.02	0.04	-0.19
T2M_MIN	0.60	0.07	0.46	0.68
RH2M	3.31	0.37	14.36	3.79
PRECTOT	0.24	0.03	0.07	0.27
WS2M	0.18	0.02	0.04	0.20
n	0.16	-0.02	0.03	-0.18
N	0.13	0.01	0.02	0.15
RTA	0.53	0.06	0.37	0.61
VPD	0.12	-0.01	0.02	-0.14
SPV	0.00	0.00	0.00	0.00
ETP	0.16	-0.02	0.04	-0.19
PETP	0.40	0.04	0.21	0.46
TA	0.77	-0.08	0.77	-0.87

The statistical model estimated that the one-components option was the optimal solution based on minimising RMSE. β-regression coefficients indicate whether the considered factor had a positive or negative effect on observed yields

of accessions in March sown plot was more luxurious as compared to the less plant growth in February sown plot. In addition, in February sown plot, the disease initiation started at 35 days after sowing and maximum disease incidence in susceptible accessions reached within 30 days. However, in March sown plot, disease appeared within 28 days after sowing and maximum disease incidence reached in vulnerable accessions within 20 days time. Results on disease screening indicated that YVMD incidence was more apparent in March sown plot as compared to the February sown plot (Table S1). Meenakshi Kumari et al. (2018) also reported that the incidence of YVMD was higher during the months of April and May because of high temperature coupled with high rainfall. Solankey et al. (2014) also suggested that hot climate with high humidity followed by heavy rainfall provides congenial conditions for the development of the vector, whitefly, thereby causing more susceptibility to YVMD.

Data presented in Table 3 displays Eco-climatic factors (EFs) with VIP and SR for YVMD incidence in Okra. Among the 17 EFs relative humidity (RH2M) recorded highest VIP score and highest selectivity ratio followed by T2MDEW and PAR. Among the three identified EFs, β-Coeff for RH2M and T2MDEW was positive, whereas, it was negative for PAR indicating that RH2M and T2MDEW had positive effect on YVMD incidence. Variations in these selected EFs between February and March is presented in Table 4. PLS model was run once again with the selected variables from SR selection method. EFs identified as per SR recorded high R^2 value with low RMSE (Table 5). Magar & Nirmal (2010) reported that the okra crop sown in January recorded lowest incidence of YVMV (10.75%) and highest (90.69%) in April. Sanwal et al. (2016) reported that in South India, the occurrence of YVMD and whitefly was highest in March to June, which supports the present study too where YVMD incidence reached to peak proportions in many of the accessions in March sown plot. Higher RH2M and T2MDEW and lower photosynthetically active radiation (PAR) are the predisposing factors responsible for higher YVMD incidence in Okra during March when compared to February.

Table 4 : Ecofactors selected as per selectivity ratio under different test environments

Parameter	par	T2MDEW	RH2M
hydfeb	115.80	11.36	34.73
hydmar	113.87	13.74	40.09

Table 5 : Partial least square (PLS) regression (calibration and validation) parameters comparison between original variables and selected variables

X	cumexpvar Y	cumexpvar	R2	RMSE	Slope	Bias	RPD
Cal	100	100	1	0	1	0	Inf

Symptoms of YVMD initiated with feeble yellowing of veins and veinlets of the leaves (Fig. 1a) almost one month after the date of sowing. Later, the yellowing of veins and veinlets became more prominent (Fig. 1b). The interveinal regions of the leaves later turned yellow or white (Fig. 1c). In case of severe infection, the affected leaves showed complete chlorosis (Fig. 1d) and the leaves showed mosaic pattern of yellow and green (Fig. 1e). The infected plants of some susceptible accessions showed stunted growth with reduced leaf size. In majority of the susceptible accessions, affected plants produced fewer flowers and fruits, and the fruits were smaller in size, deformed, harder, and yellow green to pale white in colour (Fig. 1e). Finally, the entire plant turned yellowish white in colour (Fig. 1f).

In the February sown plot, among the 158 accessions, five accessions showed 'Resistant' reaction, 13 'tolerant', 93 'susceptible' and 47 'highly susceptible' reaction. In the March sown plot, all the evaluated accessions could be categorized into resistant (8 accns), tolerant (5), susceptible (76) and highly susceptible (69) accessions. The checks, 'ABBL 102-3' showed 'tolerant' reaction, while 'Pusa Sawani' and 'Parbhani Kranthi' recorded 'susceptible' reaction in both the dates of sowing (Table 1 & S1).

PDI of accessions under resistant category

It was observed that the PDI of accessions under resistant category ranged between 4.54-9.38 in February sown plot, while the range was between 3.33-10.00 in March sown plot with $C_3$50Mizo-2(5) exhibiting the lowest and $C_3$50Mizo-3(3) recording the maximum in both the experiments. Three wild *Abelmoschus* derivatives, *viz*., $C_3$50Mizo-2(5), $C_3$50Mizo-3(3) and C350Mizo-34 exhibited Resistant reaction in both the experiments, recording <10 PDI. Coincidentally, these three derivatives were derived from the same female (IC265650) and male (*A. manihot var. pungens*) parents. The remaining two resistant accessions ($C_3$50Mizo-40 and IC218886) of February sown plot exhibited 'tolerant' ($C_3$50Mizo-40) and 'susceptible' (IC218886) reaction in March sown experiment. $C_3$50Mizo-2(5) exhibited the lowest (4.54 and 3.3 PDI) and $C_3$50Mizo-3(3) recording the maximum (9.38 and 10.00 PDI, respectively) incidence in both the experiments. Five wild okra accessions or wild okra derivatives, *viz*., IC090379 (*A. tetraphyllus*), C_2 106Mizo-8, C_2 106Mizo-20 (IC260106 x *A. manihot var. pungens*), $C_3$50Mizo-30(1) (IC265650 x *A. manihot var. pungens*) and C_2 741Mizo-8 (*A. callei* x *A. manihot var. pungens*), exhibited 'resistant' reaction in March sown plot, while these accessions were 'tolerant' to YVMD in February sown plot. However, four accessions, C2 106Mizo-33 (IC260106 x *A. manihot var. pungens*), $C_3$50Mizo-17 (3), $C_3$50Mizo-5 (8) and RJR 124 recorded similar 'tolerant' reaction in both the experiments (Table 2). Singh et al. (2007), Sanwal et al. (2014) and Venkataravanappa et al. (2022) reported that the wild accessions, including *A. tetraphyllus* were resistant to YVMD, which is in line with the present study, where IC090379 (*A. tetraphyllus*) recorded 'resistant' reaction even under high disease pressure situation. Although in the present study, the WAD, C2 741Mizo-8 (*A. callei* as female parent) exhibited 'resistant'/ 'tolerant' reaction in two different dates of sowing, some accessions of *A. callei* exhibited either 'susceptible' or 'highly susceptible' reaction in the study conducted by Venkataravanappa et al. (2022).

PDI of accessions under tolerant category

The PDI values among accessions ranged between 12.50-29.17 in February sown plot, while the range was between 12.50 and 22.92 in March sown plot.

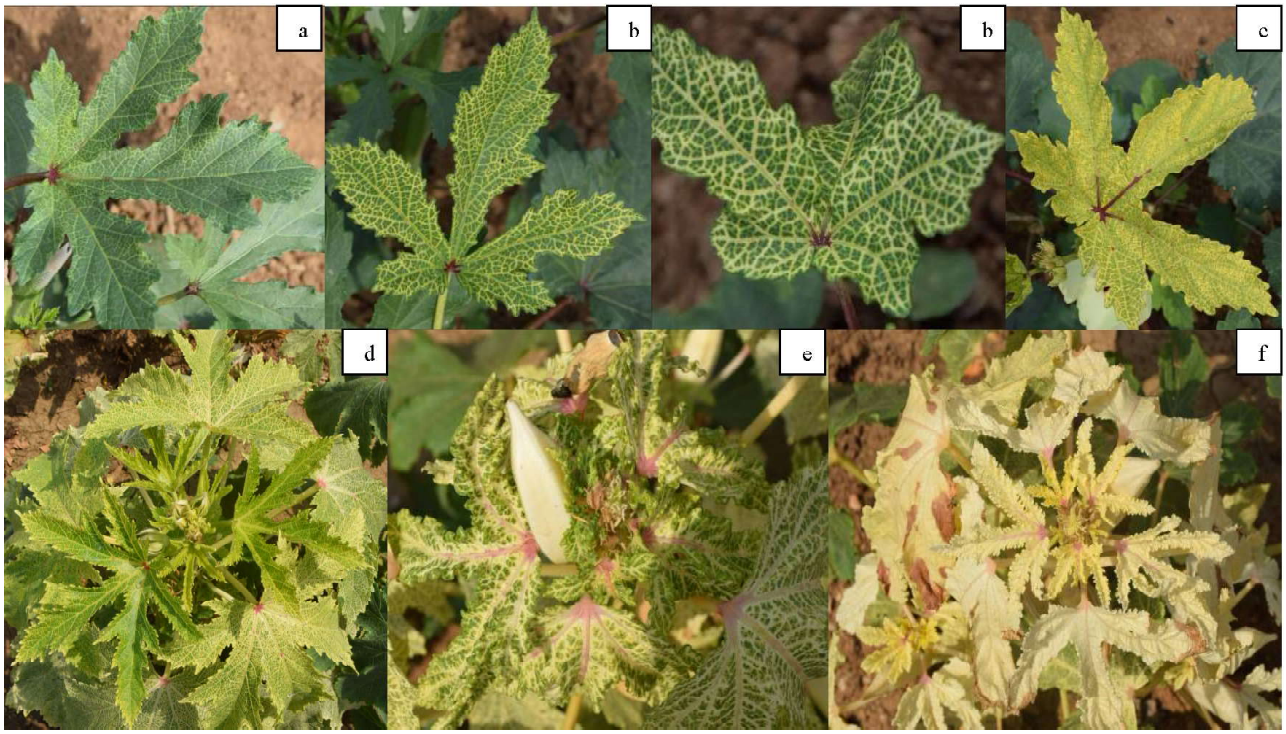

Fig. 1 : Progression of symptom development in yellow vein mosaic virus infected okra accessions

Interestingly, four accessions, *viz*., IC090379 (*A. tetraphyllus*), $C_2$106mizo-8, $C_2$106mizo-20, $C_3$50mizo-5(8), $C_3$87gr-4 recorded minimum of 12.50 PDI, while the maximum PDI was recorded by $C_2$106mizo-33 (29.17) in February sown plot. In the March sown plot, two accessions ($C_2$106mizo-33 and C350Mizo-17 (3) recorded minimum of 12.50 PDI, while the maximum PDI was recorded by $C_3$50Mizo-40 (22.92) as compared to 26.42 recorded by ABBL 102-3, the resistant check. Venkataravanappa et al. (2022) reported that the wild accessions belonging to *A. manihot* var. *tetraphyllus* recorded highly resistant (7 accns), resistant (2 accns) and moderately resistant (2 accns) reaction, besides some accessions with moderately susceptible, susceptible and highly susceptible reactions. In the present study, the cultivated okra accessions, *viz*., RJR-124 ('tolerant' in both the experiments) and PSRJ-12952 ('tolerant' in February sown plot and 'susceptible' in March sown plot) performed well against YVMD. Earlier, these two accessions were completely free from YVMD during natural field screening studies (Manju et al., 2018).

PDI of accessions under susceptible category

More number of accessions (93) exhibited "susceptible" reaction in February sown plot as compared to 76 accessions in March sown plot. However, the PDI values ranged in more or less similar fashion in both the experiments (30.17-70.00 in February and 32.86-69.74 in March). It is noticed that 59 accessions, including the local check, "Pusa Sawani" exhibited similar "susceptible" reaction in both the dates of sowing. thirty-two accessions that showed "susceptible" reaction in February sown plot showed "highly susceptible" reaction in March sown plot, which may be due to slightly increased temperatures, which are ideal for whitefly population build-up. However, $C_3$50mizo-30(1) accession that recorded "tolerant" reaction in February sown plot, did record <10.0 PDI in March sown plot, thus grouped under "resistant" category. Among the female parents (IC260106 and IC265650) that were used in developing wild derivatives, IC260106 recorded 'susceptible' reaction in both the experiments, while IC265650 exhibited 'susceptible' reaction in February sown plot and 'highly susceptible' reaction in March sown plot, including the local check, "Parbhani Kranti". Among the wild *Abelmoschus* derived accessions using (IC412987 x *A. angulosus* var. *grandiflorus*) $C_3$87gr-2 and $C_3$87gr-4 exhibited 'susceptible' reaction only in both the experiments, while $C_3$87gr-4 exhibited 'tolerant' reaction in february sown plot and 'susceptible' reaction in March sown

plot. Venkataravanappa et al. (2022) reported accessions of *A. angulosus* var *grandiflorus* recording reaction both under HR and HS categories against YVMD, which indicates that there could be variation in level of resistance among various accessions within a species.

In February sown plot, 47 okra accessions were grouped under "highly susceptible" category, while 69 accessions were grouped under the same category in March sown plot, which shows the increased intensity of disease pressure due to ideal climatic conditions for whitefly population build-up. Among 47 HS accessions, 36 accessions recorded similar 'HS' reaction even in March sown plot, and the remaining 11 accessions of this group were grouped under "susceptible" category in March sown plot. In the present study, the highly susceptible accessions recorded PDI values ranging between 70.59 and 100.0, and 71.59 and 100.0, respectively in both the experiments (Table 3). It is noted that in the present study, none of the wild *Abelmoschus* derivatives recorded HS reaction in both the experiments. Earlier studies also shown that the wild species of okra have more stable and good sources of resistance to YVMD and Okra enation leaf curl virus (Singh et al., 2007 & 2009; Sanwal et al., 2014).

The identification of resistant and tolerant sources against YVMD among wild *Abelmoschus* derivatives and *A. tetraphyllus* provides valuable genetic resources for okra improvement. These genotypes can be utilized as donor parents in resistance breeding programme aimed at developing YVMD-resistant cultivars. The superior performance of interspecific derivatives further highlights the potential of crop wild relatives in broadening the genetic base of cultivated okra and enhancing the durability of resistance. In addition, these resistant sources may serve as valuable materials for genetic studies, QTL mapping, and marker-assisted selection to accelerate the development of YVMD-resistant varieties.

CONCLUSION

Some of the wild *Abelmoschus* derivatives and okra accessions, *viz*., $C_3$50mizo-2(5), $C_3$50mizo-3(3), $C_3$50mizo-34, $C_3$50mizo-40, IC090379 (*A. tetraphyllus*), $C_2$106mizo-8, $C_2$106mizo-20, $C_3$50mizo-30(1), $C_2$106mizo-33, $C_3$50mizo-5(8), $C_3$50mizo-17(3), $C_2$741mizo-8, and RJR 124 recorded either resistant or tolerant reaction in both the experiments. These resistant and tolerant accessions should be further validated through multi-location trials to assess the stability and durability of their resistance across diverse agro-climatic conditions. Subsequently they could be utilized in future crop improvement programmes to develop cultivars resistant to YVMD in okra.

ACKNOWLEDGEMENT

Authors are grateful to the then Officer-In-Charge, ICAR-NBPGR Regional Station, Hyderabad and the Director, ICAR-NBPGR, New Delhi for their support and providing the facilities to carry out this study. Senior author is also thankful to Smt. K. Madhavi and Smt. E. Swathi for the assistance provided while recording disease observations.

REFERENCES

Aadland, E., Andersen, L. B., Resaland, G. K., & Kvalheim, O. M. (2019). Interpretation of multivariate association patterns between multicollinear physical activity accelerometry data and cardiometabolic health in children-a tutorial. *Metabolites*, *9*(7), 129. https://doi.org/10.3390/metabo9070129

Amit Kumar, Verma, R. B., Solankey, S. S., & Adarsh. A. (2015). Evaluation of okra (*Abelmoschus esculentus*) genotypes for yield and yellow vein mosaic disease. *Indian Phytopathology*, *68*(2), 201-206.

Cocchi, M., Biancolillo, A., & Marini, F. (2018). Chemometric Methods for classification and feature selection. In: Jaumot, J., Bedia, C., & Tauler, R. (Eds.), *Comprehensive Analytical Chemistry*; *Data Analysis for Omic Sciences*: *Methods and Applications*, Elsevier, Amsterdam, The Netherlands, *82*, 265-299. https://doi.org/10.1016/BS.CAC.2018.08.006

Costa-Neto, G., & Fritsche-Neto, R. (2021b). Enviromics: bridging different sources of data, building one framework. *Crop Breeding and Applied Biotechnology*, *21*(S), e393521S12. https://doi.org/10.1590/1984-70332021v21Sa39

Costa-Neto, G., Galli, G., Carvalho, H. F., Crossa, J., & Fritsche-Neto, R, (2021a). EnvRtype: a software to interplay enviromics and

quantitative genomics in agriculture. *G3 Genes|Genomes|Genetics*, *11*, jkab040. https://doi.org/10.1093/g3journal/ jkab040

Das, S., Chattopadhyay, A., Chattopadhyay, S. B., Dutta, S., & Hazra, P. (2013). Breeding okra for higher productivity and yellow vein mosaic tolerance. *International Journal of Vegetable Science*, *19*, 58-77. https://doi.org/10.1080/ 19315260.2012.683473

Gill, H. S., Kataria, A. S., Prakash, J., & Pierik, R. L. M. (1991). Resistance breeding under coordinated programme. International Seminar on new frontiers in Horticulture organized by Indo-American Proceedings of the Inter Horticulture - New Technologies and Application, 12. https://agriexchange.apeda.gov.in/International_Productions/ International_Production.aspx?Product Code=0430. Referred on 19.12.2024

Kucheryavskiy, S. (2020). "mdatools-R package for chemometrics". *Chemometrics and Intelligent Laboratory Systems*, 198. https://doi.org/ 10.1016/j.chemolab.2020.103937.

Kvalheim, O. M., Arneberg, R., Grung, B., & Rajalahti, T. (2018). Determination of optimum number of components in partial least squares regression from distributions of the root-mean-squared error obtained by Monte Carlo resampling. *Journal of Chemometrics*. https://doi.org/10.1002/cem.2993

Magar, S. J., & Nirmal, D. D. (2010). Influence of sowing time on the incidence of yellow vein mosaic disease, whitefly population and yield of okra [*Abelmoschus esculentus* (L.) Moench.]. *Indian Phytopathology*, *63*(1), 112-113.

Manju, K. P., Vijaya Lakshmi, K., Sarath Babu, B. & Anitha, K. (2018). Evaluation of okra germplasm for their reaction to whitefly, *Bemisia tabaci* and okra yellow vein mosaic virus (OYVMV). *Journal of Entomological and Zoological Studies*, *6*(2), 2491-2496.

Meenakshi Kumari, Solankey, S. S., Manoj Kumar, Shirin Akhtar & Pallavi Neha. (2018). Assessment of okra genotypes for yellow vein mosaic virus tolerance. *International Journal of Current Microbiology and Applied Sciences*, *7*, 1470-1475. https://doi.org/10.20546/ ijcmas.2018.703.175

Mehmood, T., Liland, K. H., Snipen, L., & Saebo, S. A. (2012). Review of variable selection methods in partial least squares regression. *Chemometrics and Intelligent Laboratory Systems*, *118*, 62-69. https://doi.org/10.1016/ j.chemolab.2012.07.010

Mkhabela, S. S., Shimelis, H., Gerrano, A. S., & Mashilo, J. (2022). Phenotypic and genotypic divergence in okra [*Abelmoschus esculentus* (L.) Moench] and implications for drought tolerance breeding: A review. *South African Journal of Botany*, *145*, 56-64. https://doi.org/ 10.1016/j.sajb.2021.11.023

Pun, K. B., & Doraiswamy, S. (1999). Effect of age of okra plants on susceptibility to okra yellow vein mosaic virus. *Indian Journal of Virology*, *15*, 57-58.

Rattan, P., & Kumar, S. (2020). Development of interspecific hybrids (*Abelmoschus esculentus* × *A. tetraphyllus*) in okra using embryo rescue approach. *Biosciences Biotechnology Research Asia*, *17*, 517-523. https://doi.org/10.13005/ bbra/2855

Sanwal, S. K., Singh, M., Singh, B., & Naik, P. S. (2014). Resistance to yellow vein mosaic virus and okra enation leaf curl virus: Challenges and future strategies. *Current Science*, *106*(11), 1470-1471.

Sanwal, S. K., Venkataravanappa, V., & Singh, B. (2016). Resistance to bhendi yellow vein mosaic disease: A Review. *Indian Journal of Agricultural Sciences*, *86*(7), 835-843.

Sastry, K. S. M., & Singh, S. J. (1974). Effect of yellow vein mosaic virus infection on growth and yield of okra crop. *Indian Phytopathology*, *27*, 294-297.

Singh, B. R., & Singh, M. (1989). Control of yellow vein mosaic of okra by checking its vector whitefly through adjusting dates of sowing, insecticidal application and crop barrier. *Indian Journal of Virology*, *5*, 61-66.

Singh, B., Rai, M., Kalloo, G., Satpathy, S., & Pandey, K. K. (2007). Wild taxa of okra

(*Abelmoschus* spp.): reservoir of genes for resistance to biotic stresses. *Acta Horticulturae*, *752*, 323-328. https://doi.org/10.17660/ActaHortic.2007.752.56

Singh, B., Sanwal, S. K., Rai, M., & Awadhesh Rai (2009). Source of biotic stress resistance in vegetable crops: A Review. *Vegetable Science*, *36*, 32-33, Varanasi.

Singh, Y., Jha, A., Verma, S., Mishra, V. K., & Singh, S. S. (2013) Population dynamics of sucking insect pests and their natural enemies on okra agro-ecosystem in Chitrakoot region. *African Journal of Agricultural Research*, *28*(8), 3814-3819. https://doi.org/10.5897/AJAR2013.7222

Solankey, S. S., Akhtar, S., Kumar, R., Verma, R. B., & Sahajanand, K. (2014). Seasonal response of okra (*Abelmoschus esculentus* L. Moench) genotypes for okra yellow vein mosaic virus incidence. *African Journal of Biotechnology*, *13*, 1336-1342. https://doi.org/10.5897/AJB2013.13491

Venkataravanappa, V., Sanwal, S. K., Lakshminarayana Reddy, C. N., Singh, B., Umar, S. N., & Krishna Reddy, M. (2022). Phenotypic screening of cultivated and wild okra germplasm against yellow vein mosaic and enation leaf curl diseases of okra in India. *Crop Protection*, *156*, 105955. https://doi.org/10.1016/j.cropro.2022.105955.

(Received : 6.2.2025; Revised : 12.6.2026; Accepted : 17.6.2026)