

Yellow Vein Mosaic Disease of Okra: A recent management technique

Abstract

Yellow vein mosaic is a devastating disease of okra, caused by monopartite and bipartite begomovirus and associated satellites. Yield loss due to this virus is quite high, up to 80-94 percent is reported under heavy infestation. To control of this disease very limited success has been achieved by chemical method, which also is not permanent. Development of host resistant is only a reliable mechanism to manage the disease. Availability of source of resistance for the virus is limited in the cultivated species of Okra. However, wild species *A. manihot ssp. Manihot*, *A. Callei* and *A. tuberculatus* are reported to be resistant against yellow vein mosaic virus. Understanding the genetic regulation along with the molecular mechanism of resistance to okra vein mosaic virus would result in development of resistance cultivars. Also research has been performed from all strategies behind host resistant development, need to emphasis on more advanced breeding technique to be utilized for improvement of crop like okra. In this review, attempts were made to compile all information about nature of virus, its transmission through the vector whitefly, environment affected to disease spread, strategy behind development of host resistant, source of resistant and advanced breeding technique.

Key words: *Abelmoschus esculentus*, virus, host-resistant, Okra, Advanced breeding Technique, resistant source and White fly

Introduction

Okra (*Abelmoschus esculentus* (L) Moench), is widely grown all over tropical, subtropical and warm temperature regions of the world. It is a popular crop in India due to its ease of cultivation and adaptability to varying moisture conditions. It is called lady's finger in England, Gumbo in the USA and Okra in India. Okra appears to have originated in South Africa or Asia (Thompson and Kelley, 1957). The cultivated okra containing chromosome number $2n=130$ is an amphidiploid vegetable of *Abelmoschus tuberculatus* ($2n=58$) and an unknown species with chromosome number $2n=72$ (Datta and Naug 1968). Okra is popular in India, Nigeria, Pakistan, Afghanistan, Iraq, Bangladesh, Brazil, Ethiopia and Ghana. However, India is the largest producer of okra in the world with a total area of 0.53 million ha, production of 6.36 million

tonnes and productivity of 11.9 tonnes/ha (Anonymous, 2015). It covers about 3.9% production share among the total vegetable production in India. Uttar Pradesh, Bihar, Orissa, West Bengal, Andhra Pradesh, Karnataka and Assam are the major producing state for okra in India. Though, in terms of productivity this is not good as that of other okra growing countries.

The crop is prone to damage by various diseases caused by various insects, fungi, nematodes and viruses. But **its** cultivation is seriously threatened by attacking **of one most important** Yellow Vein Mosaic Virus (YVMV) on different parts of plant (Fajinmi and Fajinmi, 2010; Sanwal *et al.* 2016) which causes heavy losses not only in respect to the fruit yield but fruit quality also affected (Venkataravanappa *et al.*, 2013) and occurred at all crop growth stages. YVMV transmitted by whitefly (*Bemisia tabaci* Gen.), first time reported by Varma (1952) and later reported by many researchers. In the recent past, frequent break down of the YVMV resistance have been observed in popular varieties like Parbhani Kranti, Punjab 7, Arka Anamika and Arka Abhay in all over the country probably due to appearance of new strains (Table 1) of viruses or due to recombination in virus strain (Sanwal *et al.* 2014).

Table 1. Diverse begomoviruses have been associated with Yellow vein mosaic disease transmitted by *Bemisia tabaci*

Genome	Virus	Reference
Monopartite	Okra yellow vein mosaic virus	Kulkarni (1924)
	Okra Yellow vein Madurai virus	
	Okra yellow vein Haryana virus	Venkataravanappa, <i>et al.</i> (2008)
	Cotton leaf curl Allahabad virus, (CLCuAIV)	Venkataravanappa, <i>et al.</i> (2013)
	Cotton leaf curl Bangaluru virus, (CLCuBaV)	
	Okra yellow vein Bhubaneswar virus (BYVBhV)	
	Okra yellow vein Maharashtra virus (BYVMaV)	Brown <i>et al.</i> , (2012)
	Okra enation leaf curl virus (OELCuV)	
	Radish leaf curl virus	Kumar <i>et al.</i> (2012)
Bipartite	Okra yellow vein Delhivirus (BYVDV)	Venkataravanappa <i>et al.</i> (2012)
	Tomato leaf curl New Delhi virus	Venkataravanappa <i>et al.</i> (2008)

The YVMV disease D was first reported by Kulkarni (1924) from Bombay and later studied by Capoor and Verma (1950) and Verma (1952). This was first described as yellow vein banding, though the disease was characterized by clearing of veins, but there was no evidence that the veins remain green and banded by stripes of yellow tissue. Uppal *et al.* (1940) established the viral origin of the disease and coined the name yellow vein mosaic (YVM).

Symptoms and economic importance of disease

The virus produces typical vein yellowing and thickening of leaves forming a network of veins and veinlets in the infected leaves. Initially, the leaves exhibit only yellow colored veins but under the severe infection, the leaves become completely chlorotic and turn yellow. There is reduction of leaf chlorophyll and the infected plants give a stunted look and produce small-sized pale yellow fruits (Gupta and Paul, 2001). If plants are infected within 20 days after germination, their growth is retarded; few leaves and fruits are formed and loss may be about 94% (Sanwal *et al.* 2014). The extent of damage declines with delay in infection of the plants. Plants infected 50 and 65 days after germination suffer a loss of 84 and 49%, respectively (Sastry and Singh, 1974).

Incidence of YVMV in Indian context

The occurrence and the severity of YVMV disease D is location and seasons specific. In nNorth India, which include Karnal, Tarai region of Uttarakhand, Nadia district of West Bengal and Varanasi area of Uttar Pradesh, rainy season, in central and sSouth India (Guntur in Andhra Pradesh, Jalgaon in Maharashtra, Surat in Gujarat and Coimbatore in Tamil Nadu), the summer season aAnd in western Maharashtra, summer season is the more conducive for YVMdY than the rainy season (Prabu *et al.* 2007 and Deshmukh *et al.* 2011). A survey on begomoviruses associated with okra in India revealed that the occurrence of YVMdY incidence ranged from 23.0 to 67.67% in Karnataka, 45.89 to 56.78% in Andhra Pradesh, 23 to 75.64% in Tamil Nadu, 42.45 to 75.64% in Kerala, 23 to 85.64% in Maharashtra, 24.85 to 65.78% in Haryana, 35.76 to 57% in Uttar Pradesh, 45.45% in Delhi, 67.78% in Chandigarh and 45.89 to 66.78% in Rajasthan (Venkataravanappa 2008).

Environment impact on occurrence of YVMdY and vector in okra

During rainy season, the temperature and relative humidity might have been high enough to support disease development. Following this, in late rainy season, a fall in temperature might have led to a decline in vector population that could reflect into the reduced expression of disease Sanwal *et al.* (2016). In north India, the crop sown in month of June, the pods reaching to marketable stage in month of July-August were least susceptible to YVMDV (4.1 %) as compared to 92.3 % infection when the crop was sown in month of July and maturing in the month of August – September. The whitefly population dynamics was monitored throughout the seasons and it was observed that it was remarkably low during February to 1st fortnight of April and reached its peak in the month of August (Chattopadhyay *et al.* 2011). It was found that the disease incidence increased with the increase in lower temperature and whitefly population decreased with increase in the relative humidity (Ali *et al.* 2005). The bright sunshine hours revealed significantly positive association and minimum temperature revealed significantly negative correlation with YVMV disease incidence (Dhankhar *et al.* 2012).

Vector of YVMV

The YVMV is neither sap transmissible nor seed transmissible. It is mainly transmitted through most important sucking pest, white fly during feeding. Under experimental conditions, it has also been transmitted by grafting. Okra leaf hopper (*Empoasca devastans*) is the 2nd most important to transmit this disease. Rail weed (*Croton sparsiflora*), and goat weed (*Ageratum sp*) are the important wild hosts of this virus.

Genetics of YVMV Resistance

Arumugam and Muthukrishnan (1978) screened different cultivars of *A. esculentus* and concluded that there is no source of resistance among cultivars found against YVMV and ultimately a search for resistance should invariably be shifted to wild relatives (Table 2). Number of scientist had been worked on resistant breeding for YVMV but got very little success (Prabu *et al.*, 2007). Deshmukh *et al.* (2011) reported that the disease resistant depends upon the environment where the cultivar had been grown. The wild source *A. manihot ssp. manihot* follow the dominance gene action to YVMV and a single dominant gene control the resistance to YVMV was also reported by Jambhale and Nerkar (1981). While, it controlled by two recessive genes (Singh *et al.*, 1962), and also controlled by two dominant complementary genes (Sharma and Dhillon, 1983; Sharma and Sharma, 1984).

From the grafting test it was confirmed by the Ali and his colleague in 2000 that the tolerance developed in the genotype IPSA Okra 1 was not due to the escape, rather it was due to the genetic. Further he confirmed that in the variety IPSA Okra 1 the tolerance to YVMV was governed by the dominant gene. The genetics of resistance pattern studied by Pullaiah *et al* (1998) suggested that the resistance to YVMV was controlled by two complementary dominant genes in susceptible \times susceptible ($S \times S$) and susceptible \times resistant ($S \times R$) crosses but in resistant \times resistant ($R \times R$) crosses by two duplicate dominant genes. Sindhumole and Manju (2015) conducted an experiment to find out the gene action of resistance to **major diseases YVMV** **diseaseD** under Kerala condition. Duplicate gene action was observed for resistance to YVMV that indicates hindrance to improvement by simple selection.

Some of the bio- molecules such as Phenols and their related enzymes play an important role in imparting either a resistance or susceptible reaction in the host (Prabu and warade 2009). According to Bajaj (1981), the biochemical analysis revealed that the parent showed resistant to YVMV contains higher moisture, phenol, orthodihydroxy phenols and total chlorophyll content than susceptible cultivars and all the characters he studied showed over dominance gene action except for total chlorophyll. It was observed that the virus multiplication may be reduced due to the higher amounts of phenols and their oxidation products such as quinones, formed by increased peroxidase and polyphenol oxidase. Hossain *et al.* (1998) reported that the total sugar, reducing or non-reducing sugar and total chlorophyll were low and total phenol; carotene and ortho-hydroxy phenol contents were high in YVMV infected leaves than the healthy one. Kousalya (2005) also reported maximum peroxidase and polyphenol oxidase activity in resistant wild *A. caillei* while, minimum in susceptible *A. esculentus*. In the resistant wild *Abelmoschus* species and their inter-specific hybrids after infection with the **OYVMV**, showed lower phenolic compound while in the susceptible cultivars these contents become increased (Prabu and Warade 2009). He also observed that the total nitrogen content was lower in the resistant wild okra species and their inter-specific hybrid as compared to susceptible *A. esculentus* cultivars. It is, therefore, concluded that the initial higher total phenols and their subsequent decrease accompanied by an increase in peroxidase and polyphenol oxidase activity after infection in the resistant lines as compared to the susceptible okra cultivars confirms that the higher enzymatic activity is important firstly in the biosynthesis of orthodihydroxy phenols from monophenols and secondly in the oxidation of phenols to more toxic quinones. These phenols and their oxidative develop the resistance against

the YVMV either by inhibiting the virus activity or by reducing their rate of multiplication (Bhaktavatsalam *et al.* 1983).

Table- 2. Wild Source of resistance to YVMV

Wild source	Gene action	Reference
<i>A. manihot ssp. manihot</i>	Dominant genes	Sharma & Dhillon 1983
	Complimentary dominant genes	Sharma & Sharma 1984
	Recessive genes	Singh <i>et al.</i> 1962
<i>A. tuberculatus</i>		Nariani and Seth (1958)
<i>A. Callei</i>		Sergius and Esther (2014)

Crop management practices

As **w**White fly is the main agent responsible to transmit the viruses that leads to YVM**V diseaseD**. Hence, management of this disease turns around the control of this vector. Moreover different host plants also need to remove from the all corners of the field. The versatile host range facilitates easy population development and smooth carryover of the pest from one crop to another.

Several approaches have been attempted to control virus. Pest can be control by the application of chemicals. Gowdar *et al.* (2007) suggested agrochemicals like Acetamiprid, Imidacloprid and Trizophos, gave positive result towards controlling the YVMV. Two spray of Acetamiprid 20SP @40g a.i/ha was effective in reducing the incidence of YVMV, **whitefly population** subsequently increase the yield of okra. Alam *et al.* (2010) used different ecofriendly management agents like oil @0.5% mixed with 0.5% washing soap, Marigold as a trap crops and planted in between rows of okra and admire (Imidacloprid) @ 0.05% to check the disease. He finally concluded that most effective one was admire spray on okra followed by neem oil and mustard oil. Imidachloprid 17.8% SL applied twice and one seed treatment significantly reduce the pest population up to 90.2%. Ansar *et al.* (2014) suggested seed treatment with Imidacloprid and sowing of two rows of maize border with spraying of Imidacloprid + Neem oil spray until fruit formation showed least incidence (15.47%) of disease.

The biological product like Azadirachtin spray at an interval of 15 days reduces the white fly population up to the 79.2%. Plant growth promoting rhizobacteria (PGPR) has been promoted as an alternative approach for disease management which is eco-friendly and safe (Patil *et al.*

2011). *Rhizobacteria* controls the viruses through systemic **defence** mechanism by activating the genes encoding chitinase, beta-1,3 glucans, peroxidase, PALase, and other enzymes. It reduces the incidence of YVMV to the maximum extent (up to 86.6%) through induced systemic resistance by triggering defense molecules. Greater fruit yield of okra, and reduction in disease incidence and whitefly population were obtained with application of Crozophera oil at 1.0 ml/litre, followed by Palmrosa oil at 1.0 ml/litre (Biswas *et al.* 2008). Fajinmi and Fajinmi (2010) concluded the easiest method of reducing YVMV **disease** is planting of resistant varieties against this disease.

Breeding for YVMV resistant

In addition to chemicals, the development of resistant varieties are the alternative tools to control the vectors, however, the problem rise as the varieties which showed resistance against YVMV earlier becomes susceptible in next 2-3 years (Dhankar *et al.* 2005). This breakdown in resistance probably happens due to development of new strains of begomovirus (Venkataravanappa *et al.*, 2012). The breeding for germplasm collection and varietal improvement had been started under the supervision of late Dr. Harbhajan Singh at 1950. Consequently, Pusa Makhmali was developed from the collection from West Bengal in 1955 and released for cultivation. Later, Joshi and his colleague developed a variety Pusa Sawani from an inter-varietal cross between IC 1542 (symptomless carrier for YVMV from West Bengal) and Pusa Makhmali. After that by the introducing a line from Ghana (highly resistant to YVMV) by the NBPGR several varieties had been developed. These are G-2 and G-2-4 from NBPGR, Punjab Padmini, Punjab-7 (PAU), Parbhani Kranti (MAU), IIHR Sel-4, IIHR Sel-10, Sel-2, Varasha Uphar, Hisar Unnat (CCSHAU), Pusa A-4 (IARI), Kashi Vibhuti, Kashi Pragati, Kashi Sathdhari and Kashi Kranti (IIVR, Varanasi). Further, the decline in the production of okra in India was seems to be due to several factors, such as loss of resistance to YVM in ruling varieties (Borah *et al.* 1992), emergence of different viruses or strains (Venkataravanappa *et al.* 2012), emergence of new biotypes of whitefly vectors (Sanwal *et al.* 2014) and development moderate to strong resistance to commonly used insecticides by vectors (Rashida *et al.* 2005). Two prominent varieties of okra namely Hisar Unnat and Varsha Uphar identified and released at National Level in the year of 1992 and 1996, respectively had wide adaptation all over the country. But no further resistant for YVMV exist in Hisar Unnat and Varsha Uphar. Therefore, Dhankar (2012) focused efforts had been taken to improve Hisar Unnat in respect to its tolerance to YVMV using wild relatives A.

manihot ssp. *manihot*. Varsha Uphar was poorly compatible with *A. manihot* spp. *manihot*. He made a cross between the Hisar Unnat and *A. manihot* ssp. *manihot*. The F₁ were partial fertile found free from YVMV disease throughout the season but the fruit, which was intermediate for most of the fruit traits. The 30% of the obtained seed from BC₁ plants were viable. He further crossed the F₁ with tolerant cultivar of cultivated species like US7109 identified as a source of tolerant to YVMV with dark green fruit. Such cross was made to remove all the intermediate traits in F₁ and just for improving the fruit shape and color characters. The segregating generation studied for the various morphological and fruit traits, found stable and uniform and further isolate line 10, 15 and 25 (0-5% disease incidence). All the three lines were resistant to YVMV having dark green color pod with smooth surface. Resistance to YVMV is not stable in the cultivated species and frequent breakdown of resistance have been observed in developed varieties (Singh *et al.* 2007). Inter-specific hybridization followed by backcrossing and selection in the segregating generations is an effective method for developing YVMV resistant varieties (Reddy, 2015).

The crossability between different *Abelmoschus* species has been given in the table - 3. Keeping view of nature of crossability among the different species of *Abelmoschus*, Reddy (2015) performed an experiment to improvement of an inbred line RNOYR-19 for YVMV, which was found superior for all traits, but susceptible to YVMV. He made a cross between RNOYR-19 as a female parent and *A. manihot* subsp. *tetraphyllus* as male parent, resulting in the normal fruit set and seed set. It was found that the crossability were 90% between two species. Complete sterility was observed in the F₁ hybrid plants of *A. esculentus* and *A. manihot* subsp. *tetraphyllus*. A fertility restoration of F₁ hybrid plants was achieved through colchipoideity. Upon colchicine treatments to the inter-specific F₁ seedlings at two leaf stage, there was no mortality (0%) in the inter-specific F₁ plants with normal fruit set (100%) and partial seed set (53.12%). Further, single cycle of selfing of raw colchipoideids (C₁) resulted into production of fully fertile stabilized colchipoideids. Crossed seeds of inter-specific crosses between *A. esculentus* and *A. moschatus* were shrivelled and non-viable due to post zygotic-incompatibility to operate between these species (Rajamony *et al.*, 2006).

Table -3 Crossability and fruit setting % between inter-specific crosses (Joseph *et al.* 2013).

Female Parent	Male Parent	Fruit setting	Reciprocal Fruit Setting
---------------	-------------	---------------	--------------------------

		(%)	(%)
<i>A. esculentus</i>	<i>A. tetraphyllus</i> var. <i>tetraphyllus</i>	92.31	19.23
<i>A. esculentus</i>	<i>A. moschatus</i> subsp. <i>moschatus</i>	57.14	11.54
<i>A. esculentus</i>	<i>A. caillei</i>	38.89	25.00
<i>A. esculentus</i>	<i>A. ficulneus</i>	35.48	0.00
<i>A. esculentus</i>	<i>A. tetraphyllus</i> var. <i>pungens</i>	100.00	0.00
<i>A. esculentus</i>	<i>A. tuberculatus</i>	30.00	85.71

.

Yellow vein mosaic disease of okra is spreading rapidly throughout India, affecting plants at all growth stages resulting in yielding unmarketable fruits. A rich biodiversity among the viruses infecting Indian okra is of major concern, since this situation undoubtedly increases incidences of mixed infections and increases the possibility of yet more novel recombinant viruses arising within this species. To control this dreaded situation, it need to utilize more advance biotechnological tools like *Gene silencing* which can occur either repression of transcription, termed Transcriptional Gene Silencing (TGS) or through mRNA degradation, termed post transcriptional gene silencing. RNAi is a favorable tool to knock down or silence a gene expression because it can target multiple gene family members by same RNAi inducing transgene. Attempts are being made for incorporation of specific genes such as CP (Coat Protein) gene and antisense RNA gene for elevated viral resistance in okra (Sanwal *et al.* 2016).

Conclusion

Okra yellow mosaic disease is one of the most devastating disease causes by the begomovirus in India. The weather condition in India is more congenial to the vector whitefly survival throughout of the region i.e. the warm and humid condition. Another issue is that whitefly is polyphagus in nature resultantly survive on other crop. Further, it cannot be control by only insecticide.

Development of host resistance to viruses is the one of the important strategy against the okra yellow vein mosaic disease which is most economical and environment- friendly process for reducing the yield potential of okra. Again the study of existing variability for YVMV in all the accession of okra is needed. At the same time, effort should be taken toward breeding for

resistance through gene pyramiding by incorporating different gene to the susceptible line. Moreover, different resistant source are available for YVMV. But due to sterility problem, it is not easy to transfer the resistant gene directly. Restoration of fertility through colchicine treatment in the crosses between resistant wild and susceptible species could be a suitable technique.

Further there is very limited work has been done regarding molecular breeding of okra due to very few availability of molecular marker or absent of all genomic information of okra. It causes problem to find the exact resistant gene in the plant. So identification and validation of molecular marker for screening of resistance is required.

References

- Alam MM, Hoque MZ, Khalequzzaman KM, Humayun MR, Akter R. Eco-friendly management agents of okra yellow vein clearing mosaic virus of okra (*Abelmoschus esculentus* L. Moench). Bangladesh Journal of Agriculture. 2010; 35(1):11-16.
- Ali S, Khan MA, Habib A, Rasheed S, Iftikhar Y. Correlation of environmental conditions with okra yellow vein mosaic virus and *Bemisia tabaci* population density. International Journal of Agriculture and Biology. 2005; 7(1):142-144.
- Anonymous. Indian Horticulture Database. National Horticulture Board, Ministry of Agriculture, Government of India, Gurgaon. 2015
- Ansar M, Saha T, Sarkhel S, Bhagat AP. Epidemiology of okra yellow vein mosaic disease and its interaction with insecticide modules. Trends in Biosciences 2014; 7(24): 4157-4160.
- Bajaj KL. Biochemical basis of resistance to yellow vein mosaic virus in okra (*Abelmoschus esculentus*). Genetica Agraria 1981;121-130.
- Bhaktavatsalam G, Nene YL, Beniwal SPS. Influence of certain physio-chemical factors on the infectivity and stability of urd bean leaf crinkle virus. Indian Phytopathology. 1983; 36: 489-493.
- Biswas, NK, Nath PS, Srikanta D, De BK. Management of yellow vein mosaic virus disease of okra (*Abelmoschus esculentus*L. Moench) through different plant oils. Research on crops. 2008; 9(2):345-347.
- Borah GC, Saikia AK, Shadeque A. Screening of okra genotypes for resistance to yellow vein mosaic virus disease. Indian Journal of Virology. 1992;8: 55-57.

272 Brown JK, Fauquet CM, Briddon RW, Zerbini M, Moriones E, Navas-Castillo J. Geminiviridae.
 273 In: King AMQ, Adams MJ, Carstens EB, Lefkowitz EJ, eds. Virus Taxonomy: Ninth
 274 Report of the International Committee on Taxonomy of Viruses. London, UK: Associated
 275 Press, 2012; 351–73.

276 Capoor SP, Varma PM. Yellow vein mosaic of *Hibiscus esculentus* L. Indian Journal of
 277 Agricultural Sciences 1950; 20: 2 17-20.

278 Chattopadhyay A, Dutta S, Shatterjee S. Seed yield and quality of okra as influenced by sowing
 279 dates. African Journal of Biotechnology 2011; 28: 5 461–7.

280 Datta PC, Naug A. A few strains of *Abelmoschus esculentus* (L.) Moench, their karyological study
 281 in relation to phylogeny and organ development. Beitr Biol Pflanzen. 1968; 45:113–126.

282 Deshmukh ND, Jadhav BP, Halakude IS, Rajput JC. Identification of new resistant sources for
 283 yellow vein mosaic virus disease of okra (*Abelmoschus esculentus* L.) Vegetable Science
 284 2011; 38(1): 79–81.

285 Dhankar SK. Genetic improvement of adopted okra cultivars for YVMV disease resistance
 286 involving wild relatives in genus *Abelmoschus*. Seaveg 2012 Regional Symposium, 24-26
 287 January 2012.

288 Dhankar SK, Dhankar BS, Yadava RK. Inheritance of resistance to yellow vein mosaic virus in
 289 an inter-specific cross of okra (*Abelmoschus esculentus*). Indian Journal
 290 of Agriculture Science. 2005; 75:87-89.

291 Dhankhar SK, Chohan PK, Singh SS. Influence of weather parameters on incidence of yellow
 292 vein mosaic virus in okra. Journal of Agrometeorology 2012; 14(1): 57-59.

293 Fajinmi AA, Fajinmi OB. Epidemiology of okra mosaic virus on okra under tropical conditions.
 294 International Journal of Vegetable Science. 2010; 16 (3): 287-296.
 295 <http://dx.doi.org/10.1080/19315261003796974>

296 Fajinmi AA, Fajinmi OB. Incidence of okra mosaic virus at different growth stages of okra plants
 297 (*Abelmoschus esculentus* L. Moench) under tropical condition. Journal of General and
 298 Molecular Virology. 2010; 2(1): 028-031.

299 Fauquet CM, Mayo MA the 7th ICTV report. Arch. Virol., 2001; 146: 189-194.

300 Gupta VK, Paul YS. Diseases of Vegetable Crops. Kalyani Publishers, Ludhiana, Punjab, India
 301 2001.

302 Hossain MD, Meah MB, Rahman GMM. Reaction of okra variety to yellow vein mosaic virus
 303 and biochemical changes in its infected leaf constituent. Bangladesh Journal of Plant
 304 pathology 1998; 14: 29–32.

305 Joseph JK, Nissar VAM, Latham., Sutar S, Patil P, Malik SK, Negi KS, Keisham M, Rao SR
 306 Bhat KV. Genetic resources and cross ability relationship among various species of
 307 *Abelmoschus*. Current Horticulture 2013; 1(1): 35–46.

308 Joshi AB, Singh HB, Joshi BS. Is yellow vein mosaic disease a nuisance in your okra, then why
 309 not grow 'PusaSawani'. Indian Farming. 1960; 10, 6-7.

310 Kousalya V. Introgression of yellow vein mosaic resistance from *Abelmoschus caillei* (A. cher.)
 311 Stevens into *Abelmoschus esculentus* (L.) Moench. M.Sc. (Agri.) Thesis, Kerala Agricultural
 312 University, Thrissur. 2005

313 Kulkarni GS Mosaic and other related diseases of crops in the Bombay Presidency. Poona Agric.
 314 College Mag. 1924 ; 6 12.

315 Kumar J, Kumar A, Singh S P, Roy J K and Lalit A.. First report of Radish leaf curl virus
 316 infecting okra in India. New Disease Reporter 2012; 7: 13–4.

317 Jambhale ND, Nerkar YS. inheritance of resistance to Okra yellow vein mosaic disease in
 318 interspecific crosses of *Abelmoschus*. Theor. Appl. Genetic. 1981; 60:313-316.

319 Nariani TK, Seth ML. Reaction of *Abelmoschus* and *Hibiscus* species to yellow vein mosaic
 320 virus. Indian Phytopath 1958; 11: 137–140.

321 Nazeer, A. Thakur, MR. Bajaj, KL, Cheema, SS.. Biochemical basis of resistance to yellow vein
 322 mosaic virus in okra. Plant Disease Research 1994; 9(1):20-25.

323 Jambhulkar PP, Singh V, Babu RS, Yadav RK. Insecticides and Bioproducts against Whitefly
 324 Population and Incidence of Yellow vein mosaic virus in Okra Indian Journal of Plant
 325 Protection. 2013;41(3): 253-256.

326 Sindhumole P, Manju P. Genetic architecture of resistance to yellow vein mosaic and leaf spot
 327 diseases in okra (*Abelmoschus esculentus* (L.) Moench). Electronic Journal of Plant
 328 Breeding, 2015; 6(1): 157-160

329 Patil. MN, Jagadeesh KS, Krishnaraj PU, Patil MS, Vastrad AS. Plant growth promoting
 330 rhizobacteria (PGPR) mediated protection in bhindi against yellow vein mosaic virus.
 331 Indian journal of plant protection 2011; 39(1):48-53.

332 Pullaiah N, Reddy TB, Moses GJ, Reddy BM, Reddy DR. Inheritance of resistance to yellow vein
 333 mosaic virus in okra (*Abelmoschus esculentus* (L.) Moench). *Indian Journal of Genetics and*
 334 *Plant Breeding* 1998; 58(3): 349-52.

335 Prabu T, Warde SD, biochemical basis of resistance to yellow vein mosaic virus in okra
 336 *Vegetable Science*. 2009; 36(3 Suppl.): 283-287

337 Prabu T, Warde SD, Ghante PH. Resistant to okra yellow vein mosaic virus in Maharashtra.
 338 *Vegetable Science* 2007; 34 (2): 119-122.

339 Rajamony L, Chandran M, Rajmohan, K. In vitro embryo rescue of interspecific crosses for
 340 transferring virus resistance in okra (*Abelmoschus esculentus* (L.) Moench). *Acta Hort*. 2006;
 341 725:235-240.

342 Rashida P, Sultan MK, Khan MA, Noor-Ul-Islam. Screening of cotton germplasm against cotton
 343 leaf curl Begomovirus (CLCuV). *J Agri Soc Sci* 2005; 3:35–238.

344 Reddy MT. Crossability behaviour and fertility restoration through colchicoidy in interspecific
 345 hybrids of *Abelmoschus esculentus* × *Abelmoschus manihot* subsp. *tetraphyllus*.
 346 *International journal of plant science and ecology*. 2015; 1(4):172-181.

347 Gowdar SB, Ramesh Babu HN, Aswathanarayana Reddy N. Efficacy of insecticides on Okra
 348 Yellow Vein Mosaic Virus and Whitefly Vector, *Bemisia tabaci* (Guenn.). *Ann. Pl. Protec.*
 349 *Sci*. 2007; 15 (1):116-119.

350 Safdar Ali, Khan MA, Habib A, Rasheed S, Iftikhar Y. Management of Yellow vein Mosaic
 351 Disease of Okra Through Pesticide/Bio-pesticide and Suitable Cultivars. *International*
 352 *journal of agriculture & biology*. 2005; 7(1):145-147.

353 Sanwal SK, Singh M, Singh B, Nai PS. Resistance to Yellow Vein Mosaic Virus and Okra
 354 Enation Leaf Curl Virus: challenges and future strategies. *Current science*. 2014;
 355 106(11):1470-1471.

356 Sanwal SK, Venkataravanappa V, Singh A. Resistance to okra yellow mosaic disease: A review.
 357 *Indian Journal of Agricultural Science*. 2016; 6(7):835-43.

358 Sastry KS, Singh SJ. Effect of yellow vein mosaic virus infection on growth and yield of okra
 359 crop. *Indian Phytopath* 1974; 27: 295-297.

360 Sergius UO, Esther DU. Screening of *Abelmoschus esculentus* and *Abelmoschus callei* cultivars
 361 for resistance against okra leaf curl and okra mosaic viral diseases, under field conditions in
 362 South Eastern Nigeria. *Afr. J. Biotechnol*. 2014; 13(48): 4419-4429.

- Sharma BR, Dhillon, TS. Genetics of resistance to yellowvein mosaic virus in interspecific crosses of okra. *Genetica Agraria*, 1983; 37(3/4): 267–275.
- Shetty AA, Singh JP, Singh D. Resistance to yellow vein mosaic virus in okra: a review. *Biological Agriculture & Horticulture*. 2013; 29 (3):159–164.
- Singh B, Rai M, Kalloo G, Satpathy S, Pandey KK. Wild taxa of okra (*Abelmoschus* spp.):reservoir of genes for resistance to biotic stresses. *Acta Horti*. 2007; 752:323–328.
- Singh HB, BS Joshi, PP Khanna, Gupta PS. Breeding for field resistance to yellow vein mosaic in bhindi. *Indian Journal of Genetics* 1962; 22(2): 137–144.
- Srinivasan, K. Surendiran G and Maathivanan N. Pathological and molecular biological investigations on sunflower necrosis virus (SNV) and ISR mediated biological control of SNV by PGPR strains. Asian conference on emerging trends in plant-microbe interaction. 2005; 8-10 december, Chennai, India.
- Thompson CH, Kelley CW. Vegetable crops. McGraw Hill Book Co., Inc., 1957; USA.
- Uppal BN, Varma PM, Capoor SP. Yellow vein mosaic of okra. *Current Science* 1940; 9: 227–228.
- Varma PM. Studies on the relationship of bhindi yellow vein mosaic virus and its vector, the whitefly (*Bemisia tabaci*). *Indian Journal of Agriculture Science*, 1952; **22**: 75-91.
- Venkataravanappa V. Molecular characterization of okra yellow vein mosaic virus. Ph D. thesis, GKVK, Bengalure. 2008.
- Venkataravanappa V, Reddy LCN, Reddy MK. Begomovirus characterization, and development of phenotypic and DNA-based diagnostics for screening of okra genotype resistance against Okra yellow vein mosaic virus. *Biotech* 2013; 3:461–470.
- Venkataravanappa, V, Reddy LCN, Jalali S, Reddy MK. Molecular characterization of distinct bipartite begomovirus infecting okra (*Abelmoschus esculentus* L.) in India. *Virus Genes*. 2012; DOI 10.1007/s11262-012-0732-y
- Venkataravanappa V, Reddy LCN, Jalali S, Reddy MK. Molecular characterization of a new species of begomovirus associated with yellow vein mosaic of okra (Okra) in Bhubhaneswar, India. *Eur J Plant Pathol* 2013; DOI 10.1007/s10658-013-0209-4.