Status of begomovirus on soybean crop and virus management strategies.

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Abstract

Soybean is a very important crop from the economic point of view of the farmers, but it has been seen that due to begomovirus (Family *Geminiviridae*) there is lots of damage to soybean cultivation. Soybean is widely cultivated throughout the country in which the total production of soybean in 2020 was 353million tons, with Brazil accounting for 66% of the production in the United State, Maharashtra, and Madhya Pradesh alone account for 89% of total soybean production in India, followed by Rajasthan, Andhra Pradesh, Karnataka, Chhattisgarh, and Gujarat with 11% production in these states. Several strategies have been adopted to protect soybean cultivars from begomovirus, including conventional and non-conventional management strategies for virus containment and are described in this article.

Keywords: Begomovirus, Soybean, Soybean mosaic disease, Management strategies.

Introduction

Soybean is a vital and nutritious crop [1]. Soybean is classified as a member of the order Fabales, the family Fabaceae, the subfamily Faboidae, and the genus Glycine. Glycine is divided into two subgenera: glycine, which contains 16 perennial species, and Soja Moench F.J. Herm, which contains two annual species, Glycine soja Siebold and Zucc (2n = 40) and Glycine max (L.) Merrill (2n = 40) [2]. Because of its numerous applications, this crop has been dubbed the "Golden Bean" or "Miracle Crop" of the twentieth century [3]. Apart from high-quality protein and oil, soybean contains a variety of therapeutic components such as lactose- free fatty acids, antioxidants such as vitamins C, K, and D, and folic acid, vitamins of the B complex group such asnicotinic acid (23 g/g), pantothenic acid, and folic acid, thiamine (12 g/g), pyridoxine (8 g/g), riboflavin (3.5 g/g), andbiotin (0.7 g/g), as well as isoflavones such as genistein and daidzein [4]. In 2020, global soybean production was over 353 million tonnes, with Brazil and the United States accounting for 66% of the total (**Figure 1**) [87]. Production has increased dramatically worldwide since the 1960s, but particularly in South America since the 1980s, when a cultivar that grew well in low latitudes was developed [5]. The industry's rapid growth has been fueled primarily bylarge increases in global demand for meat products, particularly in developing countries such as China, whichaccounts for more than 60% of imports [6]. Madhya Pradesh and Maharashtra dominate soybean production in India, accounting for 89% of total output. The remaining 11% production is contributed by state-wise soybean cultivation statistics in lakh MT Rajasthan (10.558), Andhra Pradesh (2.840), Karnataka (2.470), Chhattisgarh (1.560), and Gujarat (0.930) [7].

The losses caused by soybean viruses are difficult to estimate due to interactions between soybean cultivars, time of infection, and virus strain. Nearly 67 viral soybean diseases have been identified worldwide, with at least 27 of them considered a threat to soybean cultivation [8]. Alfalfa mosaic virus (AMV; Alfamovirus), bean yellow mosaic virus (BYMV; Potyvirus), cowpea mild mottle virus (CPMMV; Carlavirus), groundnut bud necrosis virus (GBNV; Tospovirus), mungbean yellow mosaic India virus (MYMIV; Begomovirus), soybean mosaic virus (SMV; Potyvirus), tobacco ring spot virus (TRSV; Nepovirus), and tobacco streak virus (TSV; Ilarvirus) [9]. New viral diseases such as Soybean dwarf virus, Tobacco streak virus, and Soybean vein necrosis virus can reduce yield even further. Soybean vein necrosis virus (Bunyavirales: Tospoviridae) was first identified in Tennessee in 2008 [10], Tobacco streak virus [85], Cucumber mosaic virus [11,12], Tomato spotted wilt virus [11,13,14]. Soybean chlorotic spot virus [15], Nepovirus [16], Soybean yellow shoot virus [17], African cassava mosaic virus [18-20], Cotton leaf curl Kokhranvirus and Tomato leaf curl Karnataka virus [21,22], Mung beanyellow mosaic virus (MYMV) [15] Tomato leaf curl New Delhi virus [23] and papaya leaf crumple virus [24]. One of the legume crops, soybean, is a good host for begomoviruses and a whitefly vector because of which there is widespread crop loss. There are numerous begomovirus species that infect legumes, including soybean being cited (**Table 1**).

International status of begomovirus on soybean

A Begomovirus linked to Soybean Leaf Curling and Chlorosis in Sinaloa, Mexico, is related to Pepper goldenmosaic virus [25]. Tomato Leaf Curl New Delhi Virus, a bipartite begomovirus, infecting soybean for the first time

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Table 1. Begomovirus infecting soybean.

S.No.	Virus Group	Family	Genus	Species
1.	Single-stranded DNA	*Geminiviridae*	Begomovirus	*Abutilon mosaic virus* *African soybean dwarf virus* *Bean dwarf mosaic virus* *Bean golden mosaic virus* *Horse gram yellow mosaic virus* *Mung bean yellow mosaic virus* *Rhynchotia mosaic virus* *Sida mottle virus* *Soybean crinkle leaf virus* *Soybean chlorotic spot virus* *Tomato leaf curl New Delhi virus*
2.	Double-stranded DNA	*Caulimovidae*	Caulimovirus	*Soybean chlorotic mottle virus*

in Faisalabad, Pakistan [26]. In Sinaloa, Mexico, a novel strain of Rhynchosia golden mosaic virus was identified from soybeans and weeds [27]. Soybean Crinkle Leaf Virus Complete Nucleotide Sequence and Genome Organization, Soybean crinkle leaf virus (SCLV) causes soybean crop damage in various parts of Thailand [28]. The presence of African cassava mosaic virus in a mosaic disease of soybean in Nigeria is the first report [29]. A soybean chlorotic spot virus is a new begomovirus that infects soybean in Brazil [15]. In Nigeria, two novel 'legumoviruses', Soybean chloroticblotch virus and Soybean mild mottle virus (genus Begomovirus), are naturally infected soybeans and causing symptoms such as trifoliate leaves and moderate mosaic [30]. In central Brazil, three separate begomoviruses relate to soybean, causing symptoms such as yellow and golden mosaic, chlorotic mottling, blistering, leaf deformation, and dwarfing [31]. Begomovirus genetic diversity and phylogeography in Pakistani legumes [32]. Alternate hosts of African cassava mosaic virus and East African cassava mosaic Cameroon virus in Nigeria [84]. All these viruses are shown in the **Table 2** and virus symptoms in **Figure 2**.

National status of begomovirus on soybean

Yellow mosaic virus (YMV) infestation has exacerbated the issues for soybean farming in India. Natural infection of viruses such as Cotton leaf curl Kokhran virus, Tomato leaf curl Karnataka virus, and Papaya leaf crumple virus (Genus: Begomovirus) [15-23] on soybean has been reported. Soybean plants with chlorosis, mosaic mottling, and necrosis of the leaves, petiole, stem, and the pods were gathered from the Maharashtra areas of Jalna, Beed, and Osmanabad. Mungbean Yellow Mosaic India Virus-resistant soybean cultivars promote viral RNA degradation earlier than susceptible cultivars [33]. Molecular analysis of two soybean-infecting begomoviruses from India, as well as evidence for recombination among South-East Asian legume-infecting begomoviruses on Mungbean yellow mosaic virus and Soybean mosaic virus [34].Molecular evidence of a Meghalaya, India, mid-hills-based isolation of the mungbean yellow mosaic virus containing a recombinant DNA B component [38]. Ageratum enation virus full nucleotide sequence and an alphasatellite infecting a novel host Glycine max in Palampur India [86]. All these viruses are shown in the **Table 2** and virus symptoms **Figure 2**.

Management of Begomovirus

Plant virus diseases management

Plant virus diseases cause damage to plant growth, causing billions of dollars in damage to the crops of the world's farmers every year [35]. Plant viruses are summarized as sub microscopic units. Plant viruses are enveloped by nucleic acid proteins, which are said to be responsible for replicating inside a cell, and viruses cannot survive without a living cell, therefore it is considered as the link between the living. Plants are intracellular obligate parasites, which cannot survive without living cells/tissue. Plant viruses cannot be controlled by any chemical methods. Due to which farmers and gardeners are all worried. It is difficult to control plant virus by direct methods, that is why atypical methods are adopted [36]. The main factors driving the growth of the virusare:

- The monocrops density and genetic diversity of the plant, which makes it more susceptible to pathogens and organisms.
- Trade in the world of living plants and germplasm and which takes the virus host and vector to new areas.
- Viruses that rapidly grow in population, evolve, and adapt [37]. Conventional and nonconventional methods are used for the prevention of plant virus diseases [39].

Conventional Measures

Conventional measures are based on best practices, which can control virus diseases to a great extent. Virus diseases can be controlled to a great extent by using to know the virus, its diagnostic methods tissue culture is adopted, and for this virus removal materials such as routing, intercropping, avoidance is used [36,39].

Culture control and eliminat the weed host

For a long time, weeds are considered effective for spreading plant virus infection in the plant world and these weeds that grow throughout the year cause great damage to the crops, important in these weeds are Croton bonplandium, Acalypha Indica, Malvasrtumcoromandalianum, Eclipta alba, Ageratum conozoides, LaunaeaLaunaea procumbens, Jatropha gossypifolia, Cocciniagrandis, Nicotiana plumbaginifolia, Sorghum vulgare, Parthenium hysterophorus, Physalis.

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Table 3. - *National status of Begomovirus on soybean*

S No.	Virus Name	Abbreviation	Accession Number	Symptoms	Country/Region	Reference
1.	*Ageratum enation virus*	AEV	HE861940	Leaf curling, crumpling and yellowing	Palampur, India	[37]
2.	*Cotton leaf curl Kokhran virus*	CLCKV	DQ343283	Upward and downward leaf curling, vein thickening and leaf shortening	Lucknow, India	[22]
3.	*Mungbean yellow mosaic virus*	MYMIV	AJ421642	Yellow mosaic	Madurai,Tamil Naidu, India	[35]
4.	*Mungbean yellow mosaic India virus*	MYMIV	EU523045	Yellow mosaic	New Delhi, India	[34]
5.	*Mungbean yellow mosaic India virus*	MYMIV	KU950430	Yellow mosaic	Meghalaya, India	[36]
6.	*Mungbean yellow mosaic India virus*	MYMIV	AJ416349	Yellow mosaic	Jabalpur, Madhya Pradesh	[35]
7.	*Papaya leaf crumple virus*	PaLCrV	KR071789	yellow mosaic on leaves and leaf crumpling and distortion	Lalitpur	[24]
8.	*Soybean yellow mosaic virus*	SMV	AJ582267	Yellow Mosaic	Madurai India	[35]
9.	*Tomato leaf curl Karnataka virus*	ToLCKV	DQ343284	Severe yellowing, crumpling and distortion of leaves	Lucknow	[23]

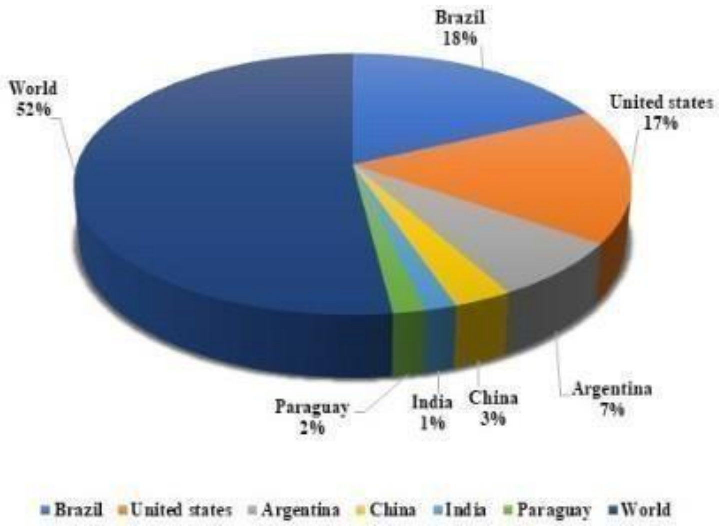

Figure 1: *Soybean production-2020 (millions of tons) - This pie chart has been the soybean production philosophy. In which 353 million of tons (55%) soybean production in the world or 11 million of tons (1%) production in India is telling the difference between the two in 2020.*

Table 2. *International status of begomovirus on soybean.*

S No.	Virus Name	Abbreviation	Accssetion Number	Symptoms	Country/ Region	Reference
1.	*African cassava mosaic virus*	ACMV	EU367500	Yellow mosaic and mottling	Nigeria	[29]
2.	*African cassava mosaic virus*	ACMV	EU685325	Mosaic and mottling	Nigeria	[33]
3.	*Bean golden mosaic virus*	BGMV	FJ665283	Yellow and golden mosaic, chlorotic mottling, blistering, leaf distortion and dwarfing	Santo Antonio de Goia´s, State of Goia´s, Brazill	[31]
4.	*Okra mottle virus*	OMoV	FJ686695	Yellow and golden mosaic, chlorotic mottling, blistering, leaf distortion and dwarfing	Brazil	[31]
5.	*Pepper golden mosaic virus*	PepGMV	AY905553	Yellowing, leaf curling, crumpling and sunted growth	Sinaloa, Mexico	[25]
6.	*Rhynchosia golden mosaic virus*	RhGMV	DQ347950	Yellowing, Curled and stunting leaves	Mexico	[27]
7.	*Soybean crinkle leaf virus*	SCLV	AB050781	Twisting or curling of leaves and development of veinal enations on the under-surface of the leaves	Thailand	[28]
8.	*Soybean chlorotic spot virus*	SoCSV	JX122965	Leaf distorsion, blistering Interveinal chlorosis, mosaic and golden mosaic	Brazil	[15]
9.	*Soybean chlorotic blotch virus*	SbCBV	NC_014141	Trifoliate leaves	Nigeria	[30]
10.	*Soybean chlorotic bloch virus*	SbCBV	GQ472985	Bright yellowing with blotchy	International Institute of Agriculture (IITA) farm in Ibadan, Oyo State, Nigeria	[30]
11.	*Soybean chlorotic bloch virus*	SbCBV	GQ472986	Foliar symptoms	Nigeria	[30]
12.	*Soybean mild mottle virus*	SMMV	NC_014140	Trifoliate leaves	Nigeria	[30]
13.	*Soybean mild mottle virus*		GQ472984	Mild mottle	Nigeria	[30]
14.	*Sida micrantha mosaic virus*	SiMMV	FJ686693	Yellow and golden mosaic,chlorotic mottling,blistering, leaf and dwarfing	Brazil	[31]
15.	*Tomato leaf curl New Delhi virus*	ToLCNDV	KX827599	leaf curling, vein thickening and leaf yellowing	Faisalabad, Pakistan	[26]
16.	*Tomato leaf curl Pakistan betasatellite*	ToLCPKV	AM922485	Typical yellow mosaic	Pakistan	[32]

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Figure 2: *Soybean Plant varieties: (a.) JS20-29, (b.) JS 93-05, (c-e) JS95-60, (f.) JS 93-05, (g-i) JS20-34, showing yellow mosaic, typically yellow mosaic, golden yellow, Blistering,and blotchy symptoms.*

minima, Sida cordifolia, and Sonchus oleraceus, these weeds have the highest risk of spreading bagomovirus and are mostly found in different places of India [36,40]. According to, 13 species of weeds are found in India. And according to there are 18 weed species, due to which Begomovirus spreads in crops. For the control of weeds growing throughout the year, weeds can be controlled to a great extent by strategies likea greenhouse, plantation planning, plant-to-plant distance and white mulch, and the productivity of the crops can be increased [41,42].

Quarantine regulation

Quarantine is a very useful method for the control of the pathogen. Plant and seed health testing is called quarantine. The European and Mediterranean Plant Protection Organization for Plant Grow Practices has been created, which has created a certification scheme for disease-free herbaceous plants, with the main goal of ensuring that plant growing practices meet their health standards. This certification scheme protects both nursery workers selling vegetatively propagated plant material and those buying nursery products, so the certification scheme was established. It mainly involves selection of health planting material, virus testing, microbial propagation, and testing for genetic fidelity [36, 43, 44].

Development and breeding for resistance

One approach is to develop different varieties of plants resistant to vactor pests using techniques to control virus diseases [45,39].An important example is the following is the resistance to tomato - infection that is represented by begomovirus from Solanum pimpinellifolium, Solanum peruvianum, Solanum chilense, and Solanum habrochaites [46]. A partially dominant major resistance gene, Ty-1, was produced by introgression from S. chilense and mapped to the short arm of chromosome 6 [47]. A major resistance quantitative trait locus (QTL) derived from S. Pimpinellifolium (Hirsute-INRA) was mapped to a different position on chromosome 6 (TG153-CT83) [48]. The mapped a dominant resistance gene, Ty-2, in S. Habrochaites-derived line H24, to the short arm of chromosome 11. A partially dominant major gene, Ty-3, derived from S. chilense(LA2779 and LA1932), was mapped to chromosome 6 [46, 49]. The Ty-3 introgression derived from LA2779 was found to be longer and linked to Ty-1. However, studies on fine mapping and characterization demonstrated that Ty-1 and Ty-3 are allelic and code for an RNA-dependent RNA polymerase [50]. An additional gene, Ty-4, was mapped tothe long arm of chromosome 3. While Ty-3 has a major effectthat accounts for 60% of the variation in symptom severity, Ty-4 accounts for only 16% of the variation [51]. A recessive resistance gene (Ty-5) has been identified on chromosome 4 in the lines derived from cultivar Ty king [52], which issuspected to be like the Ty-5 locus that accounts for morethan 40% of the variation [53]. Most of these resistance sources are known to support virus replication. However, the level of virus accumulation is lower than the levels in susceptible cultivars. It is well established that the virus level in tomato lines carrying Ty-1/Ty-3 is ,10% of the level found in susceptible cultivars [50]. Similarly, a low level of virus accumulation and a positive correlation between virus level and disease severity were found in Ty-2carrying lines [54].

Non - Conventional Measures

Some methods of reducing plant viruses have been described previously. Begomovirus has some drawbacks of its own.

The natural resistance to many viruses remains to be known. By raising resistant plants through genetic engineering, viral diseases can be saved or reduced to a great extent. The Steady introduction of genes of interest to plants from different organisms to control viruses is one of the most important developments in the lack of progress in agriculture. One is technology, which includes the use of agricultural chemicals to control pests and modern plant breeding, hybrid seed production and agricultural mechanization [55]. The Agrobacterium tumefaciens vector, the first transgenic engineering plant was produced from foreign genes, which was the first in the control of viruses. It was a great achievement. Genetic engineering produced the first virus resistance in the tobacco plant. The resulting transgenic gene from the plant's coat protein gene of the Tobacco mosaic viruswas inserted into the plant. Both stalks about the presence of foreign lines [56]. The first breakthrough was engineering herbicide resistance and resistance using the coat with the Bacillus thuringiensis toxin gene [57].

Pathogen derived resistance

Together in 1986, Powell - Abel and his co-workers used a genetic engineering method to protect plants from viral diseases that catalyse genes in plants to generate resistant transgenic plants [58], in which 30 different groups of different viruses are used, for which different genes have been used and engineering resistance has been achieved[59-67]. This method is very important for genetic engineering. And proved to be very helpful in controlling virus diseases in crops inducing resistance of pathogens by mutation called pathogen-derived resistance (PDR) with genes derived from the pathogen's genome which was first described by [39,68]. And a generalized concept expanded in 1985 by Sanford and Johnston is the binding of cross production with PDR by which a symptomless stain of the virus can cross plants [69]. Altered viral deriving genes are used to disrupt steps. Viral life cycles such as uncoating, replication, cell to cell or long distance or vector mediated transmission are where the genes of the virus are acquired or used [70]. There is coat putty, movement protein replicase (Rep) gene, antisense RNA, satellite RNA and defective interfering genes. CP is the most used transgene.

The coat protein works during the life span of the virus. It forms a shell, in which it strengthens its grip with the DNA of the virus, and protects it. In plant RNA represents and intermediate in a self-binding, nuclear targeting, or systematic movement [71]. It is extremely important for coat protein to be transmitted by insect vectors. In transgenic plants, the virus is caused by the expression of coat protein genes [72].

The protein intermediate is affected by the resistance coat protein gene in which a copy of a trans gene is inserted through which the trans gene passes, followed by a high level of transcription and translation of the protein, and is a medium level of resistance. It was considered like what happened earlier. The cross-protection coat protein hinders the uncoating of the virion and reduces or inhibits both cell-to-cell virus infection and spread, such as TMB, alpha mosaic virus to potato virus. All these viruses have transgenic coat proteins in transgenic plants, in terms of security. The coat protein messenger RNA and the coat protein were not resistant to infection [67,73-79].

The movement from cell to cell is the movement of plant virus to the outside plants, which is called movement protein mediate resistance. Externally, the movement protein in plants binds with the plasmodesmata and facilitates virus movement in the cell [80,81]. Previously used for engineering resistance to TMB in tobacco, a modified movement protein was prepared as a formof transgene resistance, which binds to the plasmodesmata side based on competition between the virus-encoded movement protein and the previously made inactive movement protein [82,83].

Conclusion

Viral pathogenicity on soybean is a serious economic threat that has a wide impact on growth and yield without being widely recognized. Even through, reports are accumulating about soybean infections with plant viruses, there is a lack of effective disease management of crops. The only way to succeed in plant disease management is having proper identification strategies to detect the viral pathogens early and accurately. Molecular assays for plant viruses are the detection method that has huge potential of accuracy. Hence, the development of new-molecular methods based on viral genomes facilitates the identification and diagnosis of plant viruses easily.

Conflict of interest

The author declares that there is no conflict of interest.

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