SYMPTOMATIC EVIDENCE OF BEGOMOVIRUS DISEASE IN VEGETABLE CROPS REPORTED FROM SELECTED DISTRICTS OF KHYBER PAKHTUNKHWA, PAKISTAN

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Abstract. Plant viruses cause major damage to several vegetables and agricultural crops. Begomoviruses (genus *Begomovirus*, family *Geminiviridae*) are plant-infecting DNA viruses that are transmitted by the whitefly vector *Bemisia tabaci.* They significantly reduce yields in several globally important vegetable crops. Due to lack of prior research, here in, we performed multiple field surveys in three districts of Khyber Pakhtunkhwa, Pakistan, keenly observed for the characteristic disease symptoms in crops, and evaluated the occurrence of the virus. Results showed that the overall disease incidence was 57.5% in District Dir Lower, 75% in District Malakand, and 78% in District Swat, respectively. Across all districts, pumpkin showed the highest overall disease incidence at 80%, followed by tomato (79%). Vein thickening and leaf curling were the most common symptoms associated with high incidence rates, especially in pumpkin, tomato, and chili. Pumpkin had the highest incidence in District Dir Lower (93%), while tomato exhibited high vein yellowing and incidences of 70% in Dir Lower and 89% in Swat. In conclusion, the preliminary study is an alarming signal for future food security in the area. The study will help to prevent the further spread of begomoviruses and serve as foundation for the future management of plant diseases.

Keywords: *plant virus, vegetable crops, disease severity, Khyber Pakhtunkhwa, Pakistan*

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Introduction

The genus *Begomovirus* includes many virus species that cause infections in a wide range of vegetable and ornamental plants, each approximately 2.7 kb in size (Azeem et al., 2022). To date, two types of Begomoviruses have been reported: bipartite and monopartite. Monopartite Begomoviruses contain a single genomic component similar to DNA-A of bipartite Begomoviruses. They are often associated with satellite molecules, known as betasatellites and alphasatellites. The betasatellite (~1.4 kb in size) is a pathogenicity determinant that encodes a single βC1 protein and depends on the helper virus for movement, replication, and encapsidation (Zubair et al., 2017). Alphasatellites (~1.4 kb in size) encodes their own replication associated (Rep) protein, replicate independently from their helper virus and are usually not required for their pathogenicity (Shakir et al., 2023). Begomovirus infect some of the key economically important plants such as vegetables, medicinal plants, decorative, and aromatic plants (Shahid and Al-Sadi, 2021). For instance, mostly infected plants include cotton (Azeem et al., 2022), cassava (Ferro et al., 2024), cucurbits (Charoenvilaisiri et al., 2020), chilly and tomato (Lavanya and Arun, 2021), pepper (Wahyono et al., 2023), bean plant (Martínez-Marrero et al., 2020), and okra (Ahmad, 2022), resulting in billions of US dollars economical loss. Begomoviruses originated in tropical and sub-tropical regions. Recently, these viruses have also been shifted to moderate regions of the world, with the possible cause being global warming and international human trade (Sandra and Mandal, 2024).

The begomoviruses are entirely transmitted from infected to healthy plants through an insect vector named *Bemicia tabaci* or commonly known as "whitefly" (Barman et al., 2022). The prevalence of begomoviruses is considered to be one of the main biotic constraints, limiting the yields of economically significant food and fiber crops. A recent study attempted to report the farmers' perception regarding begomoviruses epidemiology and practices as the pre-requisites for effective virus control. The study reported that lack of sufficient technical information regarding vector, their transmission and disease symptoms were the major hindrance to the efforts of farmers for effective virus control. In addition, the farmers lack sufficient knowledge for the control and management of begomovirus employing local methods (Bahar et al., 2023).

Begomoviruses can infect a variety of host crops, as evidenced by their appearance and mixed infections in the fields. Due to potential viral recombination, these mixed infections may also contribute to the evolution of novel viruses (Pandey et al., 2021). These viruses may cause severe disease in the field by breaking down resistance sources. For instance, three epidemics of cotton leaf curl disease in Pakistan were linked to different begomovirus/satellites complexes as reported by Iqbal et al. (2023). Furthermore, the tomato yellow leaf curl virus, a highly infamous begomovirus, has been observed to be quickly developing in several hosts and has been reported from Pakistan (Ahmed et al., 2021). Severe losses have been reported in Pakistan due to various begomovirus diseases such as Cotton leaf curl disease which has been previously reported for its multiple epidemics (Mahmood et al., 2024).

To the best of our knowledge, the incidence of begomovirus and their distribution has not yet been reported in Malakand Division of Khyber Pakhtunkhwa, Pakistan. The current study aimed to report the prevalence of begomovirus in locally grown vegetable crops in three selected Districts of Malakand Division, KP, Pakistan. The study will help to find the range of vegetable crops that are severely infected by begomoviruses, and would become the baseline for future screening of begomoviruses in the area.

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Materials and methods

Study nature and location

The current study was a field survey to document the distribution, incidence, and disease severity of begomovirus in local vegetative crops in three selected districts of Malakand Division, KP, Pakistan. Different ecological zones (Tehsils) of three selected Districts (*Fig. 1*) were visited during the field survey in the summer and the viral infected plants were observed. The fields were selected based on a systematic approach, with random visits conducted after every 2 km, to ensure an unbiased and representative sampling of the study area. All those vegetable crops which showed the typical disease symptoms of begomoviruses were observed and recorded the pictures of infected plants. Various parameters such as disease symptoms, disease severity, disease incidence and the presence of vector in the vegetables/area were recorded. The infected plants were photographed with a high-resolution digital camera.

The study was carried out in multiple areas from the regions joining the three districts of KP such as; (a) Tehsil Adenzai with villages; Ouch, Asbanr, Khanpur, Kotigram, Badwan, Tazagram, Chakdara, and Khadagzai of District Dir Lower, (b) Swat District regions; Chungi, zarakhela, Dedawar, Nagoha, Shamozai, Parrai, and Barikot, and (c) District Malakand such as Totakan, Dheri Julagram, Shahkot, Dargai, Thana, Alladand, and Batkhela.

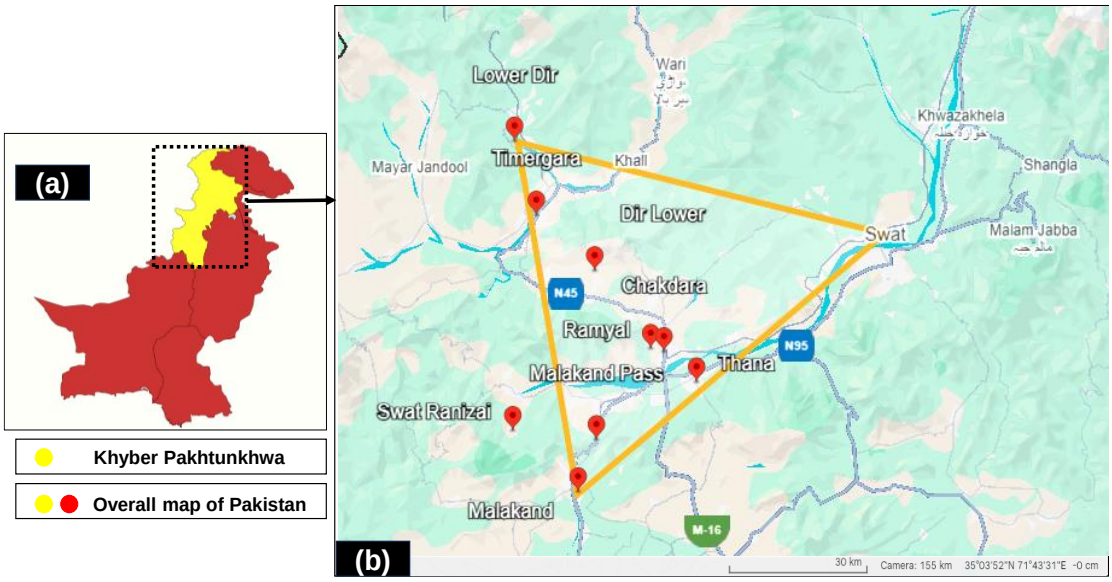

Figure 1. *Study area. (a) Shows the map of Pakistan and study province (Khyber Pakhtunkhwa), (b) Map showing the three selected districts (Dir Lower, Swat and Malakand). The map was retrieved from the Google Earth website (https://earth.google.com/)*

Disease confirmation

Various fields were visited, and plant leaves exhibiting characteristic symptoms indicative of begomovirus complex infection were observed. These symptoms included leaf vein thickening, vein yellowing, leaf folding (upward or downward), leaf curling, and vein yellowing (Nadeem et al., 2024). The presence of these symptoms confirmed the plants' positive infection with the virus.

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Percent disease incidence (PDI) and disease severity index (DSI) or percent infection (PI)

The begomovirus disease severity was scored on the scale of 0 to 5 for mild to severe disease incidence. The scale zero (0) represents no symptom displayed and classified as highly resistant plant group, the scale 1 represents 1-10% disease incidence and classified as resistant plant group, the 2 represents 11-20% disease incidence and classified as moderately resistant plant group., the 3 represents 21-30% disease incidence and classified as moderately susceptible plant group, the 4 represents 31-50% disease incidence and classified as susceptible plant group, and the 5 represents more than 50% diseased incidence and classified as highly susceptible plant group.

The percent disease incidence (PDI) and the disease severity index (DSI) or percent infection (PI) were calculated using *Equations 1* and *2*:

$$PDI = \frac{(No.of\ infected\ plants)}{(Total\ plants\ observed)} \times 100 \quad \text{(Eq. 1)}$$

$$PI\ or\ DSI = \frac{(Sum\ of\ individual\ plant\ rating)}{(Total\ plants\ observed)} \times 100 \quad \text{(Eq. 2)}$$

Statistical analysis

The statistical analysis was performed using descriptive statistics to calculate the disease incidence percentages using Microsoft Excel (2016). The data was organized and presented in Excel, where the disease incidence was analyzed, and correlations between plant types and disease symptoms were examined using simple descriptive correlation methods.

Results

Disease incidence (DI)

Incidence of begomovirus disease in vegetable crops were assessed in the Union Councils of District Dir Lower, District Malakand, and District Swat. The study was carried out on 418 samples**.** Different vegetable crops infected by begomovirus complex with 113, 147, and 158 virus infected plant leaves samples were collected from Dir Lower, Swat, and District Malakand, respectively.

District Dir Lower

Vegetable crops in District Dir Lower have been reported to test positive for begomovirus, exhibiting symptoms such as vein thickening, vein yellowing, leaf curling, and leaf yellowing, as detailed in *Table 1*. The disease incidence of begomoviruses in District Dir Lower, Tehsil Adenzai, was 57.5%, with specific incidence found in Tehsil Chakdara (69%), followed by Tehsil Tazagram (65%) and Tehsil Kotigram (61%), respectively (*Table 2*). The incidence of begomovirus disease was also calculated with aspect to vegetable plant source, with the highest incidence in pumpkin 93%, tomato (70%), lady finger (69%), and pea plant (67%), correspondingly. Moreover, the incidence rate for turnip (17%) and lettuce (17%) were recorded as the lowest (*Fig. 2*).

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Table 1. *Symptoms of begomovirus disease in vegetable crops in District Dir Lower*

Plant	Symptom(s) reported			
	Vein thickening	Vein yellowing	Leaf curling	Leaf yellowing
Pumpkin	Yes	No	Yes	No
Pea	Yes	No	Yes	No
Lady finger	Yes	No	Yes	No
Turnip	Yes	Yes	Yes	No
Lettuce	Yes	Yes	Yes	No
Brinjal	Yes	Yes	Yes	No
Cucumber	No	No	Yes	Yes
Luffa	Yes	No	Yes	No
Chili	No	Yes	Yes	No
Celery	No	No	Yes	Yes
Tomato	Yes	Yes	Yes	No

Table 2. *Incidence of infected plants with begomovirus complex in District Dir Lower*

S. No.	Common name of plants	% infected plants (No. of plants infected/No. of plants collected)							
		%	(District Lower Dir Tehsil Adenzai Union Councils)						
			Chakdara	Tazagram	Asbanr	Khanpur	Ouch	Kotigram	Badwan
1.	Pumpkin	93 (13/14)	5/5	3/3	2/2	1/1	0/1	1/1	1/1
2.	Pea	67 (06/09)	0/0	0/1	2/2	1/2	0/1	3/3	0/0
3.	Lady Finger	69 (09/13)	4/4	2/2	0/1	1/1	2/3	0/1	0/1
4.	Turnip	17 (01/06)	0/1	0/1	0/1	0/0	0/1	1/2	0/0
5.	Lettuce	17 (01/06)	0/0	0/0	0/1	0/1	0/2	1/2	0/0
6.	Brinjal	58 (07/12)	1/1	1/2	1/1	1/2	1/3	1/2	1/1
7.	Cucumber	25 (02/08)	0/1	1/3	0/0	0/1	0/1	1/2	0/0
8.	Luff a	44 (04/09)	0/1	1/3	1/2	1/1	0/0	1/1	0/1
9.	Chili	56 (09/16)	1/3	3/4	1/2	1/3	1/2	1/1	1/1
10.	Celery	33 (01/03)	0/0	0/0	0/0	0/1	0/0	1/2	0/0
11.	Tomato	70 (12/17)	2/3	6/7	2/3	1/1	1/1	0/1	0/1

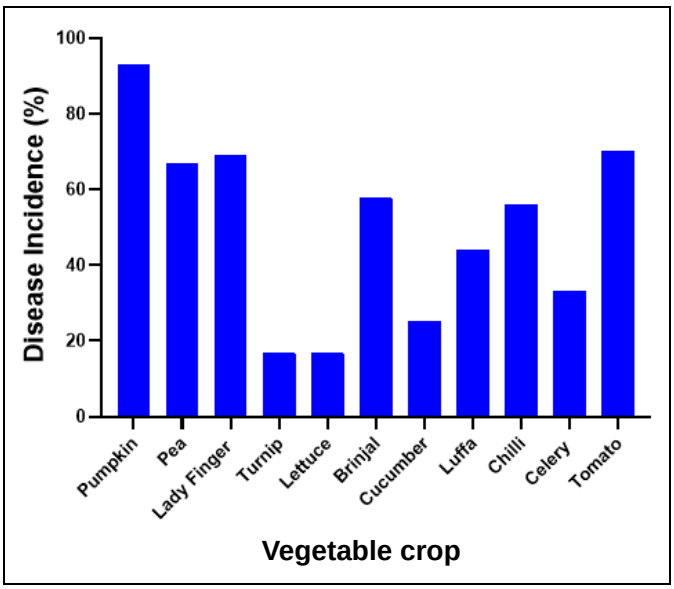

Figure 2. *Incidence of begomoviruses in vegetable crops of different Union Councils of Tehsil Adenzai District Dir Lower*

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District Malakand

The incidence of begomovirus disease in study region District Malakand, KP, was reported to be 75% in total wide-ranging area percentage, however maximum incidence was reported in Thana (92%), Alladand (74%), and Batkhela (73%). The lowest incidence was reported in Dheri Julagram (59%) and Totakan 58% (*Table 3*). The incidence of begomovirus disease was calculated within characteristic vegetable plants, Taro (89%), 88% in Bell Pepper, 86% in peppermint, 82% in Bottal Gourd, Black-nightshade 79%, chili 78%, 76% in mint, 73% spinach, 67% pumpkin, Bitter Gourds 62% and lady finger 50% (*Fig. 3*). Reported symptoms such as vein thickening, vein yellowing, leaf curling, and leaf yellowing for each vegetable crop in District Dir Lower is presented in *Table 4*.

Table 3. *Disease incidence of in infected vegetable plants in District Malakand*

S. No.	Common name of plants	% of No. of plants infected with begomoviruses (No. of plants infected/No. of plants collected)							
		Total	Malakand District (Union Councils and Tehsil Villages)						
			Batkhela	Alladand	Thana	Dargai	Shahkot	Dheri Julagram	Totakan
1.	Black-nightshade	79 (11/14)	4/5	2/3	2/2	1/1	1/1	0/1	1/1
2.	Chili	78 (18/23)	2/3	4/5	6/7	1/1	1/1	2/3	2/3
3.	Taro	89 (08/09)	3/4	3/3	1/1	0/0	0/0	1/1	0/0
4.	Spinach	73 (11/15)	3/4	2/4	4/4	0/0	0/0	1/2	1/1
5.	Mint	76 (13/17)	6/7	2/3	1/1	2/3	1/1	1/2	0/0
6.	Bottal Gourd	82 (09/11)	2/3	3/3	1/1	2/3	0/0	1/1	0/0
7.	Bell Pepper	88 (07/08)	3/4	2/2	1/1	0/0	0/0	1/1	0/0
8.	Peppermint	86 (06/07)	1/1	1/2	2/2	0/0	0/0	1/1	1/1
9.	Pumpkin	67 (14/21)	5/7	4/4	2/2	1/2	0/0	1/3	1/3
10.	Lady Finger	50 (06/12)	1/2	1/3	2/2	0/0	0/0	1/2	1/3
11.	Bitter Gourds	62 (13/21)	3/5	5/7	1/2	2/3	2/4	0/0	0/0

Table 4. *Symptoms of begomovirus disease in vegetable crops in District Malakand*

Plant	Symptom(s) reported			
	Vein thickening	Vein yellowing	Leaf curling	Leaf yellowing
Black-nightshade	Yes	No	Yes	No
Chilli	No	No	Yes	Yes
Taro	No	Yes	Yes	No
Spinach	Yes	No	Yes	No
Mint	No	Yes	Yes	No
Bottal Gourd	Yes	Yes	Yes	No
Bell Pepper	Yes	Yes	No	No
Peppermint	Yes	Yes	Yes	No
Pumpkin	Yes	No	Yes	No
Lady Finger	Yes	Yes	No	No
Bitter Gourds	Yes	Yes	No	No

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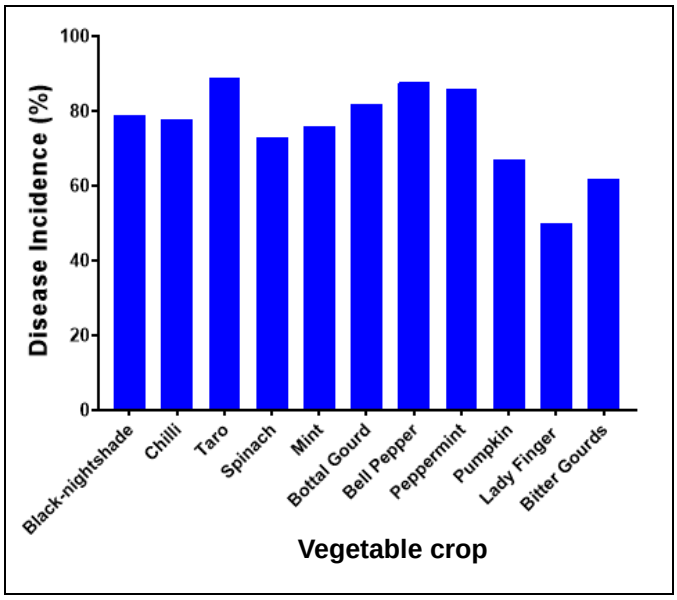

Figure 3. *Incidence of begomoviruses in vegetable crops in different areas of District Malakand, KP, Pakistan*

District Swat

The disease incidence of begomovirus in study area Swat was reported 78%, maximum incidence was determined in Chungi (89%), Shamozai (87%), Parrai (83%), Barikot (79%), and Dedawar (73%). Moreover, a lower prevalence was reported from Zarakhela (71%), and Nagoha (63%) (*Table 5*). The disease incidence of begomovirus in vegetable plants reported in Swat region turned to be higher in green pepper and eggplant (each with 92%), followed by Tomato (89%), pumpkin (79%), and bell pepper (76%) (*Fig. 4*). The major reported symptoms were vein thickening, and leaf curling (*Table 6*).

Table 5. *Disease incidence in infected plants in District Swat*

S. No.	Common name of plants	% of No. of plants infected with begomovirus (Infected/Total plants collected)							
		Total	(District Swat Tehsil and Union Councils)						
			Barikot	Parrai	Shamozai	Nagoha	Dedawar	Zarakhela	Chungi
1.	Egg plant	92 (23/25)	7/8	4/5	3/3	3/3	2/2	3/3	1/1
2.	Green pepper	92 (12/13)	1/1	1/1	3/3	2/2	1/1	3/3	1/2
3.	Tomato	89 (16/18)	4/4	3/4	1/2	1/1	3/3	2/2	2/2
4.	Spinach	50 (02/04)	1/1	0/1	1/1	0/0	0/1	0/0	0/0
5.	Mung bean	75 (03/04)	2/3	0/0	0/0	0/0	0/0	1/1	0/0
6.	Bell pepper	76 (16/21)	2/3	3/4	5/6	3/5	0/0	2/2	1/1
7.	Radish	43 (03/07)	2/3	0/0	0/0	0/1	0/1	1/2	0/0
8.	Pumpkin	79 (11/14)	4/6	3/3	2/2	1/1	0/0	1/1	0/1
9.	Okra	69 (11/16)	3/3	3/4	2/2	2/3	1/2	0/1	0/1
10.	Taro	67 (04/06)	1/2	2/1	1/1	0/1	0/0	0/1	0/0
11.	Black-nightshade	74 (14/19)	3/4	6/7	2/3	1/2	1/1	0/1	1/1

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Table 6. *Symptoms of begomovirus disease in vegetable crops in District Swat*

Plant	Symptom(s) reported			
	Vein thickening	Vein yellowing	leaf curling	Leaf yellowing
Egg plant	Yes	Yes	Yes	No
Green pepper	Yes	No	Yes	No
Tomato	Yes	No	Yes	No
Spinach	Yes	No	Yes	No
Mung bean	Yes	No	Yes	No
Bell pepper	Yes	Yes	No	No
Radish	No	Yes	Yes	No
Pumpkin	No	Yes	Yes	No
Okra	Yes	Yes	No	No
Taro	No	Yes	Yes	No
Black-nightshade	Yes	No	Yes	No

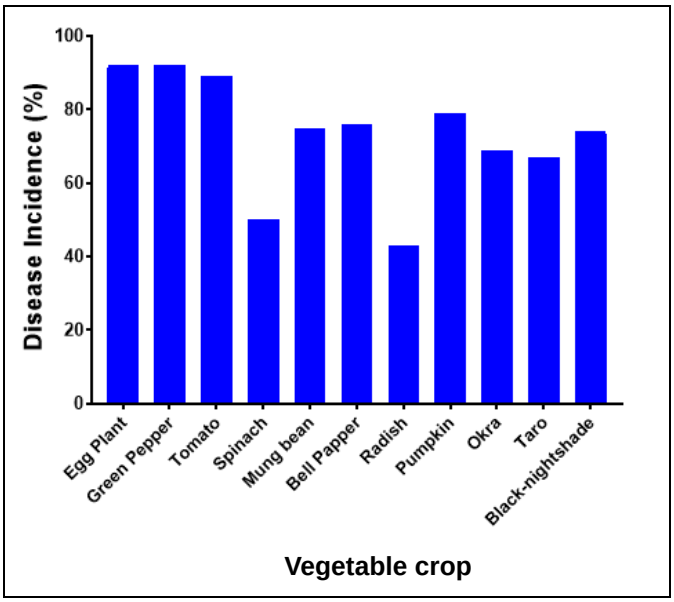

Figure 4. *Incidence of begomoviruses in vegetable crops of different regions of Swat, KP, Pakistan*

Correlation analysis

Plant type and disease incidence

Correlation analysis showed that pumpkin has the highest overall incidence (80%), followed by tomato (79%) and lady finger (65%), as shown in *Table 7*. Furthermore, pumpkin had a significant disease incidence in District Dir Lower (93%), eggplant and green pepper in Swat (92% each), while taro in District Malakand (89%), respectively. Lowest disease incidence was reported for turnip (17%), lettuce (17%), and cucumber (25%), all in District Dir Lower.

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Table 7. *Plant type and disease overall incidence in the study location*

S. No	Plant name	Incidence (%)			Overall incidence (%)
		Dir Lower	Malakand	Swat	
1	Pumpkin	93	67	79	80
2	Pea	67	-	-	67
3	Lady finger	69	50	76	65
4	Turnip	17	-	-	17
5	Lettuce	17	-	-	17
6	Brinjal	58	-	-	58
7	Cucumber	25	-	-	25
8	Luffa	44	-	-	44
9	Chili	56	78	76	70
10	Celery	33	-	-	33
11	Tomato	70	-	89	79
12	Black-nightshade	-	79	74	77
13	Eggplant	-	-	92	92
14	Green pepper	-	-	92	92
15	Spinach	-	73	50	62
16	Mung bean	-	-	75	75
17	Bell pepper	-	88	76	82
18	Radish	-	-	43	43
19	Taro	-	89	67	78

Plant symptoms and disease incidence across regions

Plant symptoms and disease incidence across the three districts are presented in *Table 8*. From results, vein thickening and leaf curling are associated with high incidence of begomovirus disease, especially in plants like pumpkin, tomato, and chili. Pumpkin showed high vein thickening and leaf curling with the highest incidence rate of 93% in District Dir Lower. Similarly, turnip, lettuce, brinjal, and tomato showed high vein yellowing, but with varying disease incidence rates. Tomato has high vein yellowing and a high disease incidence of 70% in District Dir Lower and 89% in District Swat.

Symptom-region specificity

Symptom correlations of begomovirus in vegetable crops are presented in *Table 9*. Results showed that vein thickening had a stronger correlation in District Swat and Malakand than in Dir Lower. Additionally, leaf curling was more prevalent in District Swat and Dir Lower, suggesting it as a key symptom of begomovirus in vegetable crops of the mentioned regions. Vein yellowing and leaf yellowing showed weaker correlations, indicating these symptoms are not region-specific.

Discussion

Plant viral diseases are widely distributed and are extensively studied around the globe. There are number of viruses, infecting a wide range of plants. Among other

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plant-infecting viruses, the family Geminiviridae is the most important (Varsani et al., 2017). These viruses cause diseases in economically important plants including medicinal, aromatic and horticultural plants and pose serious threat to global food security. Multiple studies in literature have reported the presence of begomovirus infection in various regions around the globe (Ferro et al., 2024; Srivastava et al., 2023). Begomoviruses can infect numerous vegetable crops, particularly in tropical and sub-tropical regions of the world (Pandey et al., 2021). However, very recently, these viruses have also been reported in temperate regions of the world due to changes in the global climatic conditions and international human trade of infected plant materials (Oliveira et al., 2024).

Table 8. *Plant symptoms and disease incidence across regions*

Plant name	Symptom(s) reported				Incidence (%)		
	Vein thickening	Vein yellowing	Leaf curling	Leaf yellowing	Dir Lower	Malakand	Swat
Pumpkin	High	Low	High	Low	93	67	79
Pea	High	Low	High	Low	67	-	-
Lady finger	High	Low	High	Low	69	50	76
Turnip	High	High	High	Low	17	-	-
Lettuce	High	High	High	Low	17	-	-
Brinjal	High	High	High	Low	58	-	-
Cucumber	Low	Low	High	High	25	-	-
Luffa	High	Low	High	Low	44	-	-
Chili	High	Low	High	Low	56	78	76
Celery	Low	Low	Low	High	33	-	-
Tomato	High	High	High	Low	70	-	89
Black-nightshade	High	Low	High	Low	-	79	74
Eggplant	High	High	High	Low	-	-	92
Green pepper	High	Low	High	Low	-	-	92
Spinach	High	Low	High	Low	-	73	50
Mung bean	High	Low	High	Low	-	-	75
Bell pepper	High	High	Low	Low	-	88	76
Radish	Low	High	High	Low	-	-	43
Taro	Low	High	High	Low	-	89	67

Table 9. *Prevalence and regional symptom correlations of begomovirus in vegetable crops*

Symptom	Dir Lower	Malakand	Swat	Correlation with Region
Vein thickening	58%	68%	77%	Strong correlation in District Swat and Malakand
Vein yellowing	40%	53%	56%	Moderate correlation in District Swat and Malakand
Leaf curling	65%	60%	70%	Strong correlation in District Swat and Dir Lower
Leaf yellowing	37%	40%	38%	Low correlation across all regions

The viral diseases particularly the diseases caused by the members of Geminiviridae family (Begomoviruses and satellites) have been studied and reported extensively in the

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Punjab and Sindh provinces of Pakistan (Iqbal et al., 2023; Mahmood et al., 2024). According to one study, begomovirus and satellite disease symptoms with mild to severe disease severity were common in Kohat region, Khyber Pakhtunkhwa (Shah et al., 2020). In the present study, we evaluated the symptomatic incidence of begomoviruses in vegetable crops from different three districts of Kyber Pakhtunkhwa.

Previously, it has been reported that plants infected with begomovirus disease have certain symptoms such as reduction in leaf size, curled leaves, yellow and thick veins, and vein and leaf yellowing (Srivastava et al., 2021). In the present work, we found four common symptoms in infected plants, including vein thickening, vein yellowing, leaf curling, and leaf yellowing. Vein thickening and leaf curling were more common in pumpkin, tomato, and chili, while vein yellowing was high in tomato plants. In District Dir Lower, the incidence of begomoviruses was high in Tehsil Chakdara (69%), followed by Tehsil Tazagram (65%), Tehsil Kotigram (61%), and Tehsil Adenzai, (57.5%), with the highest incidence in pumpkin (93%), tomato (70%), lady finger (69%), and pea plant (67%), respectively. In District Malakand, highest incidence was reported in Thana (92%), followed by Alladand (74%), and Batkhela (73%), with the disease being common in certain vegetable crops including taro (89%), 88% in bell pepper (88%), and 86% in peppermint (86%). Furthermore, in District Swat, the overall incidence was 78%, with high prevalence in Chungi (89%), Shamozai (87%), and Parrai (83%). The disease mostly affected green pepper and eggplant (each with 92%), followed by tomato (89%), and pumpkin (79%).

Multiple studies reported the incidence of begomovirus in various vegetable crops such as pumpkin (Singh et al., 2009), tomato (Zaidi et al., 2017), turnip (Heydarnejad et al., 2018), and chili (Tahir et al., 2010). Major reported symptoms were vein yellowing (pumpkin) (Singh et al., 2009), and leaf curling (tomato and chili) (Tahir et al., 2010; Zaidi et al., 2017). Specifically, in tropical and subtropical regions of the world, tomato begomoviruses are a significant source of tomato production limitation. Yield losses might reach 100% when there is a lot of whitefly pressure (Yan et al., 2021). According to literature, more than 60 species of begomoviruses that infect tomatoes have been identified globally as a result of the phenomena known as local evolution (Souza et al., 2022). When *B. tabaci* biotype B was introduced, at least 14 different native begomoviruses that infect tomatoes began to appear locally (Li et al., 2021). In fact, the situation in Brazil is a prime example of this phenomenon. Tomato Golden Mosaic, which was originally documented in the 1960s, was the first tomato begomovirus disease in Brazil. The disease was revealed to be transmitted by whiteflies and was characterized by deformed growth and a mosaic of yellow to light green leaves (Marchant et al., 2023).

Furthermore, in the present work we performed correlation analysis to determine the highest incidence among specific vegetable crops, most common disease symptoms, and symptom-region specificity. Results showed that pumpkin has the highest overall incidence (80%), followed by tomato (79%) and lady finger (65%). A similar nature study from North Bengal, India, reported begomovirus disease incidence higher in bitter gourd (64-100%), followed by cucumber (40-80%) (Tamang et al., 2024). Based on region, disease incidence in pumpkin was higher in District Dir Lower (93%), eggplant and green pepper in Swat (92% each), while taro in District Malakand (89%), respectively. A previous study in Thailand reported that begomovirus disease incidence varied with region. Results showed that the disease was more common in the northern regions of Thailand, while northeastern and central regions showed moderate disease

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incidence. Tomato, pepper, and cucurbits were among the commonly infected plants (Charoenvilaisiri et al., 2020). In the present study, we assessed disease symptom correlation with region. Results showed that vein thickening had a stronger correlation in District Swat and Malakand than in Dir Lower, while leaf curling was a more common symptom in vegetable crops reported from District Swat and Dir Lower. The overall results underline the necessity for focused management measures by highlighting the extensive effects of begomoviruses on a variety of vegetable crops in the mentioned districts of Khyber Pakhtunkhwa, Pakistan.

Conclusion

The current study provides the first ever documented evidence of symptomatic begomovirus infection in numerous vegetable crops across areas connecting three neighboring districts of Khyber Pakhtunkhwa, Pakistan. The incidence and severity of the disease varied amongst different vegetable crops as well as the diverse locations within the study area. Such diseases adversely affect the quality and yield of vegetable crops, leading to significant economic losses for food industry and agriculture sector in Pakistan. Further comprehensive molecular studies would be needed to confirm the existence and molecular biodiversity of begomoviruses and other genera within the *Geminiviridaea* family in the study region. We recommend the plant protection agencies and the agricultural sector authorities to take preventive control measures against begomovirus diseases since it could infect a lot of vegetable and medicinal plants in the region.

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REFERENCES

[1] Ahmad, S. (2022): Population assessment of Bemisia tabaci (Gennadius.) and disease occurrence of Begomovirus in okra, Abelmoschus esculentus L. – Journal of the Saudi Society of Agricultural Sciences 21(2): 77-86.
[2] Ahmed, N., Zaidi, S. S.-e.-A., Amin, I., Scheffler, B. E., Mansoor, S. (2021): Tomato leaf curl Oman virus and associated Betasatellite causing leaf curl disease in tomato in Pakistan. – European Journal of Plant Pathology 160: 249-257.
[3] Azeem, H., Perveen, R., Tahir, M. N., Umar, U.-U.-D., Ölmez, F., Ali, A. (2022): Prevalence, transmission and molecular characterization of cotton leaf curl Multan virus infecting hollyhock plants in Pakistan. – Molecular Biology Reports 49(6): 5635-5644.
[4] Bahar, T., Rauf, M., Muqeet, S., Haider, M. S. (2023): Farmers' perception and knowledge in begomovirus epidemiology and control in Pakistan. – International Journal of Phytopathology 12(1): 37-47.
[5] Barman, M., Samanta, S., Chakraborty, S., Samanta, A., Tarafdar, J. (2022): Copy number variation of two begomovirus acquired and inoculated by different cryptic species of whitefly, Bemisia tabaci in Okra. – PloS ONE 17(3): e0265991.
[6] Charoenvilaisiri, S., Seepiban, C., Phironrit, N., Phuangrat, B., Yoohat, K., Deeto, R., Chatchawankanphanich, O., Gajanandana, O. (2020): Occurrence and distribution of begomoviruses infecting tomatoes, peppers and cucurbits in Thailand. – Crop Protection 127: 104948.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2303_42034216

[7] Ferro, C. G., Favara, G. M., Kraide, H. D., Mesquita, N. L. S., Novaes, Q. S. d., Rezende, J. A. M. (2024): Evidence of infection of cassava plants with the begomovirus passionfruit severe leaf distortion virus in Brazil. – Scientia Agricola 81: e20230215.
[8] Heydarnejad, J., Kamali, M., Hassanvand, V., Massumi, H., Shamshiri, M., Varsani, A. (2018): Turnip leaf curl disease associated with two begomoviruses in south-eastern Iran. – Tropical Plant Pathology 43: 165-169.
[9] Iqbal, M. J., Zia-Ur-Rehman, M., Ilyas, M., Hameed, U., Herrmann, H. W., Chingandu, N., Manzoor, M. T., Haider, M. S., Brown, J. K. (2023): Sentinel plot surveillance of cotton leaf curl disease in Pakistan-a case study at the cultivated cotton-wild host plant interface. – Virus Research 333: 199144.
[10] Lavanya, R., Arun, V. (2021): Detection of Begomovirus in chilli and tomato plants using functionalized gold nanoparticles. – Scientific Reports 11(1): 14203.
[11] Li, Y., Mbata, G. N., Punnuri, S., Simmons, A. M., Shapiro-Ilan, D. I. (2021): Bemisia tabaci on vegetables in the southern United States: Incidence, impact, and management. – Insects 12(3): 198.
[12] Mahmood, M. A., Ahmed, N., Hussain, A., Naqvi, R. Z., Amin, I., Mansoor, S. (2024): Dominance of Cotton leaf curl Multan virus-Rajasthan strain associated with third epidemic of cotton leaf curl disease in Pakistan. – Scientific Reports 14(1): 13532.
[13] Marchant, W. G., Mugerwa, H., Gautam, S., Al-Aqeel, H., Polston, J. E., Rennberger, G., Smith, H., Turechek, B., Adkins, S., Brown, J. K. (2023): Phylogenomic and population genetics analyses of extant tomato yellow leaf curl virus strains on a global scale. – Frontiers in Virology 3: 1221156.
[14] Martínez-Marrero, N., Avalos-Calleros, J. A., Chiquito-Almanza, E., Acosta-Gallegos, J. A., Ambriz-Granados, S., Anaya-López, J. L., Argüello-Astorga, G. R. (2020): A new begomovirus isolated from a potyvirus-infected bean plant causes asymptomatic infections in bean and N. benthamiana. – Archives of Virology 165: 1659-1665.
[15] Nadeem, S., Riaz Ahmed, S., Luqman, T., Tan, D. K., Maryum, Z., Akhtar, K. P., Muhy Ud Din Khan, S., Tariq, M. S., Muhammad, N., Khan, M. K. R. (2024): A comprehensive review on Gossypium hirsutum resistance against cotton leaf curl virus. – Frontiers in Genetics 15: 1306469.
[16] Oliveira, I. A. d., Reis, L. d. N. A. d., Fonseca, M. E. d. N., Melo, F. F. S., Boiteux, L. S., Pereira-Carvalho, R. d. C. (2024): Geminiviridae and Alphasatellitidae diversity revealed by metagenomic analysis of susceptible and tolerant tomato cultivars across distinct Brazilian biomes. – Viruses 16(6): 899.
[17] Pandey, V., Srivastava, A., Gaur, R. (2021): Begomovirus: a curse for the agricultural crops. – Archives of Phytopathology and Plant Protection 54(15-16): 949-978.
[18] Sandra, N., Mandal, B. (2024): Emerging evidence of seed transmission of begomoviruses: implications in global circulation and disease outbreak. – Frontiers in Plant Science 15: 1376284.
[19] Shah, A., Ayub, A., Shuja, M. N., Ali, T., Akbar, F. (2020): Molecular characterization of the Begomovirus associated satellites infecting Spinacia oleracea and Capsicum annum plants in Kohat, Pakistan. – BioScientific Review 2(4): 43-56.
[20] Shahid, M. S., Al-Sadi, A. M. (2021): Begomovirus Diseases of Ornamental and Fruit Plants: Discoveries and Management Approaches. – In: Raj, S. K. et al. (eds.) Virus Diseases of Ornamental Plants: Characterization, Identification, Diagnosis and Management. Springer, Singapore, pp. 381-396.
[21] Shakir, S., Mubin, M., Nahid, N., Serfraz, S., Qureshi, M. A., Lee, T.-K., Liaqat, I., Lee, S., Nawaz-ul-Rehman, M. S. (2023): REPercussions: how geminiviruses recruit host factors for replication. – Frontiers in Microbiology 14: 1224221.
[22] Singh, A., Mishra, K., Chattopadhyay, B., Chakraborty, S. (2009): Biological and molecular characterization of a begomovirus associated with yellow mosaic vein mosaic disease of pumpkin from Northern India. – Virus Genes 39: 359-370.

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DOI: http://dx.doi.org/10.15666/aeer/2303_42034216

[23] Souza, J. O., Melgarejo, T. A., Vu, S., Nakasu, E. Y., Chen, L.-F., Rojas, M. R., Zerbini, F. M., Inoue-Nagata, A. K., Gilbertson, R. L. (2022): How to be a successful monopartite Begomovirus in a bipartite-dominated world: emergence and spread of Tomato mottle leaf curl virus in Brazil. – Journal of Virology 96(18): e00725-00722.
[24] Srivastava, A., Pandey, V., Al-Sadi, A. M., Shahid, M. S., Gaur, R. (2023): An insight into emerging begomoviruses and their satellite complex causing papaya leaf curl disease. – Current Genomics 24(1): 2.
[25] Srivastava, S., Tiwari, N., Prajapati, M. R., Jain, R., Singh, J., Tiwari, A. (2021): Begomovirus on Ornamental Plants: Diversity and Management. – In: Raj, S. K. et al. (eds.) Virus Diseases of Ornamental Plants: Characterization, Identification, Diagnosis and Management. Springer, Singapore, pp. 359-379.
[26] Tahir, M., Haider, M. S., Briddon, R. W. (2010): Chili leaf curl betasatellite is associated with a distinct recombinant begomovirus, Pepper leaf curl Lahore virus, in Capsicum in Pakistan. – Virus Research 149(1): 109-114.
[27] Tamang, S., Saha, S., Saha, D., Saha, A. (2024): Investigation on disease incidence, distribution and diversity of Begomoviruses infecting cucurbitaceous crops in North Bengal, India. – Journal of Environmental Biology 45(2).
[28] Varsani, A., Roumagnac, P., Fuchs, M., Navas-Castillo, J., Moriones, E., Idris, A., Briddon, R. W., Rivera-Bustamante, R., Murilo Zerbini, F., Martin, D. P. (2017): Capulavirus and Grablovirus: two new genera in the family Geminiviridae. – Archives of Virology 162: 1819-1831.
[29] Wahyono, A., Murti, R. H., Hartono, S., Nuringtyas, T. R., Wijonarko, A., Mulyantoro, M., Firmansyah, D., Afifuddin, A., Purnama, I. C. G. (2023): Current status and complexity of three begomovirus species in pepper plants in lowlands and highlands in java island, Indonesia. – Viruses 15(6): 1278.
[30] Yan, Z., Wolters, A.-M. A., Navas-Castillo, J., Bai, Y. (2021): The global dimension of tomato yellow leaf curl disease: current status and breeding perspectives. – Microorganisms 9(4): 740.
[31] Zaidi, S. S. E. A., Martin, D. P., Amin, I., Farooq, M., Mansoor, S. (2017): Tomato leaf curl New Delhi virus: a widespread bipartite begomovirus in the territory of monopartite begomoviruses. – Molecular Plant Pathology 18(7): 901-911.
[32] Zubair, M., Zaidi, S. S.-e.-A., Shakir, S., Farooq, M., Amin, I., Scheffler, J. A., Scheffler, B. E., Mansoor, S. (2017): Multiple begomoviruses found associated with cotton leaf curl disease in Pakistan in early 1990 are back in cultivated cotton. – Scientific Reports 7(1): 680.

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