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FARMERS' PERCEPTION AND KNOWLEDGE IN BEGOMOVIRUS EPIDEMIOLOGY AND CONTROL IN PAKISTAN

[a,b]Tehmina Bahar, [a]Mehwish Rauf, [b]Sidra Muqeet, [a]Muhammad S. Haider
[a] *Department of Plant Pathology, University of the Punjab, Lahore, Pakistan.*
[b] *Pest Warning and Quality Control of Pesticides, Punjab, Pakistan.*

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ABSTRACT

Agriculture is the backbone of Pakistan, and the growing crops are called as the "spinal cord" of the state but still import bill of the country agricultural products is rising day by day and issues of the food security is also becoming grave because of less knowledge of farmers about the emerging abiotic and biotic stresses affecting the crop productivity. Among various biotic stresses, prevalence of begomoviruses is considered to be a major constraint in reducing the yields of economically important food and fiber crops. Farmers' perception and their knowledge regarding begomoviruses epidemiology and practices are the pre-requisites for effective virus control. A farmer survey mostly having less than 12.5 acres land mostly of vegetables, rice and maize growers involving 250 randomly selected respondents from five major districts (Nankana, Sheikhupura, Gujranwala, Gujrat, and Lahore) of Punjab, Pakistan to inquire from them whether they are familiar with begomoviruses identification, their means of transfer from diseases inoculum to healthy plants and associated losses in fields, proper management of these losses on time, was conducted to better understand the farmer knowledge and practices and to set the possible pathways for intervention of effective virus control. Lack of sufficient technical information regarding vector of begomovirus, their transmission and disease symptoms was the major hindrance to the efforts of farmers for effective virus control. In addition, the farmers did not have sufficient knowledge of locally available methods of begomovirus control. The highest prioritization aspect of virus control for immediate attention were determined by decision making such as spider diagram. Use of effective pesticides, certified planting material, and begomovirus tolerant cultivars were found to be the most attention requiring virus control aspects which could have a greater influence to lower the virus prevalence in field crops. Present study suggests that enhancing the farmer knowledge is a highest prioritized key determinant of effective virus control strategy for implementation in Pakistan.

Corresponding Author: Tehmina Bahar
Email: tehminabahar21@gmail.com

INTRODUCTION

The agriculture-based economy of Pakistan is threatened by abiotic (heat, drought, frost, salinity, etc.) and biotic stresses (insect pests, fungi, bacteria, viruses, etc.). Among biotic stresses, diseases caused by begomoviruses pose a major threat to crops in Pakistan particularly in Punjab province. Several cash crops of Pakistan like tomato, cotton, chilies, soybean, and mung bean are severely infected by begomoviruses. In Pakistan, most of the economically important begomoviruses that infect important cash crops of different families including Malvaceae (cotton, okra),

Solanaceae (tobacco, tomato, potato, petunia, and pepper), Cucurbitaceae (melon, watermelon, squash, and gourds), Fabaceae (soybean, cowpea, common bean, mung bean, and lima bean) and Euphorbiaceae (cassava) are Cotton Leaf Curl disease associated begomoviruses (CLCuD), Tomato leaf curl New Delhi virus (ToLCNDV), Cotton leaf curl Kokhran virus (CLCuKoV), Chili leaf curl virus (ChiLCV), Pepper leaf curl Lahore virus (PepLCLaV), Legume yellow mosaic viruses (LYMVs), Rhynchosia yellow mosaic virus (RYMV), Pedilanthus leaf curl virus (PeLCV), papaya leaf curl virus (PaLCuV) and Tobacco leaf curl betasatellite (TbLCB) (Nawaz-ul-Rehman *et al.*, 2017; Seal *et al.*, 2006).

Geminiviruses (Begomoviruses) transmitted by *Bemisia tabaci* (whitefly) are largely known for causing several plant diseases across the world (Sani *et al.*, 2020; Chi *et al.*, 2020). Begomoviruses are single-stranded circular DNA plant viruses with two genomic forms i.e., monopartite and bipartite having ~2700 nucleotides (Anwar *et al.*, 2020; Fiallo-Olivé and Navas-Castillo, 2020). Begomoviruses are very diverse across the world and a major threat for economically important food and fiber crops including tomato, potato, chilies, peppers, cucurbits, tobacco and cotton (Varma *et al.*, 2013; Nagendran *et al.*, 2017; Charoenvilaisiri *et al.*, 2020; Pandey *et al.*, 2021). Common symptoms of begomoviruses infection includes leaf yellowing, curling, mosaic discoloration and stunted plant growth (Charoenvilaisiri *et al.*, 2020). East Asian countries have been reported as hotspots for the begomovirus diversity as ~300 different species have been identified in tomato, chilies, peppers, cucurbits, tobacco and cotton etc. (Malathi *et al.*, 2017).

Weeds infestation is also playing a devasting role in persistence and spread of these viruses. No doubt, theses weeds are now serving as potential sources for the primary inoculums of begomoviruses as the economically important crops just stay for a particular time or season in the fields but weeds grow in the fields throughout the year (Khan, 2000). In Pakistan, tropical and sub-tropical areas are serving as the favorable regions for the emergence of newly diversified begomoviruses and are causing severe disease epidemics of our economically important staple food crops and cash crops such as cotton, legumes, maize, tomato, chilies and grains etc. (Khan, 2000). This study was designed because devasting effects of these begomoviruses in term of yield losses are increasing in these regions day by day, which triggered to determine the farmer's perceptions and practices to control it. In the fields farmers can mostly recognize the symptoms associated with the infections of begomoviruses on leaves and stem parts of the plants. However, they have limited knowledge regarding their epidemiology i.e., spreading mechanisms and effective control methods. Broken resistance of cultivars and availability of alternate host plants are also the factors enhancing the chances of viral infections.

Therefore, to effectively manage the infections associated with these diverse begomoviruses, farmers really need to learn about their epidemiology but unfortunately, no study is yet reported in Pakistan for the capacity building of farmers highlighting the diversity, distribution and agricultural yield losses because of begomoviruses in economic crops like tomato, legumes, pepper and cucurbits. After understanding the role of farmers' knowledge, present study was designed for capacity building of farmers to combat with the begomovirus infections in Pakistan.

MATERIAL AND METHODS

Survey Sites

Farmer survey in high production regions in Punjab Province of Pakistan i.e., Nankana, Sheikhupura, Gujranwala, Gujrat, and Lahore districts (Figure 1) were conducted in 2018 during the months of July, August and September.

Sampling and Data Collection

Total of 250 farmers were interviewed in the survey as a representative sample using equation;

$$N = {Z2\ pq}/{e^z}$$

(Singh and Masuku, 2014).

Where "Z^2" is normal variate and its value is 1.96, p is an estimated proportion of measured parameters and its value is 0.5, q is (1-p) and e is the desired precision which is equal to 5%. Farmers (n = 50) were selected from crop growing regions of each District using simple random sampling. Semi-structured questionnaire was completed by asking open-ended questions from farmers to collect the information. Positions of the farmers were recorded by using global positioning system (GPS) in an android smart phone application (Maduka *et al.*, 2017). The mean separation analysis of extracted data was performed using LSD test function in the agricolae package with alpha = 0.05 in in R. Studio

3.4.4 (De Mendiburu, 2014).

Spider diagrams were used for decision making of effective begomoviruses control (Onditi *et al.*, 2021). Decision making involves to set overall goal and set criteria to achieve that overall goal for effective Begomoviruses control in the Pakistan farming systems (Florin *et al.*, 2014). In present study, the canon for effective begomoviruses control was to advance farmers' insight, and knowledge regarding (i) identification of whitefly (vector) and its role in begomovirus transmission, (ii) begomovirus transmission through planting material, (iii) begomovirus transmission to the target crops by mechanical means, (iv) begomovirus inoculum sources around the target crop, (v) minimum use of begomovirus resistant cultivars, and (vi) lack of pesticides use to control begomovirus vector.

Figure 1. Map showing the distribution of all districts reviewed across different sub-regions in Punjab, Pakistan (created using QGIS v2.18.25).

As all the indicators of each criterion have different weight on the basis of relative potential impact on the overall sustainability of agricultural system (Struik *et al.*, 2014). All the measurable indicators were assigned different weight from 0-10 on basis of the farmer's response (Florin *et al.*, 2014; Marinus *et al.*, 2018). Values of all indicators of each criterion were added up to 1. Relative weight for each scored indicator was determined by expert opinion from a panel of four plant scientists (pathologist, breeder, socio-economist and virologist) to distinguish their impact on the overall sustainability of agricultural system (Marinus *et al.*, 2018).

The overall final scores were calculated as the sum of the product of each indicator and the corresponding indicator weight, and the final value visualized in the spider diagrams. Zero score in spider diagram represented a situation which definitely need more urgent interventions compared to a score of ten which indicated a situation in which viruses were seamlessly controlled and farmers also did not need any support for their control measures.

Images of whiteflies on the leaves of different infected plants and common begomoviral symptoms such as upward and downward curling, mosaic, necrosis, chlorosis and stunted growth were shown to farmers to understand their knowledge and perceptions about the begomovirus infection and their transmission through whitefly vectors. Farmers were then asked to tell the name of insects by recognizing the disease symptoms present in the images respectively.

Information about eight plant species (*Verbesina enceilidous, Datura inoxia, Sonchus arvensis, Solanum nigrum, Solanum muricatum, Calotropis procera, Physalis spp, and Mimosa pudica*) which all are weeds and grow around vegetables and other crop fields and serve as the potential alternative host vessels for begomovirus infections (Prajapat *et al.*, 2014; Marwal *et al.*, 2013; Mubin *et al.*, 2010; Ansar *et al.*, 2021; Pohl and Wege, 2007; Zaidi *et al.*, 2017; Fonseca *et al.*, 2013) was also calculated from all the targeted farmers.

RESULTS

Targeted Survey Sites

Local farmers have small sized farms (0.6 to 1.0 ha) for agricultural farming in targeted districts Nankana, Sheikhupura, Gujranwala, Gujrat, and Lahore of Punjab in Pakistan (Figure 1). Farmers in all the districts mainly used 30-40% land of their farms for the cultivation of some food crops such as pulses, vegetables and fruits and the remaining 60%-70% for major crops such as wheat, rice, maize and sugarcane etc. Number of male respondents were higher (> 95%) in all targeted districts while number of female respondents was less than 5%.

Farmer's Knowledge and Practice in Begomovirus Control

Farmer's knowledge of virus symptoms and vector virus transmission

Farmers' perceptions and their understanding about role of whiteflies in transmission of begomovirus and disease symptom of these viruses were very poor. The majority of respondents did not know regarding the whiteflies (70.6%) and their role in transmission of Begomoviruses (9.4%) in all the districts under study. Similarly, a high number of respondents (99.16%) did not identify begomovirus symptoms correctly (100% in Nankana, 98.7% in Sheikhupura, 100% in Gujranwala, 98.3% in Gujrat and 96.8% in Lahore). Only 5.8% of farmers understand that whiteflies transmit the begomoviruses by plant sap from infected to healthy plants (Table 1).

Use of insecticides to control whiteflies

Farmers were also asked about practices in applications of chemical pesticides to understand their knowledge regarding usage of pesticides for effective control of begomovirus vector, (Table 1). Respondents were asked about pest scouting of their fields for early detection of insect pests and diseases and more than half of them (55.8%) answered that they did not follow any such practice in their fields. Among the farmers who scouted their crops to check the pest infestation and disease incidence, only a small fraction (20.6%) checked specifically for vector whitefly and begomovirus on their crops. While farmers who scouted their crops to know the status of insect pests and diseases 30% in Nankana, 30% in Sheikhupura, 30% in Gujranwala, 25% in Gujrat and 18% in Lahore did not adopt this practice even at an average of 30 days interval. More than 60% of farmers did not apply any pesticides on their crops to control the pests. Response of the farmers on the point that why they did not encourage the use of chemical pesticide is summarized in (Table 1). Availability of exact information to the farmers required for appropriate use of chemical pesticides for effective control of virus vectors but knowledge of the majority farmers was found away from the accurate use of these pesticides.

Use of host plant resistance for the effective control of begomoviruses and improved crop yield

Information about resistance potential of grown cultivars that may also act as alternating host vessels for begomovirus infections for biotic and abiotic stress factors in targeted areas of Pakistan enlisted in (Table 2). Farmers prefer to grow high yield varieties having high market demand, good taste and quality but they did not have knowledge about biotic and abiotic stress factors causing quality deterioration and yield reduction. Hence, a few respondents (7.3%) cultivate begomovirus resistant cultivars of maize, potato, rice, tomatoes and chilies only in Lahore and Sheikhupura districts among the farms visited in all districts.

Virus transmission through planting material

Farmers' knowledge on begomovirus transmission through planting material (seeds, buds, cuttings, tubers etc.) was limited. Majority (93.7%) of respondents were unaware that use of non-certified planting material is one of the major source for transmission of begomovirus infections into the healthy crops. Only few of the farmers

(2.46% in Nankana, 4.3% in Sheikhupura, 7.11% in Gujranwala, 7.32% in Gujrat and 13.5% in Lahore) used certified planting material from certified seed producers (Table 1). Mostly farmers used planting material bought from local markets, obtained from neighbors or their own previous stock.

Table 1. Description of the farmer's knowledge and practice in begomovirus transmission and vector control.

Questions	Farmer's Perceptions	Response Percentage					
		Nankana	Sheikhupura	Gujranwala	Gujrat	Lahore	Mean
Farmer's knowledge of the role of whiteflies in begomovirus transmission	Farmer doesn't know, what is whitefly?	62.2	68.4	73.1	75.2	74.2	70.6 [a]
	Transmission of begomoviruses by whitefly.	5.2	8.12	8.4	10.1	15.2	9.4 [f]
	Farmer's knowledge about sucking of plant sap by whitefly.	0.0	0.3	7.45	7.9	13.6	5.8 [g]
	Transmission of begomoviruses by planting material.	2.5	4.3	7.1	7.3	13.5	6.9 [g]
	Transmission of begomoviruses by mechanical means.	40.9	43.8	47	48.9	50.5	46.2 [b]
	Farmer's observations about the effect of whitefly on crop plant.	0	1.3	0	1.7	3.2	1.24 [h]
	Whitefly role in causing disease symptoms.	3.2	2.1	2.5	1.4	0	1.84 [h]
Farmer's practice about pest scouting and pesticide use	Farmers do pest scouting in their farms	30	33	60	40	58	44.2 [b]
	Farmers do scouting for whiteflies	19.3	18	20	22	24	20.6 [e]
	Farmers use pesticides in their farms to control pests	27.1	29.3	50.4	37.2	50	38.8 [c]
Why farmers do not apply pesticides on their crop	Whiteflies have no effect on crop	18.7	19.6	21.2	23.8	24.9	21.6 [e]
	Lack of technical information	23.6	24.2	25.9	26.7	27.9	25.6 [de]
	No reason	16.7	17.5	18.9	20.2	25.8	19.8 [e]
	Not available	23.8	25.7	27.9	28.9	33.9	28.1 [d]
	Not effective	0	0.9	1.9	2.8	4.9	2.1[h]
	Too costly	0	1.3	2.6	2.6	5.7	2.4 [h]

Mechanical transmission of begomoviruses

Majority of the farmers (40.9% in Nankana, 43.87% in Sheikhupura, 47.0% in Gujranwala, 48.9% in Gujrat and 50.5% in Lahore) were aware that mechanical tools used in cutting, grafting are source of disease transmission from infected to healthy plants. Despite this knowledge, high number of farmers did not take precautions to stop mechanical transmission of diseases as it hectic, laborious and time consuming and they did not think it profitable (Table 1).

Role of alternative host plants and other sources of virus inoculum virus transmission

Information about all eight weeds species that serve as alternate hosts for the spreading of viral infections enlisted in (Table 3). Wild sunflower (*Verbesina enceilidous,* 21.5%), moonflower (*Datura inoxia,*

16.3%), sowthistle (*Sonchus arvensis,* 31.2%), black nightshade (*Solanum nigrum,* 11.6%), sweet cucumber (*Solanum muricatum,* 22.4%), were more frequent while milkweed (*Calotropis procera,* 9.1%), gooseberry (*Physalis spp,* 5.04%), touch-me-not (*Mimosa pudica,* 1.16%) were least common.

Table 2. Characteristics that farmers prefer in crop cultivation in five districts of Punjab in Pakistan.

Farmer's Perceptions	Response Percentage					
	Nankana	Sheikhupura	Gujranwala	Gujrat	Lahore	Mean
High market demand	11.7	11.9	12.9	15.7	17.8	14.1[b]
High yielding cultivars	40.9	43.8	47	48.9	50.5	46.2 [a]
Early maturity	4.8	5.8	9.9	10.9	14.7	9.3 [c]
Late Maturity	3.9	4.5	7.9	9.9	13.8	8.0 [c]
Well adapted to local cultivation conditions	2.9	3.9	7.9	9.8	10.9	7.1 [c]
Good taste	0.3	0.9	1.8	2.9	3.9	2.0 [d]
Lack of better alternative varieties	0.3	0.9	1.9	3.6	4.7	2.3 [d]
Fungal disease tolerance	0.9	0.9	1.1	2.9	4.1	2.0 [d]
Bacterial disease tolerance	0.2	0.7	0.9	1.7	2.9	1.3 [e]
Virus tolerance	0.3	0.9	0.7	1.3	2.9	1.2 [e]
Begomovirus tolerance	0	3.2	0	0	4.1	1.4 [e]
Heat tolerance	0.2	0.4	0.6	0.9	1.4	0.7 [f]
Drought tolerance	0	0.3	0.7	0.8	0.9	0.5 [f]
Salt tolerance	0.1	0.3	0.4	0.7	0.9	0.5 [f]

Table 3. Farmer's perception of the potential of alternative host plants in or around their farms, contributing to spread of viruses to their crop and weed management.

Questions	Farmer response (s)/practice (s)	Response Percent					
		Nankana	Sheikhupura	Gujranwala	Gujrat	Lahore	Mean
Farmers with weeds in/around their farms	*Verbesina enceilidous*	18.9	19.7	20.8	22.2	25.9	21.5 [c]
	Datura inoxia	13.3	14.9	16.7	17.9	18.7	16.3 [d]
	Sonchus arvensis	27.9	28.9	29.8	33.3	35.9	31.2 [b]
	S. muricatum	19.6	20.7	21.8	23.2	26.7	22.4 [c]
	S. nigrum	8.7	9.4	9.9	13.8	15.9	11.6 [f]
	Calotropis procera	5.9	6.7	8.9	10.9	12.8	9.1 [g]
	Physalis spp	1.9	2.8	4.9	6.9	8.4	5.0 [h]
	Mimosa pudica	0.1	0.6	0.9	1.2	2.8	1.1 [i]
Farmers knowing weeds can be source of inoculum for virus transmission	*Verbesina enceilidous*	10.9	11.7	13.8	15.9	17.9	14.1 [e]
	Datura inoxia	18.8	21.8	23.8	26.9	27.9	23.9 [c]
	Sonchus arvensis	13.8	14.5	16.7	18.8	20.9	17.0 [d]
	S. muricatum	3.5	5.7	8.7	9.8	10.4	7.6 [g]
	S. nigrum	11.3	13.7	16.8	18.9	20.8	16.3 [d]
	Calotropis procera	9.8	11.4	13.7	15.9	17.9	13.7 [ef]
	Physalis spp	1	0.8	1.82	2.3	4.8	2.1 [i]
	Mimosa pudica	1	2	1	3	2	1.8 [i]
Weed Management	Intercropping	23.8	25.2	45.8	35.2	46.4	35.2 [b]
	Crop rotation	39.4	43.7	49.3	51.8	60.5	48.9 [a]
	Hand weeding	36.8	31.1	4.9	13	6.9	18.5 [d]

Most of these weeds were long last and overlap with main crops affected by begomoviruses. Intercropping (35.2%) and crop rotation practices (48.9%) were practiced by some farmers. On the other hand, most farmers were hand weeding which is neither effective nor profitable.

Overlap of cultivation seasons and begomovirus transmission

Farmers were asked about the time of crop plantation and harvest to know whether two host crops overlap in a season in the fields or not. Begomovirus host crops in

the field overlapped throughout the year in every region of Punjab.

Analysis of order of priority in intervention in begomovirus control using spider diagrams

Individual scores on the different aspects of virus control (criteria) and ranking of the orders of priority of different aspects of virus control from the spider diagram of the five districts are presented in (Figure 2).

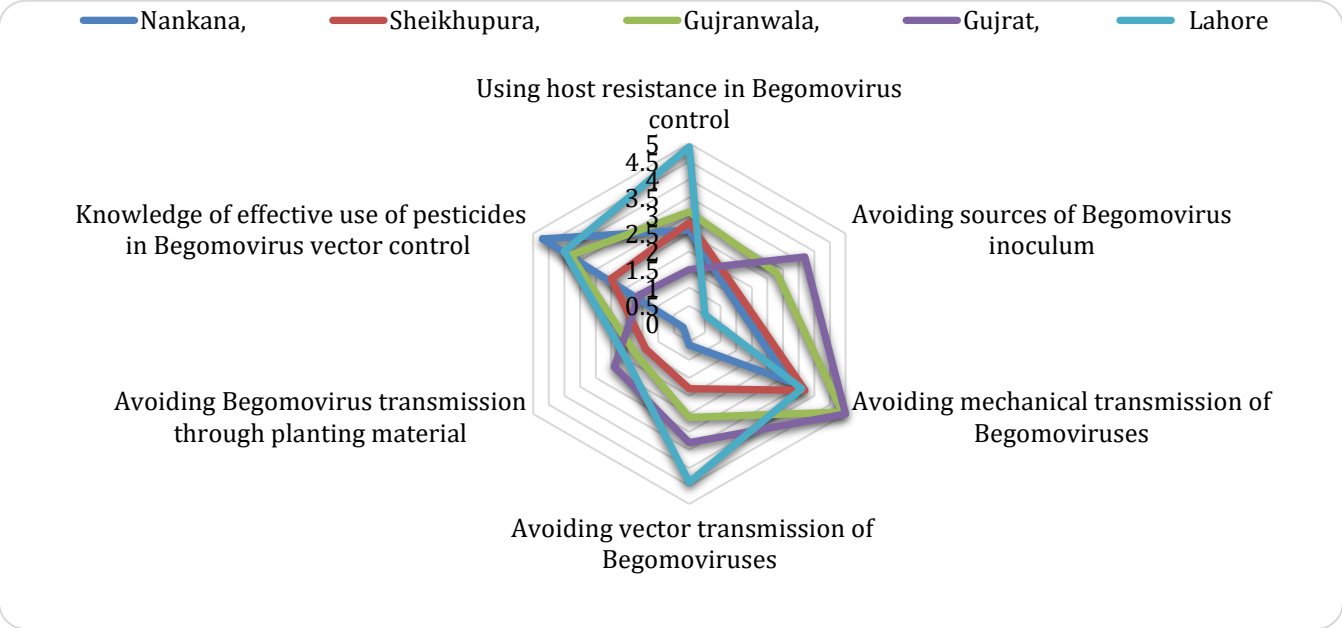

Figure 2. Different aspects of virus control (criteria) and ranking of the orders of priority of different aspects of virus control from the spider diagram from the Nankana, Sheikhupura, Gujranwala, Gujrat and Lahore districts of Punjab, Pakistan.

In Nankana district, the order of priority in begomovirus control on the basis of respective final scores in the spider diagram starting from highest priority requiring was (i) avoiding virus transmission through planting material (0.2), (ii) avoiding vector transmission of viruses (0.6), (iii) avoiding begomovirus inoculum sources (1.4), (iv) begomovirus control using host resistant cultivars (2.6), (v) avoiding mechanical transmission of viruses (3.2), and (vi) role of pesticides usage in control of begomovirus vector (4.7).

In Sheikhupura district, the order of priority in begomovirus control on the basis of respective final scores in the spider diagram starting from highest priority requiring was (i) avoiding virus transmission through planting material (1.4), (ii) avoiding begomovirus inoculum sources (1.6), (iii) Avoiding vector transmission of viruses (1.8), (iv) Role of pesticides usage in control of begomovirus vector (2.5), (v) Begomovirus control using host resistant cultivars (2.8), and (vi) Avoiding mechanical transmission of viruses (3.7).

In Gujranwala district, the order of priority in begomovirus control on the basis of respective final scores in the spider diagram starting from highest priority requiring was (i) Avoiding virus transmission through planting material (1.7), (ii) Avoiding vector transmission of viruses (2.6), (iii) Avoiding begomovirus inoculum sources (2.8), (iv) Begomovirus control using host resistant cultivars (3.1), (v) Role of pesticides usage in control of begomovirus vector (3.8), and (vi) Avoiding mechanical transmission of viruses (4.9).

In Gujrat district, the order of priority in begomovirus control on the basis of respective final scores in the spider diagram starting from highest priority requiring was (i) Begomovirus control using host resistant cultivars (1.5), (ii) Role of pesticides usage in control of begomovirus vector (1.6), (iii) Avoiding virus transmission through planting material (2.4), (iv) Avoiding vector transmission of viruses (3.3), (v) Avoiding begomovirus inoculum sources (3.7), and (vi) avoiding mechanical transmission of viruses (5.0).

In Lahore district, the order of priority in begomovirus

control on the basis of respective final scores in the spider diagram starting from highest priority requiring was (i) Avoiding begomovirus inoculum sources (0.5), (ii) Avoiding virus transmission through planting material (2.0), (iii) Avoiding mechanical transmission of viruses (3.6), (iv) Role of pesticides usage in control of begomovirus vector (4.0), (v) Avoiding vector transmission of viruses (4.4), and (vi) using host resistance in virus control (4.9).

Moreover, in all districts, the use of pesticides in virus control and certified planting material were the two aspects of virus control that had the lowest scores ranging from 0.0 to1.76. Improving farmer knowledge on effective use of pesticides in virus vector control, avoiding virus transmission through planting, host resistant cultivars could be most useful approach to control begomovirus spread and yield losses can be minimized. Under each of the above thirteen criteria, the indicators used to generate the criteria are displayed in the spider diagram (Figure 3). These too had scores which varied under each criterion and had different orders of priority based on the scores in all five districts.

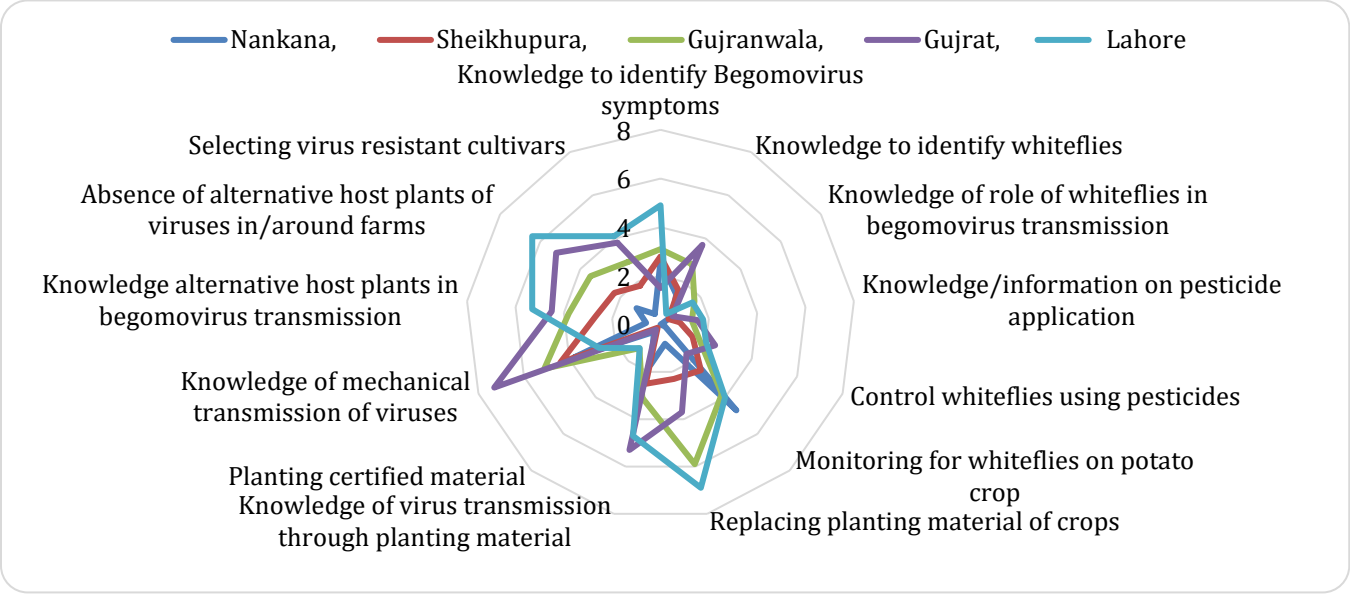

Figure 3. Spider diagram showing scores which varied under each criterion and had different orders of priority based on the scores in the five districts of Punjab, Pakistan.

DISCUSSION

In the current study, different queries such as transmission of begomoviruses by mechanical sources, whitefly, damages occur in plants in response to attack of begomoviruses, identification of symptoms caused by these viruses were analyzed. The concept about mode of transmission of begomoviruses through whitefly insect vectors, mechanical means, their spread and associated symptoms and damages such as sucking of cell sap was commonly not understood by local farmers in Pakistan. Farmers were not even able to clearly identify viruses and their vectors as major constraints for reducing crop production and it also negatively impacted the virus control strategies. Lack of knowledge is one of the major reasons for the high begomovirus prevalence (Yaqoob *et al.*, 2020). Therefore, farmers need to have a sufficient knowledge about begomoviruses and their vectors (whiteflies) to maximize the crop yield by effective virus control (Sani *et al.*, 2020). Begomovirus infection identification through visual observation of symptoms is a challenge to farmers because begomovirus symptoms differentially expressed in plants according to virus strains, resistance level of host, and climatic conditions of region (Sarwar, 2020).

For the control of whitefly populations to stop or minimize transmission of begomoviruses in crop fields necessitate more pesticide application but inappropriate and more pesticide usage was found among local farmers of five targeted districts of Punjab that induces pesticide resistance in whiteflies populations which may lead further outbreaks as well as pollution of hazardous chemicals in the environment and human health risks

(Saghafipour *et al.*, 2020). Weekly monitoring of whiteflies may reduce the exponential viruses spread. Hence, farmers' knowledge in distinguishing symptoms associated with the infections of begomoviruses and usage of selective pesticides is essential to reduce the whiteflies populations (Rodríguez *et al.*, 2019).

Farmers normally grow high yield varieties and try to maintain the planting material for next cropping seasons without knowing its purity and health status (Pautasso *et al.*, 2013). Hence, farmers need to know about the potential use of host resistant crop cultivars and selection of disease-free planting material. Begomovirus spread through mechanical means was very less compared to viral transmission through already infected planting materials in all targeted districts of Pakistan.

Increased yield losses are directly associated with high infection rate of begomoviruses and reduced resistance of cropping cultivars in all the targeted areas of Pakistan. Moreover, abundance of wild alternate begomovirus host plant species surrounding crop fields is also a major cause of virus transmission. In the present study, field crops of mostly farmers were found infested with weeds, so begomovirus spread was relatively high due to abundance of alternate host species.

Present study suggests that improving farmers' perception and knowledge about begomovirus epidemiology could be an effective strategy to control the virus spread and minimize the yield losses. It is necessary to prioritize the different virus control aspects to bring significant impact in begomovirus control by making effective policies. Farmers' knowledge can further be enhanced by experts opinions and their experiences in understanding begomovirus epidemiology and spider diagram is the most appropriate analyzing technique to determine the priority-based rank of farmers needs to control the begomoviruses infections effectively.

RECOMMENDATIONS

Farmer's knowledge on begomovirus epidemiology is as important as knowledge on other agricultural practices to cater the problem of begomovirus causing yield losses. Present study suggests that farmers are unaware to begomovirus epidemiology and there is a dire need to improve farmers' knowledge on epidemiology of the viruses. After analyzing the inadequacies of knowledge of domestic farmers, policies need to be made for capacity building of farmers for effective management of viral infections in the country to enhance the yield.

AUTHOR CONTRIBUTIONS

Tehmina Bahar, Mehwish Rauf and Sidra Muqeet designed the project. Tehmina Bahar has worked as a research scholar for this project. Tehmina Bahar, Mehwish Rauf and Sidra Muqeet conceived and wrote the manuscripts and prepared the final version. Muhammad Saleem Haider has provided technical guidance for various analyses.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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