Journal of Entomology and Zoology Studies

Available online at www.entomoljournal.com

E-ISSN: 2320-7078
P-ISSN: 2349-6800
www.entomoljournal.com
JEZS 2020; 8(4): 2427-2433

Received: 18-05-2020
Accepted: 20-06-2020

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Aphid-borne potato virus Y(PVY) is an emerging disease of potatoes in Punjab, Pakistan

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Abstract
Potato virus Y (PVY) is one of the most devastating viruses of solanaceous crops worldwide including Pakistan. Among the solanaceous crops, potatoes followed by tomatoes are severely affected. About 10-100% yield loss on potato crops and 39-75% on tomato crops have been reported worldwide. The virus has different strains which cause variety of symptoms depending on host plant species. In potatoes, the most determinant symptoms are potato tuber necrotic ring spot which renders potatoes unmarketable and therefore result in a significant economic loss. Initially there were three strains namely of PVY viz. PVY^{C}, PVY^{N} and recently recombinant strains mostly from the PVY^{N} such as $PVYN^{-Wi,}$ PVY^{NTN} and $PVY^{N: O}$ have emerged in potato crop. PVY belong to largest genus of plant viruses known as potyvirus. It is single strand of positive sense RNA (+ssRNA) and the length is about 9700 kb in length excluding the poly (A) tail. The virus is transmitted from plants by aphids primary *Myzus persicae* in non-persistent, non-circulative manner or by mechanical means. The virus has been controlled by breeding of resistant cultivars or by controlling its vectors (aphids) with insecticides and mineral oils. Knowing PVY importance the present review was written which highlight some biological and serological properties of PVY, its relationship with the vector and environmental factors and finally about its management strategies.

Keywords: Potato, PVY, biology, management, symptoms, transmission

Introduction
Potato (*Solanum tuberosum* L.) belongs to family *Solanaceae*. It is cultivated in tropical and subtropical zones of the world. It is high nutritional and starch enriched food. It contains 79% water, 18% starch, 2% protein and 1% vitamins. It contains minerals, trace elements and fats [1]. More than 100 billion people depend upon potatoes for their survival in developing countries. Major potato growing countries are China, India, Russia, Ukraine, United States, Germany, Bangladesh, Poland France and Belarus [2]. China is the world's leading potato producing country and 1/3 of world's potato is harvested in India and China. In Pakistan potato is grown on the area of 15403 thousand hectares giving production of 2539.0 thousand tons [3]. Main potato production areas are Okara, Pakpattan, Sahiwal, Gujranwala and Gilgit Baltistan (GB). However, the potato production in Pakistan is minimum as compared to the production of other countries of the world. Potatoes are very important vegetable crop for low income countries including Pakistan. Three crops spring (Feb-April), summer (May-Aug) and autumn (Oct-Jan) are cultivated in Pakistan. Moreover, the climatic conditions of Pakistan are ideal for production of potatoes.

The soil is sandy and clay loam, having good water retention capacity because of shallow and weak root system favor high production of potato crop [4]. However, the production in potato crop is low due to biotic and abiotic factors. Among the biotic factors, diseases play a significant role in reducing the yield of potato crop. Several different fungal, bacterial, viral and nematodes diseases are threatening the production of potato crop. Among these diseases, viral diseases are most aggressive and damaging pathogens affects the potato. There are 40 viruses affecting the cultivated potato crop [5]. Eight potato viruses have been reported in Pakistan namely Potato virus Y (PVY), Potato virus X (PVX), Potato leaf roll virus (PLRV), Potato mop top virus (PMTV), Potato virus S (PVS), Potato virus A (PVA), Alfalfa mosaic virus (AMV), Potato virus M (PVM) [6]). Among these PVY, PVX and PLRV are widely distributed in Pakistan.

Potato virus Y belongs to family *Potyviridae*, which contains economically most important and largest group of plant viruses [7]. PVY was described by Smith in 1931 but now it is ranked 5th out of ten most harmful plant viruses on the basis of economic and scientific importance [8, 9]. PVY is single stranded RNA virus contacting different strains including PVY^N (tobacco venial necrosis strain), PVY^O (common strain) PVY^C (stipple streak strain also includes Potato virus C). Recently recombinant strains mostly from the PVY^N such as $PVYN^{-Wi,}$ PVY^{NTN}, and $PVY^{N:O}$ have emerged in potato crop. Some of these strains are restricted in some continents and some are localized [10]. PVY is very prevalent and more destructive economically virus affecting the potato yield. Worldwide losses are up to 85% when crop is grown from infected tubers and up to 83% in Pakistan [11, 12]. PVY is transmitted mechanically and through insect vector in non-persistent manners. Virus is acquired in minutes and transmitted in seconds [13]. More than 50 aphid species are responsible for the transmission of virus but some species are most important than others [14]. Green peach Aphid plays an important role in disease transmission. Mosaic, leaf drop streak, necrotic lesions rugos mosaic are the major symptoms induced by PVY.

Environment plays an important role in disease development. The study of environmental factors is very useful to manage the disease [15]. Abiotic stresses such as temperature, rainfall, relative humidity, wind speed and clouds play an important role in the severity of PVY. Similarly, the aphid population also positively correlates with environment and early summer is considered favorable as compared to winter season [16]. Some antiviral compounds (Thiouracil, Ribavirin, Malachite green) may reduce severity of virus symptoms after spray or injection into plants however not cost effective. Therefore, the present review will assist to understand the biology of PVY, population dynamics of vector and help to developed ecofriendly management approaches in relation to environmental factors.

The Pathogen

Potato virus Y (PVY) belongs to the genus *Potyvirus* and family *Potyviridae*. Potyvirus is the largest genus of plant viruses and possibly the most destructive one in potato crops. PVY is a monopartite, single stranded RNA virus that infects mainly Solanaceous plants including, potato, tomato, pepper, tobacco and eggplant. There are multiple strains of the virus including the common strain, PVY^O, which causes mosaic symptoms in most hosts [5]. The necrotic strains PVY^N and PVY^{NTN} both cause a venial necrosis on tobacco; PVY^{NTN} also causes a tuber necrosis in certain potato varieties. This necrosis is referred to as potato tubers necrotic ringspot disease (PTNRD). In general, the necrotic strains tend to cause a milder mosaic symptom than PVY^O in potato. The distinction among strains is imprecise because recombination among PVY strains is common, i.e. the recombinant isolates contain genome information from both common and necrotic strains. Recent surveys indicate that recombinant isolates are not common in many potato production areas.

Symptomology

The investigation of PVY in potato plants on the basis of symptoms [17]. The infection starts from blocky mottling and affect upper leaves of the plant. The necrosis extending with the veins of leaves. The effected leaves show complete necrosis but remained with stem. Upper leaves of plant do not show necrosis but were crinkled and mottled. The whole plant was rosette and dwarfed (Fig. 1). Tubers appeared normal and not showing necrotic spots. The plants show malformed symptoms and yellow lines and spots in the leaves. Plants were tested with gold labeled decoration, protein sandwich enzyme linked immunosorbent assay, immunoelectron microscopy and using antiserum to PVY. It was confirmed by ELISA that PVY isolated from sage was same as the tobacco venial necrosis strain of PVY [18].

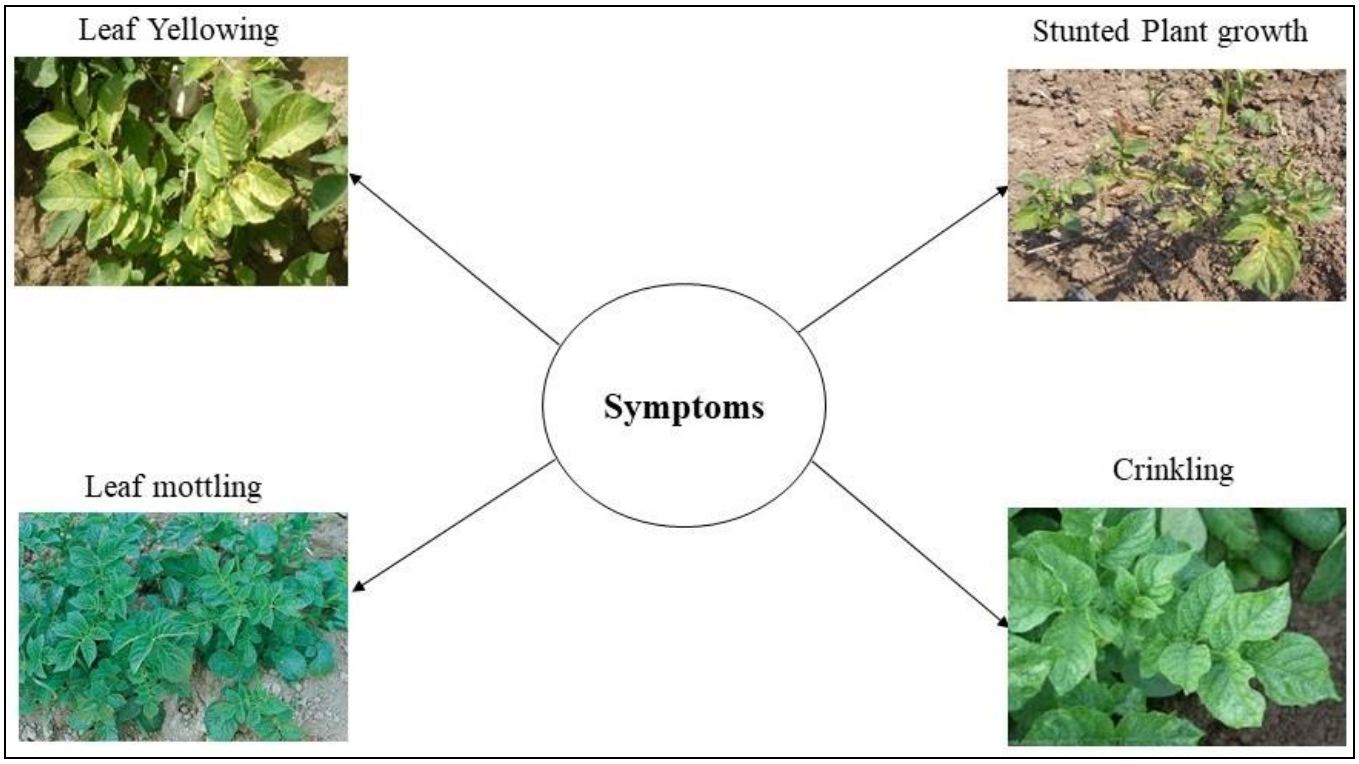

Fig 1: Characteristic symptoms of PVY strain on potato crop

Detection

The viral diseases of potato were observed in Punjab province [19]. The diseases reported was Potato virus Y, potato virus X, potato leaf roll virus, and potato virus A. They also observed the Callco virus in Red bed variety and potato virus S in Norland variety. An experiment and showed that all clones of potato crops were attacked by Potato virus Y and Potato virus X. the clone B-9423-4 showed highest frequency for potato virus Y. clone B-9335-35 show high percentage of Potato virus X [20]. The eight potato viruses were detected from different fields through serological and biological tests (ELISA) viz; Potato virus Y, Potato virus X, potato leaf roll virus, Potato virus S, potato virus A, potato mop top virus potato virus M and Alfalfa Mosaic Virus (AMV) [6]. Most prevailing viral diseases were Potato virus Y, Potato virus X and potato leaf roll virus in Pakistan [21]. The prevalence of major potato virus i.e. Potato virus Y, Potato virus X and Potato leaf roll virus in the major potato sowing areas of KPK, Pakistan. On the basis of transmission, serology, symptomology and host ranges the researcher found that all above diseases were present in the fields [22]. The Potato virus Y causes superficial ring spot necrosis in potato tubers [23].

First time this disease was observed in Lebanon in 1988 on Lola potato seeds. Severe necrosis was found on the surface of disease affected tubers which was varying in shape. Skin cracking of potato tubers were also noticed [24]. Symptoms appeared at the time of harvest on large number of tubers. After that symptoms occurred at the time of storage. The disease was sap and tuber transmitted. Potato virus y and potato virus x was identified by IEM, and ELISA. It was believed that necrosis on the tubers were produced by Potato virus Y [24]. A total Number of 3920 samples were collected from all plantations of seed tubers of potato from Poland. It was concluded that seed tubers were heavily infested by PVY which were harvested from different seed production stations. The 58% and 48% market seeds were infected with potato viral diseases Potato leaf roll virus (PLRV) and potato virus Y (PVY) respectively. These seeds were collected from the harvested crop of spring and autumn season [25].

A research on natural spread of PVY strains O and N. 23% of transgenic plants become infected with PVY^{O} when ELISA performed with monoclonal antibodies. This was the most common strains in potato fields. Next year Bt6 show excellent resistance and PVY was detected in only 7-10% in transgenic plants. Control plants were affected 86%. CP gene show complete resistance to PVY^{N} and also to PVY^{O} in the field under natural aphid transmission [26]. The PLRV, PVX, and PVY (was serious threats in Punjab province in autumn season. 1277 samples were collected from 169 fields. ELISA test was performed for the assessment of diseases and found that PLRV, PVX, and PVY were present in al localities [27]. The incidence of viruses in different localities in Punjab was confirmed with the help of ELISA [28]. Most prevalent diseases were Potato virus Y (PVY), Potato virus X (PVX), Potato virus S (PVS), Potato virus M (PVM), Potato leaf roll virus (PLRV) in upper Kagaan valley of Pakistan [29]. The attack of PVX was less common. A research in Chile in 1994-95 during the growing season for the determination of potato viruses. The 227 samples were collected which was showing Virus like symptoms [30].

Serological (ELISA) and biological (Indicator Plants) techniques were applied for the confirmation of Virus. Viruses detected were AMV, Potato virus Y (PVY), Cucumber mosaic virus (CMV), Tomato spotted wilt virus (TSWV), potato virus X (PVX), Tobacco mosaic virus (ToMV). Most prevalent virus in the region was ToMV. The 26% samples were affected by ToMV. The easy and fast protocol of DAS ELISA to detect three common Potato viruses, Potato virus Y (PVY), potato virus X (PVX), Potato virus S (PVS). Five different combinations of incubation periods were tested. All three potato viruses were able to detect at the incubation period of 37 ºC but at the longer incubation periods values were significantly higher. At the substrate reaction of 15 minutes it was possible to detect the PVS and PVX. But PVY was detected after 30 minutes [31]. The DAS-ELISA technique used at the same time for the detection of PVY, PLRV, and PVX. They also studied by using homogeneous antiserum of all the viruses [32].

ELISA was conducted with 50- and 100-liter antigen per well and with different dilutions and combinations. The favorable parameters for the flexible and sensitive immune electron microscopic diagnosis of PVY, PVX, PVS, CMV and PLRV. The pH for extraction buffer and antiserum for diagnosis of PVY and PVS was, 7.2 and 8 while for the PVX it was 6 and 7.2 respectively [33]. The 0.1 M EDTA was added in extraction buffer for the detection of PVY. The incidence and distribution of Potato virus Y and potato leaf roll virus in dominant potato cultivated areas of KPK, Pakistan. Maximum incidence of PVY 42% and PLRV 18% was recorded [34]. The ELISA (Enzyme linked immune sorbent assay) used for easy isolation of PVY in Iraq. PVY was detected and isolated from potato plants which were naturally infected from PVY. Samples were collected on the basis of symptom expression, serological test, host range, sap stability, and diagnostic host. Purification of virus was done and used for the production of antiserum. PVY was detected by ELISA in sap of infected plants and at low concentration in purified preparation [35]. The incidence of different viral diseases in KPK province. They collected samples from different cities of KPK and confirmed the viral infection through DAS ELISA. Incidence of PVY was 83% in all over the province [36]. The six Potato viruses during growing season of 2003- 2004. He studied on PVY, PVA, PVX, PLRV, PVS and PVM. Leaf samples were collected from commercial potato plots and research area and determined by ELISA. In 2002, 205 samples were analyzed on the basis of symptoms, 182 for PVY, 173 for PVS, 55 for PVX, 12 for PVA, 36 for PVM and 1 for PLRV [37].

A surveyed was carried out main potato growing areas (Okara, Sahiwal, Gujranwala, Sialkot, Kasur, Jhang and Toba Take Singh) of the Punjab province for the presence of PVY, PVX and PLRV. At least, 169 fields were surveyed at 7 different localities. From those fields, about 1227 leaves samples were collected from these fields and assayed by ELISA. The 23.06% samples were infected with PVY while PLRV infected sample was 54% and PVX infection was 13.18% [28]. A surveyed was conducted and collected 1030 samples randomly from plants which were producing No symptoms. Initially samples were tested with serological assay. Different virus specific antibodies were used to know if plants were infected with PVS, PLRV, PVY, PVM and PVA. About 68% of the symptomatic plants were infected with PVY, PVS was also present in high percentage. Many of the samples show mix infection of PVY and PVS. Incidence of PVX was 10% and in less than 1% samples were infected with other viruses [38]. In Slovenia disease free seeds of the variety Igor were planted in different locations. Harvested tubers were visually evaluated for the presence of Necrosis. Elisa test was performed with monoclonal antibodies $PVY^{O/C}$

of Adgen, PVY^N of Bioreba, and poly clonal antibodies of PVY. Predominant strain was PVY^{NTN} present on all locations in 1997-98 [39].

In the year 2000 highest infection of PVY O was found in the Rackican and Pivka. During study PVY^C strain was not found. In isolated parts of Slovenia i.e. Podcetrtek, Brezula, Libelicae, Trbonje, Tolmin, Vrtojba infection rate was not higher and it is decreased in 1997-2000. Electron microscopy was used for the identification and detection of viruses. Samples were gathered from main potato growing areas of Yunnan. The number of detected virus were 5 i.e. PVY, PLRV, PVX, PVM and PMTV. Virus was detected through Electron microscopy and TAS ELISA [40].

Transmission

The occurrence of aphids on potato cultivars. Highest numbers of aphids were recorded in the month of June and August. Minimum number of insects were found in the month of July. In the third week of August highest number of insects were captured in insect traps [41]. An experiment on potato germplasm to ensure the transmission of Potato virus Y using some sucking insects i.e. aphid and whitefly. Mechanical transmission was also recorded. The highest disease severity was 73.33% through aphid transmission. No variety was free from Potato virus Y [42]. The Aphid appeared in yellow traps in the end of October in 1977, mid-January 1978 and mid-December in 1981. From July to September there no aphid activity was recorded. In the month of October and December there was very low flights of aphid and this was autumn crop season [43]. A varietal trial was conducted for yield potential and aphid population. The verity chieftain, patroness, and Atlantic show good performance. Aphid was collected from two locations on yellow traps. Aphid started appearing earlier in the month of august. Maximum number of aphids were caught on yellow traps in the middle of August. He reported that chances of virus infection maximum in this month [44]. The viruses were main threat which can reduce the tuber quality and yield of potato. Most threatening and important virus is PVY among all potato viruses. Aphid (*Myzeus Persicae*) can acquired the virus within seconds from infected plants and transmit it to healthy plants in non-persistent manner. PVY can also be transmitted mechanically (tools and machinery) but mostly it is transmitted through aphids [13]. The incidence of PLRV spread by means of Aphid. They surveyed in Malakand Division and North Buner Agency in Pakistan in 1989 and found that 48% plots and fields were infected with PLRV and Aphid activity was very high in these areas. It was concluded that incidence of PLRV can minimize if aphid controlled because aphid was main vector of PLRV [45].

Relation of PVY with environmental factors

Three main destructive potato viruses PVY, PLRV, PVX and their vectors were studied. He also studied the correlation of PLRV and PVY vector with environmental conditions. Aphid population and disease severity of five varieties was recorded and subjected to correlation analysis with different environmental conditions. The overall correlation of minimum and maximum air temperature and wind speed with disease severity of PVY, PLRV, and PVX was significant but relative humidity and rainfall had negative correlation with disease severity [46]. Two different experiments were conducted for producing virus free (tissue cultured) plants by using heat therapy from sprouted tubers and from sprouts of infected potato plantlets. Four groups of infected plantlets with potato virus Y, potato virus S, potato virus X, and potato leaf roll virus were made visible to temperatures of 25-40 ºC for the time period of 4 hours and 15 days for each group. In the second experiment shoots were incubated at the temperature of 37 ºC for 15 days to isolation of 3-4mm shoot tips for the purpose of virus free plant production. When infected potato plantlets were exposed to fluctuating temperatures there was 100% removal of PVY, PLRV, PVX and 91.7% of PVS [47]. Disease severity was maximum in the month of January at the temperature of 7.3-10.3°C, 27.1-23.3°C and relative humidity was 53.80%-51.20%, 87.1%-90.71% [48]. The 15 lines/varieties against Potato virus Y (PVY) and Potato leaf roll virus (PLRV), and none of the variety was found to be resistance against PVY and PRLV. The lines/varieties i.e. FSD-Red, Desiree x juse B, 384636-1, Cardinal, 9616, and 9620 was Moderate resistant to PLRV. Moderately susceptible response to PLRV was showed by the lines/varieties, TPS-9801, Dura, TPA, 9808, Sante, 3384093-844, 384640-3, SH-5, Desiree and 9804. The weekly correlation of minimum and maximum air temperature, wind speed, relative humidity, wind direction and pan evaporation with PLRV disease was checked at variety level. None of the line showed significant correlation with wind direction and wind velocity. Maximum temperature was significantly correlated in 13 varieties. Relative humidity was showed significant effect in eleven lines. Pan evaporation was significantly correlated in thirteen lines. Maximum disease incidence was recorded at 80-86% relative humidity 11-13 ºC minimum temperature and 25-28 ºC maximum temperature and pan evaporation was 2-2.9mm [27].

The results showed that environmental factors have positive relation with PVY and PVX incidence. PVY have Significant and non-significant result at high and low temperature but it is negatively correlated. PVY have no significant result with clouds. They reported in another experiment that at temperature 24-28°C and 9-12°C PVY show severe expression. At that time Relative Humidity was 78-84% [49]. The correlation of epidemiological conditions with PLRV disease incidence was reported. None of the variety showed significant correlation with pan evaporation and wind velocity. The varieties showed significant correlation with minimum air temperature were Desiree x juse B, FSD-red, FSD white, and P-33286 [50].

The correlation of environmental factors (Relative Humidity, Maximum and minimum temperature, clouds, wind velocity, wind direction and pan evaporation) with Potato virus Y disease. Maximum incidence of PVY was recorded at 9-12 ºC and 24-28 ºC as minimum and maximum temperatures. At higher r values (0.98) there was an increasing trend. At 1.7-2.5mm disease severity was recorded as by higher r values. There was no significant correlation with wind velocity, clouds and wind direction [51]. The PVY and PVX cause heavy losses to potato crop in Pakistan. They studied the relation of environmental factors (rainfall, temperature, humidity) with incidence of PVY and PVX and show that infection spread in rainfall and humidity and have non-significant result with high and low temperature [52].

Management of Potato Virus Y

Through different strategies, Potato Virus Y can be managed and some are discussing here (Fig.2).

Screening

The research was conducted and found some resistance varieties against PVY. They did experiment on 28 cultivars of potato and resulted that Flisak, Lemino, Ewerest, Osa and Wulkan were the resistant against PVY [53]. The detection of viruses and other potato pathogens for seed certification program of potato ELISA tests were applied on the selected samples and resulted that PVY was the prominent virus, followed by Potato virus S and potato leaf roll virus. Some samples were infected with single virus some have double and other have multiple infections. Infection rate was much higher in the locally produced uncertified seeds. While in the imported certified seeds infection rate was less [54]. The epidemiology of Potato virus Y, Potato virus X and cucumber mosaic virus studied carried out in Henen (China). Survey was conducted in different tobacco growing divisions of Henen in the month of May and June 2000. 10-85% plants were showing the symptoms of Mosaic, mottling, vein necrosis, vein clearing. Highly susceptible varieties were K526, NC89, and K 346. These were also widely gown cultivars. Potato virus Y, PVX, CPV and TMV was detected. Thus, more prevalent disease was Potato virus Y [55]. The incidence of PLRV, PVY, cutworm and tuber rot were significantly varied in different varieties in Bangladesh. Lowest incidence of PLRV was showed by variety Ailsa followed by cardinal and dheera. The highest infection was showed by the variety patrones. There was no incidence of PVY in varieties Chamak, Dheera, Arinda, Karuda and Heera. PVY incidence was highest in Variety Multa. Best result of disease severity was showed in Dheera and Chamak [56].

The variety shepodey and red lasoda show the expression of disease in low light intensity as compared to high light intensity, and variety Russet Norkotah is resistant to PVY [57]. The susceptible varieties were used and show that virus present in leaves and stem. For the purpose he uses PCR and TEM. Viral particles were present in outer layer of tissue of leaf in much quantity [58].

Bio and Synthetic Products

The 1% potassium permanganate can reduce the activity of virus. They also studied that a virulent vaccine could be made at 70-75 ºC for successful treatment of virus [59]. The oil was sprayed as aqueous solution or ethanol suspension. Aphids transferred to indicator plants (tobacco) and leave them for overnight. When oil suspension spray was done on the virus affected leaves, the aphids did not penetrate the stylet on effected leaves. They did not transmit PVY on indictor plants [60]. Aphid population, different control strategies, efficacy of control strategies and damage, identification of virus and survey of producers recorded. They used right amount of mixture of pesticides for the identifying and Monitoring the aphid and also confirmed the presence of Potato virus Y, which was non persistent [61]. A review of virus forecasting scheme and on aphid monitoring. The discussion was about green peach Aphid (*Myzus persicae*), foxglove aphid (*Aulocorthum solani*) a potato aphid (*Macrosiphum euphorbiae*) [62]. Many Aphid species are responsible for the transmission of PVY and also a severe problem for production of potato. Mulching showed significant result in reduction of PVY incidence in potato tubers as well as aphid infestation on weed [63]. The huge damage was caused by PVY and PLRV in past 30 years. The factors involve in disease distribution was the virus infected seed and Environment factors. The result is a need to use resistant varieties against virus and raise environment friendly approaches for management of virus [16].

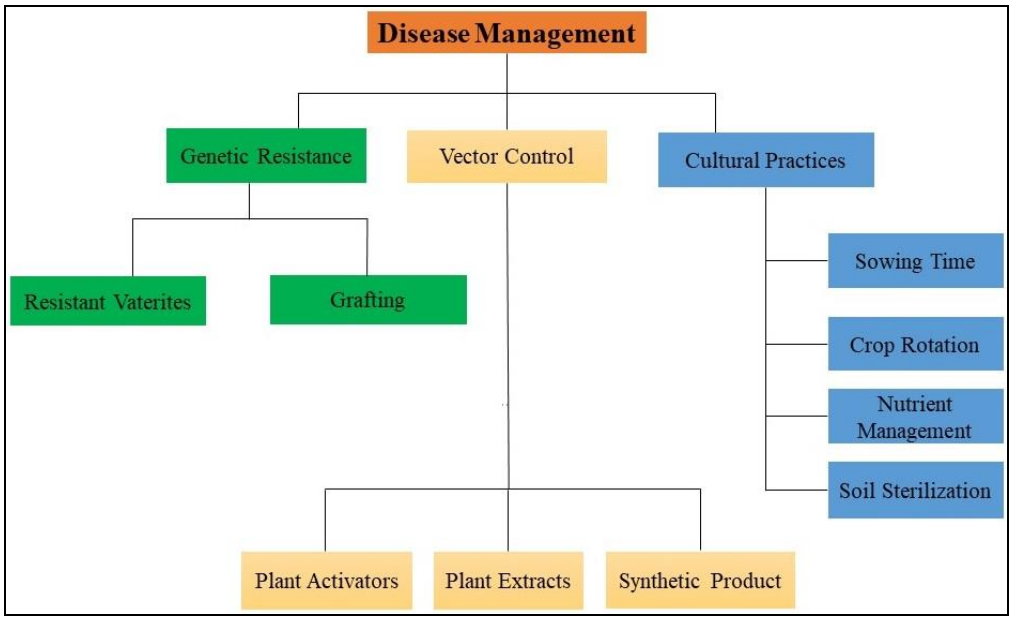

Fig 2: Disease management strategies for the control of PVY

Conclusion

Among the potato viruses, PVY is the most detrimental virus to potato production worldwide including Pakistan. The management of this virus is essential to lessen the potato yield losses. Breeders are trying to develop resistant varieties however to find a robust source and permanent resistance cultivars is very difficult. Since disease resistance is not only property that a cultivar should have, other agronomic parameters especially yield factor also need to be addressed. As virus is transmitted by aphids, therefore resistance against aphid should also be incorporated. Consequently, the development of resistant varieties for both virus and vector become very difficult task. The other method to control virus is immediate roughing, and destruction of secondary hosts such as weeds and volunteer potatoes are also very important. Because weeds and volunteer potatoes are also host of PVY.

Mechanical barriers including polyethylene sheets and barrier crops can reduce the spread of PVY. These are short strategies to control PVY and its vector. In future, researcher should develop early warning system than can provide accurate counts of aphids in the fields. By applying management strategies at right time can reduce the severity of PVY. Moreover, scientist should integrate molecular, serological as well as phenotypic properties of PVY and its vectors to understand the relationship between them to control both effectively.

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